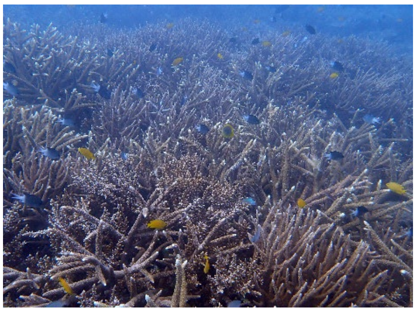
SEA RESEARCH



Port of Abbot Point Ambient Coral Monitoring Surveys: 2020-2021

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

Report No. 21/45

Port of Abbot Point Ambient Coral Monitoring Surveys: 2020-2021

A Report for North Queensland Bulk Ports

Report No. 21/45

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

Centre for Tropical Water & Aquatic Ecosystem Research (TropWATER)
James Cook University
Townsville
Phone : (07) 4781 4262
Email: TropWATER@jcu.edu.au
Web: www.jcu.edu.au/tropwater/

SEA RESEARCH

Information should be cited as:
Chartrand KM, Hoffmann LR, Ayling A, and Ayling T. 2021. Port of Abbot Point Ambient Coral Monitoring Surveys: 2020-2021. Centre for Tropical Water & Aquatic Ecosystem Research (TropWATER) Publication 21/45, James Cook University, Cairns.

For further information contact:
Centre for Tropical Water & Aquatic Ecosystem Research (TropWATER)
James Cook University
Katie.Chartrand@jcu.edu.au
PO Box 6811
Cairns QLD 4870

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

© James Cook University, 2021.

Except as permitted by the *Copyright Act 1968*, no part of the work may in any form or by any electronic, mechanical, photocopying, recording, or any other means be reproduced, stored in a retrieval system or be broadcast or transmitted without the prior written permission of TropWATER. The information contained herein is subject to change without notice. The copyright owner shall not be liable for technical or other errors or omissions contained herein. The reader/user accepts all risks and responsibility for losses, damages, costs and other consequences resulting directly or indirectly from using this information.

Enquiries about reproduction, including downloading or printing the web version, should be directed to Katie.Chartrand@jcu.edu.au

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 wish to thank the Sea Research staff for their valuable assistance in the field and data processing.

KEY FINDINGS

1. Coral monitoring at Holbourne Island and Camp Island was completed in October 2020 and June 2021 as part of a bi-annual ambient monitoring program. The 2020/21 results are compared with data collected since May 2016, the program's inception, for the Port of Abbot Point to measure benthic cover, coral health, sedimentation and coral recruitment.

2. Reefs in the Abbot Point region went through a mass bleaching event prior to and during the May 2020 survey with a mean of 32% of Camp Island and 30% of Holbourne Island hard corals bleached.

3. Hard coral decreased by 54% at Camp Island from October 2019 to June 2021; a drop from 24% to 11% coral cover for this inshore location. *Acropora* and *Montipora* were the two main coral groups affected by bleaching-related mortality. The decline in these two coral groups was similar at nearby Mackay coral monitoring locations. Holbourne Island had no measurable loss in hard coral from the bleaching event due to its slightly cooler water temperatures at its mid-shelf location and deeper sites. Broad-scale surveys confirmed bleaching throughout the central and southern GBR sectors at inshore and mid-shelf reefs but with relatively low mortality observed from this regional event.

4. Macroalgae in October 2020 at Camp Island was at the highest levels since monitoring began in 2016. Cover returned to more typical levels in June 2021 while Holbourne had minimal macroalgae during the pre- and post-wet surveys (in line with the long-term low macroalgae at this location).

5. The Holbourne Island locations were severely impacted by Cyclone Debbie in late March 2017 with a mean 77% reduction in hard coral cover. Coral communities in the Holbourne Island monitoring locations have been very slow to recover since this impact, with a grand mean of 4.9% coral cover in October 2017 and only 5.0% cover in May 2020. The slow recovery of hard coral communities in these fringing reef locations since Cyclone Debbie is a cause for concern.

6. An adjusted monitoring program design was implemented in October 2020 at Holbourne Island with all shallow sites and two deep sites decommissioned while two new sites were established on the eastern face of the island's reefs. The new sites provide a more representative spread of coral cover and community assemblage. These changes were made to align with the broader NQBP ambient coral monitoring program and to better represent potential impacts and recovery at this location.

7. Holbourne Island coral cover nominally increased in October 2020 by 10% due to the adjusted location design. Historical comparisons at this location should be considerate of this monitoring design change.

8. Coral community composition was still dominated by *Acropora* and *Montipora* corals on the Holbourne and Camp Island sites despite losses from the bleaching event.

9. Coral recruit densities were low at Camp Island in October 2020 before returning to more normal levels in June 2021. The new sites at Holbourne Island together with increased recruitment at existing sites drove a significant increase to the highest recruitment levels recorded at Holbourne Island.

10. Sediment on corals and sediment damage were relatively low on Holbourne Island and higher on Camp Island; a reflection of the more inshore, shallow environment of Camp Island. Sediment levels during the 2020/21 surveys remained high following peaks directly after the 2020 bleaching event, probably due to bleaching stress of the coral colonies reducing sediment removal capacity. However, an increasing trend in sediment levels at Camp Island since 2018 could be a sign of concern.

11. Crown-of-thorns starfish continue to occur at Holbourne with a small number of animals at the newly established sites. None have been observed at Camp Island since monitoring began.

12. Data from these surveys was used to determine a coral condition index score under the Mackay Whitsunday Regional Report Card. The regional score is based on post-wet season surveys and was rated 'poor' following June 2021 in large part due to high macroalgae and low cover at Camp Island.

IN BRIEF

Coral monitoring sites were set up at three locations in the vicinity of the Port of Abbot Point in mid-2016 as part of North Queensland Bulk Ports ambient reef monitoring program. These locations were shallow depth stratum on Holbourne Island (~2m below LAT), deep stratum on Holbourne Island (~5m below LAT) and Camp Island (~2m below LAT). Four sites of five permanently marked 20 m survey transects were set up at each location along the required depth contour. These surveys were instigated in order to gain a greater understanding of ambient conditions, and the drivers of these conditions, which would also allow for a greater capacity to manage potential influences during periods of port related activities such as dredging. The Australian Institute of Marine Science initially established these monitoring sites using their fringing reef survey protocols and carried out three further surveys during 2016/2017. TropWATER, in association with Sea Research, continued this program using the same sites and transects in 2018-2021.

A recent review of the program has led to the reduction in the program to two locations, deep Holbourne and Camp Island in order to align with other inshore coral monitoring in the Mackay region. In addition, two sites at Holbourne Island were re-positioned to better represent the coral communities at this location equating to four sites at both Camp Island Holbourne Island locations. Each site continues to have five, 20m long transects. All datasets reviewed in the current report have been back calculated to account for trends at the current four sites to ensure current and future trends in the program are comparable with the historical record.

Holbourne Island is a mid-shelf fringing reef about 30 km offshore from Bowen and 30 km from the Port of Abbot Point. Camp Island is a shallow inshore reef 20 km west of the Port that is only 2.5 km offshore from the mouth of the Elliot River.

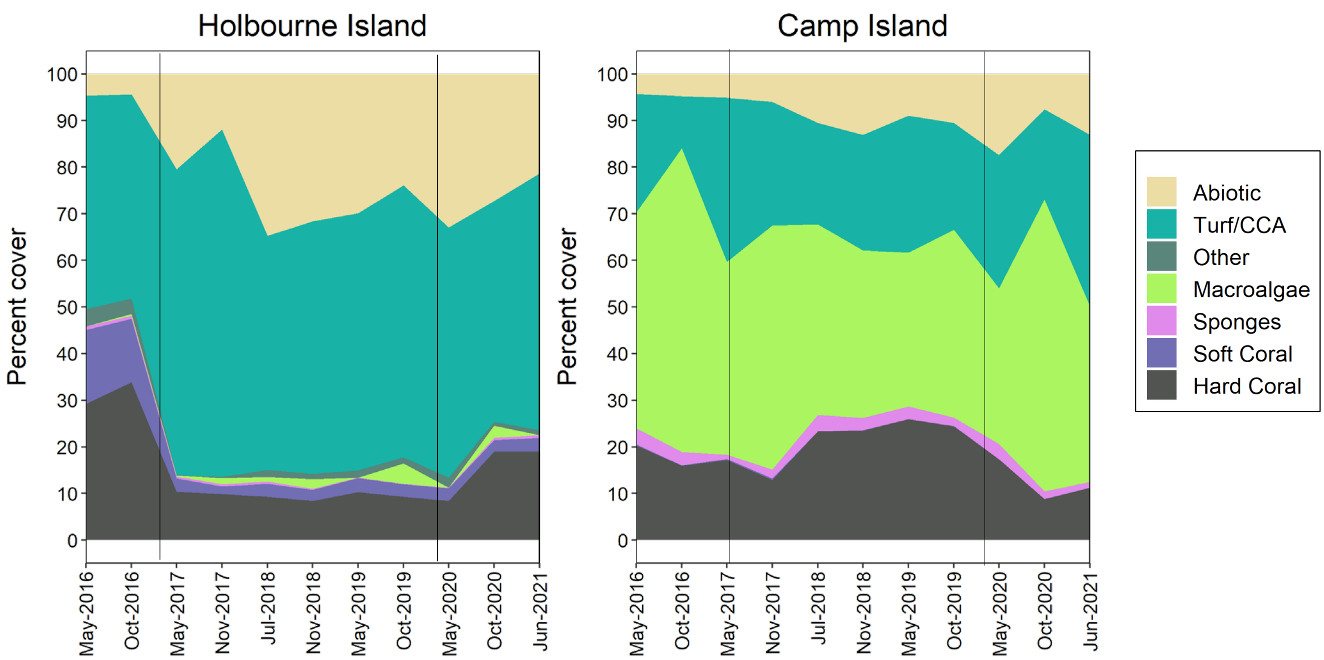


Figure i. Summary of changes in the major benthic categories at the two Abbot Point locations.

Graphs show cumulative percent cover from all ambient surveys. Solid vertical line indicates the time of Cyclone Debbie (2017) and the 2020 mass bleaching event. 'Other' is comprised of fire coral and zoanthids.

Holbourne Island is a more mid-shelf location and reefs around this island did not support stands of *Sargassum* macroalgae as is usually the case on inshore fringing reefs. Camp Island has patchy cover of a dense *Sargassum* forest, especially at the East 1 and West 2 sites (Fig. 3). Macroalgal cover fluctuated on Camp Island over the two ambient surveys from a peak in the pre-wet survey of 63%, down to 37% in the post-wet June 2021 survey. The seasonal fluctuation appears to be normal for this location, however the peak in October was relatively high even for this location which may be due to additional nutrients released from local coral necrosis following bleaching stress. However, the post-bleaching trend in macroalgae at similar inshore reef locations in Mackay did not see the same macroalgae increase and rather declined in macroalgae over the same period. At the site level, macroalgae only declined significantly at West 1 in June 2021. Benthic communities are unlikely to be impacted by the low levels of macroalgal cover recorded on Holbourne Island but may be damaged by the lush algal communities on Camp Island.

The Holbourne Island sites were severely impacted by Cyclone Debbie in late March 2017. Extensive physical damage from the wave action generated by this severe category 4 cyclone devastated coral communities on the SW face of Holbourne Island where all the survey sites were located. In the deep Holbourne sites, mean coral cover was less than 8% following the cyclone, down from 29%. Camp Island reef communities, although only 50 km west of Holbourne, were minimally damaged by Cyclone Debbie and mean coral cover actually increased slightly following the cyclone. The proximity of Camp Island to the coastline and the unusually shallow depths around the island (<5m), may have minimised impacts compared to Holbourne where wider fetch and deeper water (25 m at the base of the reef slope) led to the development of 10+ m wave height during this cyclone. The two new sites on the east face of Holbourne Island and the decommissioning of the shallow location were instigated in order to better represent recovery or further impacts to coral cover and trend at this location.

The reefs in this region experienced high temperatures during the first three months of 2020 and this caused a severe coral bleaching episode. At Holbourne, 30% of corals bleached in the Holbourne deep location and 32% on Camp Island at the time of the May 2020 survey. Broad-scale surveys of the GBR during this warming event found widespread bleaching both at inshore and mid-shelf reefs, which was most prevalent in the central and southern sectors (Townsville to Gladstone; ARC Centre of Excellence for Coral Reef Studies).

Hard coral cover declined by over 50% at Camp Island from October 2019 to June 2021 due to the bleaching event in early 2020. Measurable declines in the dominant *Acropora* were recorded in October 2020 and further losses of *Montipora* and *Acropora* led to coral cover dropping to 11% in the latest survey, down from 24% pre-bleaching. The original Holbourne sites did not have measurable losses in coral cover over the same period which is likely due to the slightly cooler water at this mid-shelf location. The newly established sites in October 2020 led to an overall location increase of about 10% in hard coral cover.

With the new Holbourne sites, coral community composition was fairly similar at the two locations. Over 60% of hard coral was *Acropora* and *Montipora* at both locations with poritids being a larger proportion of the coral assemblage at Holbourne Island than Camp Island. The proportion of *Acropora* and *Montipora* changed on Camp Island reefs over the 2020/21 period declining from over 80% of coral composition prior to the high bleaching mortality of these two coral groups in 2020.

Sediment on living hard corals and sediment damage were relatively low on Holbourne Island and higher on Camp Island. These differences reflect the more inshore, shallow environment of Camp Island. Sediment levels during the 2020/21 surveys remained high following peaks directly after the 2020 bleaching event, probably due to bleaching stress of the coral colonies reducing sediment removal capacity. Sediment deposition on living coral colonies can cause patches of mortality but only a very small number of corals were affected during these surveys with a grand mean of around 0.3 coral colonies per 40 sqm partially damaged by sediment deposition. Physical damage to corals from cyclonic events is more than an order of magnitude higher than any direct sedimentation damage. However, an increasing trend in sediment levels at Camp Island since 2018 could be a sign of concern.

Disease sometimes affects hard coral colonies and may cause partial or occasionally total mortality. Only a small number 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. No colonies at either location were affected by disease in October 2020. This may be a result of the significant mortality of *Acropora* and *Montipora* colonies which have historically been the groups with disease present during previous surveys. Disease returned, albeit at extremely low levels, at both locations in June 2021. In general, the impact of disease on hard corals is at least an order of magnitude less than physical cyclone damage.

Crown-of-thorns starfish (CoTS) were again found at Holbourne Island East site in October 2020 as well as in the newly established sites. No CoTS have been observed at Camp Island sites since the monitoring program began.

Coral recruitment was low at Camp Island in October 2020 with mean recruit density of 0.25 per sqm before returning to more normal levels at this location of 2 per sqm in June 2021. As is often the case on near-shore reefs, *Turbinaria* corals were common in the coral recruit population at Camp Island, accounting for 22% of all recruits recorded. In contrast *Turbinaria* corals only made up about 1% of the overall coral community. Acroporid corals, on the other hand, made up 45% of the recruit population but 74% of the overall coral community. On Holbourne Island a range of different coral groups were present in the recruit population but very little *Turbinaria* at this more offshore location. The new sites at Holbourne Island together with increased recruitment at existing sites drove a significant increase to the highest recruitment levels recorded at Holbourne Island in June 2021. In Mackay locations, recruitment was much greater over the same period, however, mainly *Turbinaria* and not Acroporid recruits.

The slow rates of coral community recovery at the original Holbourne Island sites following Cyclone Debbie, both from coral growth and recruitment, is cause for concern. Prior to the summer 2020 coral bleaching event, reefs around Camp Island appeared healthy and growing apart from periods of high algal growth and smothering at some sites. The May 2020 bleaching, however, caused a significant loss in hard coral cover. Long-term shifts in GBR-wide inshore coral communities suggest recovery is questionable with increased risks of cyclones and warm water events driving more frequent bleaching due in large part to climate change.

TABLE OF CONTENTS

FIGURES

TABLES

ACRONYMS AND ABBREVIATIONS

TropWATER	Centre for Tropical Water & Aquatic Ecosystem Research
NQBP	North Queensland Bulk Ports Corporation

1 INTRODUCTION

1.1 Project Background

The Port of Abbot Point is located 25 km north of Bowen and is an offshore coal loading terminal with a current export capacity of 50 million tonnes per annum and a 2018/19 throughput of 29 million tonnes. North Queensland Bulk Ports Corporation Limited (NQBP) is the port authority and port manager for this port 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.

NQBP began development of ambient coral monitoring programs for two other ports that they manage, the Ports of Mackay and Hay Point, during 2015. These programs were designed to gain a greater understanding of ambient reef 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. Beginning in 2016 NQBP initiated ambient monitoring at key reef locations surrounding the Port of Abbot Point (Figure 1): Holbourne Island (Figure 2) and Camp Island (Figure 3). The Australian Institute of Marine Science (AIMS) carried out the first survey event at these locations late in 2016 and made two more surveys during 2017: a post wet survey in mid-year and a pre-wet survey late in the year. TropWATER and Sea Research have continued the Abbot Point surveys since mid-2018. The last two surveys of these locations were: October 2020 and June 2021.

1.2 Objectives of Survey

NQBP proposed relating surveys to the seasons, with the first survey being in the Spring, pre-wet season period and the second in the late Autumn post-wet season period. This ensured that surveys were made before and immediately after the period of maximum likely natural impacts, whether floods, cyclones or bleaching, enabling the causes of any benthic changes to be established reliably. The exact timing of these surveys is not critical; surveys just need to be regular enough to enable the causes of any changes to be established reliably.

AIMS established eight sites on Holbourne Island and four sites on Camp Island for the Abbot Point ambient monitoring program. In keeping with their fringing reef survey protocols they set up sites in two depth strata: 2m and 5m below LAT on Holbourne Island. Coral reefs on Camp Island do not extend below 2m depth and only a single stratum was surveyed there. Sea Research and TropWATER continued the Abbot Point surveys using the same 12 sites established by AIMS.

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 latest surveys from the two Abbot Point locations made between October 2020 and June 2021. As of October 2020, sites within Holbourne Island were adjusted to reflect a review of the monitoring program to better represent coral and the benthic habitat communities. A modification of methods from line-intercept to photoquadrat analysis of benthic cover was also initiated from October 2020 in order to align with broader inshore coral monitoring programs through AIMS.

Figure 1. Location of the Port of Abbot Point showing the position of the Port and the Holbourne Island and Camp Island ambient coral monitoring locations.

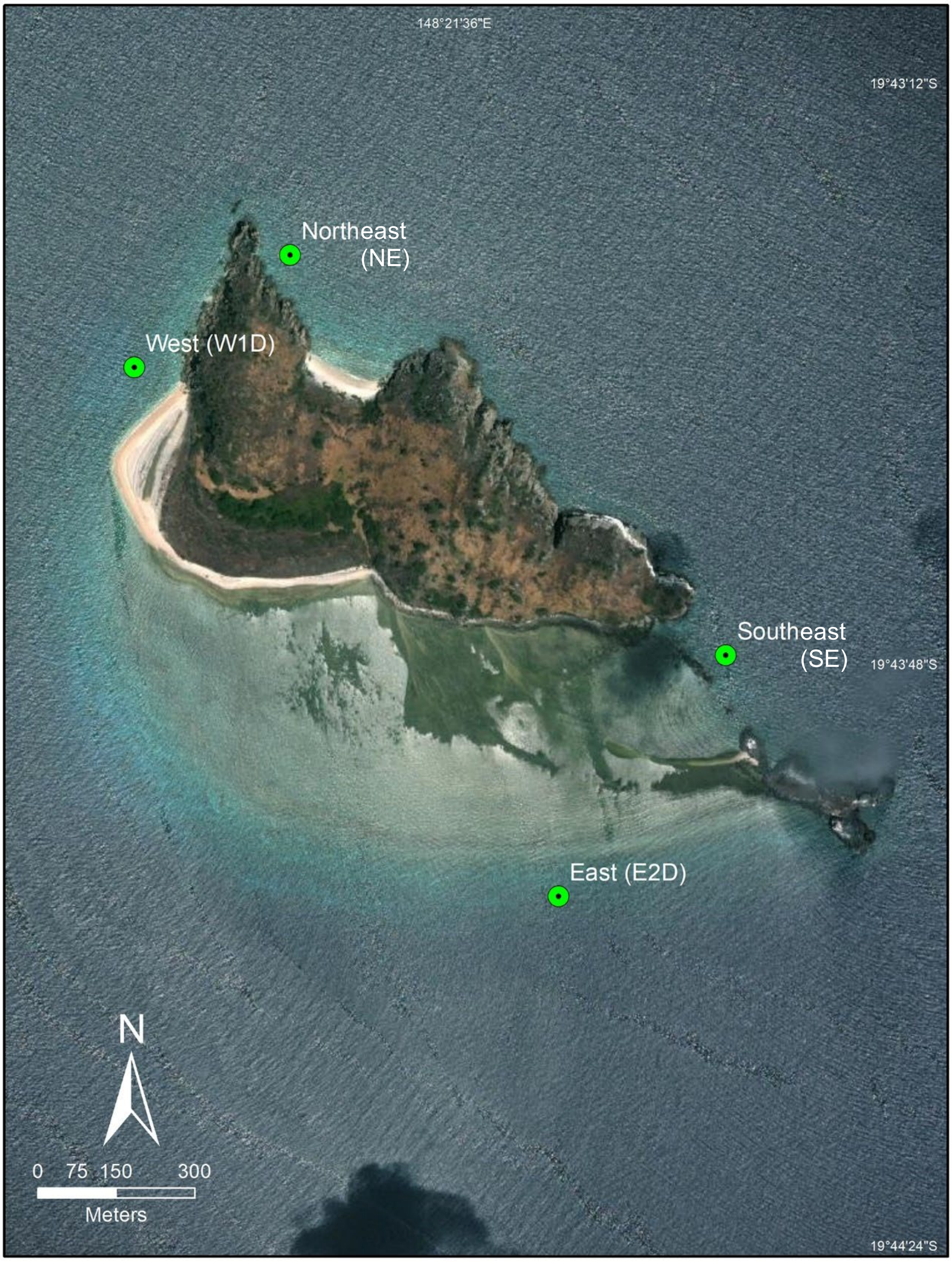


Figure 2. Holbourne Island showing the position of the coral monitoring sites. Note: 'Northeast' and 'Southeast' are the newly commissioned sites.

Figure 3. Camp Island showing the position of the four coral monitoring sites.

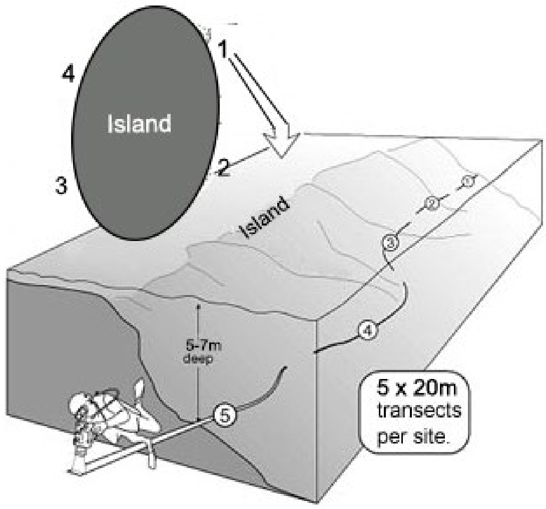
2 METHODS

2.1 Abbot Point Locations

Fringing reefs were surveyed around two island locations in the Abbot Point region (Figure 1, Table 1). Holbourne Island is a small mid shelf island surrounded by a fringing reef that is 32 km NNE of the Port of Abbot Point (Figure 2). Camp Island is a small near-shore island 19 km west of the port and only 2.5 km off the Elliot River mouth near the eastern side of Cape Upstart (Figure 3).

Four monitoring sites of five, 20m long permanently marked transects were established in two depth strata on Holbourne Island and a single depth stratum on Camp Island in 2016 by AIMS.

The sites at Holbourne Island were adjusted in October 2020 following a coral monitoring program review by NQBP and advice by Sea Research and JCU (Table 2). The Holbourne Island shallow locations were dropped from the program due to the lack of coral cover (<2%) making them poor representatives of the slightly deeper local coral communities. These sites were established based on the importance of aspect and depth on key coral community health indicators; noting though that Camp did not have 2 depth strata given the reef slope transitioned to sand beyond 2m depth (and supported seagrass). Two new sites were established in October 2020 at Holbourne Island in a similar depth stratum to the continued deep sites but in areas under represented on the northeast face of the island (Table 1, Figure 2).



Schematic diagram of the sampling design of a single location with four sites per island with five, 20m long transects at a single depth contour (*adapted from AIMS LTMP*).

Table 1. GPS coordinates of each monitoring site.

Location	Ambient monitoring site ID	Latitude	Longitude
Holbourne Island	Northeast (NE)*	-19.723	148.3572
Holbourne Island	East 2 (E2D)	-19.734	148.3618
Holbourne Island	West 1 (W1D)	-19.7249	148.3545
Holbourne Island	Southeast (SE)*	-19.7299	148.3647
Camp Island	East 1	-19.8508	147.9052
Camp Island	East 2	-19.8541	147.9012
Camp Island	West 1	-19.8533	147.8942
Camp Island	West 2	-19.8512	147.8950

* Shallow sites were dropped from the program in October 2020 and two new sites replaced the deep sites at the same depth contour but in reef areas not currently represented in the program on the northeast face of the island.

Table 2. Summary of all coral surveys made at the two Abbot Point survey locations.

Survey date:	Camp Island	Holbourne Island
May 2016†	X	X
Oct 2016†	X	X
May 2017	X	X
Oct 2017	X	X
Jul 2018	X	X
Nov 2018	X	X
May 2019	X	X
Oct 2019	X	X
May 2020	X	X
October 2020*	X	X
June 2021*	X	X

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

2.2 Survey Period

This report provides a summary of coral conditions observed during two different surveys undertaken at all Abbot Point reef locations over the period October 2020 to June 2021. The two survey periods were pre-wet 2020: 19-20 October and post-wet 2021: 3-4 June. Two surveys are included each year to ensure that the reasons for any observed impact are clear; with more than about eight months between surveys it may be difficult to determine the cause of any change in benthic cover.

Holbourne Island is a mid-shelf location and underwater visibility is usually between 5 and 15 m making the surveys consistently reliable. Although Camp Island is close to the coast and only a few kilometres off the Elliot River mouth underwater visibility there has been good during all surveys to date, ranging from 5-12 m, and surveys have not been compromised by poor water conditions.

2.3 Benthic Line Intercept Surveys

Abundance surveys of the marine communities surrounding these two islands were made at four sites around each island. On Holbourne Island where the reef extends down to over 20 m depth two depth strata were surveyed at each site (2m and 5m below Lowest Astronomical Tide (LAT)) but at Camp Island the reefs were very shallow and only a single depth stratum was surveyed (~2m below LAT). At each site and depth stratum, cover of major benthic reef organisms was assessed by five 20 m line intercept transects run along the required depth contour with a 5m gap between each transect. The transects were permanently marked with a star picket at the start and 12 mm reinforcing rod stakes driven into the seabed at 10 m intervals.

These sites were set up by the AIMS after the wet season in mid-2016 and re-surveyed in October/November 2016. All transects were re-located and repaired by AIMS following Cyclone Debbie in mid-2017. The marker stakes are remarkably resistant to cyclone waves and the majority of markers survived the cyclone although many of them were bent over or broken off near the base. TropWATER and Sea Research took over the survey of these transects in mid-2018 using the same markers and methods.

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

- Sand and mobile rubble;
- Macroalgae;
- Algal turf and crustose coralline algae;
- Sponges, fire corals and zoanthids;
- All hard corals identified to genus level (or to growth form if more appropriate); and
- All soft corals.

These techniques have been used in many other surveys of fringing and offshore reefs in the Great Barrier Reef (GBR) region (Ayling and Ayling 2005; 2002; 1995; Mapstone et al. 1989). These methods align with the MMP methodologies thereby ensuring data collected under this ambient program is able to be compared to, and incorporated in, the broader State-wide mapping and reporting programs.

2.4 Photoquadrat Intercept Surveys

Photoquadrats along each transect were taken approximately 0.5m above the benthos on the shoreward side of the tape in order to shift from line intercept to a photoquadrat method in line with the Australian Institute of Marine Science (AIMS) methodology for calculating benthic cover of coral reef communities. Note that during the AIMS surveys (2016/2017) line intercepts were not recorded but percentage cover measurements were assessed using this transect photographic record.

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

2.5 Sediment Deposition on Corals

Depth of sediment deposition (whether natural or dredge derived) was measured on 20 hard coral colonies haphazardly selected within a metre of each transect. If sediment was present on living parts of the colony surface the point of maximum sediment depth was measured in mm using a plastic ruler. Sediment usually only covered a portion of the colony surface and a single measurement of sediment depth was recorded where it was deepest. Sediment depths were not measured during the AIMS surveys of these locations.

2.6 Damaged, Diseased, or Bleached Coral Colonies

Although line intercept transects give a good estimate of coral cover, the sample size of coral colonies immediately beneath the transect lines is not sufficient to encounter relatively rare events such as coral disease or sediment damage. To sample a wider area the following parameters were also measured along each transect line:

- Counts of bleached or partially bleached colonies along a 20 x 2 metre transect centred on each transect line were recorded for each of the major coral groups.
- Counts of all sediment damaged colonies along a 20 x 2 m transect centred on each transect line were recorded for each of the major hard coral groups. Colonies were not recorded as sediment damaged if there was an actively growing edge encroaching into an old sediment-smothered dead patch.
- Counts of all diseased coral colonies along a 20 x 2 m transect centred on each transect line were recorded for each of the major hard coral groups. As for sediment damage, if there was an actively growing edge reclaiming a disease-caused dead patch that colony was not recorded as diseased.
- Counts of all colonies damaged by sponge overgrowth or *Drupella* or crown-of-thorns (CoTS) grazing along the same 20 x 2 m transects.

2.7 Coral Recruitment

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 AIMS 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 five 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 confidence intervals are non-overlapping. All analyses were performed in R version 4.1.1 (R Core Team) using packages lme4 and mgcv.

2.9 Photomosaic Trials

Photomosaic technology has the potential capacity to provide a relatively low cost, fast, and high-quality means to capture broader scale coral condition. The technology, is a composite of many high resolution images of the seafloor that affords a “landscape view” of the reef. Photomosaics can provide opportunities to explore high resolution imagery to support scientific research that goes beyond the existing monitoring program for added research needs not identified but that can benefit from hindcasting with a photomosaic image library. With such interest from NQBP, JCU explored the application of photomosaic image capture in the 2020/21 field surveys.

Initial trials are focused at Camp Island where both benefits from good water quality and challenges from three dimensional macroalgae stands provides a useful test site to explore the technology’s application for inshore coral monitoring.

Images were captured along all transects at each Camp Island site using two GoPro cameras. Cameras were fixed to a pvc arm at a set distance apart to ensure ~80% image overlap. Cameras and a tethered surface-based GPS unit were synchronized to capture photographs every second over the recorded gps track. The pvc arm was swum by a diver on scuba approximately 2m above the benthos to ensure an approximately 2m band view on either side of the transect at all times. Images and the associated gps track were post-processed using the software package AgiSoft where photos were aligned and stitched into the final orthomosaics.

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 July 2020 to June 2021 and compares these conditions to data collected since coral monitoring began around Abbot Point in 2016. The Don River which discharges into the nearshore environment just north of Bowen, 30 km from Holbourne Island, and the Elliot River which discharges only 2.5 km inshore from Camp Island are used here as indicators of local river inputs.

3.1.1 Rainfall and River Flows

The rainfall measured by the Bureau of Meteorology (BOM) at the Bowen Airport (BOM 2020) is provided graphically in Figure 4. The Don River discharge rate at Reeves (23km from the mouth of the River) is presented using data provided by the Queensland Government Water Monitoring Information Portal (WIMP

2020) in millions of litres per day (ML/day) (Figure 5). Elliot River discharge rates are recorded at Guthalungra seven kilometres upstream from the river mouth and are shown from July 2016 to June 2020 (Figure 5).

The Bowen region is in the dry tropics and mean annual rainfall is only 861mm with the majority falling in the four-month wet season (Dec-Mar). Rainfall for the 2020/21 wet season was slightly below average for this region with 670mm recorded for the December-March period. Maximum daily rainfall during the 2020/21 period was only 74mm, but more regular rainfall over the wet season resulted in a significant increase back to average levels.

Large sustained rainfall events typically cause large river discharges. Water discharges from the Don River were very low during 2020/21, peaking at only 11,000 ML/day in January 2021. There have been 13 events of 35,000 ML/day or greater flow since records began at this site in 1984. Flows of over 100,000 ML/day were recorded in 2008 and during the passage of Cyclone Debbie in March 2017. The Elliot River is a smaller system and flows are usually smaller, however they reached 23,000 ML in January 2021 during a monsoon weather event. Flows from this river system peaked at 32,000 ML/day during Cyclone Debbie and 25,000 ML/day during the 2019 monsoonal event. Elliot River flows equal to or greater than those recorded during Cyclone Debbie have occurred on only seven occasions since 1973 (TropWATER 2019).

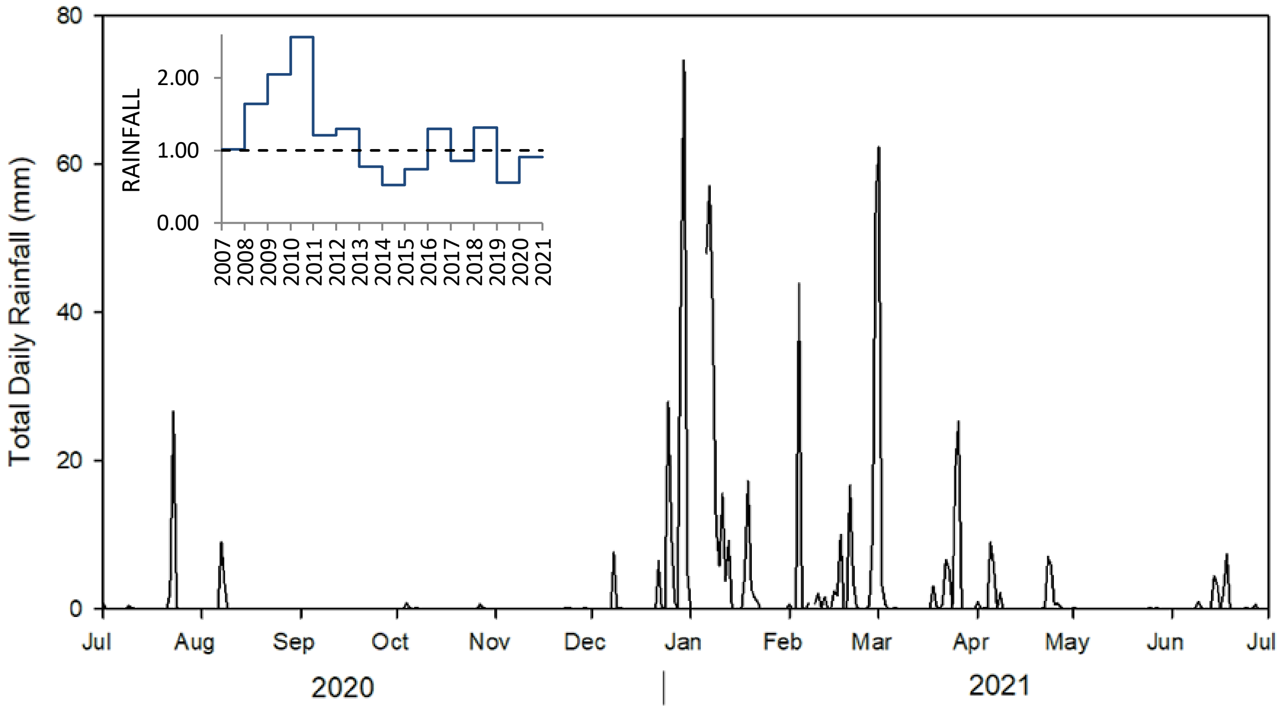


Figure 4. Daily rainfall measured at the Bowen Airport with inset of change in rainfall as a proportion of the long-term average.

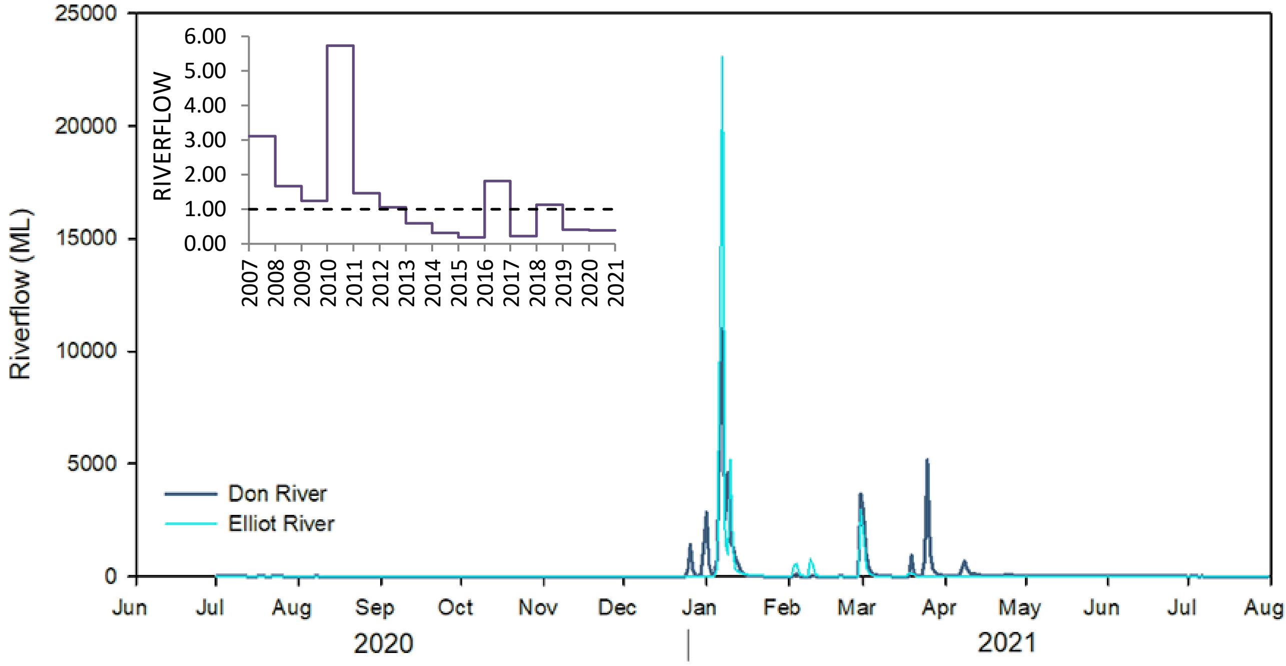


Figure 5. Daily discharge rates (mega litres) for the Don River measured at Reeves, 23 km upstream from the river mouth and the Elliot River discharge at Guthalungra with inset (Don River) of change in river flow as a proportion of the long-term average.

3.1.2 Cyclones

During the 2020/21 ambient monitoring period no cyclones passed near Abbot Point and only minor 2020/21 monsoonal rainfall with no event >100mm over a 24 hour period in the region. Peak river flows for 2020/21 were recorded for both the Don and Elliot Rivers during the January 2021 rain event and was otherwise the major weather event of the past 12 months for the Abbot Point region (Figure 5). Long term averages for river flow and rainfall remained below average for the year.

Prior to 2018 only one cyclone passed close to Abbot Point leading to strong or damaging winds and high rainfall that may have impacted the benthic communities in the coral monitoring locations since they were established. Severe Tropical Cyclone Debbie in late March 2017 generated gale force winds in the Bowen to Mackay region for more than 50 hours. Wave heights recorded near Holbourne Island during this event were over 8 m for many hours and peaked at 11.5 m. This system caused severe physical damage to the Holbourne Island benthic communities but minimal damage at the Camp Island location (AIMS 2018).

3.1.3 Sea Water Temperatures

Sustained elevated water temperatures that cause coral bleaching were not recorded during the 2020/2021 summer period in the Abbot Point region. Sea temperature measurements are collected by TropWATER at a number of sites in the nearshore environment offshore from Bowen. Overall, temperatures were near the long term average in the Central Region of the GBR and no alert levels were reached over the monitoring period. However, the previous mass bleaching event driven by elevated sea surface temperatures in February and March 2020 led to significant bleaching that was recorded during the pre-wet October 2020 surveys. Overall, the inshore Camp Island site has the highest and lowest seasonal temperatures compared to the more offshore Holbourne Island (Figure 6A).

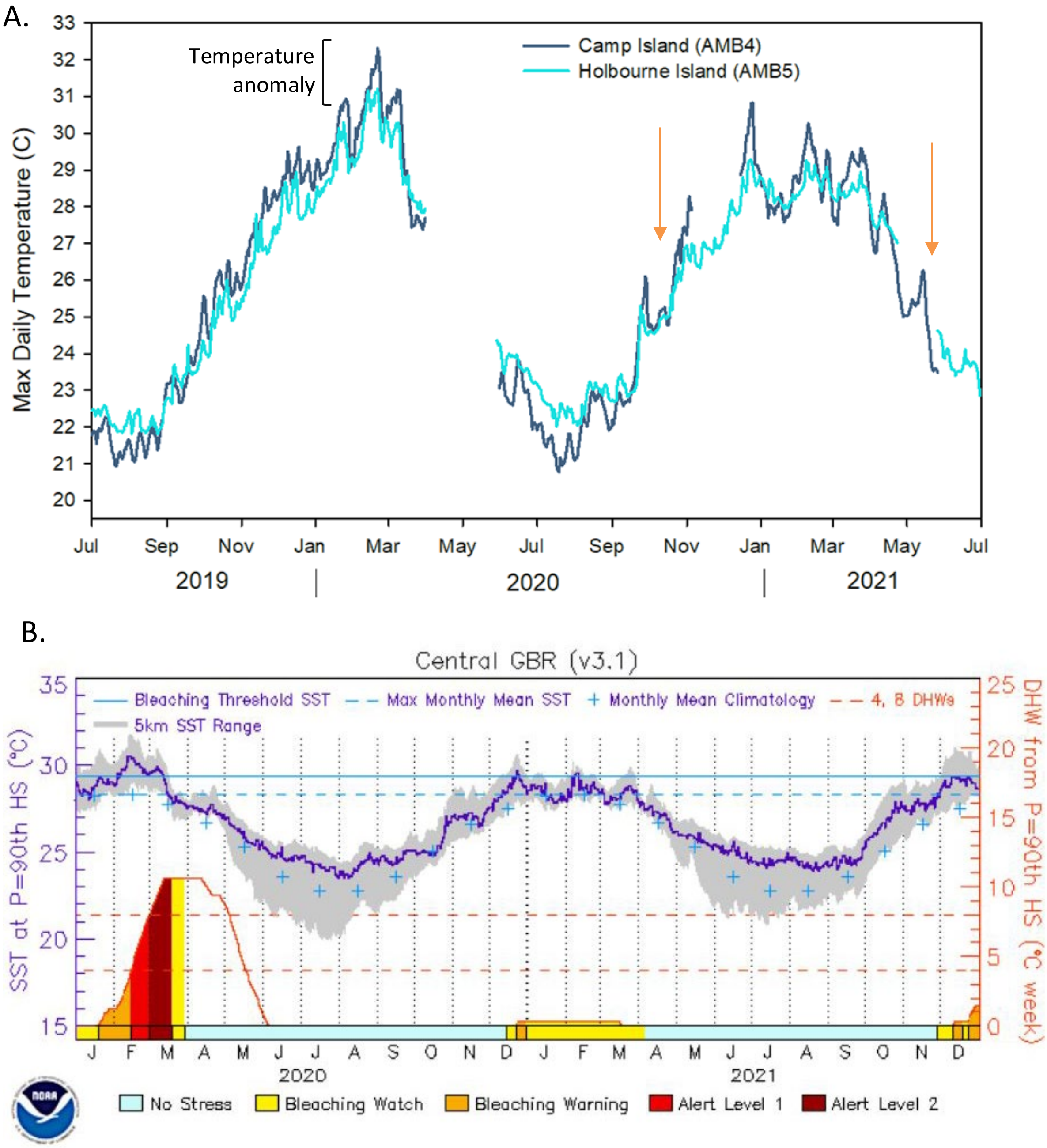


Figure 6. A. Maximum daily temperature at Holbourne Island and Camp Island water quality monitoring sites from 2019-2021. Arrows indicate approximate survey dates. B. NOAA Coral Reef Watch 2020-2021 5km satellite regional virtual station time series data for Central GBR.

3.2 Benthic cover during the ambient surveys

Benthic communities on the Holbourne Island sites were severely affected by Cyclone Debbie with >75% coral cover lost at Holbourne sites between 2016 and 2017 (Figure 9; AIMS 2018). At the original sites, East (E2) and West (W1), recovery has been very slow and the majority of the reef surface is still occupied by sand/rubble, crustose coralline algae and turfing algae. These three categories accounted for about 75% of the substratum in the old sites during the latest survey, consistent with the last two years of surveys (Figure 7). The new sites Northeast (NE) and Southeast (SE) add a significant increase of approximately 10% to the Holbourne Island hard coral community (Figure 7). Overall, hard coral cover was about 11% in the old sites and 27% in the new sites with a mean hard coral cover of 19% for Holbourne Island. The uncharacteristic but temporary macroalgae that appeared at Holbourne Island reefs in October 2019 due to a strong bloom of *Padina* macroalgae had reappeared in a smaller proportion of about 3% in October 2020. Soft coral covered around 2-3% at all sites.

Benthic communities on Camp Island had not been devastated by Cyclone Debbie. This location is an inshore site and macroalgal cover varied between 38-63% seasonally, an increase from the previous year. Sand/rubble, crustose corallines and turfing algae accounted for 27-50% of the substratum in this location during the last two ambient surveys (Figure 7). Sponges covered around 1.5% of the substratum at Camp Island. Hard coral cover decreased for a second consecutive year from 24% in October 2019 down to 11% cover in June 2021. Soft corals continue to be rare at this location covering less than 0.1% of the substratum.

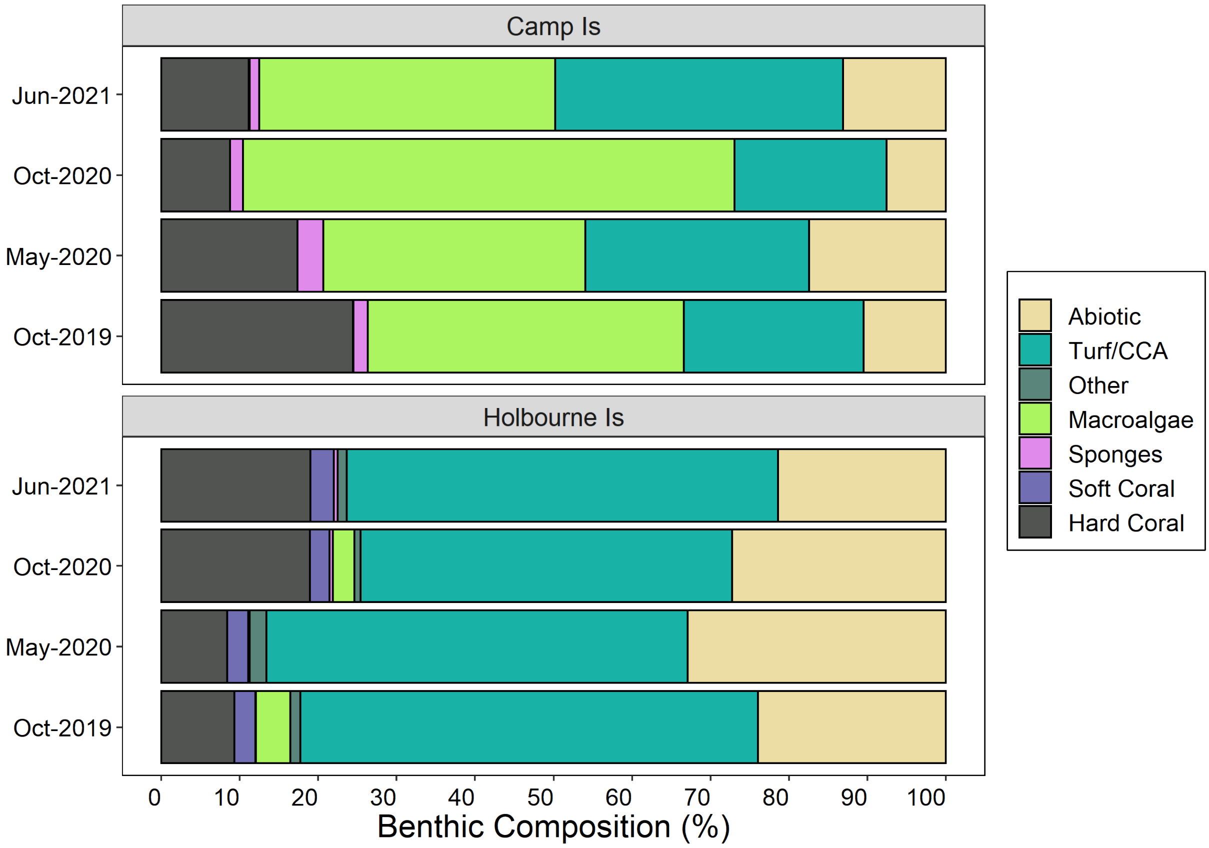


Figure 7. Changes in benthic composition in the two locations between October 2019 and June 2021. Benthic category Benthic category 'Abiotic' = sand + rubble + bare reef, Other = *Millepora* + zoanthids.

Holbourne Island is a mid-shelf location and macroalgae are not usually a feature of the benthic community. As mentioned above, Holbourne Island had a small and temporary bloom of *Padina* macroalgae that reappeared in October 2020 following its first appearance in October 2019 (Figure 8). This algal species forms low clumps and does not usually smother or shade adjacent hard or soft corals. Camp Island is an inshore location and had a high cover of *Sargassum* macroalgae and hence there were strongly significant differences in algal cover among the locations (Figure 8). The consistent but small presence of *Padina* created only a significant effect of time but not site at Holbourne (Table 3).

Macroalgae cover at Camp Island was at its highest levels since monitoring began with a significant increase to 63 ± 4% during the seasonal peak in October 2020 before dropping to similar levels on average in other post-wet season years (Figure 8, Table 3). However, at the site level, algae cover remained high at E1 and W2 in June 2021 at around 60% and driving significant site, time and site x time interactions over the last four surveys (Table 3).

Sponges were not common in any of these locations (Figure 7) but were most abundant on Camp Island where the cover of this benthic group was 1.2% during the June 2021 ambient survey. The most abundant sponge as the green *Haliclona cymaeformis* (formerly known as *Sigmadocia symbiotica*) that often grew amongst the branching corals at this location. Sponge cover, although low, was variable among sites and surveys leading to significant site, time, and site x time interactions (Table 3).

Table 3. Benthic changes between the four most recent surveys (Oct 2019, Apr 2020, Oct 2020 and June 2021) from the site level data of the two 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.

	CAMP ISLAND			HOLBOURNE ISLAND		
Family/Group	**Site**	**Time**	**S x T**	**Site**	**Time**	**S x T**
Total algae	***	***	***	NS	***	NS
Total sponges	***	**	**	***	NS	NS
Total hard corals	***	***	**	***	NS	NS
Acropora spp.	***	***	***	***	NS	NS
Montipora spp.	***	***	NS	***	NS	NS
Agariciidae	***	NS	NS	NS	NS	NS
Faviidae	*	NS	NS	*	NS	NS
Poritidae	***	NS	NS	***	NS	NS
Total soft coral	NS	NS	NS	**	NS	NS

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

Total hard coral cover had been significantly higher at the Camp Island location than at Holbourne Island following Cyclone Debbie but this trend has reversed in the last two surveys (Figure 9, Table 3). This reversal is in part due to bleaching impacts driving hard coral losses at Camp Island while an equivalent location increase at Holbourne Island with the addition of two sites with higher hard coral cover in October 2020 with the revised monitoring program (Figure 9). Coral loss was most notable at Camp Island W1 and W2 from May 2020 to October 2020 driving site, time and site x time interactions (Table 3, Figure 9). Coral cover reduced by more than 50% going from 27% to 12% and 23% to 10% on W1 and W2 respectively over this six month period post-bleaching. No change was further measured among Camp Island sites from October 2020 to June 2021 (Figure 9).

As mentioned above, the newly established Holbourne Island sites led to a significant increase in overall hard coral for the location and resulted in significant differences across site, time and site x time as well but no differences recorded between 2020 pre-wet and 2021 post-wet surveys (Figure 9, Table 3). Mean coral cover between the 2020/2021 surveys was 9-11% on Camp Island and around 19% on Holbourne reefs with new and old sites combined. With the added sites at Holbourne Island and the coral loss at Camp Island, locations are no longer significantly different in hard coral cover as of October 2020 (Figure 9B).

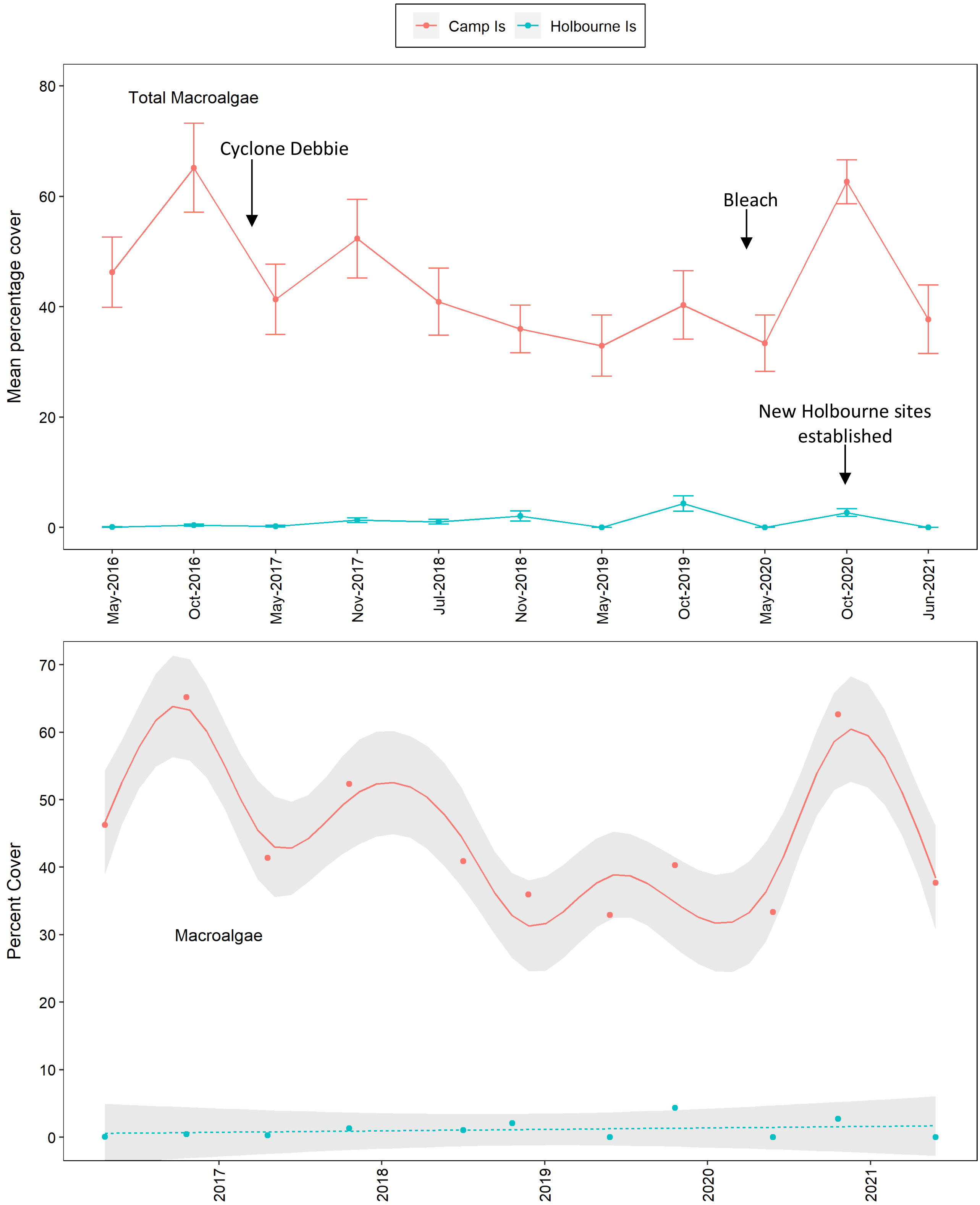


Figure 8. Changes in percentage cover of macroalgae. Graphs show A) grand mean percentage macroalgal cover from the 2020/2021 ambient surveys and from all previous surveys at each island location (five 20m line intersect transects surveyed at four sites for each location). Error bars are standard errors. B) Generalised additive model of trends in mean coral cover. Significant differences among locations are apparent where 95% confidence bands do not overlap.

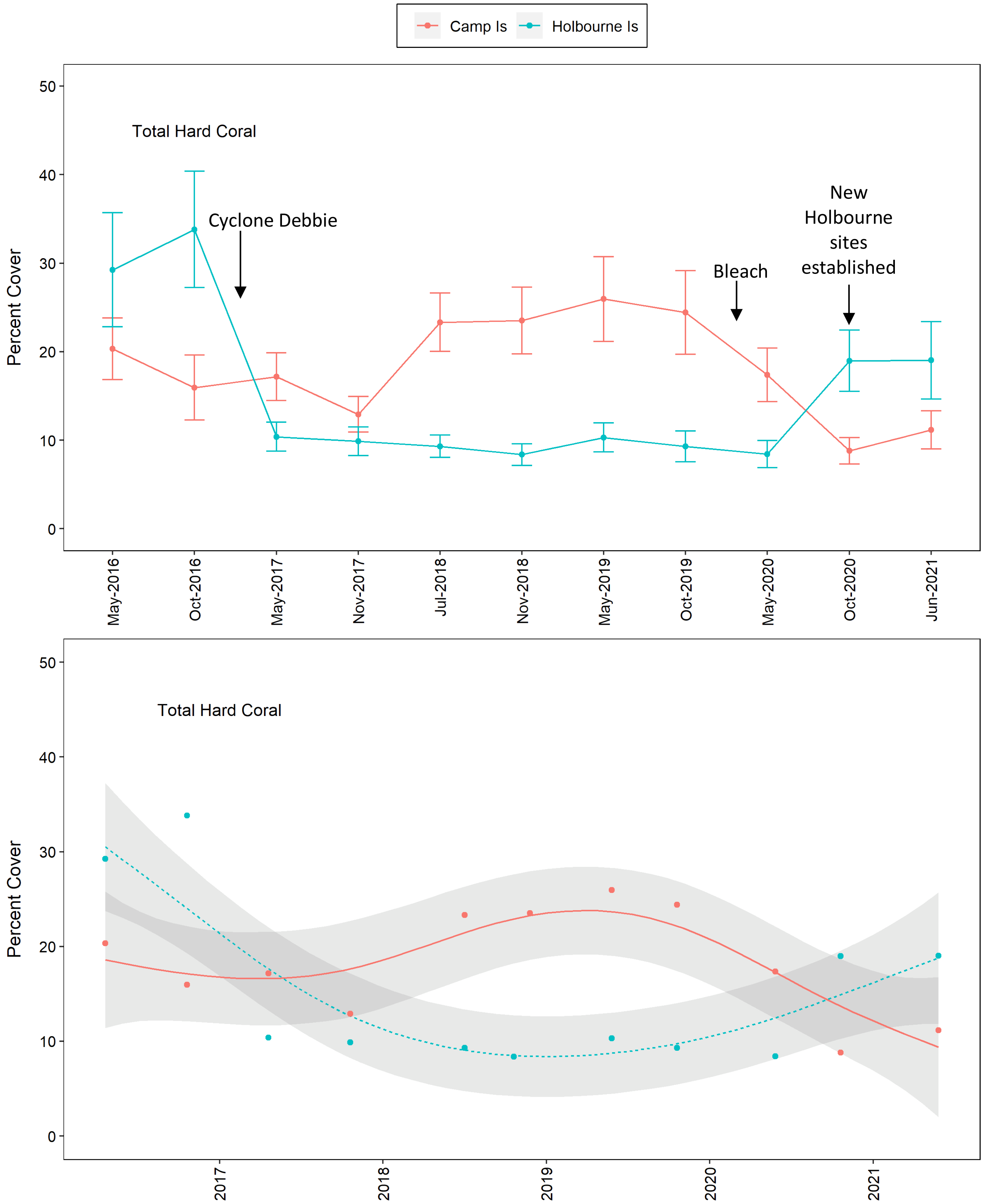


Figure 9. Changes in percentage cover of total hard coral. Graphs show A) grand mean percentage macroalgal cover from the 2020/2021 ambient surveys and from all previous surveys at each island location (five 20m line intersect transects surveyed at four sites for each location). Error bars are standard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

Hard coral community composition is somewhat similar between locations with the new Holbourne sites and the bleaching impacts at Camp (Figure 10). Coral communities at both are dominated by *Acropora* (71% at Camp and 60% at Holbourne) followed by *Montipora* spp. (31% at Camp and 26% at Holbourne of total coral cover) and faviid corals (~10% of total coral cover). In the Holbourne sites poritids were still prevalent with 15% of total hard coral compared to 4% at Camp. Agariciid corals are also still prevalent on Camp Island, but only at one of the four sites, with large colonies of *Pavona decussata* accounting for almost 20% of coral cover at the West 1 site. Mussids, siderastreids, dendrophyllids and merulinids all made up a smaller composition at both locations (Figure 10).

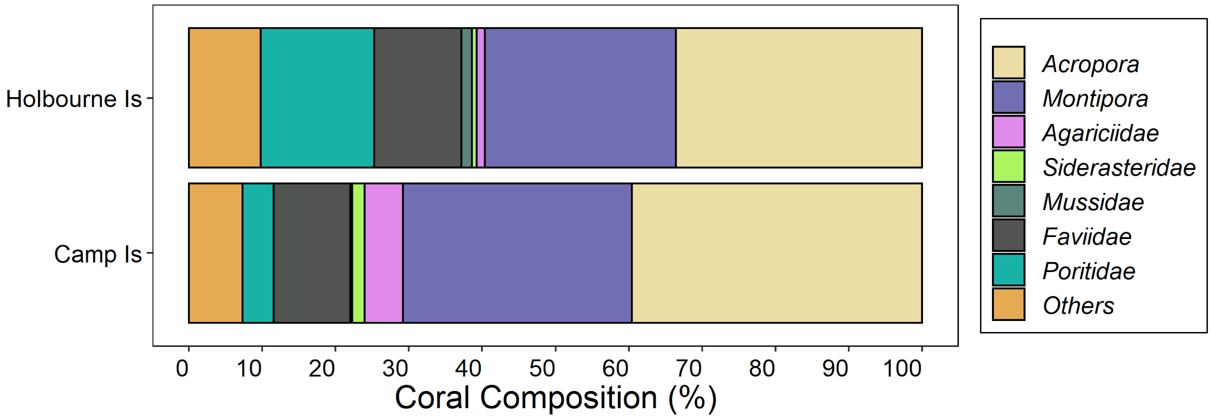


Figure 10. Coral community composition at the two locations for the latest June 2021 ambient survey.

Only *Acropora* and *Montipora* corals showed significant site, time and site x time differences during the last four ambient surveys (Table 3). *Acropora* and *Montipora* both significantly increased at Holbourne due to the newly commissioned sites and significantly declined at Camp due to bleaching impacts in early 2020 (Figures 11 and 12, Table 3). These changes at each location have led to no significant difference in overall *Acropora* and *Montipora* coral cover among locations (Figure 11B and 12B). The increases in these two coral groups at Holbourne were largely a result of the new sites while the existing sites were unchanged with little bleaching-related loss documented at the old sites. This is in contrast to the coral loss at the more inshore location of Camp where bleaching stress appeared to drive the significant declines recorded in these two coral groups from October 2019. Most notable is the decline in *Acropora* since October 2019 to October 2020 from 12.6% to 3.8%, a 70% decline in this coral group related to the bleaching stress event in early 2020 (Figure 11, Table 3). *Montipora* at Camp Island declined significantly from 8.5% to 3.1% over this same period due to bleaching stress (Figure 12, Table 3). Since monitoring began, Holbourne Island has had overall greater abundance of favids, poritids and soft corals while Camp has a larger coverage of agariciids (Figures 13-17). Siderastreids have both been a relatively small proportion of the benthos at both locations (Figure 16). In general, both locations have had relatively stable assemblages of coral families except for the loss of soft corals from Holbourne following Cyclone Debbie with no overall shift in the latest surveys outside of the significant shifts in *Acropora* and *Montipora* in the most recent surveys due to bleaching and site changes (Figures 13-17).

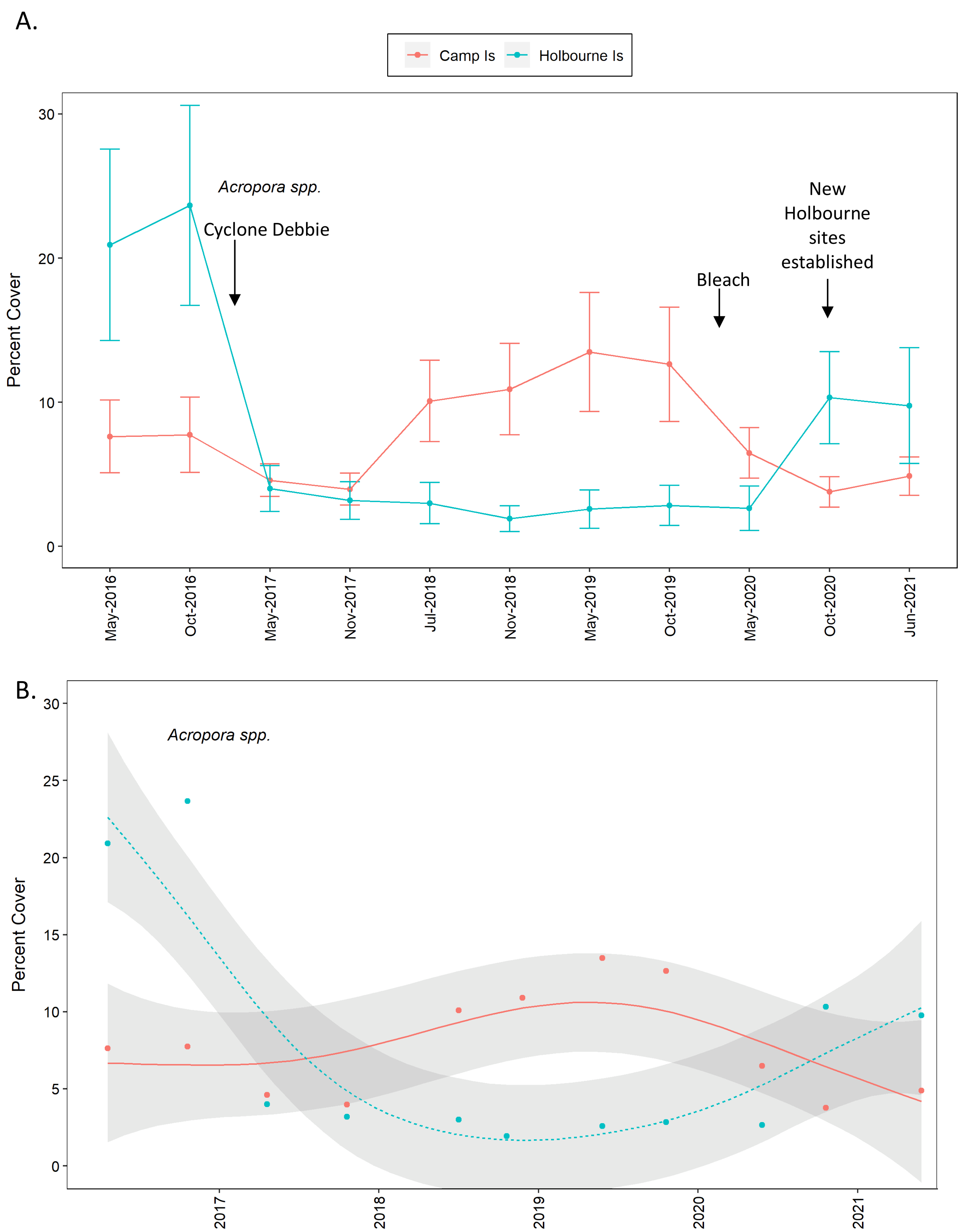


Figure 11. Changes in the cover of *Acropora* corals.

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

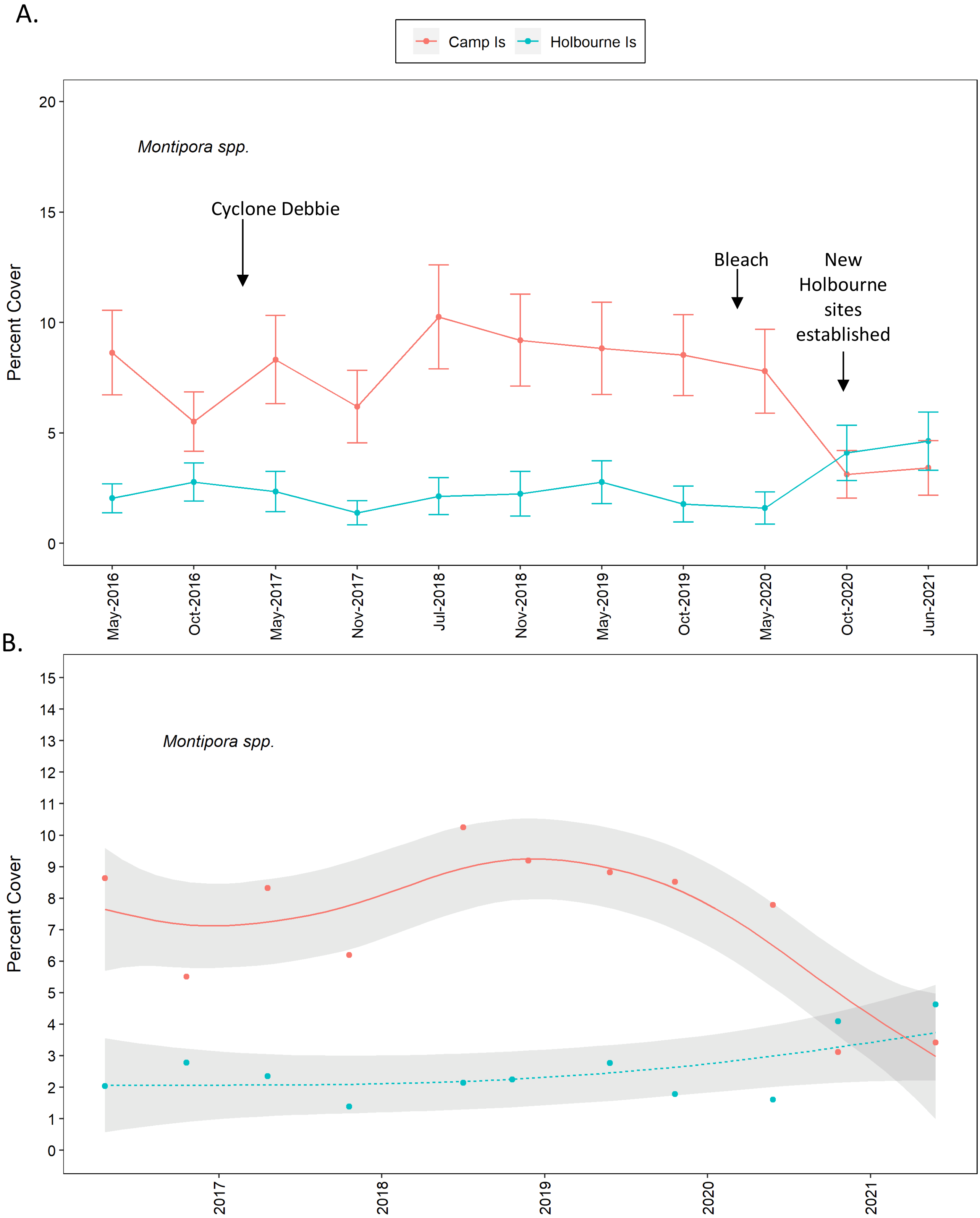


Figure 12. Changes in the cover of *Montipora* corals.
Graphs show A) grand mean percentage benthic cover from the 2020/2021 ambient surveys and from all previous surveys at each island location (five 20m line intersect transects surveyed at four sites for each location). Error bars are standard errors.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

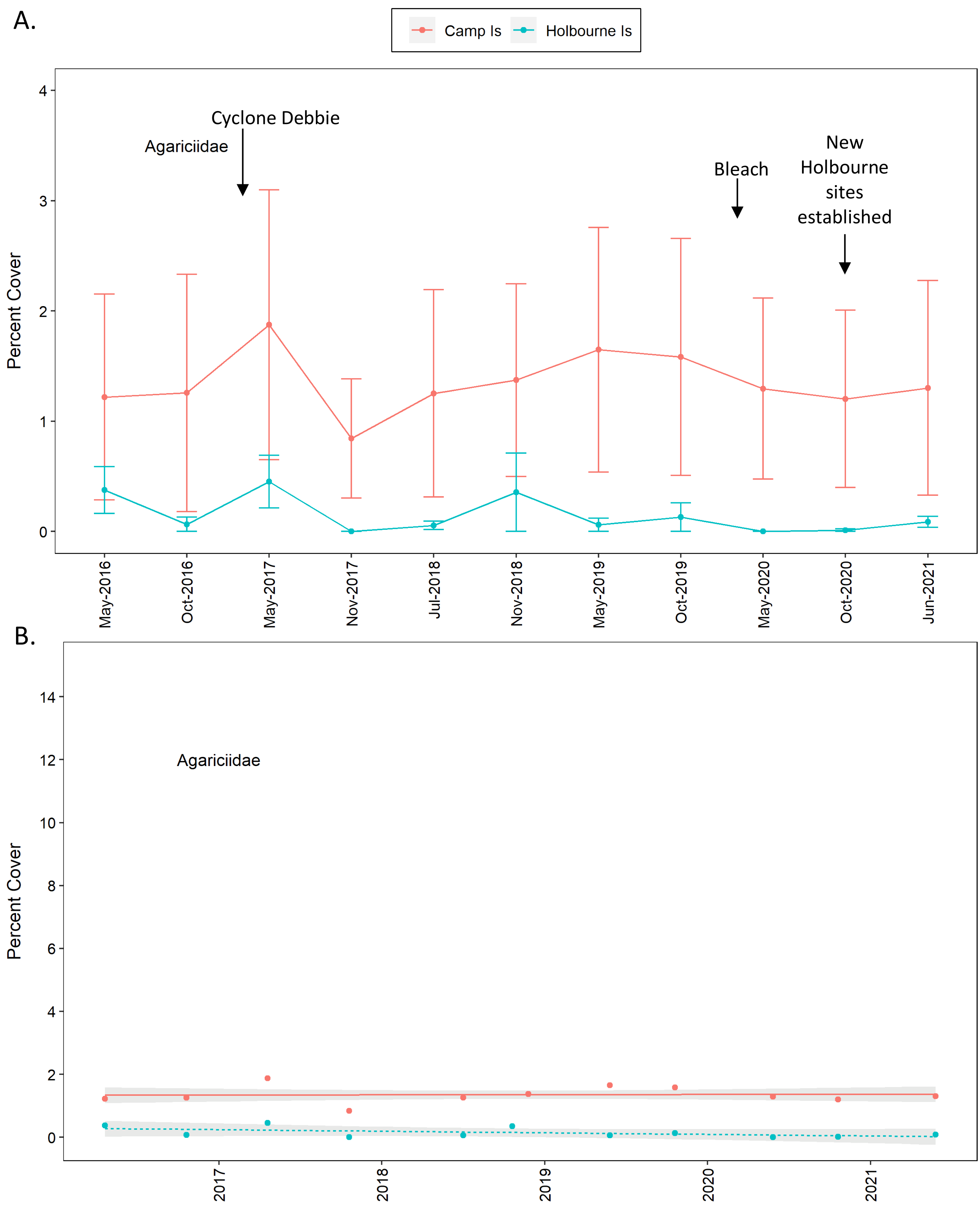


Figure 13. Changes in the cover of Agariciid corals.

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

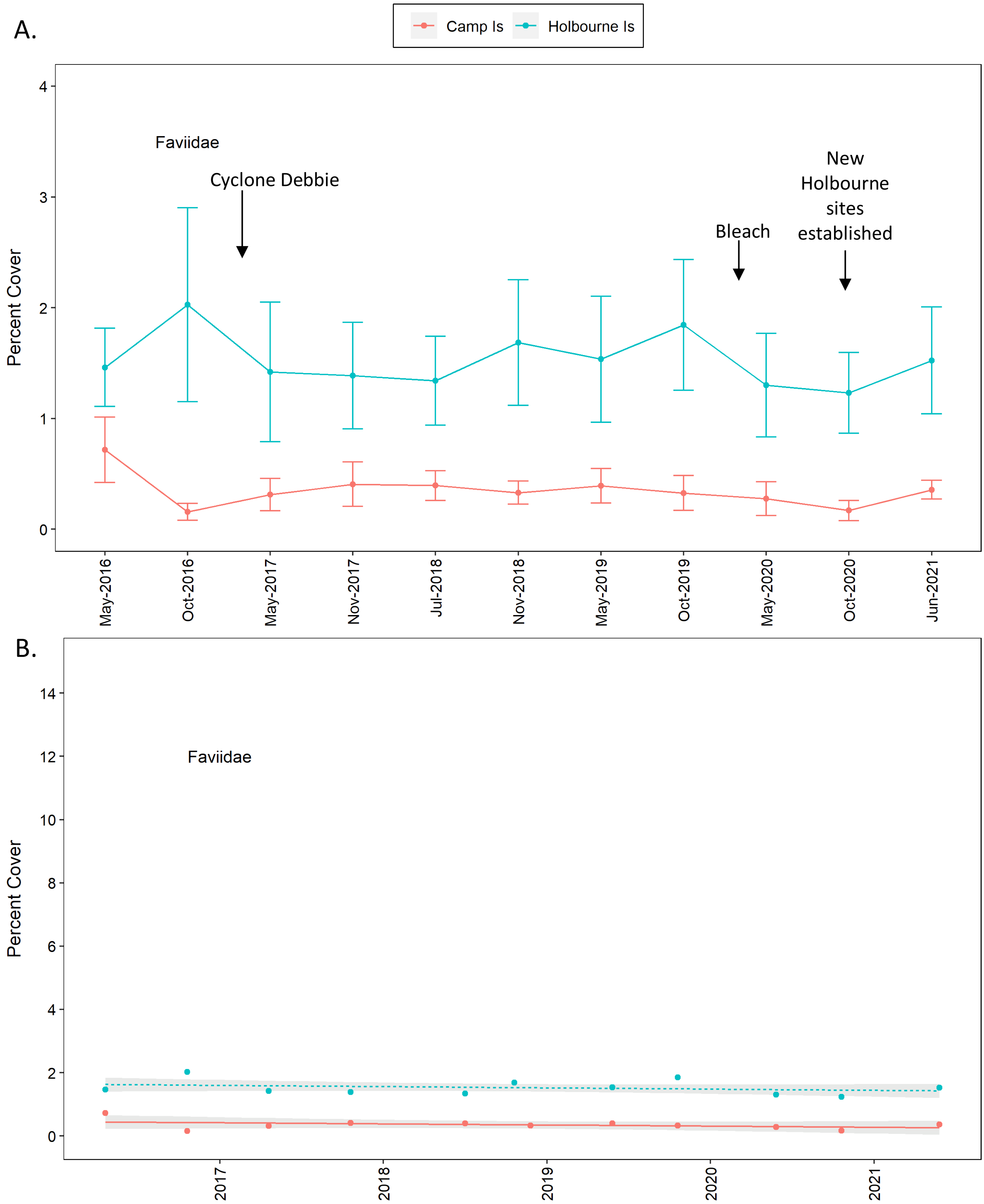


Figure 14. Changes in the cover of Favid corals.

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

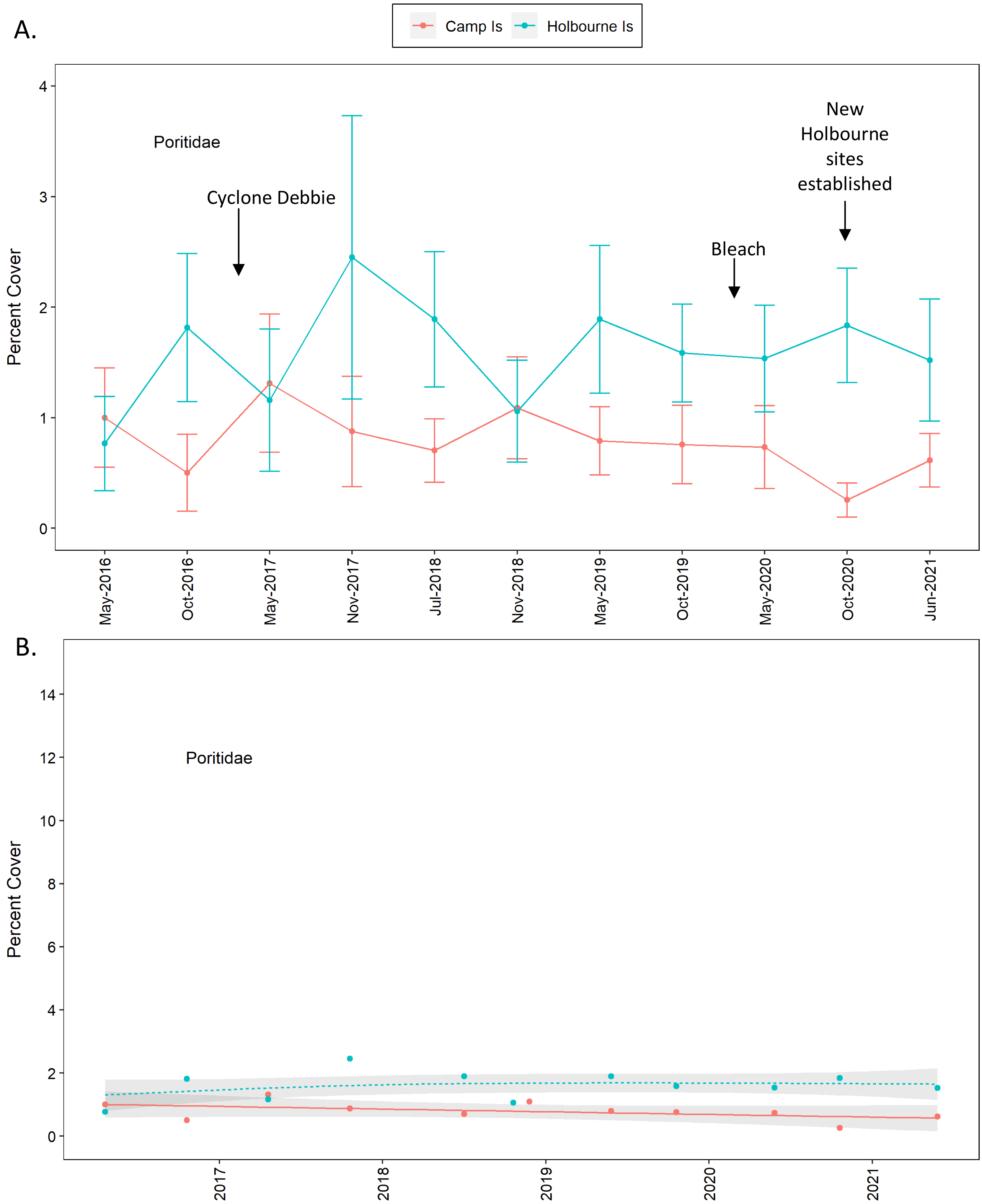


Figure 15. Changes in the cover of Poritid corals.

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

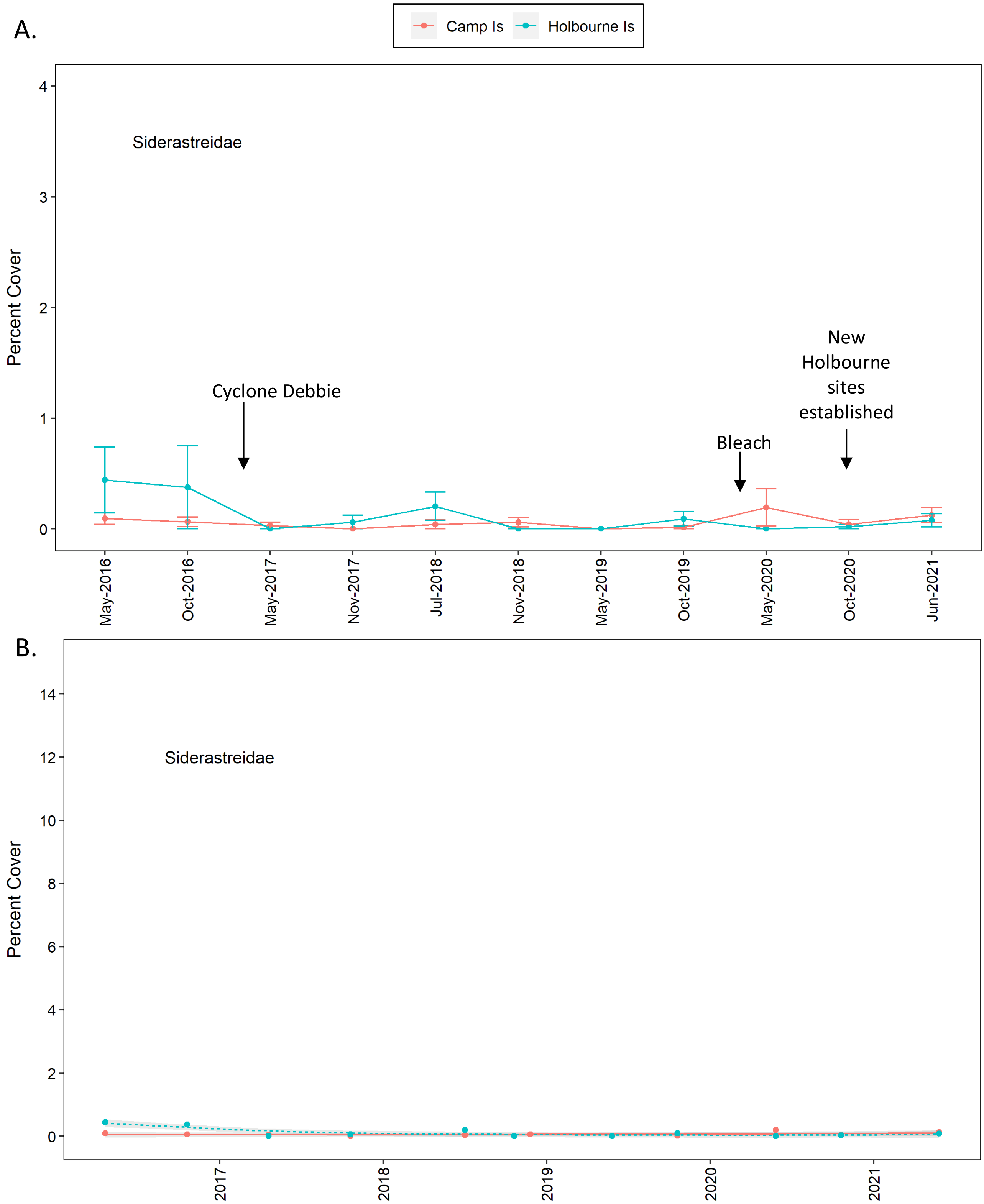


Figure 16. Changes in the cover of Siderastreid corals.
Graphs show A) grand mean percentage benthic cover from the 2020/2021 ambient surveys and from all previous surveys at each island location (five 20m line intersect transects surveyed at four sites for each location). Error bars are standard errors. B) Generalised additive model of trends in mean coral cover. Significant differences among locations are apparent where 95% confidence bands do not overlap.

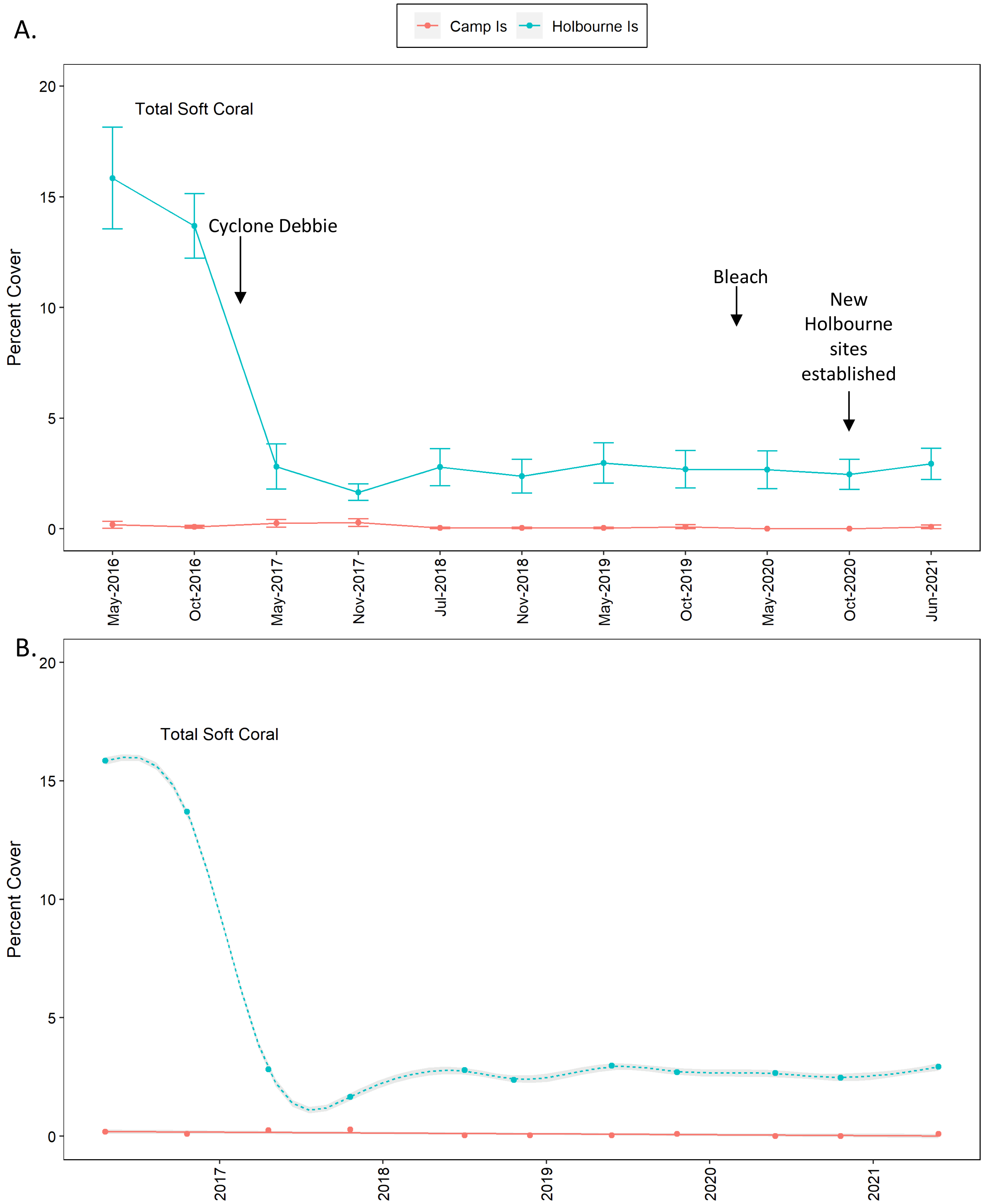


Figure 17. Changes in the cover of soft corals.

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

3.3 Photoquadrat vs Line-intercept method

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

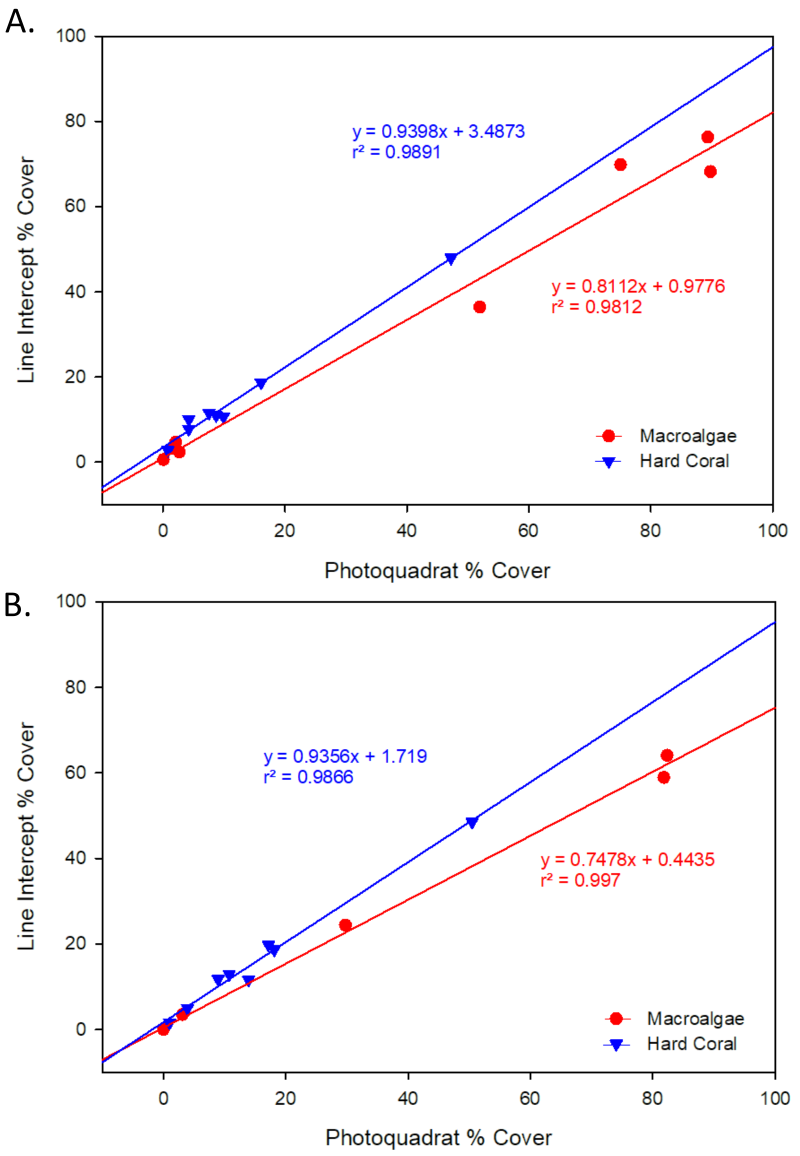


Figure 18. Photoquadrat vs line intercept approximation of macroalgae and hard coral cover. Site data from the two survey locations in A) October 2020 and B) June 2021.

Differences in benthic cover between the techniques were most pronounced at Camp Island (Figure 18). Holbourne Island has very low macroalgae cover to impact on the view of the underlying substrate. Consequently, the difference between the line intercept method and photoquadrats was very small at only 1% and 2% for macroalgae cover estimates and hard coral cover respectively in October 2020. In June 2021, both methods found no macroalgae at any Holbourne Island site and therefore the difference in techniques of 0.50% for hard coral cover is solely the variance between technique rather than an effect from obstruction of view.

Camp Island sites in contrast all have considerable cover of *Sargassum*, particularly during the late spring months when pre-wet surveys occur. The effect of an obstructed view was therefore more significant with a 14% higher estimate of macroalgae by photoquadrats compared to the line intercept method. Somewhat surprisingly, the effect on hard coral cover was much less with only a reduction of 3% hard coral cover estimates due to the macroalgae canopy (Table 4). In June 2021, these *Sargassum* canopies persisted at relatively high levels at all but West 1 where a negligible difference was found between photoquadrat and line intercept macroalgae cover. At the other three sites, overall macroalgae cover was estimated to be approximately 15% greater using the photoquadrat technique. Difference in hard coral estimates between techniques was only on average 1%. At the site level, East 1 coral cover was so low at only 1-1.5% for either technique making the effect of macroalgae perhaps irrelevant. At West 2, hard coral still only varied by 3% between techniques despite the relatively high macroalgae (82% photoquadrat or 59% line intercept; Table 4).

Irrespective of the magnitude of difference in the linear relationship between techniques, a site- and time-of-year specific adjustment will be considered for historic data when running statistical analyses where historic and new data is compared with disparate techniques. Plotted data will continue to show the historic record with a clear delineation from which the change in methodology takes effect. As discussed in earlier sections, the line intercept transect data was used in the present report while other significant changes to statistical techniques were applied. The next annual report (2021/22) will have both the new statistical methods and photoquadrat analysis used throughout.

Table 4. Mean macroalgae and hard coral cover estimates from photoquadrat (PQ) versus line intercept estimates from the site level data of the two locations of the ambient monitoring project. Holb = Holbourne.

October 2020						
Site	**PQ Macroalgae**	**Line Intercept Macroalgae**	**PQ Hard Coral**	**Line Intercept Hard Coral**	**Diff. Macroalgae**	**Diff. Hard Coral**
Holb E2D	2.1	4.7	8.71	11	2.62	2.29
Holb W1D	2.7	2.4	4.22	7.8	0.29	3.58
Holb NE	1.8	3.2	16.09	18.7	1.35	2.61
Holb SE	0.1	0.6	47.23	48	0.52	0.77
Camp E1	89.8	68.2	0.79	2.8	21.59	2.01
Camp E2	52.0	36.4	9.92	10.7	15.56	0.78
Camp W1	75.0	69.8	7.55	11.6	5.25	4.05
Camp W2	89.3	76.3	4.25	10.1	13.03	5.85
June 2021						
Site	**PQ Macroalgae**	**Line Intercept Macroalgae**	**PQ Hard Coral**	**Line Intercept Hard Coral**	**Diff. Macroalgae**	**Diff. Hard Coral**
Holb E2D	0	0	10.76	12.9	0	2.14
Holb W1D	0	0	3.93	5	0	1.07
Holb NE	0	0	18.11	18.7	0	0.59
Holb SE	0	0	50.46	48.6	0	1.86

Camp E1	82.4	64.1	1.00	1.6	18.26	0.60
Camp E2	29.7	24.4	13.91	11.6	5.35	2.31
Camp W1	3.1	3.5	17.16	19.8	0.38	2.64
Camp W2	81.8	58.9	8.93	11.8	22.92	2.87

3.4 Coral Bleaching

A severe temperature anomaly during the early months of 2020 led to a mass coral bleaching event caused by high temperature stress (Figure 6B). A large number of coral colonies from a range of families were either partially or totally bleached as of the May 2020 surveys (Figure 19, Table 5), with some bleached colonies dead or dying but others starting to recover. By October 2020, much of the significant bleaching had subsided with colonies either dead or regaining their algal symbiont at both locations (Table 5-6) . Bleaching relative to coral cover was highest on Camp Island in May 2020 (Figure 19, Table 5, Table 7). Many of the *Acropora* corals on Camp Island that had bleached in May 2020 were partially or completely dead which resulted in a second consecutive decrease in *Acropora* cover from 6.5% to 3.8% between May 2020 to October 2020 (Figure 11). Some of the bleached *Montipora* corals recorded in May 2020 also died back by October 2020 as had parts of some colonies from other coral groups such as pocilloporids, poritids and mussids (Figure 20).

Table 5. Average coral colony health status during the last four ambient surveys by location.

Location	Oct 2019*		May 2020*		Oct 2020		June 2021	
	mean	*se*	mean	*se*	mean	*se*	mean	*se*
HOLBOURNE								
Partially bleached colonies	0.0	*0.0*	15.8	*3.4*	0.0	*0.0*	0.0	*0.0*
Disease damaged colonies	0.0	*0.0*	nr		0.0	*0.0*	0.1	*0.1*
Sediment damaged colonies	0.0	*0.0*	nr		0.0	*0.0*	0.1	*0.1*
COT damaged colonies	0.0	*0.0*	0.0	*0.0*	0.4	*0.2*	0.3	*0.15*
CAMP								
Partially bleached colonies	1.3	*0.4*	37.4	*8.2*	0.1	*0.1*	0.2	*0.1*
Disease damaged colonies	0.7	*0.3*	nr		0.1	*0.1*	0.1	*0.1*
Sediment damaged colonies	0.0	*0.0*	nr		0.1	*0.1*	0.5	*0.2*
COT damaged colonies	0.0	*0.0*	0.0	*0.0*	0.0	*0.0*	0.0	*0.0*

Damaged corals are recorded as mean number per 40 sq m transect. COT=crown-of-thorns; nr=not recorded due to bleaching.
* Note Holbourne Island Oct 2019 and May 2020 mean data are from the two old monitoring sites only

Table 6. Abbot Point fringing reefs: changes in the density of partially bleached, diseased, sediment damaged and CoTS damaged corals between the four most recent surveys (Oct 2019, May 2020, Oct 2020 and June 2021) from the site level data of the two 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.

	CAMP ISLAND			HOLBOURNE ISLAND		
Factor	**Site**	**Time**	**S x T**	**Site**	**Time**	**S x T**
Partial bleaching changes	***	***	***	**	***	***
Coral disease changes	**	***	**	NS	NS	NS
Sediment damage changes	**	**	**	NS	NS	NS

COT damage changes	NS	NS	NS	***	***	***

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

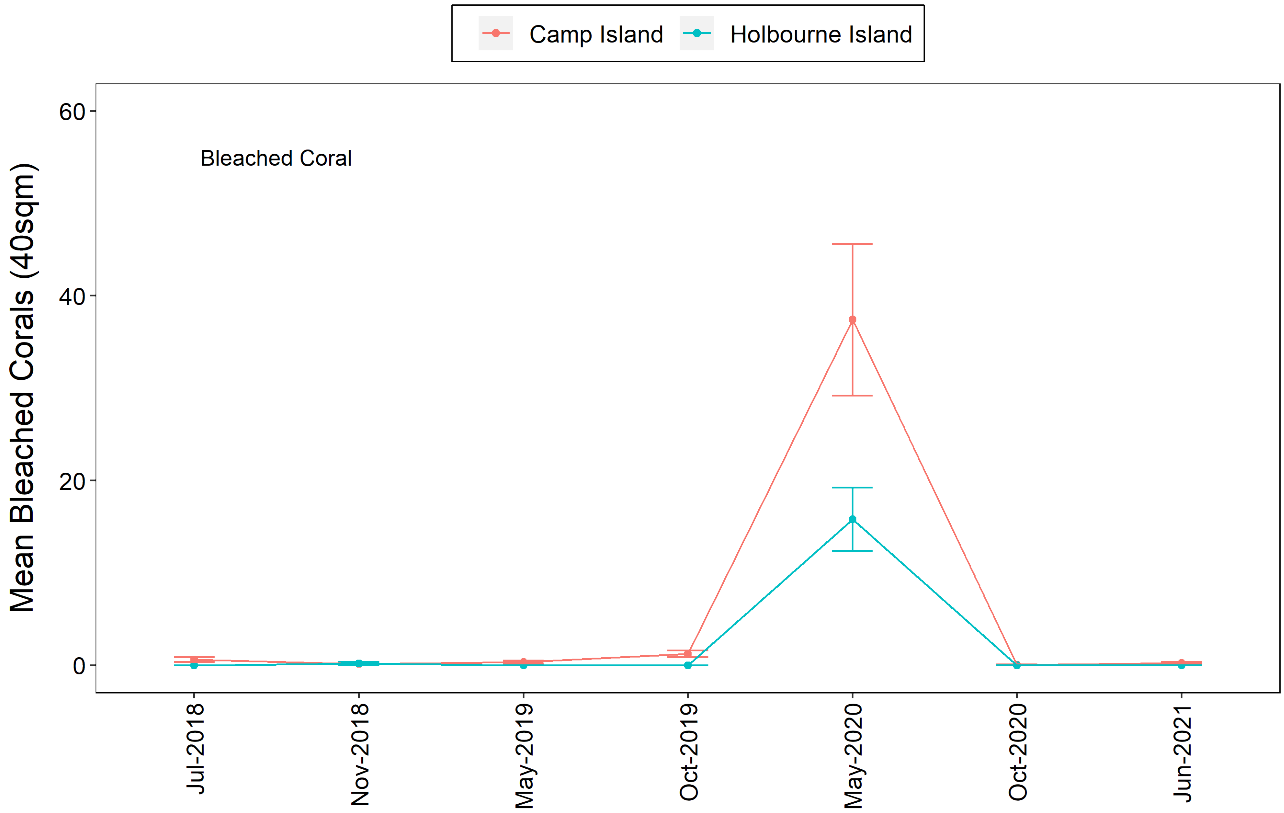


Figure 19. Changes in density of bleached and partially bleached hard coral colonies. Graphs show grand mean density of bleached and partially bleached corals per $40m^2$ from four sites of four 20 x 2m transects in each location from the 2020/2021 ambient surveys and all previous surveys. Error bars are standard errors.

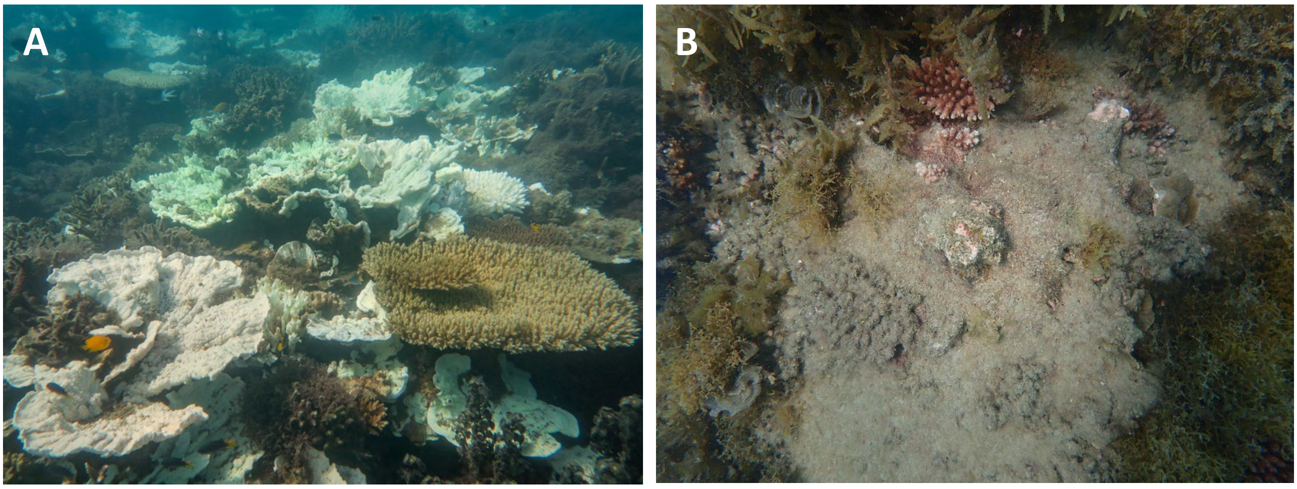


Figure 20. A. Bleached *Montipora* colonies on Camp Island along with some bleached *Acropora* colonies and a few corals that have died from bleaching in May 2020. B. Dead *Montipora* colony with a small healthy *Acropora* colony (upper middle).

3.5 Sediment Deposition on Coral Colonies

Many corals on fringing reefs have some sediment on their surface as a result of natural sediment resuspension and movement during strong winds and/or spring tides. Port related activities such as dredging also have the potential to contribute to sediment in the water column but no port related activities of this sort occurred during the period covered by these ambient surveys. The percentage of corals with sediment load increased in May 2020 immediately after the warm water event in early 2020 at both Camp and Holbourne (Figure 21, Table 7). At Holbourne Island, sediment loads decreased by the October 2020 surveys and remained lower in June 2021 (Figure 21, Table 7). The number of colonies with sediment at Camp Island appears to be a longer term trend of increasing prevalence with no declines since the increase recorded in May 2020 (Figure 21). The depth of sediment on colonies at Camp Island also increased significantly in June 2021 surveys from both October 2019 and October 2020 levels (Figure 21, Table 7, Table 8). As would be expected sediment levels were much lower on the more offshore Holbourne Island locations than in the more coastal Camp Island location (Table 7).

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

Location:	**Holbourne**		**Camp Is.**	
PERCENT OF TOTAL COLONIES WITH SEDIMENT LOAD				
Oct 2019	9.0%		19.3%	
May 2020	20.0%		33.0%	
Oct 2020	5.0%		19.0%	
June 2021	6.0%		26.2%	
MEAN MAXIMUM SEDIMENT DEPTH (mm)				
Oct 2019	0.04	*0.01*	0.13	*0.01*
May 2020	0.10	*0.01*	0.23	*0.02*
Oct 2020	0.03	*0.01*	0.13	*0.02*
June 2021	0.04	*0.01*	0.30	*0.04*

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

Table 8. Abbot Point Fringing Reefs: Changes in sediment depth on corals between the last four ambient surveys: Anova Results

	CAMP ISLAND			**HOLBOURNE ISLAND**		
Factor:	**Site**	**Time**	**S x T**	**Site**	**Time**	**S x T**
Coral sediment changes	**	***	***	NS	NS	NS

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

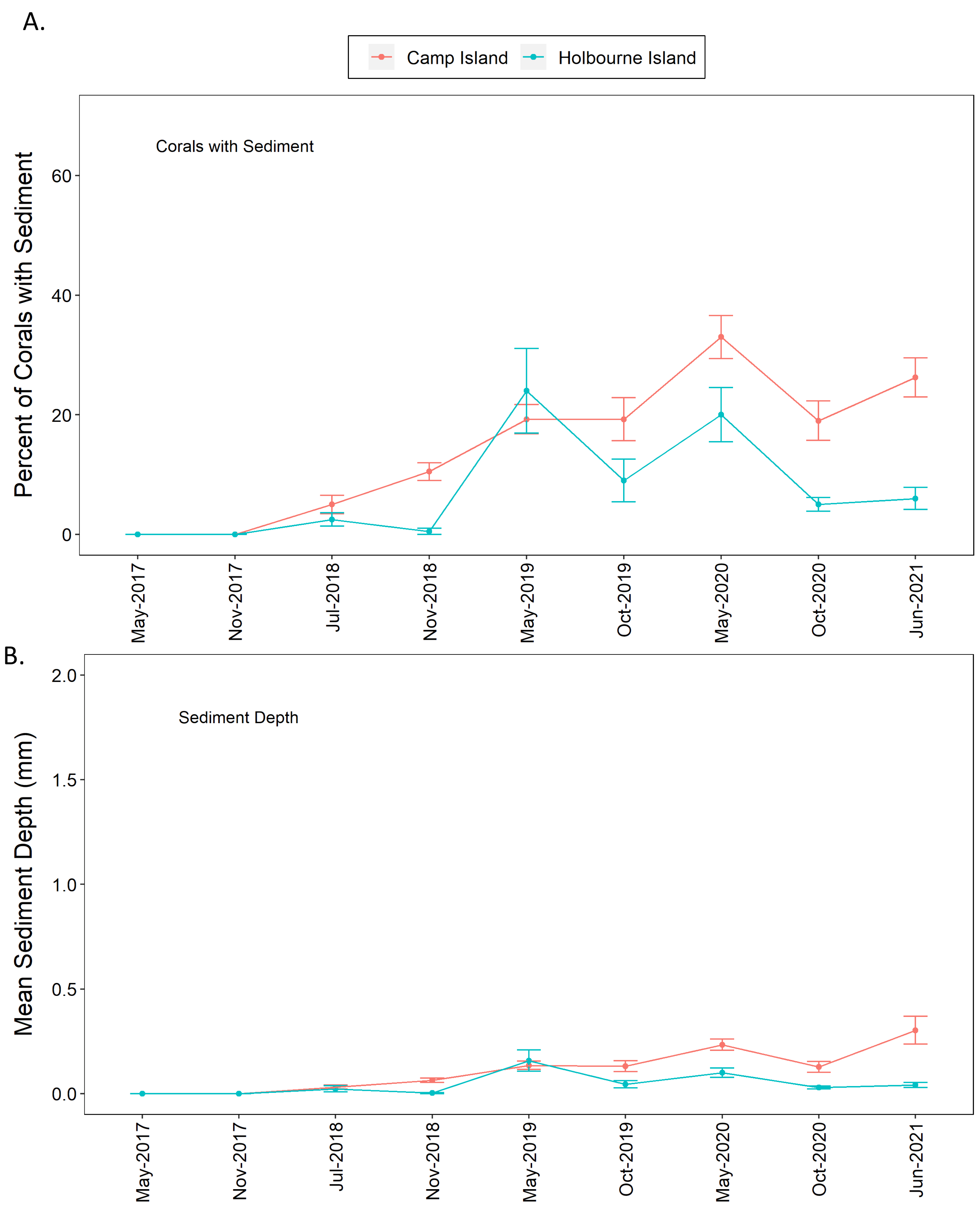


Figure 21. Changes in Number of Corals with sediment load and sediment depth. Graphs show percentage of the 400 coral colonies examined in each location that had measurable sediment on part of the surface during each survey and the mean depth in mm of that sediment for the 2020/2021 ambient surveys and for all previous surveys. Error bars where appropriate are standard errors.

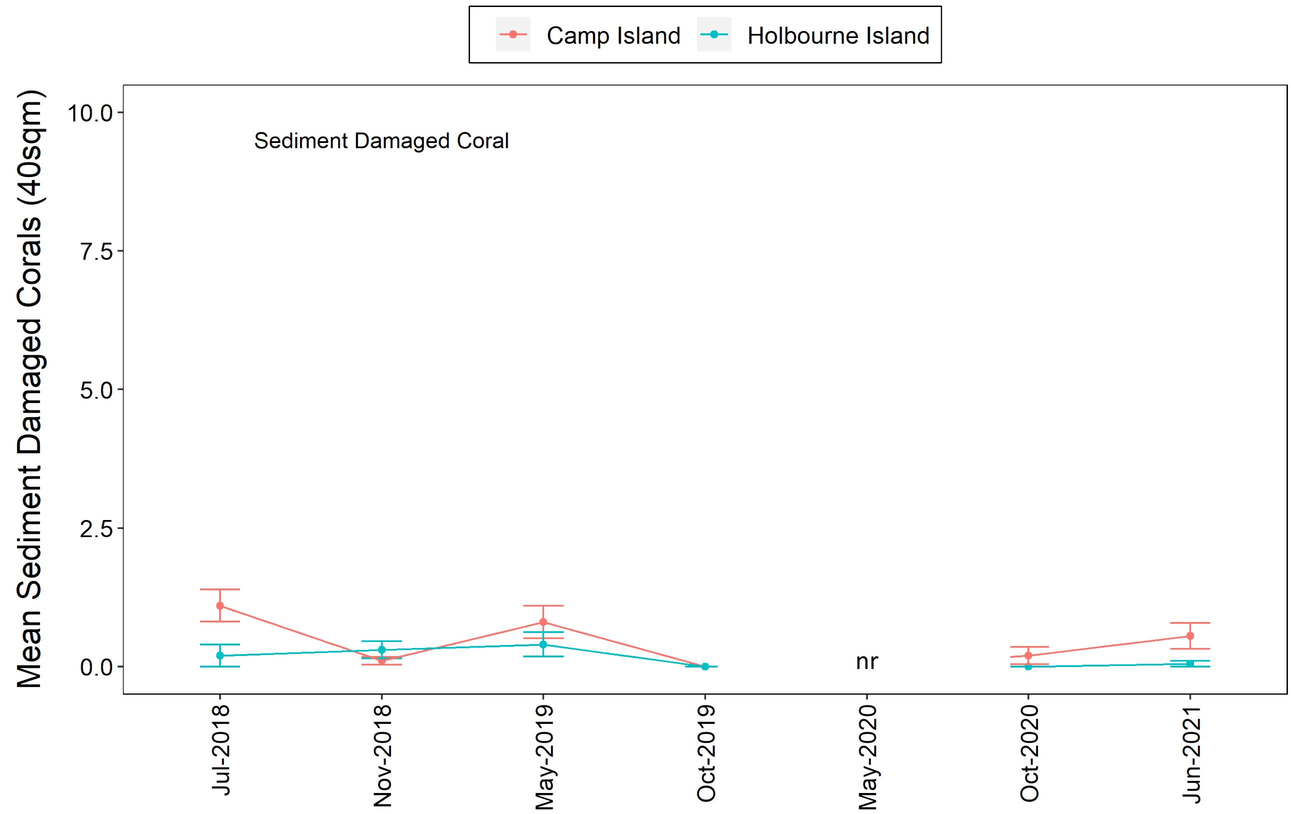
2.6 Sediment Damage and Disease in Coral Colonies

Heavy sediment deposition on living coral can cause patches of mortality on the coral surface. Despite the increase in sediment prevalence and depth in May 2020, October 2020 surveys found no sediment damage on Holbourne Island sites and very low levels on Camp Island (Figure 22). It was not possible to record reliably the coral colonies that were damaged by disease or sediment accumulation during the May 2020 survey because of the high number of bleached corals. Damage scars did not show up on bleached corals even with careful examination.

Small levels of sediment damage at Camp Island were again present in June 2021, not statistically any greater than in October 2020 but a significant increase from October 2019 levels (Figure 22, Table 6). No sediment damage was found at Holbourne in June 2021 (Figure 22). The fluctuations in levels of coral sediment damage on Camp Island corresponds with the increased sediment load also found in June 2021 (Figure 21, Table 7). Corals can remove sediment from their surface and it is only when these processes are overloaded, such as during extended periods of rough weather or during extreme weather events, that any mortality results. One-off measures of sediment depth are useful but do not give an indication of the temporal extent of sediment load which sediment damage may more accurately represent.

A small number of diseased corals are present in most coral reef communities. The coral group most often affected by disease in the Abbot Point region was *Acropora* but a few pocilloporid corals were also found damaged by disease at Holbourne sites (Figure 22). Disease levels were low during the 2019 ambient surveys with a grand mean of 0.3 diseased corals per 40 sq m and disease was significantly down in October 2020 and June 2021 from even this low level (Figure 22, Table 6). No disease was detected at Holbourne in October 2020 and extremely low levels found in June 2021 at this location.

A.



B.

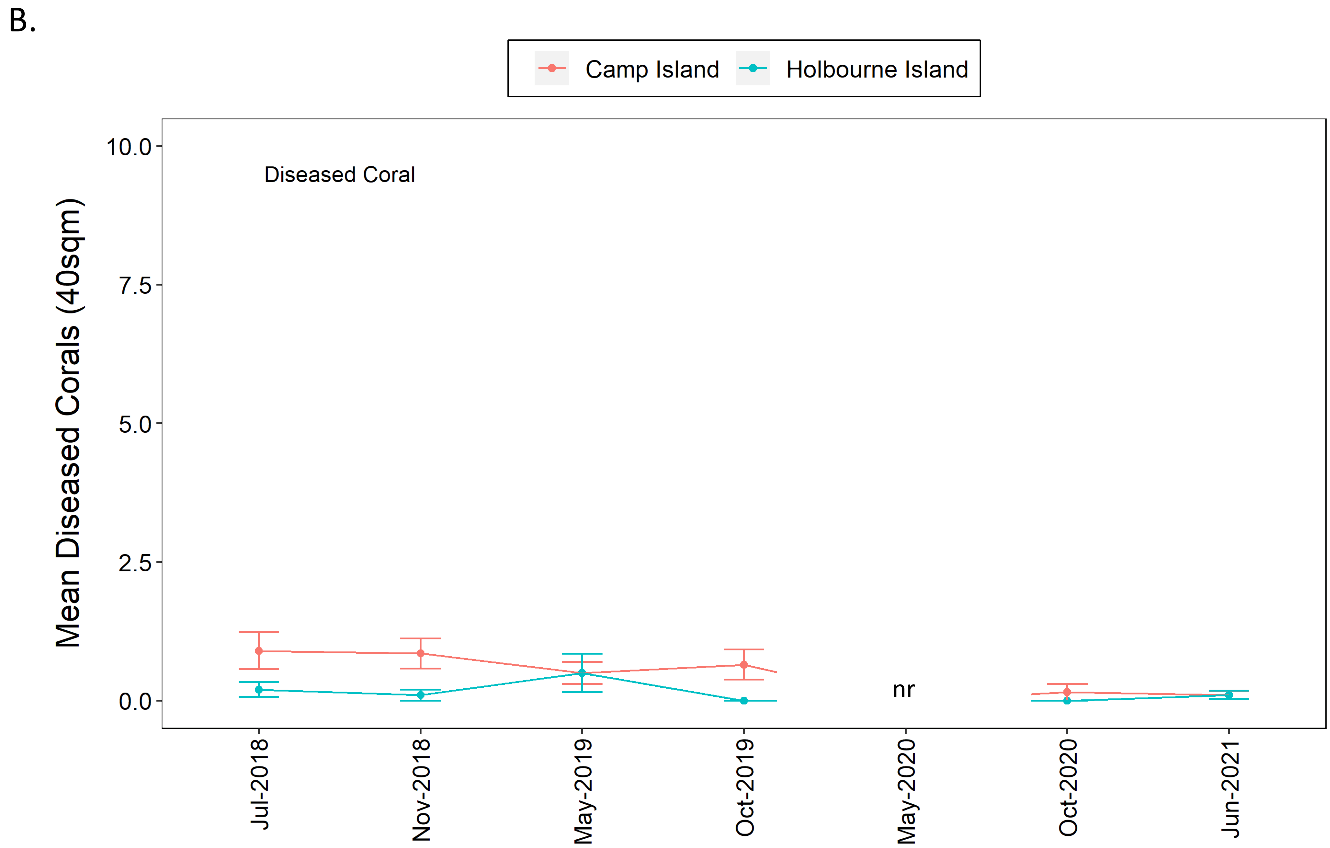


Figure 22. Changes in density of sediment damaged and diseased coral colonies. Graphs show grand mean density of sediment damaged corals (A) and diseased coral colonies (B) per 40 m^2 from four sites of five 20 x 2m transects in each location from the 2020/2021 ambient surveys and all previous surveys. Error bars are standard errors. Not Camp Island is identical to Holbourne data in Oct 2020 and June 2021 and therefore hidden on the plot in (B).

2.7 Other Coral Health Issues

Other coral health issues are also recorded during these ambient surveys. A small number of coral colonies were recorded as damaged due to grazing by the coralivorous *Drupella* snails only in June 2021 at Holbourne but not Camp (Figure 23). This damage was at a very low level with only 1-2 damaged colonies recorded in total for the two locations during each survey. Low *Drupella* numbers were also recorded during previous surveys of these locations except for the October 2017 post-Debbie survey at the Holbourne East sites where 113 *Drupella* snails were recorded in three corals. Given the big reduction in coral cover caused by Cyclone Debbie *Drupella* snails had probably temporarily concentrated in a few remaining coral colonies at this time.

Physical damage was also recorded at several of the locations during these surveys. One of the Camp Island east sites (East 2) is shallow and exposed to the SE winds. There are usually some broken branching coral colonies and turned over *Montipora* colonies at this location during each survey (Figure 23). The broken branches are still living and eventually regrow into new colonies or fuse with the parent colonies.

No CoTS were detected at Camp Island in October 2020 or June 2021; none have been detected at these sites since monitoring began. There is an ongoing low level of CoTS at Holbourne Island with animals observed at East 2 site in October 2020 damaging a mean of 1.6 coral colonies per 40 sqm at that site. In June 2021, the two new sites had a small amount of damage with on average 0.6 and 0.8 colonies damaged per 40 sqm at NE and SE, respectively (Figure 23).

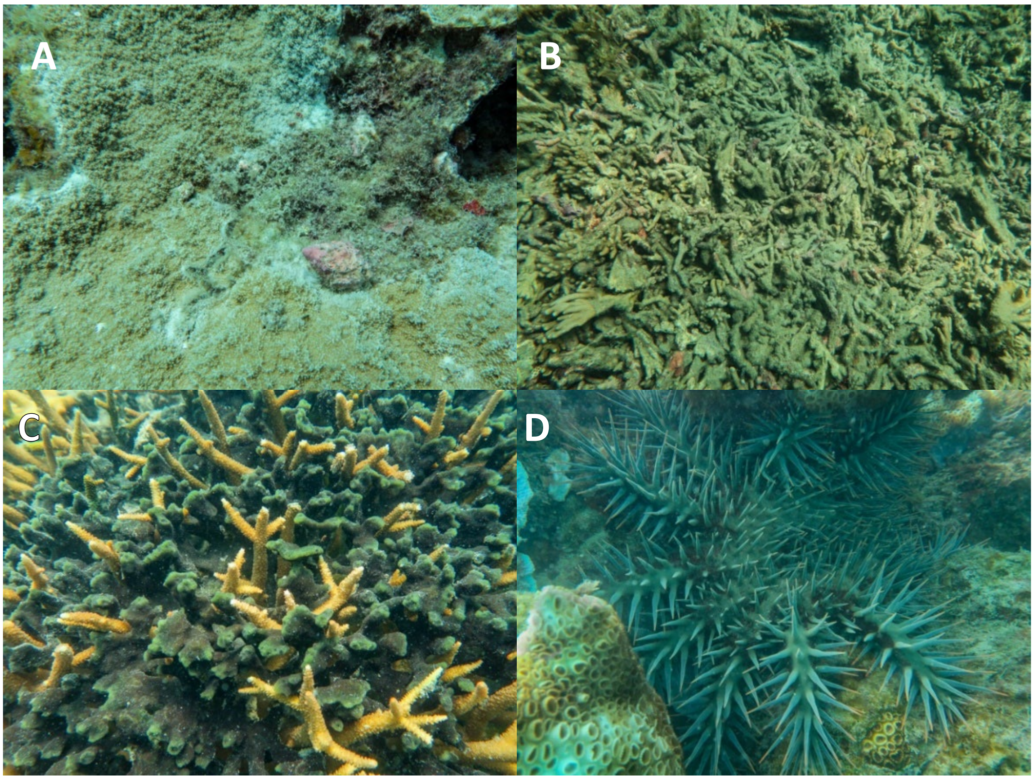


Figure 23. Coral health issues: A. *Drupella* snails grazing on an encrusting *Montipora* coral at the Holbourne deep location. B. Rubble and broken coral fragments caused by wave action in the Camp Island East 2 site. C. The sponge *Haliclona* growing amongst an *Acropora* colony in the Camp Island location. D. A small number of *Acanthaster* sea stars were still damaging corals in the new Holbourne sites in June 2021.

2.8 Coral Recruitment Patterns

Numbers of hard coral recruits less than 10 cm in diameter were not different among locations at either of the October 2020 and June 2021 surveys (Figure 24). Previously, Camp Island had an overall greater number of recruits than Holbourne but new sites at Holbourne and the decline in recruits in October 2020 at Camp Island have likely led to this shift. Grand mean recruit density in October 2020 was 0.25 per sq m at Camp Island, much lower than typical for the time of year at this location and likely related to the early 2020 bleaching event (Figure 24). Recruit density in October 2020 at Holbourne Island was 0.5 per sq m which is in line with previous surveys for this location. Recruit density in June 2021 increased to 1.3 per sq m at Holbourne in part due to the two newly established sites as well as stronger recruitment at the West site. Camp Island mean recruit densities also increased to relatively high levels in June 2021 with 2.2 per sq m (Figure 24).

Holbourne is on the low side and Camp on the high side of means ranging from 0.6 to 1.8 per sq m from surveys of other GBR fringing reef areas using the same method (A.M. Ayling unpublished data). Recruit numbers did significantly increase from the low in October 2020 to July 2021 at Camp but not a change over this period at Holbourne Island (Figure 24, Table 9). Neither locations had significant changes at the site level (Table 9).

The dominant coral groups represented in the recruit population for the Holbourne Island location were *Acropora* and faviids with most coral groups represented to a small extent (Figure 25). The main increase with the new monitoring sites was an increase in Acropora recruits and the introduction of siderastreids and other mixed species at these high coral cover sites. On Camp Island *Acropora* corals were the dominant recruit groups accounting for over 40% of total recruit numbers (Figure 25). In June 2021, a decline in the proportion of *Turbinaria* recruits to 18% led to a greater proportion of *Fungia* recruits accounting for total recruitment at Camp Island. This compares to approximately 33% and 27% of *Acropora* and *Montipora* respectively during the two previous post-Debbie surveys conducted by AIMS (AIMS 2018).

Table 9. Abbot Point fringing reefs: patterns in the density of hard coral recruits between the last four ambient surveys: ANOVA Results

	CAMP ISLAND			HOLBOURNE ISLAND		
Factor:	**Site**	**Time**	**S x T**	**Site**	**Time**	**S x T**
Hard coral recruits	NS	*	NS	NS	NS	NS

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

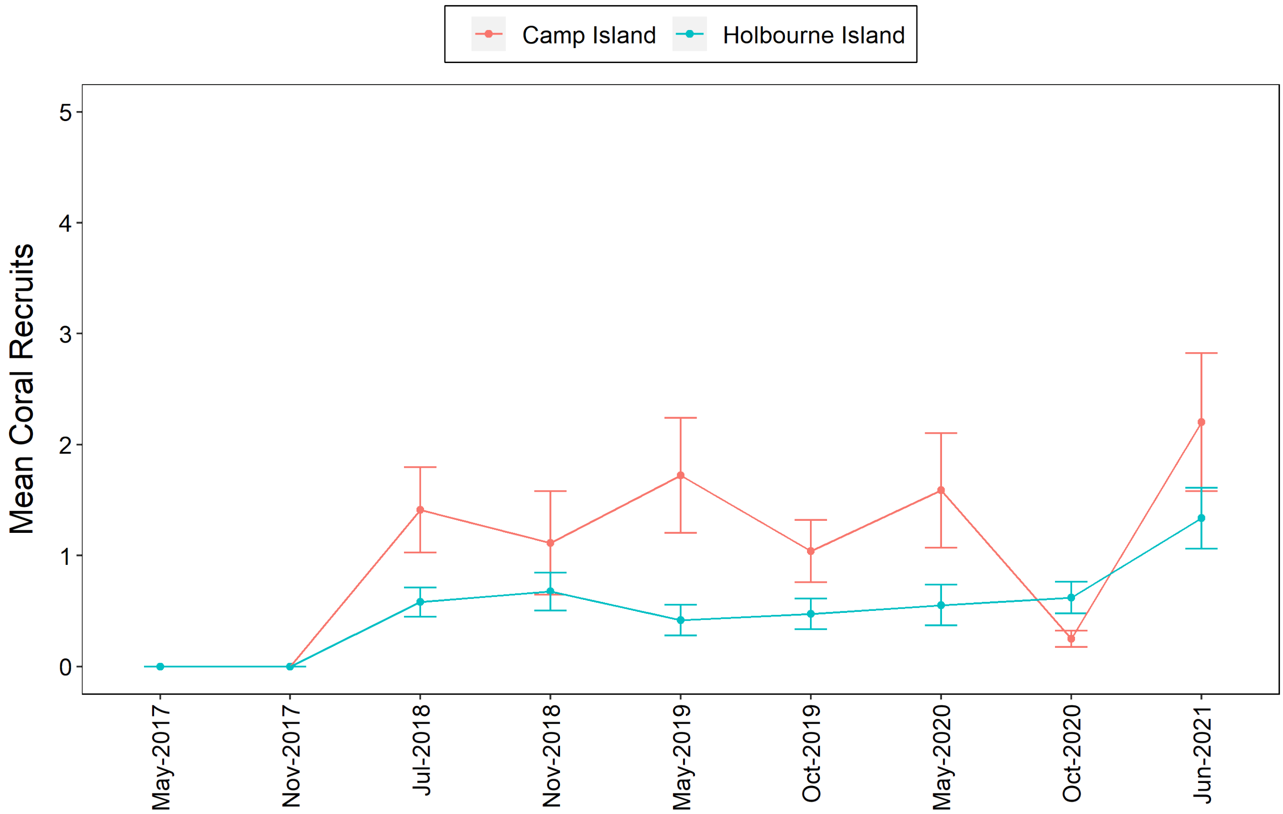


Figure 24. Changes in density of hard coral recruits over the ambient surveys. Graphs show mean density of hard coral recruits per m^{-2} from four sites in each location for the past nine ambient surveys. Error bars are standard errors.

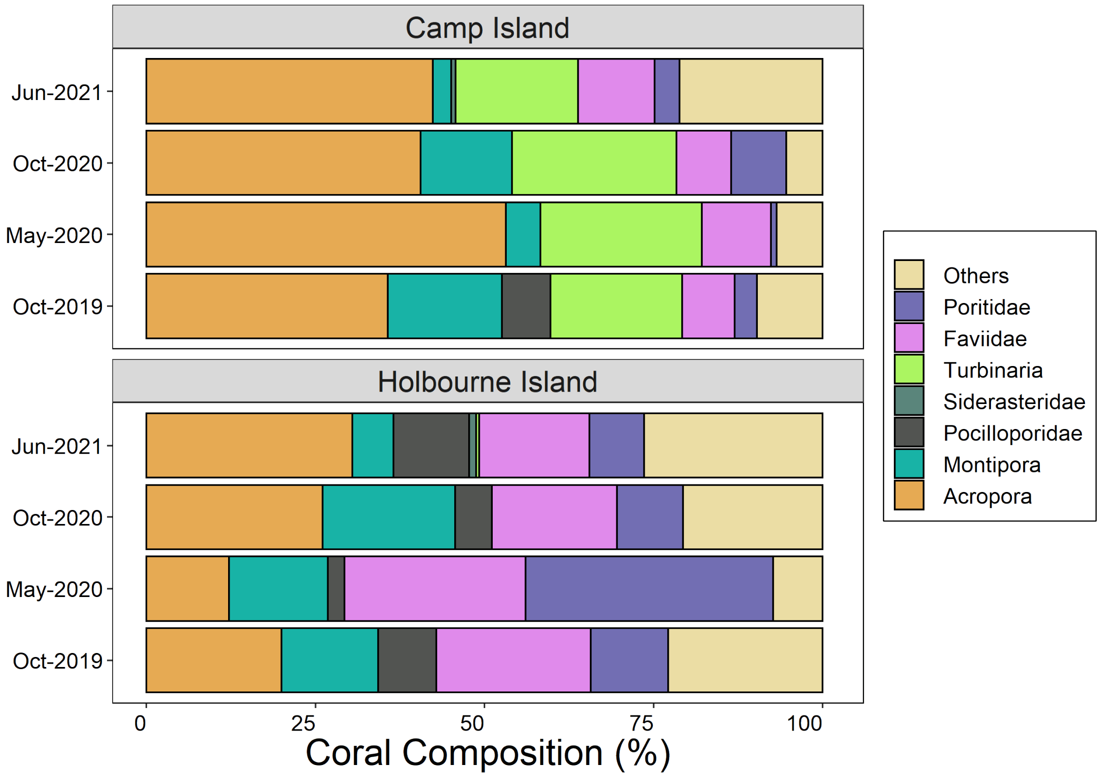


Figure 25. Composition of the hard coral recruit population in the two locations over the last four ambient surveys.

2.9 Coral Community Indicators

The Reef Report Card uses a series of indicators to provide an unbiased scale of overall reef condition and resilience. The full reef report card uses five indicators to derive report card scores (Thompson et al. 2016) but two of these require multiple annual observations and other information and are not used here. This follows the precedent set by AIMS in their report on the first four Abbot Point ambient surveys (AIMS 2018). The three indicators used were: Coral Cover; Juvenile Density and Macroalgae Proportion. For details of methods for these indicators see AIMS (2018) and Thompson et al. 2016). Note the coral cover recorded and reported in this report at both locations since 2018 uses the line intercept method and therefore may show slight differences in final scores compared to coral cover estimated from photoquadrats (the AIMS method). A comparison of photoquadrat versus line intercept for each benthic category is under way and will help explain any differences between score results between those shown in Table 10 and those incorporated into the regional report card by AIMS in the 2019/20 period. Future NQBP monitoring will be carried out using the photoquadrat method and coral cover estimates and scores will be adjusted based on this method review.

At the time of the October 2020 survey the Holbourne Island sites had improved from 'very poor' in October 2019 to 'poor' reef index in October 2020 (Table 10). The improvement in score was driven largely by the reduction in macroalgae at Holbourne from the previous year's peak. By the time of the June 2021 survey macroalgae cover was largely absent and the reef index improved to 'moderate' despite relatively low recruitment over the last 12 months very little increase in coral cover. The Camp Island reefs were rated 'very poor' in both October 2020 and June 2021 due to the low coral cover caused by the coral bleaching event, high macroalgae cover and low recruitment.

Table 10. Reef condition and indicator values during the last two ambient surveys.

Location	Survey	Coral cover	Macroalgae proportion	Juvenile density	Coral cover score	Juvenile score	Macro-algae score	Overall Index
Holbourne Island	Oct 2020	21.4%	5.4%	1.3	0.28	0.10	0.47	0.28
	June 2021	22.0%	0.0%	2.2	0.29	0.17	1	0.49
Camp Island	Oct 2020	8.8%	76.4%	1.4	0.12	0.11	0	0.08
	June 2021	11.2%	37.7%	4.5	0.15	0.34	0	0.16
Regional Mean	Oct 2020	15.1%	40.9%	1.3	0.20	0.10	0.23	0.18
	June 2021	16.6%	25.3%	3.3	0.22	0.25	0.50	0.32

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

2.10 Photomosaic Trials

Trials into utilising new technologies to enable the photomosaic mapping of benthic coral cover at transect sites was performed as part of the June 2021 surveys at Camp Island. Camp Island was selected due to its consistent overall good water quality for an inshore location and for the potential parallel challenges that its high macroalgae canopy may create for photomosaic-based monitoring tools.

Photomosaic quality varied among sites. Higher macroalgae cover and canopy height, particularly at East 1, led to misalignment in the stitched imagery where movement of macroalgae between overlapping photos caused software uncertainty and the resulting gaps in the final image output (Figure 26). In fact, any water motion or surge even during the benign field conditions (<10 knots of wind) led to transect tape movement which also led to some misalignment issues when you zoom to finer scale resolution (Figure 27). While not an issue at Camp Island, low visibility at other locations, in particular at the Victor and Slade Islet monitoring locations in Mackay would restrict the use of this approach or impede entirely the ability to assess coral cover during most survey periods.

As an additional communication tool, the imagery is extremely valuable to relay in situ conditions however, it does come with other challenges and limitations. Firstly, the imagery requires an additional diver to collect during regular monitoring surveys. It would not be possible to utilise the photomosaic output as an alternative to divers because other metrics used in the ambient long term coral monitoring program such as sediment damage and disease, sediment depth, coral recruits and more cryptic organisms including *Drupella* and CoTS would not be detected or able to be recorded using this type of technology alone. Overall, the technology provides a valuable means to communicate about overall benthic cover and condition, but misses the more nuanced detail required from in-water diver assessments.

Figure 26. Photomosaic trials at Camp Island in June 2021 showing a bird's eye view of transect 5 at East 1, East 2, West 1, and West 2 from left to right. Gaps in the imagery are almost entirely due to the presence of macroalgae which creates stitching issues due to movement between photos. Note macroalgae cover is typically higher during pre-wet Oct/Nov surveys.

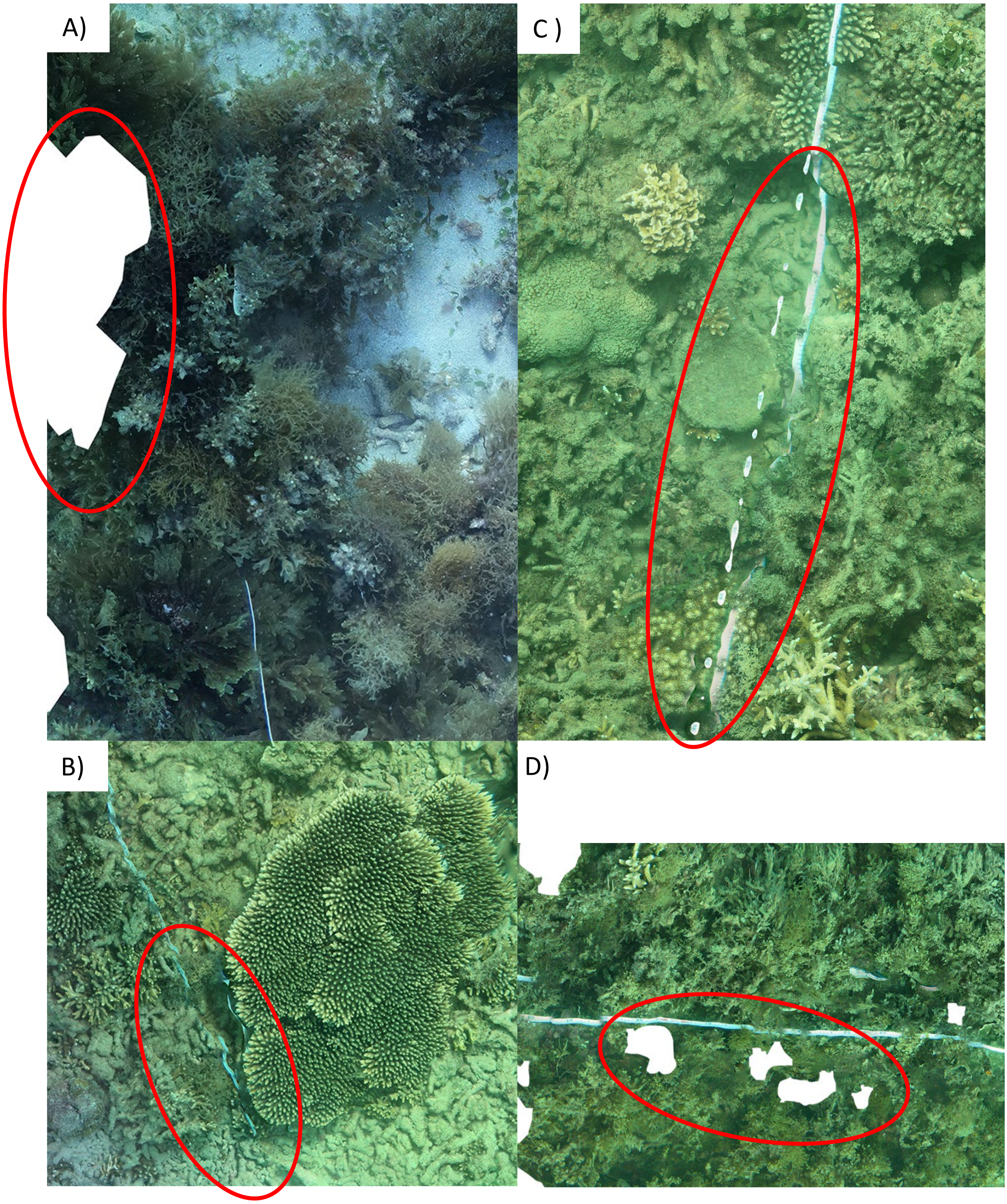


Figure 27. A close up view of photomosaic imagery stitched from each representative transect at Camp Island, June 2021 sites A) East 1, B) East 2, C) West 1, and D) West 2. Examples of gaps in imagery and misaligned transect tapes are circled in red and are a result of water movement during image capture.

2.11 Benthic Community Images

Examples of the benthic community structure at each location and examples of coral health impacts are provided in Figure 22 to Figure 39.

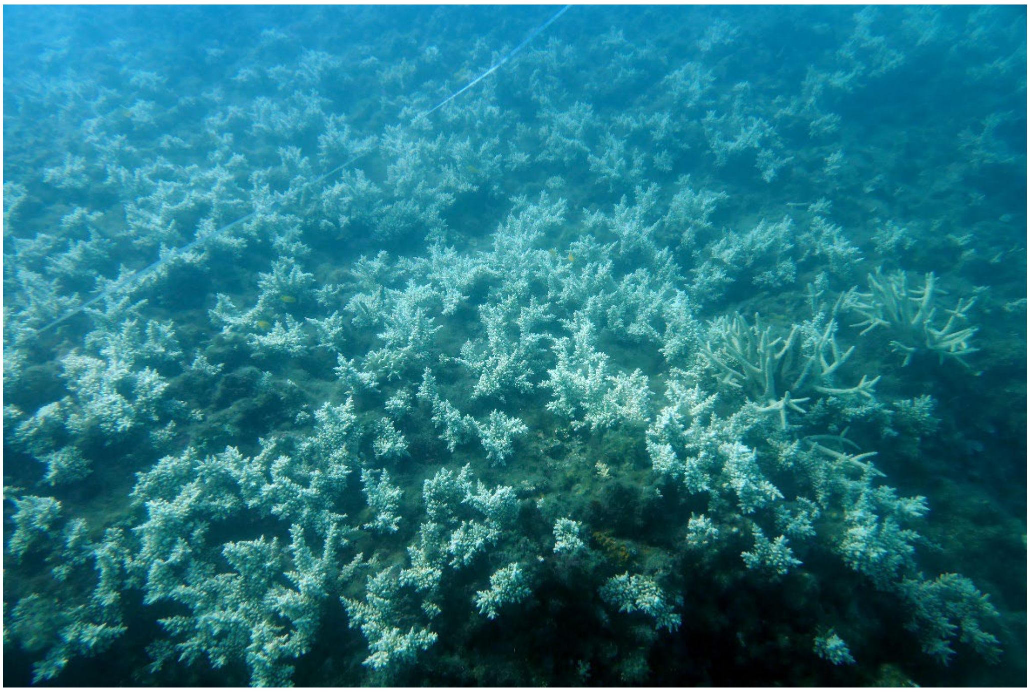


Figure 28. Persisting signs of bleaching recovery with pale *Acropora* coral at Holbourne Island East location during the October 2020 ambient survey.

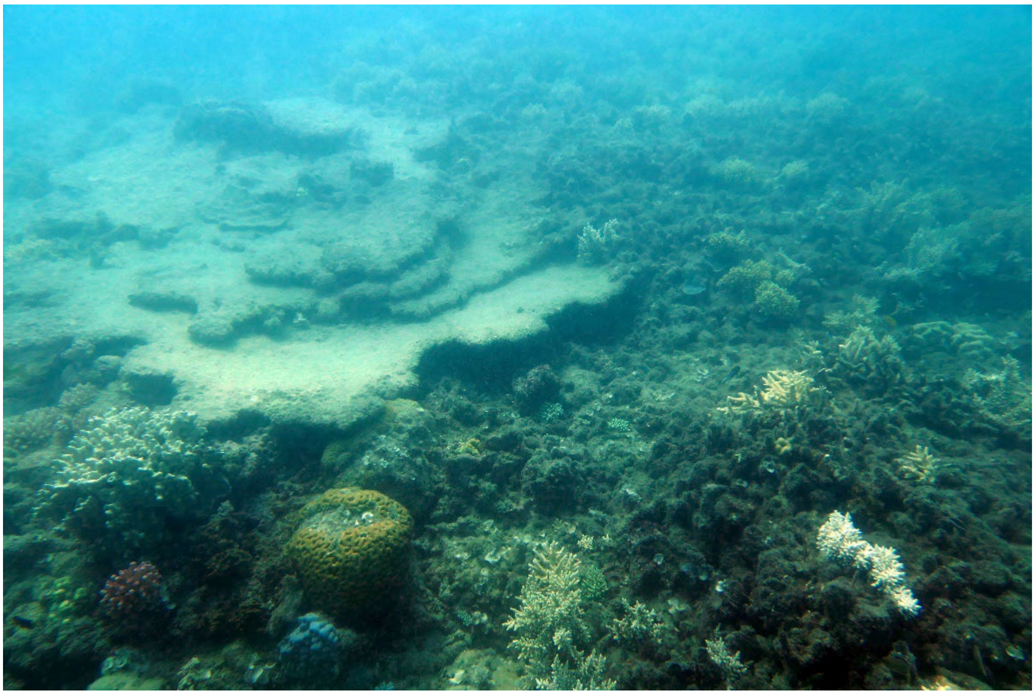


Figure 29. Some coral mortality evident at Holbourne deep locations following the May 2020 bleaching event.

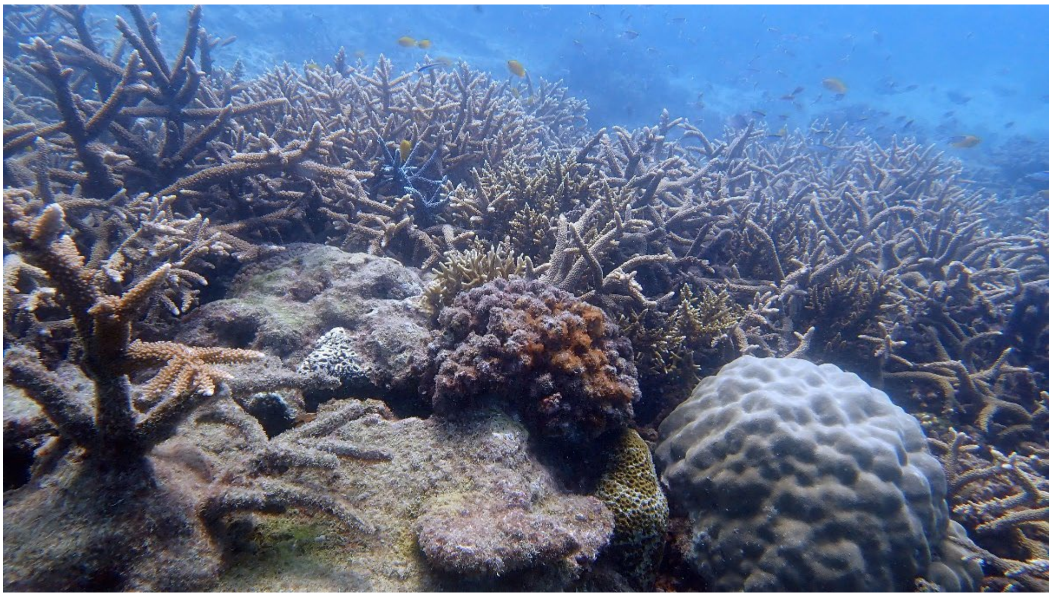


Figure 30. Coral assemblage at the new Northeast (NE) Holbourne site established to replace shallow Holbourne sites which had <2% coral remaining.

Figure 31. Good coral cover and diversity at the new Southeast (SE) Holbourne site setup in October 2020.

Figure 32. Seven to eight mantas were observed at the manta cleaning station at the East site in October 2020 with sitings also during June 2021.

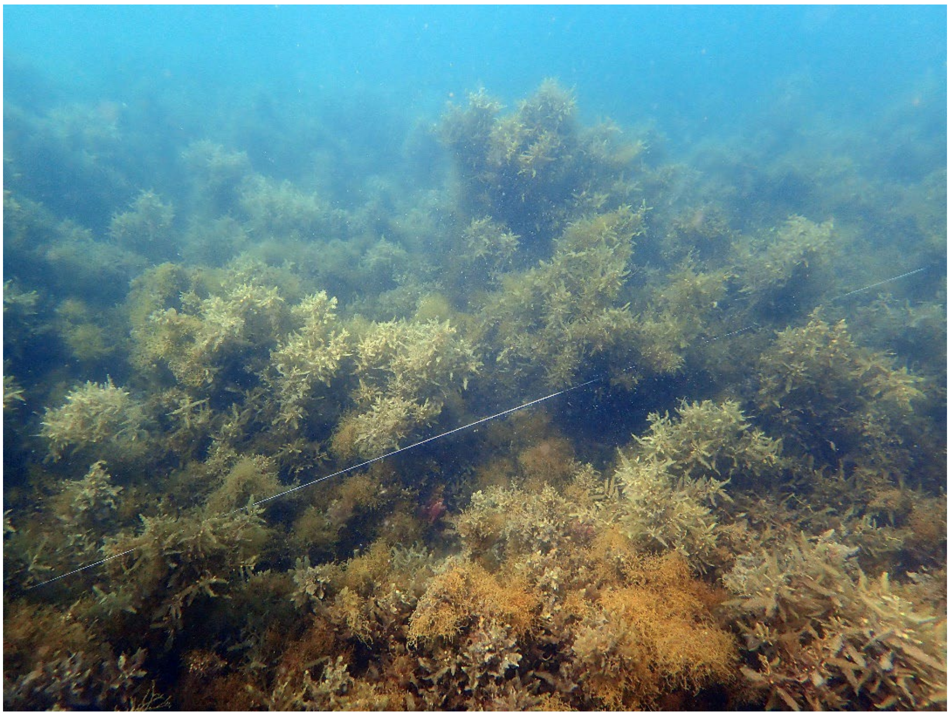


Figure 33. Dense forest of *Sargassum* macroalgae at the East 1 Camp Island site in October 2020. Macroalgae canopy was less substantial during the May 2020 survey, a typical seasonal cycle at this location.

Figure 34. Regular wave exposure at the East 2 site leads to regular presence of turned over colonies (middle left) and rubble amongst coral macroalgae stands typical at this site.

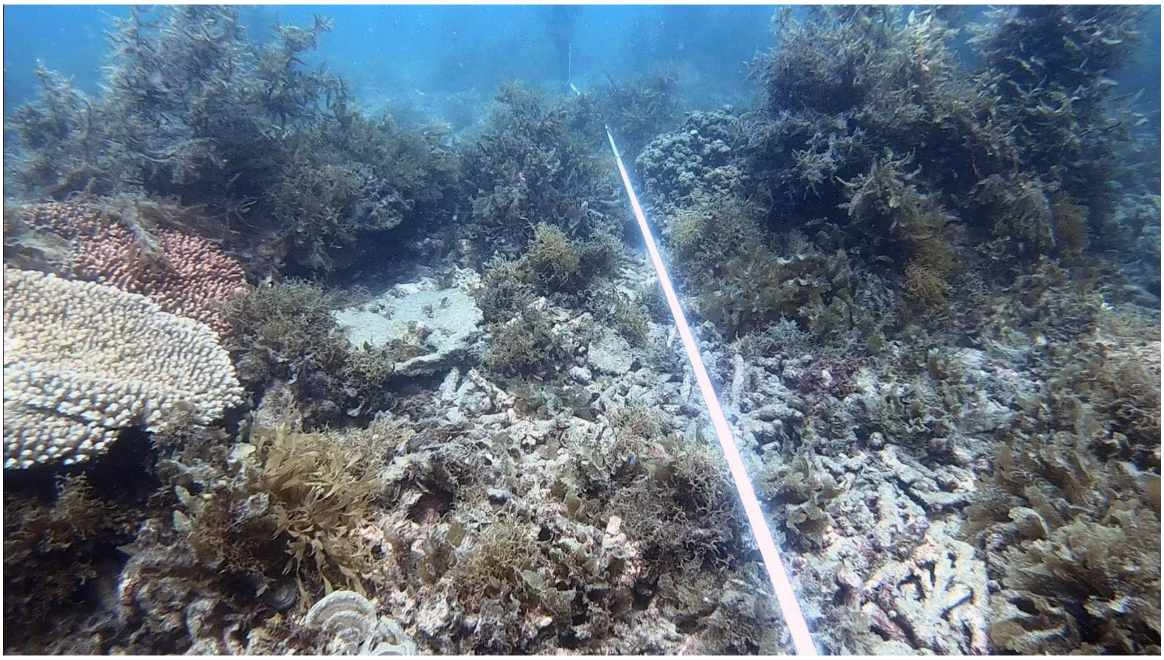


Figure 35. Some healthy *Acropora* plate corals amongst dead *Montipora* and rubble along an East Site 2 transect.

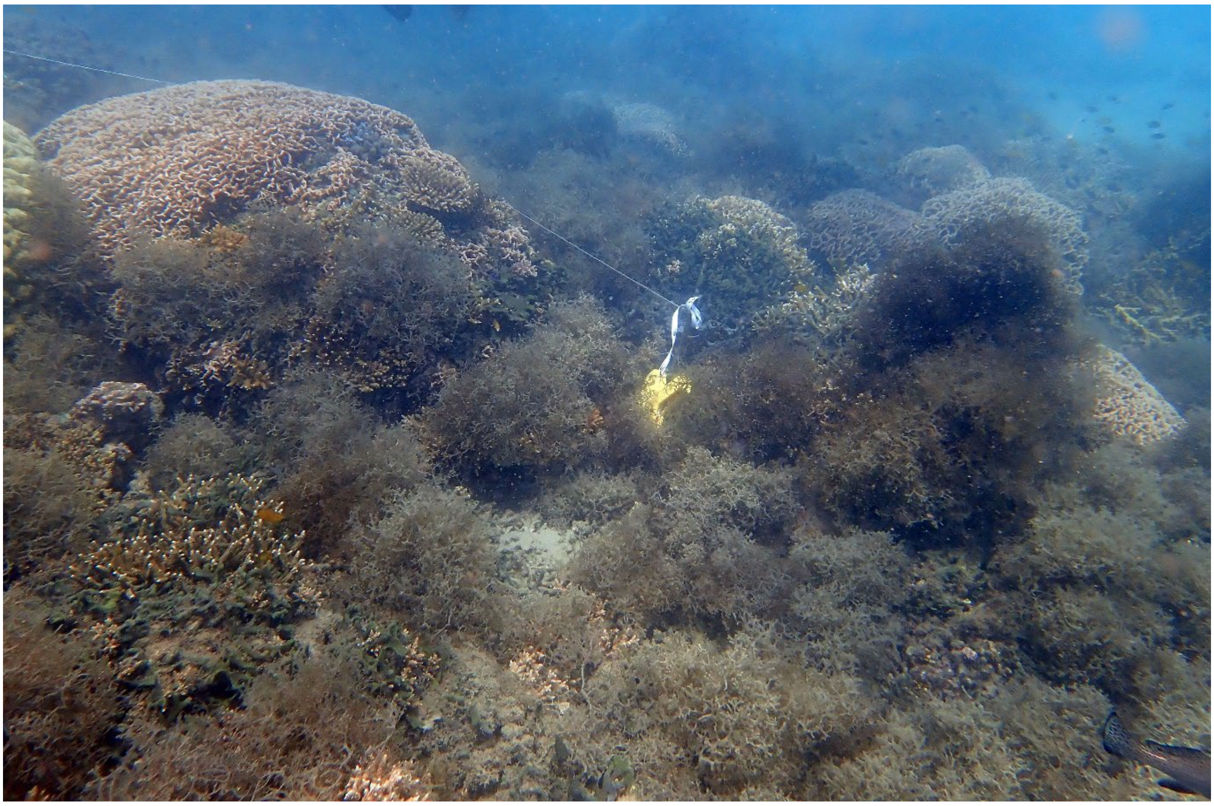


Figure 36. High macroalgae cover amongst *Pavona* and *Acropora* colonies at Camp Island site West 1.

Figure 37. Healthy colony of *Pavona decussata* at the West 1 Camp Island site.

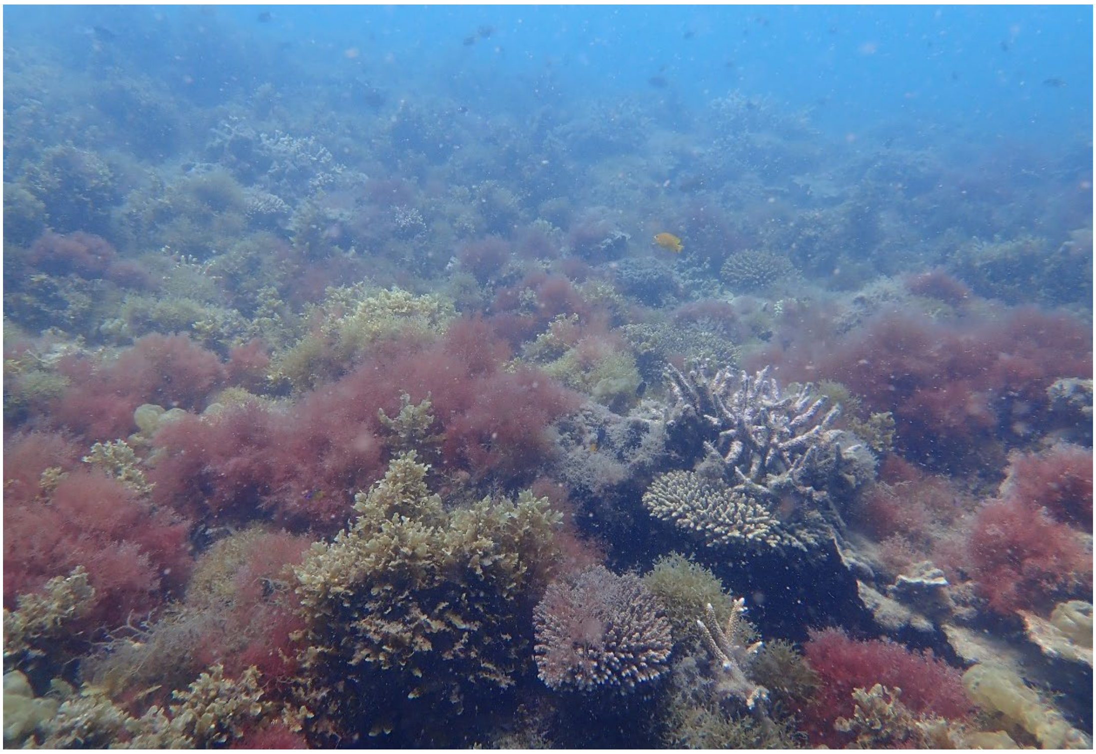


Figure 38. A substantial red/brown algal bloom that was nearly half a metre thick at West Site 2.

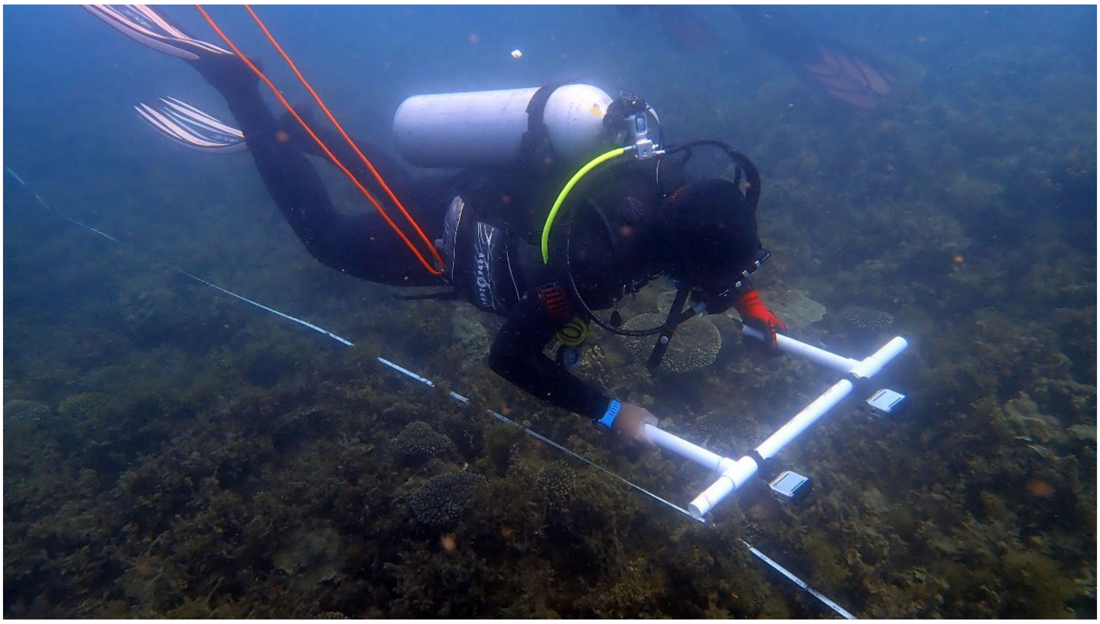


Figure 39. Photomosaic trials using diver swum overlapping image capture with a tethered GPS to the surface at West Site 2.

4 DISCUSSION

4.1 Benthic Cover during the 2020/21 Ambient Surveys

Overall, the 2020/21 ambient coral surveys at Abbot Point found 1) further significant declines in coral cover at the inshore Camp Island sites due to the early 2020 mass bleaching event, and 2) the adjusted site design at Holbourne Island with two new monitoring sites led to an increased representation of live coral cover at this location. The existing Holbourne Island sites did not have the same measurable decline in coral cover likely due to the less extreme water temperatures and duration of the bleaching event at this location.

Sites were originally selected at Holbourne Island according to the AIMS inshore fringing reef sampling protocol with transects in two depth strata: 2m below LAT and 5m below LAT. This is appropriate on inshore reefs where turbid water leads to strong depth stratification of reef communities but is not ideal on less turbid offshore reefs such as around Holbourne Island. The AIMS long-term reef monitoring protocol of a single depth stratum at about 8m below LAT was recommended as more appropriate around this more offshore island. Coral communities on the SW face of Holbourne below the 5m depth stratum were less impacted by Cyclone Debbie and a deeper stratum would have documented this. Another issue with site selection around Holbourne Island is that all the original sites are on the South and West facing sides of the island with no sites on the NE or SE face. Recommendations were acted upon for Holbourne sites to be in a single deep stratum incorporating two existing deep sites (E2, W1) on the SW face of the island and two new deep sites on the NE and SE face of the island to give more balance to the overall reef community condition monitoring. This report has detailed the first results of the two new sites as part of the long term monitoring dataset. Care was taken to assess how the new sites may alter the long term trends in location information. Holbourne sites, NE and SE, increased the overall coral cover by about 10% for this location compared to assessing the old sites alone. The coral assemblage is also more diverse and representative of hit mid-shelf location and provides a better baseline from which further impacts or recovery can be measured at the appropriate depth stratum.

The coral cover at the four sites at Camp Island had all significantly declined in this year's surveys following the mass bleaching event. Coral cover ranged from only 1.5% at East 1 to a high of 19.8% at West 1 following the loss of *Acropora* and *Montipora* colonies. Macroalgal cover in October 2020 was also back to the high levels last recorded in October 2016 with all but West 1 around 70%. This higher than normal macroalgal cover may in part be fuelled by the release of nutrients on top of typical levels due to localised coral necrosis following bleaching stress feeding a larger than normal *Sargassum* bloom. Macroalgae did decline back to more typical seasonal levels in June 2021 for this location. Sites were selected by AIMS haphazardly from the surface on areas of substrate suitable for corals (AIMS 2018) but a slight repositioning of several of the sites would have given more consistency and increased the grand mean coral cover significantly. Although the present site selection does cover a good range of possible reef types from algal dominated (e.g. site East 1 and West 2) to hard coral dominated (site West 1), it is future trajectories of coral dominated sites that most aligns with the objectives of this ambient program.

Coral communities at all survey sites around Holbourne Island had been decimated by Cyclone Debbie (AIMS 2018) and no signs of recovery were found at the long term old monitoring sites during the last two surveys. 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 Holbourne reefs following Cyclone Debbie. Surviving corals have been slow to re-grow and recruitment of new coral colonies has been unusually slow despite available open substrate for colonisation. Similar slow recovery was noted by AIMS during the decade after CoTS outbreaks damaged coral communities around Holbourne Island in 1987 (AIMS 2018). The isolation of this reef in the middle of the shipping channel may be partly responsible: it is at least 40 km inside the band of mid-shelf reefs in this region of the GBR and about 30 km from the inner fringing reefs. Overall, the declines in hard coral at the Holbourne locations are consistent with documented impacts on coral reefs from acute storm events (Lam et al. 2018). A better understanding of this location with the newly established sites will also help determine if recruitment issues and recovery issues are limited to the more western portions of the fringing reefs or whether the eastern reefs have similar long-term trends. While reported trends appear to show an increase in coral over the 2020/21 reporting period, a clear demarcation of the new site effects on the long term dataset will be important to ensure the data is considered carefully.

Although Camp Island is only 50 km west of Holbourne Island damage from Cyclone Debbie was minimal at this inshore island location; attributed to TC approach angle and wave height and direction as compared to reef slope aspect. Hard coral communities at Camp Island are dominated by fast growing *Acropora* and *Montipora* species that are particularly sensitive to extreme wave action but these communities showed little evidence of damage following the cyclone (AIMS 2018).

The major change recorded during the 2020/21 ambient surveys covered in this report was the significant decline in hard coral and strong increase in macroalgal cover at all sites between the May 2020 and October 2020 surveys and the equally strong decline by the time of the June 2021 surveys. The severe bleaching episode recorded during the first three months of 2020 had already impacted coral cover, with a 33% reduction in the Camp Island location in May 2020 and an overall 54% reduction in coral cover from October 2019 to June 2021 dropping from 24% to 11% coral cover at Camp Island by June 2021. Cover of the dominant *Acropora* corals at Camp Island reduced by 60% over these ambient surveys. Broad-scale surveys of the GBR during this early 2020 warming event found widespread bleaching both at inshore and mid-shelf reefs, which was most prevalent in the central and southern sectors (Townsville to Gladstone; ARC Centre of Excellence for Coral Reef Studies) and therefore in line with this report's findings. In addition, the Port of Mackay and Hay Point ambient coral monitoring program found similar significant coral mortality of the same species at some inshore locations over this same period due to the bleaching event (Chartrand et al. 2021).

4.2 Sedimentation and Coral Damage

Corals on inshore 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 to actively remove surface sediment unless rates remain very high for long periods or corals are under stress and have reduced sediment removal capacity (e.g. during bleaching). It takes extreme events like cyclones or prolonged rough weather to overwhelm coral colonies natural sediment removal mechanisms. 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.

The Holbourne locations, being further offshore, in a generally less turbid water mass and with lower levels of silt in the bottom sediment (AIMS 2018) have much lower rates of sedimentation and sediment damage to corals than most fringing reefs. Camp Island, although only 2 km from the coast and the Elliot River mouth, appears to be in an unusually clear water mass most of the time and has historically during the monitoring program had relatively low rates of sedimentation and sediment damage. AIMS reported that they experienced 5m+ underwater visibility during their surveys and Sea Research has recorded 5-10m underwater visibility on all five visits to the location.

Over time, the sediment found on colonies, sediment depth and sediment damage appears to be increasing in frequency at Camp Island. A continued loss of live coral cover and increasing macroalgae at Camp Island may enable further retention of fine particles and sediment, creating further burdens to the surviving coral community. The bleaching stress over the 12 months may have interfered with the ability of corals to remove sediment from their surface, leading to an unusual number of corals with recorded surface sediment over the latest monitoring surveys. Additional sediment loads from the Elliot River may also be driving localised increases around Camp Island. Further monitoring will help to understand if this is a short- or long-term trend at this location.

4.3 Other Sources of Coral Mortality

Levels of coral disease during these ambient surveys was quite low with no disease recorded in October 2020 and only 0.1 diseased colonies per 40 sqm at Camp Island and Holbourne Island in June 2021. Corals usually affected by disease during these surveys were acroporids and a small number of pocilloporids. Disease of *Montipora* colonies, atramentous necrosis, on Camp Island had been regularly found by both Sea Research and AIMS during previous surveys but was not present following the dieback of *Montipora* from the bleaching event. Coral disease is usually more prevalent when water temperatures and nutrient levels are higher (AIMS 2018). Monitoring of disease long term will help to explain whether this disease returns as the corals at this location stabilise following bleaching stress and the dieback events. In general, a small number of corals are affected by disease on most fringing reef locations at any one time and this rarely causes significant coral mortality (Ayling and Ayling 2005). Black band disease in *Turbinaria* and *Psammocora* corals was responsible for a small but significant reduction in overall coral cover in the Hay Point region during the summer of 2006 (GHD 2006) and the atramentous necrosis mentioned above caused a slight reduction in *Montipora* cover at Camp Island over the four surveys between July 2018 and October 2019 but has not been noted as a concern since.

The ongoing presence of *Acanthaster* starfish (CoTS) at Holbourne Island could further damage coral communities that are struggling to recover from Cyclone Debbie damage and now the latest bleaching event further slowing recovery. The presence of CoTS at the new Holbourne Island monitoring sites has the potential to negatively affect the higher coral cover areas on the NE and SE face of the island. However, the scale of the outbreak to date has not led to widespread losses over recent surveys.

Large numbers of coral grazing *Drupella* snails were recorded by AIMS in the Holbourne East deep sites in October 2017 but no snails were recorded during the 2020/2021 surveys reported here. Cyclone Debbie reduced coral cover markedly on Holbourne and this has the effect of concentrating low densities of *Drupella* into the few remaining corals. This can lead to a pulse of coral damage but the *Drupella* reduce in numbers as they destroy the corals they have retreated into (A.M. Ayling personal observations).

4.4 Changes to the Ambient Monitoring Program

The current ambient coral monitoring program has realigned the program with other inshore coral monitoring in the Mackay and Hay Point region as well as broader regional reporting through the Reef Catchments Regional Report Card program. The move to photoquadrats in place of the line intercept technique for estimating benthic assemblage cover was reviewed as part of this 2020/21 report. Overall, some measurable effects from the change in technique were detected but they were relatively small and related to sites with high macroalgae cover at Camp Island. Nevertheless, impacts on coral cover from large standing macroalgae canopies did have some effect on cover estimates but not at a level that disrupts the ability to move to a photoquadrat based program as part of the ongoing monitoring. The change in technique will be clearly demarcated in all trend and analysis in future reports to account for any potential effects from this methodological change.

As discussed in Section 4.4, the Abbot Point coral monitoring program was also changed based on recommendations following the 2019/20 survey period in order to more appropriately represent the coral communities at Abbot Point locations and to align with other regional programs including the NQBP Mackay and Hay Point coral monitoring. Shallow water sites (<2m below LAT) at Holbourne Island were dropped due to extremely low coral cover (<2%) and their shallow depth creating a mismatch with program objectives. Newly commissioned sites on the NE and SE face of Holbourne Island reefs have led to an increase in overall coral cover at this location. All datasets statistically analysed and plotted in the current report have been back calculated to represent the current four transects (two prior to October 2020) to ensure current and future trends in the program are comparable with the historical record. These changes have better placed the NQBP ambient coral monitoring program to represent regionally important inshore coral reef communities which can also be used in broader reporting through the Reef Catchments Regional Report Card.

During the first year of the updated ambient coral monitoring program, a photomosaic mapping of Camp Island sites was tested as a new innovative technique to monitor sites. The exercise created a high resolution image of transects in June 2021. The output provides a useful communication tool by visually providing a snapshot of the benthic communities that can be related back to the detailed data from in-water monitoring activities. However, multiple issues were identified through the trial. First, large moving objects such as a macroalgae canopy, soft corals and even motion from transect tapes during the image capture process creates gaps in the stitched imagery due to software uncertainty between overlapping images. For example, a swaying soft coral colony can occur in one frame and it is not there in the next despite not actually changing its true footprint on the reef. The final photomosaic output is produced with large gaps where movement is greatest and other areas with offset or out of focus structures such as where the transect tape shifted from surge along the benthos. Second, this technique was trialled at the best water quality location in the NQBP coral monitoring program across Abbot Point, Mackay and Hay Point with visibility regularly >5m. The distance from the benthos must be at least 3m in order to capture a wide enough field of view of the substrate and many sites in the program would often have too poor of visibility for this technique to work as part of an inshore reef monitoring program. Lastly, many elements of the existing monitoring program require extremely close assessment of the substrate including moving macroalgae aside in order to look for coral recruits, disease, CoTS, and other cryptic organisms surveyed. The long-term data used to monitor trend in reef condition would not be possible using photomosaic imagery alone. However, this technique does provide a valuable visual map to these inshore reef systems that can be used, where feasible with water quality conditions, as an additional means to communicate reef state and trend over time. We therefore recommend repeating a photomosaic mapping exercise of sites every two years during the post-wet surveys when macroalgae is likely at its lowest point to generate a long-term visual key to these reef locations. Further exploration of this technique will be considered during the 2021/22 survey period.

4.5 Implications of Coral Assessment

Cyclonic impacts more than acute effects of the recent bleaching event has reduced coral cover significantly at Holbourne Island. The slow rate of recovery of hard coral communities on these fringing reefs in the greater than four years since Cyclone Debbie is a cause for concern but is in line with the decadal long recovery times reported by AIMS following CoTS grazing damage to Holbourne coral communities in 1987. Further damage caused by CoTS grazing and coral bleaching is now exacerbating this slow recovery. The established Holbourne Island survey sites are all on the continuous fringing reef that sweeps in a crescent around the south and west faces of the island. The addition of the newly commissioned sites on the eastern face of the island based on recommendations by A.M. and A.L. Ayling show that corals were not as badly impacted by Cyclone Debbie on these reefs. A more balanced view of coral recovery on Holbourne as a whole may assist in better understanding the bigger picture of recovery and trend at this location.

Until the 2020 coral bleaching episode coral communities on Camp Island appeared to be healthy and growing well although smothered by algal growth as a seasonal challenge at this location. There has been little evidence that macroalgae are increasing on Camp Island reefs at the expense of coral cover. It is probable that the algal communities recorded during these surveys have been present on this island for many decades. However, coral bleaching has now significantly reduced coral cover on Camp Island, especially the dominant *Acropora* and *Montipora* species. Coral cover has been reduced by a mean of 54% from pre-bleaching surveys in October 2019 to the lowest coral cover observed at Camp of 11% since monitoring began. It is concerning to see these significant declines given the unique and rather high coral cover of this inshore location compared to other inshore reefs of the GBR in recent decades. Strong recruitment, relatively good water quality and open substrate will be important for these reefs to recover. The unique macroalgae community and increasing pattern in sediment load on corals at Camp Island suggests there will be factors that may hinder recruitment success, survivorship and therefore recovery.

Overall, 2020/21 surveys at Camp Island and Holbourne Island found differing effects from the recent 2020 bleaching event with little overall impacts to Holbourne Island while Camp Island had the most significant decline since monitoring began at this location. Recovery will likely take a decade or more based on studies of similar reef systems with a real risk that further climate-related impacts such as bleaching and cyclones may hinder any recovery that occurs. In addition, ongoing CoTS outbreaks on the GBR and the presence of these animals at Holbourne Island create further potential to drive long-term declines in in coral assemblages, adding to the cause for concern for these local reef systems.

5 REFERENCES

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

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

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

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

Chartrand KM, Hoffman L, Ayling A, and Ayling T. 2021. Ports of Mackay and Hay Point Ambient Coral Monitoring Surveys: 2020-2021. Centre for Tropical Water & Aquatic Ecosystem Research (TropWATER) Publication 21/44, James Cook University, Cairns.

BOM. 2020. Daily rainfall measured at the Mackay Airport (Station number 033045).

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

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

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

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

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

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

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

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

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

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

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

WIMP. 2020. Queensland Government Water Monitoring Information Portal for The Pioneer River at Dumbelton Weir (Station Id: 125016A)