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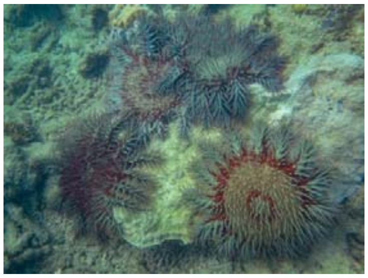

Port of Abbot Point Ambient Coral Monitoring Surveys: 2018-2019

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

Report No. 20/03
August 2020

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A Report for North Queensland Bulk Ports

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KEY FINDINGS

1. Coral monitoring at Holbourne Island and Camp Island was completed on three occasions in 2018/2019 as part of a bi-annual ambient monitoring program begun in May 2016 for the Port of Abbot Point to measure benthic cover, coral health, sedimentation and coral recruitment.

2. The Holbourne Island locations were severely impacted by Cyclone Debbie in late March 2017.

3. Coral communities in the Holbourne Island monitoring locations have been very slow to recover following the Cyclone Debbie impact, only increasing from a grand mean of 4.7% cover to 5.6% cover. The slow recovery of hard coral communities in the monitoring locations on these fringing reefs since Cyclone Debbie is a cause for concern.

4. Macroalgae were only important on the Camp Island location where cover decreased from 41% to 33% over the course of these three surveys.

5. Hard coral cover increased significantly on Camp Island over these three surveys from a mean of 23.4% cover to 26% cover.

6. Coral community composition was dominated by *Montipora* and faviid corals on the shallow Holbourne sites, by *Acropora*, *Montipora*, faviid and poritid corals on the deep Holbourne sites and by *Acropora* and *Montipora* corals on the Camp Island sites.

7. New coral recruits were recorded at low densities on Holbourne Island, despite there being plenty of suitable free space, but recruit densities were relatively high on Camp Island.

8. Sediment levels on corals were relatively low on Holbourne Island but higher on Camp Island where a grand mean of 11.6% of corals had sediment on the surface with mean sediment depth of 0.08 mm. These differences reflect the more inshore, shallow water environment of Camp Island.

9. No temperature driven coral bleaching was recorded in these locations during these three surveys. The small amount of coral bleaching that was recorded was mainly attributed to temporary shading of a few coral colonies.

10. Coral disease affected a mean of about 0.4 colonies per 40 sqm at these locations with the disease rate per unit of coral cover higher at Holbourne compared to Camp Island locations. Crown-of-thorns sea stars moved in to one of the Holbourne deep sites between November 2018 and May 2019 where they damaged over 6 colonies per 40 sqm. This outbreak is continuing.

11. Due to the extremely low hard coral cover at the shallow Holbourne sites (ca. 2%), we recommend relocating monitoring effort to the under-represented northeastern quadrant of the island at the same depth contour as the Holbourne deep sites (5m).

12. Data from the ambient coral monitoring program was provided to Reef Catchments to determine a coral condition index score under the Mackay Whitsunday Regional Report Card. The regional score has been rated ‘poor’ during all surveys to date but declined temporarily even lower in the ‘poor’ range due to TC Debbie in 2017.

IN BRIEF

Coral monitoring sites were set up on three locations in the vicinity of the Port of Abbot Point in late 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 two further surveys during 2017. TropWATER, in association with Sea Research, continued this program using the same sites and transects in 2018/2019.

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.

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. Mean macroalgal cover on Holbourne during these three ambient surveys was only around 1.5%, primarily small *Padina* and *Tricleocarpa* species. Camp Island had patchy cover of dense *Sargassum* forest, especially at the East 1 site, with grand mean macroalgal cover of around 35%. Macroalgal cover remained the same on Holbourne during these three ambient surveys but decreased significantly on Camp Island from 41% down to 33% cover, probably due to normal seasonal nutrient fluctuations. 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 survey locations 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. Mean hard coral cover on the shallow Holbourne Island location was less than 2% during these 2018/2019 ambient surveys. In the deep Holbourne stratum mean coral cover was less than 10%. Camp Island reef communities, although only 50 km west of Holbourne, were minimally damaged by Cyclone Debbie and mean coral cover was around 25% during these surveys. The proximity of Camp island to the coastline and the unusually shallow depths around the island (<5m), may have minimised impacts to sites located on the western aspect of the island compared to those impacts seen at Holbourne where wider fetch and wave impact was evident.

Hard coral cover did not increase significantly in the Holbourne locations during the 2018/2019 period but increased from 23.4% to 26% on Camp Island, primarily due to increases in the cover of fast growing *Acropora* species.

Coral community composition was different at the three locations. In the shallow Holbourne location *Montipora* and faviid corals were dominant, accounting for 67% of hard coral cover between them. No coral group was dominant in the deep Holbourne location with *Acropora*, *Montipora*, faviids and poritids all accounting for 15-30% of coral cover. On Camp Island fringing reefs *Acropora* and *Montipora* corals between them made up more than 85% of coral cover. The proportion of *Acropora* to *Montipora* changed on Camp Island reefs over these three surveys, with *Acropora* increasing due to normal growth and *Montipora* decreasing due to atramentous necrosis disease and sediment damage.

Sediment levels on living hard corals were low on both Holbourne Island locations during the two 2018 surveys (mean of only 1% of corals with sediment) but was significantly higher during the May 2019 survey when about 10% of corals had surface sediment. More corals had surface sediment on the inshore Camp Island location, with 5-20% of corals recorded with surface sediment and a steady increase in both number of corals with sediment and sediment depth over the three surveys. 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 sedimentation damage.

Coral bleaching has only affected a few individual coral colonies during these surveys and has caused no measurable changes to coral cover. The small amount of bleaching that has been recorded has been due to other stressors such as shading rather than high water temperatures.

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. A mean of about 0.4 coral colonies per 40 sqm had been affected by disease during these surveys and the rate of disease per unit of coral cover was similar for all three locations. At Camp Island almost all disease was atramentous necrosis of *Montipora* colonies and this caused a slight but significant decline in *Montipora* cover over the three surveys covered here. In general, the impact of disease on hard corals is at least an order of magnitude less than physical cyclone damage.

A small crown-of-thorns sea star aggregation was impacting corals in the West deep Holbourne location during the May 2019 survey and had damaged many corals at one of the survey sites.

Coral recruitment was low on the Holbourne sites during these surveys with mean recruit density of less than 1 per sqm, possibly due to the relatively isolated position of this island in the shipping channel 40 km inside the main body of mid-shelf reefs and 30 km from the nearest inshore fringing reefs. Recruit densities were higher on the Camp Island sites where a mean of about 2 recruits per sqm was recorded. As is often the case on near-shore reefs *Turbinaria* corals were common in the coral recruit population at Camp Island, accounting for 29% 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 42% of the recruit population but 86% of the overall coral community. On Holbourne Island a range of different coral groups were present in both the recruit population and the overall coral community.

The slow rates of coral community recovery on Holbourne Island following Cyclone Debbie, both from coral growth and recruitment, is cause for concern. The reefs around Camp Island appear healthy and growing but suffer from algal smothering at some sites during periods of high algal growth. These Camp Island reefs are very shallow with a loose rubble structure and would be severely impacted by even a small cyclone event and its angle of approach.

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ACRONYMS AND ABBREVIATIONS

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

1 INTRODUCTION

1.1 Project Background

The Port of 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 (**Error! Reference source not found.**): Holbourne Island (**Error! Reference source not found.**) and Camp Island (**Error! Reference source not found.**). 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 during the 2018-2019 time period making three more surveys: June 2018, November 2018 and May 2019.

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 three surveys from the three Abbot Point locations made between June 2018 and May 2019.

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 sites.

Figure 2. Holbourne Island showing the position of the shallow strata coral monitoring sites. The equivalent deep sites are all about 50 m down slope from the shallow sites.

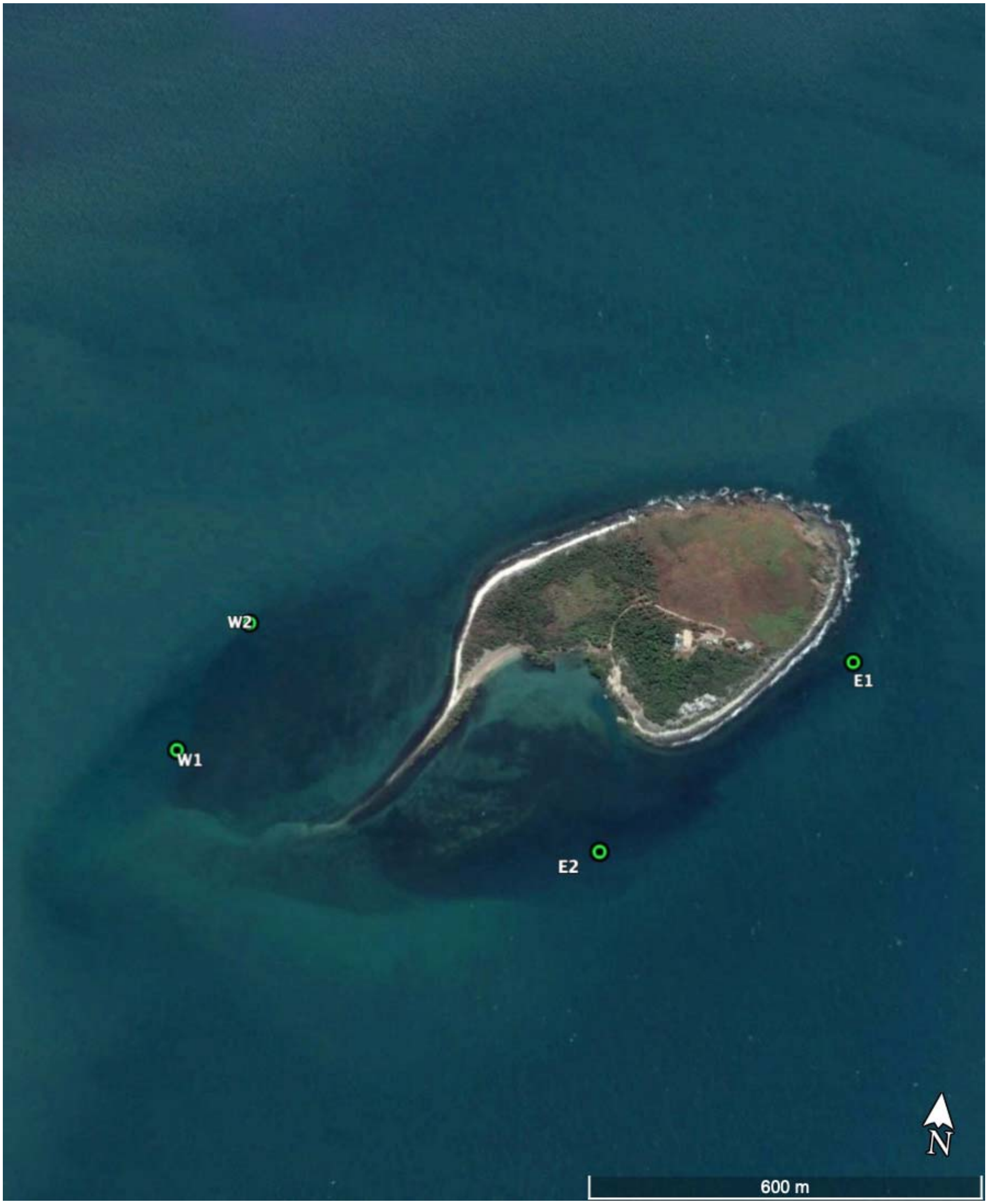


Figure 3. Camp Island showing the position of the four coral monitoring sites.

2 METHODS

2.1 Abbot Point Locations

Fringing reefs were surveyed around two island locations in the Abbot Point region (Figure 1). 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 20 m long permanently marked transects were established in two depth strata on Holbourne Island and a single depth stratum on Camp Island. 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 supporting seagrass).

Table 1. GPS coordinates of each monitoring site.

Location	Ambient monitoring site ID	Latitude	Longitude
Holbourne Island	East S1 Shallow	-19.7332	148.3644
Holbourne Island	East S2 Shallow	-19.7336	148.3618
Holbourne Island	West S1 Shallow	-19.7252	148.3547
Holbourne Island	West S2 Shallow	-19.7233	148.3556
Holbourne Island	East S1 Deep	-19.7338	148.3647
Holbourne Island	East S2 Deep	-19.7340	148.3618
Holbourne Island	West S1 Deep	-19.7249	148.3545
Holbourne Island	West S2 Deep	-19.7232	148.3553
Camp Island	East S1	-19.8508	147.9052
Camp Island	East S2	-19.8541	147.9012
Camp Island	West S1	-19.8533	147.8942
Camp Island	West S2	-19.8512	147.8950

2.2 Survey Period

This report provides a summary of coral conditions observed during three different surveys undertaken at all Abbot Point reef locations over the period January 2018 to May 2019. The three survey periods were post-wet 2018: from 10 June to 7 July, pre-wet 2018: 4-6 November and post-wet 2019: 27-29 May. 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 in 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 prior the wet season in late 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.

Digital photographs were taken in a strip along each transect on the shoreward side of the tape with a photograph taken every 0.5m.

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

2.4 Sediment Deposition on Corals

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

2.5 Damaged, Diseased, or Bleached Coral Colonies

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

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

2.6 Coral 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.

2.7 Analysis

Given the large amount of natural patchiness in the abundance of all marine organisms, and the variation in abundance changes through time within each patch, it is necessary to use statistical analysis to determine if any change is significant. The variation may be so high that what appears to be quite a large nominal change may not be a real change but just due to sampling the natural variation within the community differently. Analysis of variance techniques are usually used to determine the significance of any apparent changes in abundance between successive benthic surveys. The design of the benthic abundance surveys was established to enable a repeated measures analysis of variance after subsequent surveys (Table 2). Because the transects were fixed and the same bits of the benthic community were assessed during each survey a more powerful repeated measures analysis is appropriate in this case. This analysis tested the significance of changes in a number of factors that may have influenced benthic abundance.

1. The first factor was the three locations (the two depth strata at Holbourne were treated as separate locations) i.e. to determine whether there were significant differences in benthic abundance among these locations.
2. The second factor 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. Site is said to be nested within the location factor because site 1 at one location is not necessarily subject to the same influences as site 1 at the other locations e.g. what affects each site is unique to that site. Nested factors are indicated with brackets e.g. Site (Location) indicates that the site factor is nested within the location factor.
3. The third factor in the analysis design was time i.e. to determine whether there were any significant changes in benthic abundance between successive surveys at the same sites.

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

Changes in sediment depth on coral colonies were tested for each location using a two-factor analysis of variance. As sediment depth is measured on a different random selection of corals during each survey then repeated measures analysis is not appropriate. Two factor repeated measures analyses of variance were used to check the significance of changes in the density of damaged and diseased coral colonies in each location. In this case damaged and diseased colonies were assessed within the same transect area during each survey enabling the use of repeated measures analysis.

The significance of changes over the 11 months covered by the three most recent surveys of all locations (June 2018, Nov 2018, May 2019) was tested with one series of anovas (Table 2) but another series of analyses were used to establish the significance of any benthic or coral damage changes over all the surveys that have been carried out since 2016.

Table 2. Repeated measures benthic cover analysis of variance design for determining significance of differences between the last three ambient surveys at three locations (df = degrees of freedom)

Source of variation	df	Denominator
Between Transects:		
Location	2	Error (transects)
Site (location)	9	Error (transects)
Error (transects)	48	
Within Transects:		
Time	2	Error (transects x Time)
Location x Time	4	Error (transects x Time)
Site (location) x Time	18	Error (transects x Time)
Error (transects x Time)	96	

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 June 2018 to July 2019 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 2019) is provided graphically in Figure 4. The Don River discharge at Reeves (23km from the mouth of the River) is presented using data provided by the Queensland Government Water Monitoring Information Portal (WIMP 2019) in millions of litres per day (ML/day) (Figure 5). Rainfall and Elliot River discharge rates are recorded at Guthalungra seven kilometres upstream from the river mouth and are shown from July 2016 to June 2019 (Figure 6).

The Bowen region is in the dry tropics and mean annual rainfall is only 893mm with 660mm of that falling in the four-month wet season (Dec-Mar). Rainfall for the 2018/2019 wet season was well above average for this region with over 1,062mm recorded for the December-March period compared to the 660mm average. More than 750mm of rain fell in the widespread two-week monsoonal event in late January and early February 2019 that affected much of Queensland.

Large sustained rainfall events typically cause large river discharges. Water discharges from the Don River were moderately high during the February monsoonal event, peaking at 37,000 ML/day. There have been 13 events of equal 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 (Figure 5). The Elliot River is a smaller system and flows are usually smaller, peaking 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.

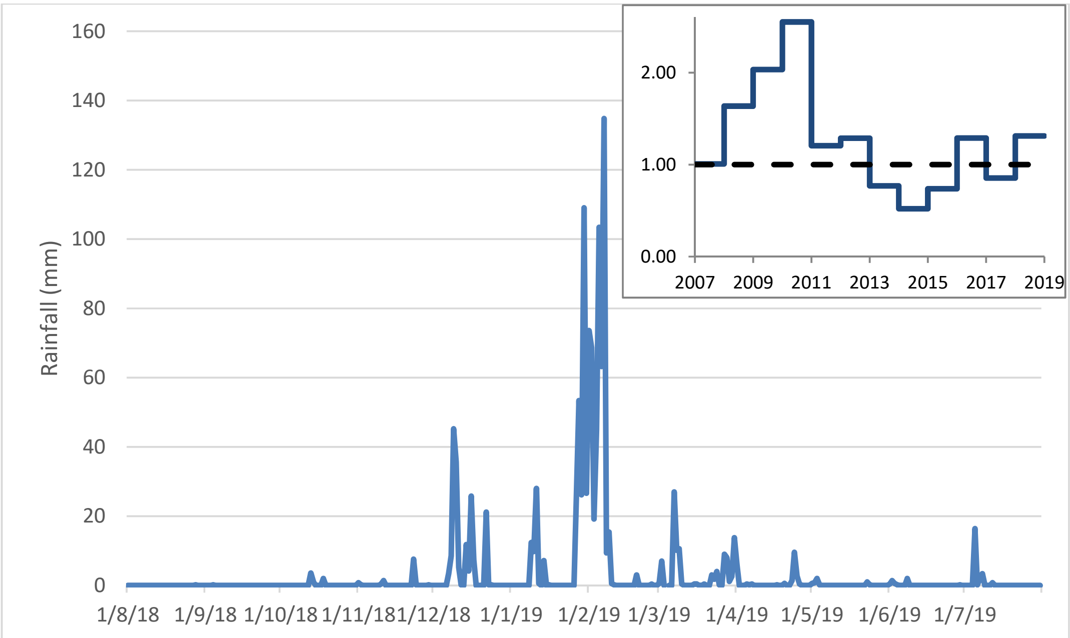


Figure 4. Daily rainfall measured at the Bowen Airport with inset of change in rainfall as a proportion of the long-term average .

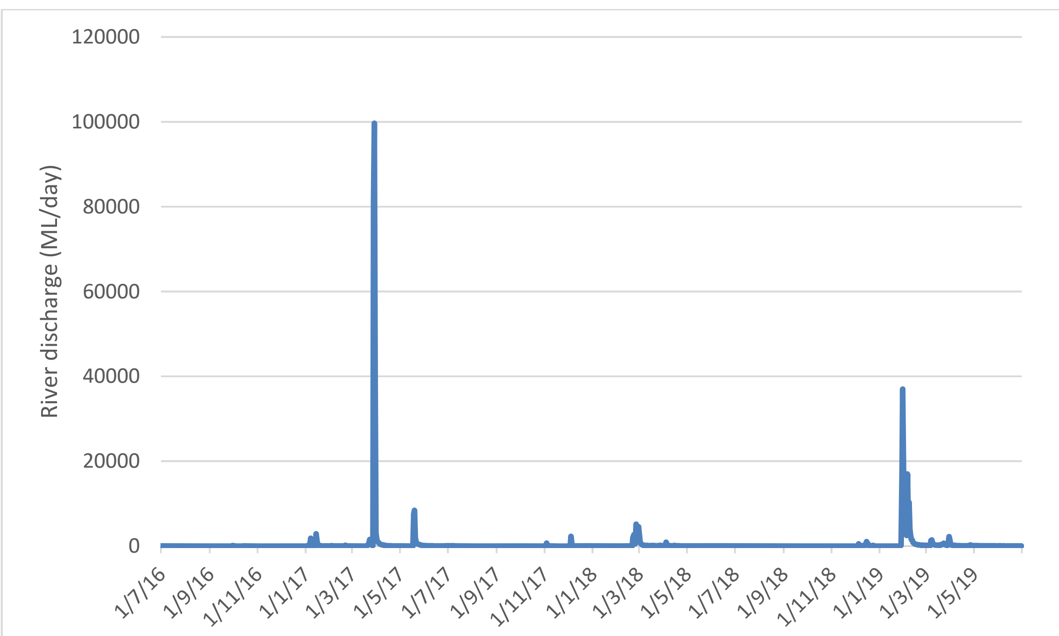
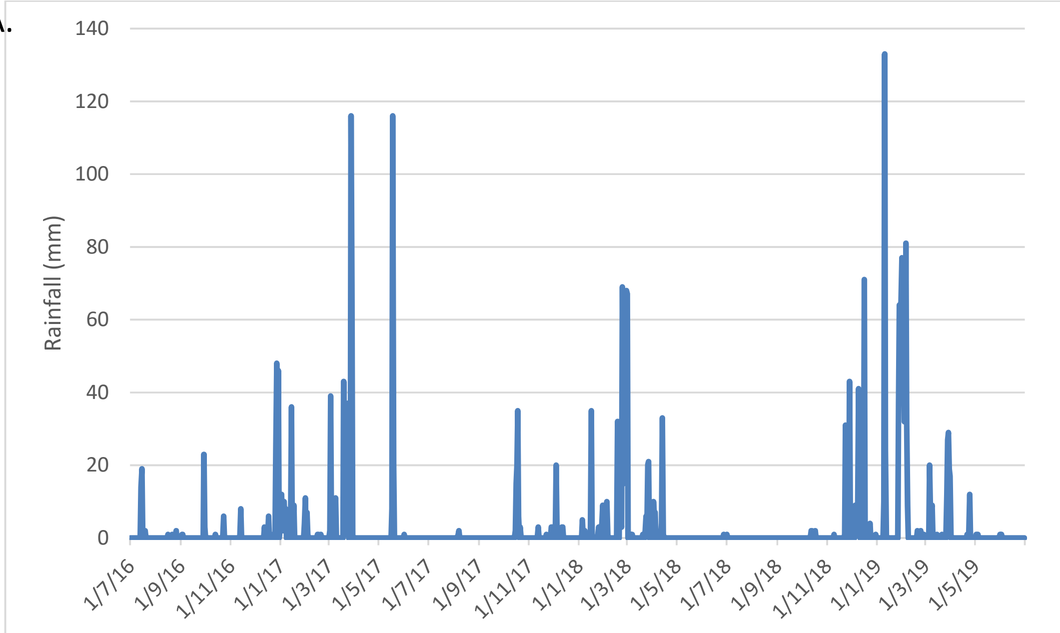


Figure 5. Don River discharge rates measured at Reeves, 23 km upstream from the river mouth.

A.



B.

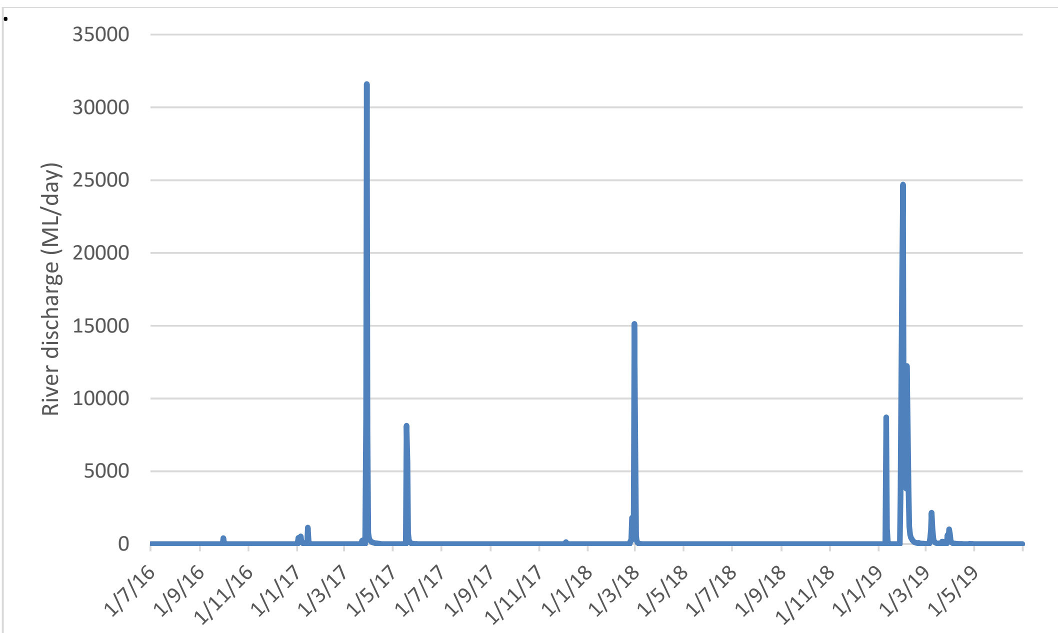


Figure 6. A. Daily rainfall measured at Gathulungra, 7 km upstream from the Elliot River mouth, B. Elliot River discharge at Gathulungra.

3.1.2 Cyclones

During the 2018/2019 ambient monitoring period no cyclones passed near Abbot Point but a severe monsoonal event between 4-9 February 2019 impacted the region. Strong SE winds and widespread heavy rainfall were associated with this event. Sustained winds between Townsville and Mackay were between 35-50 km/hr for the six day event with gusts of between 40-70 km/hr. Almost 750mm of rain fell at Bowen Airport during this event and Don River flows peaked at about 37,000 ML (Figure 6B). RMS water height records around Holbourne Island were significantly elevated from this event indicating strong wave shear stress on the sea floor (Waltham et al. 2019). This was the major weather event of the past 12 months in terms of wind, rain and river flows.

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. This system caused severe physical damage to the Holbourne Island benthic communities but minimal damage at the Camp Island location (ref AIMS report).

3.1.3 Sea Water Temperatures

Sustained elevated water temperatures that may cause coral bleaching were not recorded during the 2018/2019 summer period in the 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 slightly higher at the inshore Camp Island site compared to the more offshore Holbourne Island (Figure 7). The highest temperature was recorded in December 2018 at Camp Island which reached 30.7^{o}C. The coolest temperature occurred in July each year where temperatures dropped to a low of 21^{o}C (Figure 7).

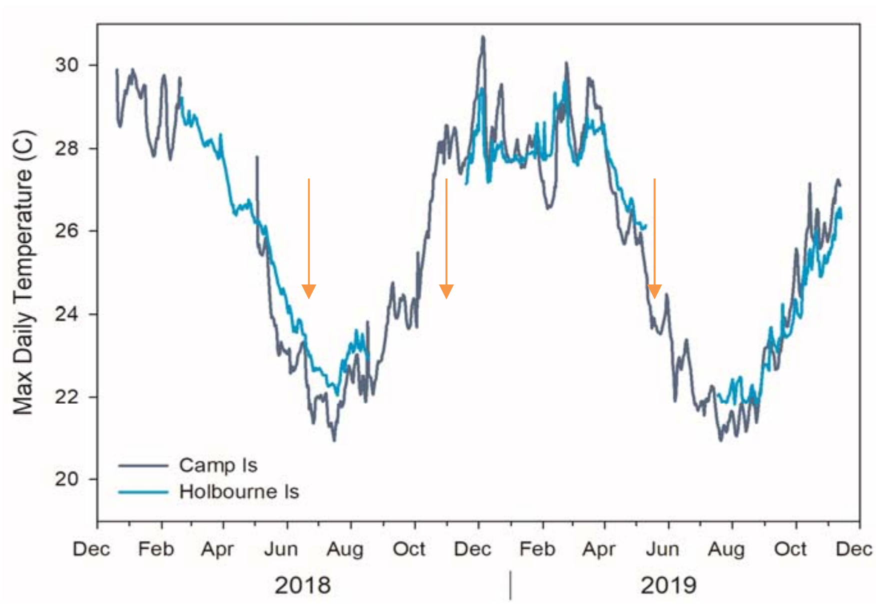


Figure 7. Maximum daily water temperature at Holbourne Island and Camp Island water quality monitoring sites. Arrows indicate approximate survey dates.

3.2 Benthic cover during the last three ambient surveys

Benthic communities on the Holbourne Island sites were severely affected by Cyclone Debbie with 78% lost on Holbourne East and 86% on Holbourne West between 2016 and 2017 (AIMS Report). 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 95% of the substratum in the shallow sites and 85% in the deep sites (Figure **8**8). Macroalgae were uncommon on the Holbourne Island reefs with around 2% cover. *Milleopora* fire corals covered 1% of the shallow sites and 1.5% of the deep sites. Hard coral cover was about 2% in the shallow sites and 8-9% in the deep sites, while soft coral covered less than 1% of the shallow sites and around 3% in the deep sites. Benthic communities on Camp Island had not been devastated by Cyclone Debbie. This location is an inshore site and macroalgal cover varied between 30-40%. Sand/rubble, crustose corallines and turfing algae only accounted for 30-40% of the substratum in this location (Figure **8**8).

Sponges covered 2-4% of the substratum at Camp Island and hard corals around 25%. Soft corals were rare at this location covering less than 0.1% of the substratum.

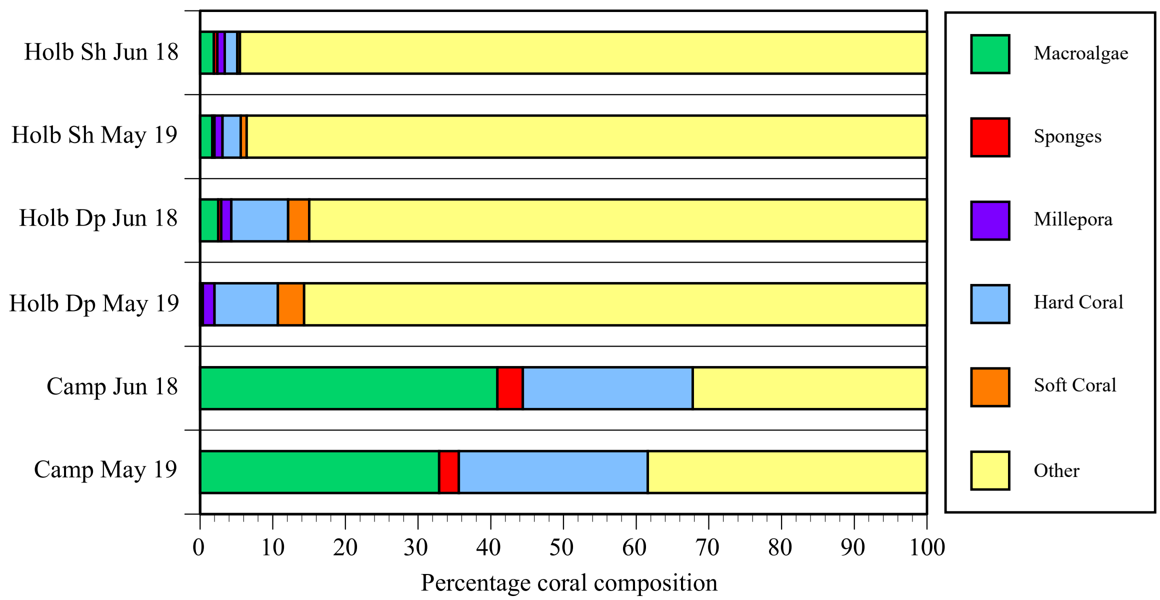


Figure 8. Changes in benthic composition in the three locations between June 2018 and May 2019. Plot shows mean percentage benthic composition from two recent ambient surveys at each location. Benthic category 'Other' = sand + bare reef + crustose corallines + algal turf. Holb Sh = Holbourne Island shallow stratum; Holb Dp = Holbourne Island deep stratum.

Holbourne Island is a mid-shelf location and macroalgae are not a feature of the benthic community. The clumping red alga *Tricleocarpa* covered about 2% of the substratum at this location. 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 moderate cover of *Sargassum* macroalgae (30-40%) and hence there were strongly significant differences in algal cover among the locations (Figure 9, Table 4). Algal cover decreased significantly over the past three ambient surveys. This decrease was driven primarily by the Camp Island location and hence the Location x Time interaction was also significant.

Sponges were not common in any of these locations (Table 3**Figure 8**) but were most abundant on Camp Island where the cover of this benthic group was 2.7% during the May 2019 ambient survey. The most abundant sponge was the green *Haliclona cymaeformis* (formerly known as *Sigmadocia symbiotica*) that often grew amongst the branching corals at this location. Sponge cover did not change during the past three ambient surveys (Table 4).

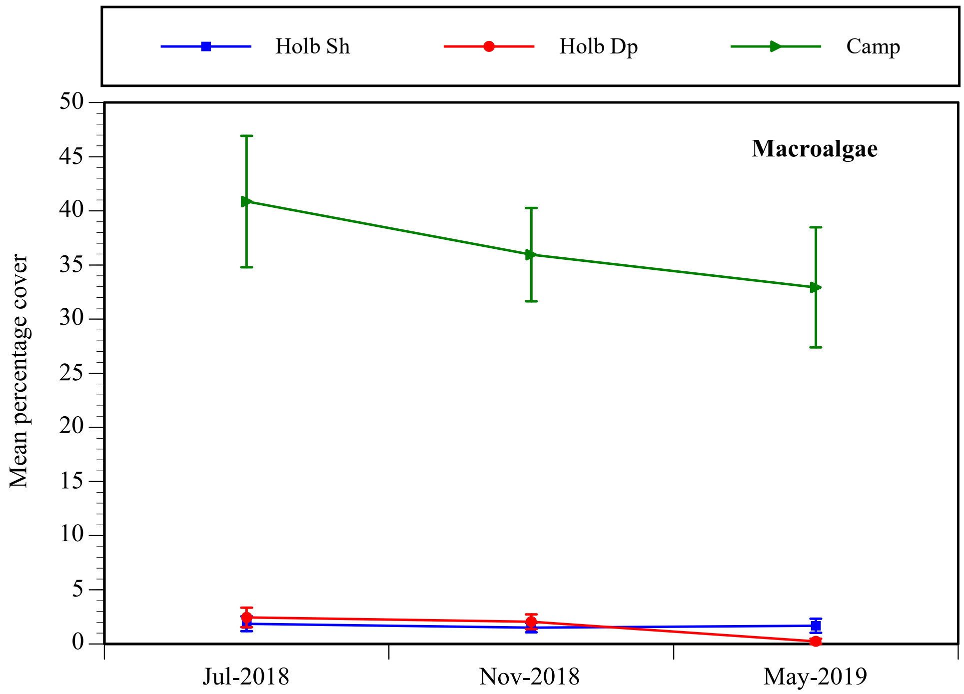


Figure 9. Changes in percentage cover of macroalgae.
Graphs show grand mean percentage algal cover from the last three ambient surveys at each location (five 20m line intersect transects surveyed at four sites for each location). Error bars are standard errors. Holb Sh = Holbourne Island shallow stratum; Holb Dp = Holbourne Island deep stratum.

Table 3. Abbot Point fringing reefs benthic organism abundance during the last three ambient surveys (mean percentage cover with standard deviations)

Family/Group	June 2018		November 2018		May 2019	
	mean	***sd***	**mean**	***sd***	**mean**	***sd***
HOLBOURNE SHALLOW						
Total macroalgae	1.9	*3.1*	1.5	*2.0*	1.7	*2.8*
Total sponges	0.5	*1.2*	0.2	*0.5*	0.3	*0.8*
Total hard corals	1.7	*2.4*	2.0	*2.9*	2.5	*2.9*
Acropora spp.	0.1	*0.2*	0.1	*0.1*	0.1	*0.1*
Montipora spp.	0.7	*1.3*	1.0	*1.9*	0.9	*1.5*
Agariciidae	-	-	0.1	*0.1*	0.1	*0.1*
Siderasteridae	0.2	*0.7*	0.2	*0.6*	0.3	*0.9*
Mussidae	0.2	*0.7*	0.1	*0.4*	0.3	*0.8*
Faviidae	0.4	*0.7*	0.5	*1.0*	0.6	*1.2*
Poritidae	0.1	*0.2*	0.1	*0.3*	0.2	*0.3*
Total soft corals	0.4	*0.9*	0.3	*0.7*	0.8	*1.4*
HOLBOURNE DEEP						
Total algae	2.5	*5.1*	2.1	*3.1*	0.2	*1.1*
Total sponges	0.4	*0.8*	0.4	*0.5*	0.2	*0.5*

Total hard corals	7.8	*4.7*	7.0	*4.3*	8.7	*5.0*
Acropora spp.	2.0	*3.4*	1.3	*2.2*	1.9	*3.3*
Montipora spp.	2.2	*2.3*	2.2	*2.8*	2.6	*2.7*
Agariciidae	0.1	*0.1*	0.2	*0.8*	0.1	*0.3*
Siderasteridae	0.2	*0.5*	-	-	-	-
Mussidae	0.2	*0.3*	0.2	*0.2*	0.3	*0.5*
Faviidae	1.2	*1.2*	1.4	*1.5*	1.3	*1.4*
Poritidae	1.6	*2.0*	1.0	*1.1*	1.6	*1.7*
Total soft corals	2.9	*3.6*	2.8	*3.6*	3.6	*4.7*
CAMP						
Total algae	40.9	*27.1*	36.0	*19.3*	32.9	*24.8*
Total sponges	3.5	*4.3*	2.7	*3.3*	2.7	*2.9*
Total hard corals	23.4	*14.7*	23.5	*16.8*	26.0	*21.4*
Acropora spp.	10.1	*12.6*	10.9	*14.2*	13.5	*18.5*
Montipora spp.	10.3	*10.5*	9.2	*9.3*	8.8	*9.4*
Agariciidae	1.3	*4.2*	1.4	*3.9*	1.7	*5.0*
Siderasteridae	0.1	*0.2*	0.1	*0.2*	0.1	*0.1*
Mussidae	-	-	0.1	*0.1*	0.1	*0.1*
Faviidae	0.4	*0.6*	0.3	*0.5*	0.4	*0.7*
Poritidae	0.7	*1.3*	1.1	*2.1*	0.8	*1.4*
Total soft corals	0.1	*0.2*	0.1	*0.2*	0.1	*0.2*

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

Table 4. Benthic changes between the three most recent surveys of the Abbot Point ambient monitoring project: Anova Results

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

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

Total hard coral cover was significantly higher in the Camp Island location than in the two Holbourne Island locations during the last three ambient surveys and significantly higher in the deep stratum on Holbourne Island than in the shallow sites (Table 4, Figure 10). Mean coral cover during these surveys was between 23% and 26% on Camp Island, 1.5-2.5% on shallow Holbourne reefs and 7-9% on deep Holbourne reefs. Coral cover increased significantly over the eleven months covered by these three surveys but the increase was similar at all three locations and the Time x Location interaction was not significant for total hard coral cover.

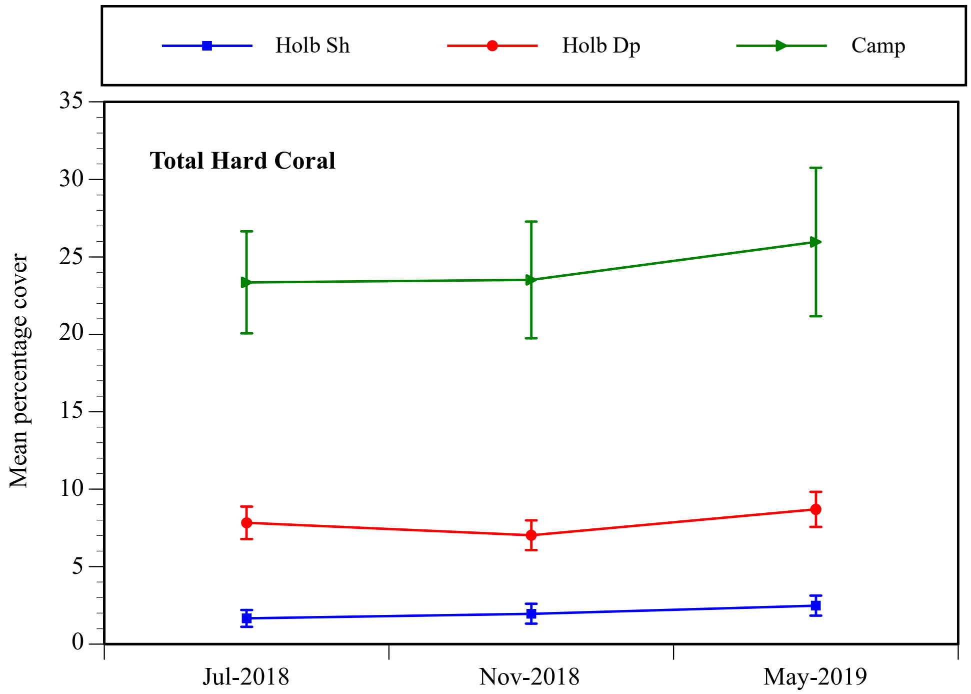


Figure 10. Changes in the cover of total hard coral.
Graphs show grand mean percentage benthic cover from the last three ambient surveys at each location (five 20m line intersect transects surveyed at four sites for each location). Error bars are standard errors. Holb Sh = Holbourne Island shallow stratum; Holb Dp = Holbourne Island deep stratum.

Hard coral community composition was different in each location (Figure 11). Coral communities in the shallow stratum at Holbourne Island were dominated by *Montipora* spp. (43% of total coral cover) and faviid corals (24% of total coral cover). In the deep Holbourne stratum *Montipora* spp. corals, *Acropora* spp. corals, faviids and poritids were all abundant (86% of coral cover between them). Camp Island coral communities were dominated by fast growing *Acropora* spp. corals (47% of coral cover) and *Montipora* spp. corals (39% of coral cover). Agariciid corals were also present on Camp Island, but only at one of the four sites, with large colonies of *Pavona decussata* accounting for almost 12% of coral cover at the West 1 site. Coral composition was affected by Cyclone Debbie on Holbourne Island but has not changed over the past three surveys at any location.

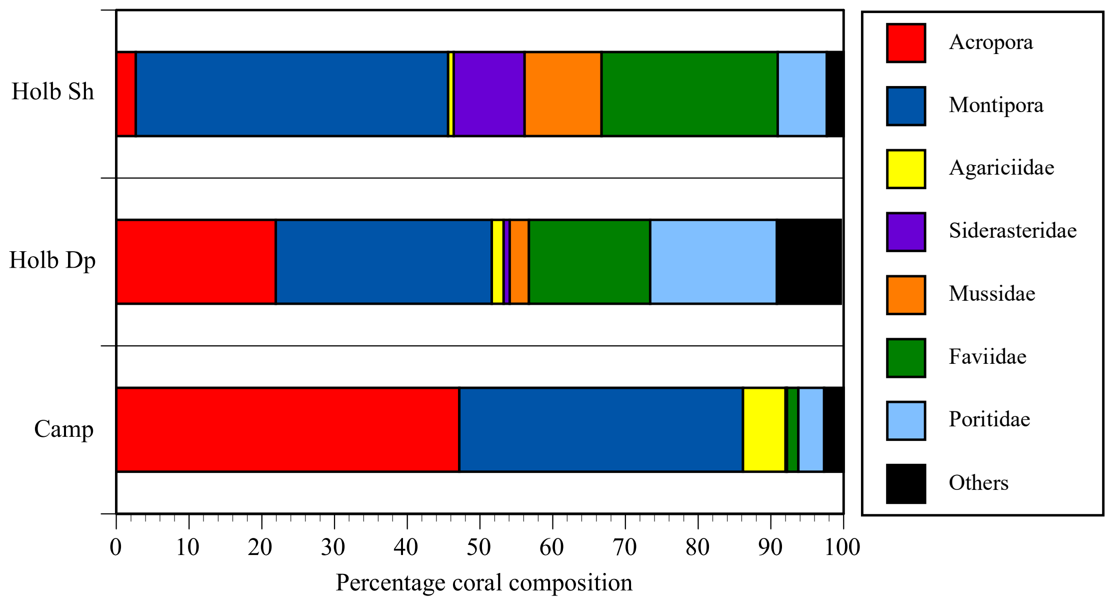


Figure 11. Coral community composition at the three locations for the last three ambient surveys. Graphs show mean percentage composition of the major coral groups from the three locations. Composition is averaged over the past three surveys. Holb Sh = Holbourne Island shallow stratum; Holb Dp = Holbourne Island deep stratum.

All but the agariciid coral group showed significant location differences during the last three ambient surveys (Table 4). *Acropora* and *Montipora* corals were significantly more abundant on Camp Island than in the two Holbourne locations (Figure 12). Although agariciid corals were nominally more abundant on Camp than in the Holbourne locations these differences were not significant because of the huge variability in abundance of this group at both the site and transect level. Faviid and poritid corals were significantly more abundant on the deep Holbourne Island location than the other two locations (Figure 13, Figure 14). Over the eleven months spanned by the last three ambient surveys significant changes in cover were recorded only for the *Acropora* coral group. This group increased in abundance at Camp Island but did not change in the two Holbourne locations and hence the Location x Time interaction was also significant. Although *Montipora* corals decreased slightly but not significantly in cover on the Camp Island location over the past eleven months they did not change on the Holbourne locations and the Location x Time interaction was also significant for this group (Table 4).

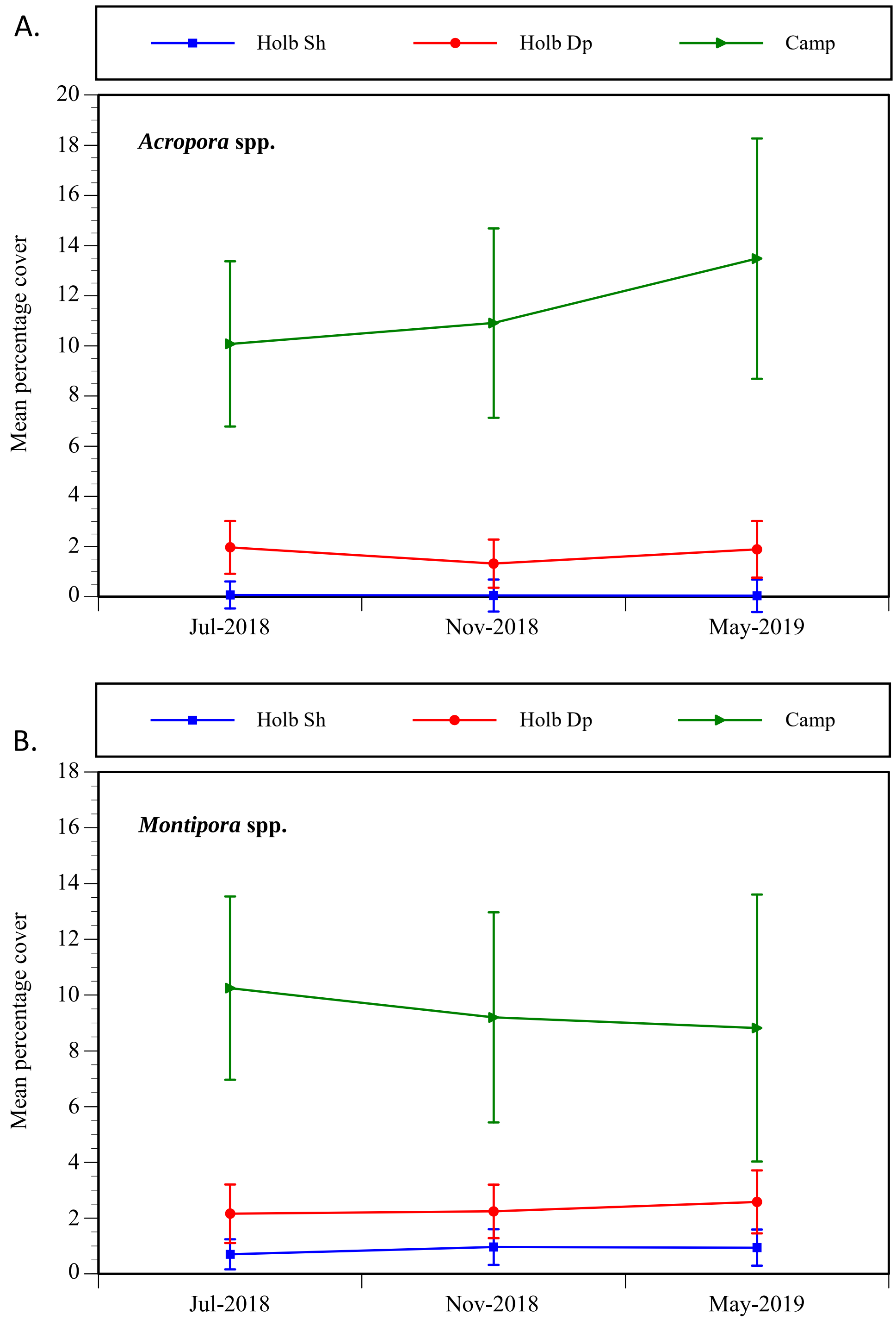


Figure 12. Changes in the cover of coral groups: *Acropora* corals and *Montipora* corals. Graphs show grand mean percentage benthic cover from the last three ambient surveys at each location (five 20m line intersect transects surveyed at four sites for each location). Error bars are standard errors. Holb Sh = Holbourne Island shallow stratum; Holb Dp = Holbourne Island deep stratum.

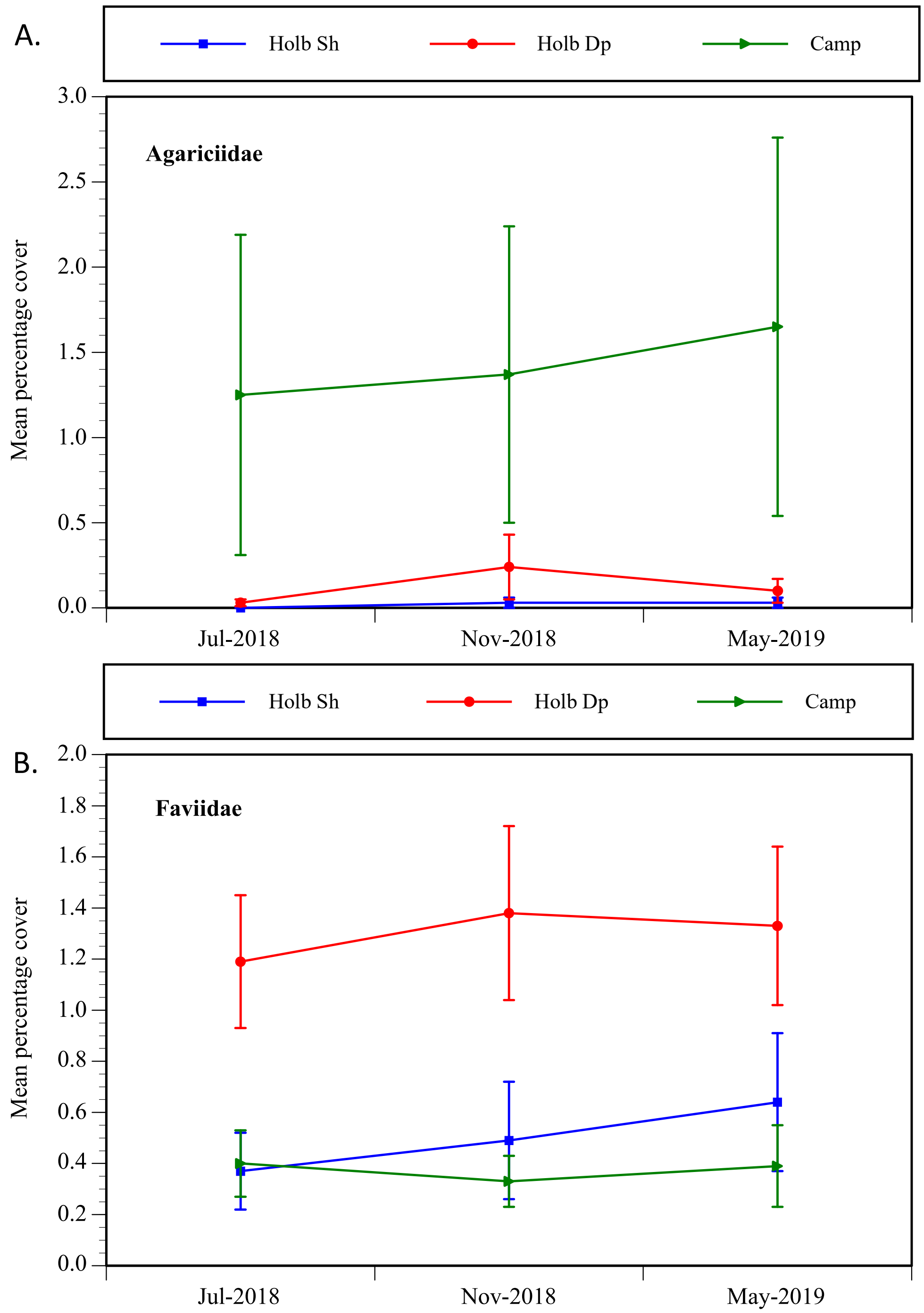


Figure 13. Changes in the cover of coral groups: Agariciid corals and Faviid corals.
Graphs show grand mean percentage benthic cover from the last three ambient surveys at each location (five 20m line intersect transects surveyed at four sites for each location). Error bars are standard errors. Holb Sh = Holbourne Island shallow stratum; Holb Dp = Holbourne Island deep stratum.

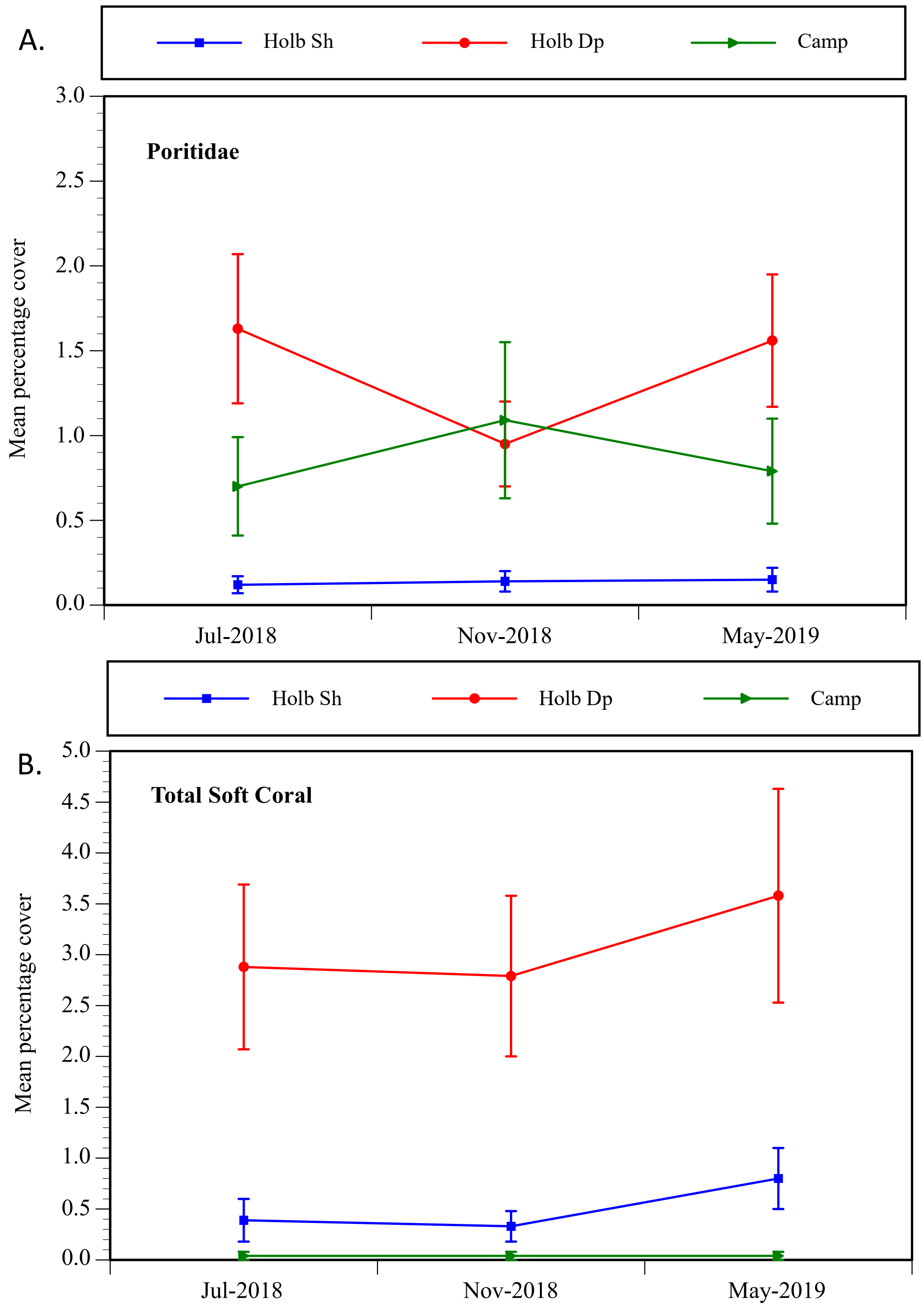


Figure 14. Changes in the cover of benthic groups: Poritid corals and Total Soft corals. Graphs show grand mean percentage benthic cover from the last three ambient surveys at each location (five 20m line intersect transects surveyed at four sites for each location). Error bars are standard errors. Holb Sh = Holbourne Island shallow stratum; Holb Dp = Holbourne Island deep stratum.

Soft corals were significantly more abundant on the deep Holbourne location during the last three ambient surveys, where this group covered a mean of around 4% of the substratum, than in the other two locations (Table 3, Table 4, Figure 14). Soft coral cover increased significantly at both Holbourne Island locations between November 2018 and May 2019, but was very low and unchanging on Camp Island giving significant Time and Location x Time factors (Table 4).

3.4 Coral Bleaching

Mass coral bleaching is caused by high temperature stress but corals may also bleach due to other stresses such as excessive shading. There were very low levels of bleaching in these locations over the past three ambient surveys. Bleaching was highest on Camp Island giving a significant location difference and lowest on the shallow stratum at Holbourne (Figure 15, Table 5, Table 6). Most bleached corals at Camp Island were loose *Montipora* colonies that had been newly turned over by wave action, exposing the partially bleached living under-surface. The coral rapidly regains zooxanthellae on the upper surface and bleaches beneath. This happens regularly and the colony manages to stay alive on both surfaces (Figure 16). The number of bleached colonies on Camp fluctuates depending on recent wave action, giving a significant Time factor (Table 6), but has not changed on Holbourne shallow location so the Time x Location interaction is also significant (Table 6).

Table 5. Coral colony health status during the last three ambient surveys

Location	Jul 2018		Nov 2018		May 2019	
	mean	*se*	mean	*se*	mean	*se*
HOLBOURNE SHALLOW						
Partially bleached colonies	0.0	*0.0*	0.1	*0.1*	0.1	*0.1*
Disease damaged colonies	0.0	*0.0*	0.1	*0.1*	0.1	*0.1*
Sediment damaged colonies	0.1	*0.1*	0.0	*0.0*	0.2	*0.1*
COT damaged colonies	0.0	*0.0*	0.0	*0.0*	0.0	*0.0*
HOLBOURNE DEEP						
Partially bleached colonies	0.0	*0.0*	0.3	*0.1*	0.0	*0.0*
Disease damaged colonies	0.4	*0.2*	0.3	*0.1*	0.4	*0.2*
Sediment damaged colonies	0.1	*0.1*	0.2	*0.1*	0.3	*0.2*
COT damaged colonies	0.0	*0.0*	0.0	*0.0*	1.6	*0.9*
CAMP						
Partially bleached colonies	0.6	*0.3*	0.2	*0.1*	0.4	*0.2*
Disease damaged colonies	0.9	*0.3*	0.9	*0.3*	0.5	*0.2*
Sediment damaged colonies	1.1	*0.3*	0.1	*0.1*	0.8	*0.3*
COT damaged colonies	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

Table 6. Abbot Point fringing reefs: changes in the density of partially bleached, diseased, sediment damaged and COT damaged corals between the last three ambient surveys: ANOVA Results

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

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

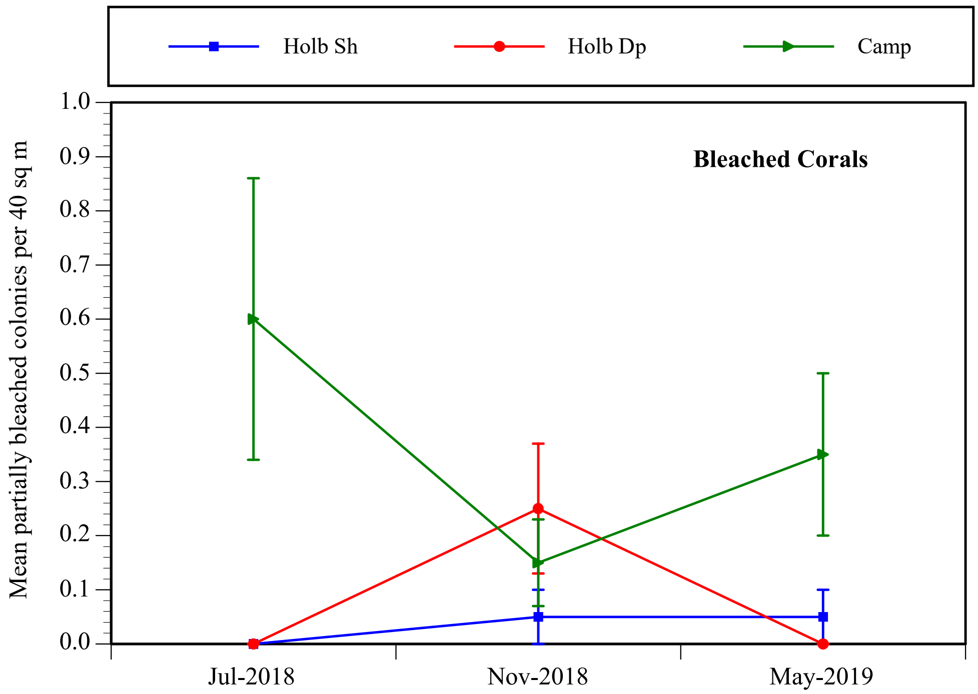


Figure 15. Changes in Density of Bleached and Partially Bleached Hard Coral Colonies. Graphs show grand mean density of bleached and partially bleached corals per 40sq m from four sites of five 20 x 2m transects in each location from the last three ambient. Error bars are standard errors. Holb Sh = Holbourne Island shallow stratum; Holb Dp = Holbourne Island deep stratum.

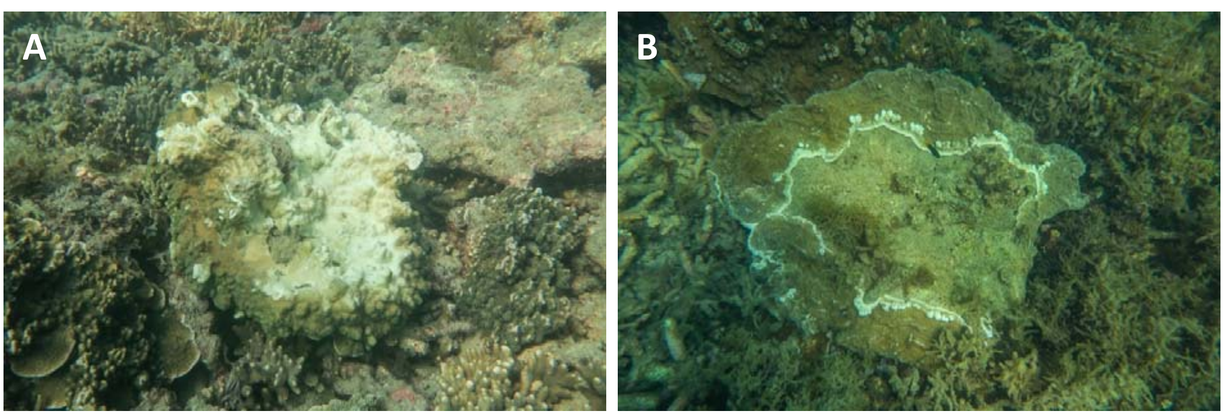


Figure 16. A. Partially bleached *Montipora* colony on Camp Island that has been turned over by wave action. B. Previously turned over *Montipora* that has recovered zooxanthellae.

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. During the two 2018 ambient surveys both the percentage of corals with sediment load and the depth of that sediment was low in all locations but both measures were significantly higher at the time of the May 2019 survey (Figure 17, 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). Both the number of corals with surface sediment and the sediment depth was lowest on Holbourne Island in November 2019 but on Camp Island lowest levels were recorded in July 2018 giving a significant Time x Location interaction for sediment depth. Sediment depths on Camp Island have increased steadily over the past 12 months but have only increased on Holbourne Island over the past six months (Figure 17).

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

Location:	**Holbourne Shallow.**		**Holbourne Deep**		**Camp Is.**	
PERCENT OF TOTAL COLONIES WITH SEDIMENT LOAD						
Jul 2018	1.3%		1.8%		5%	
Nov 2018	0.5%		1.0%		10.3%	
May 2019	7.3%		12.5%		19.3%	
MEAN MAXIMUM SEDIMENT DEPTH (mm)						
Jul 2018	0.01	*0.07*	0.02	*0.19*	0.03	*0.14*
Nov 2018	0.01	*0.04*	0.01	*0.05*	0.06	*0.20*
May 2019	0.04	*0.14*	0.08	*0.25*	0.14	*0.35*

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

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

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

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

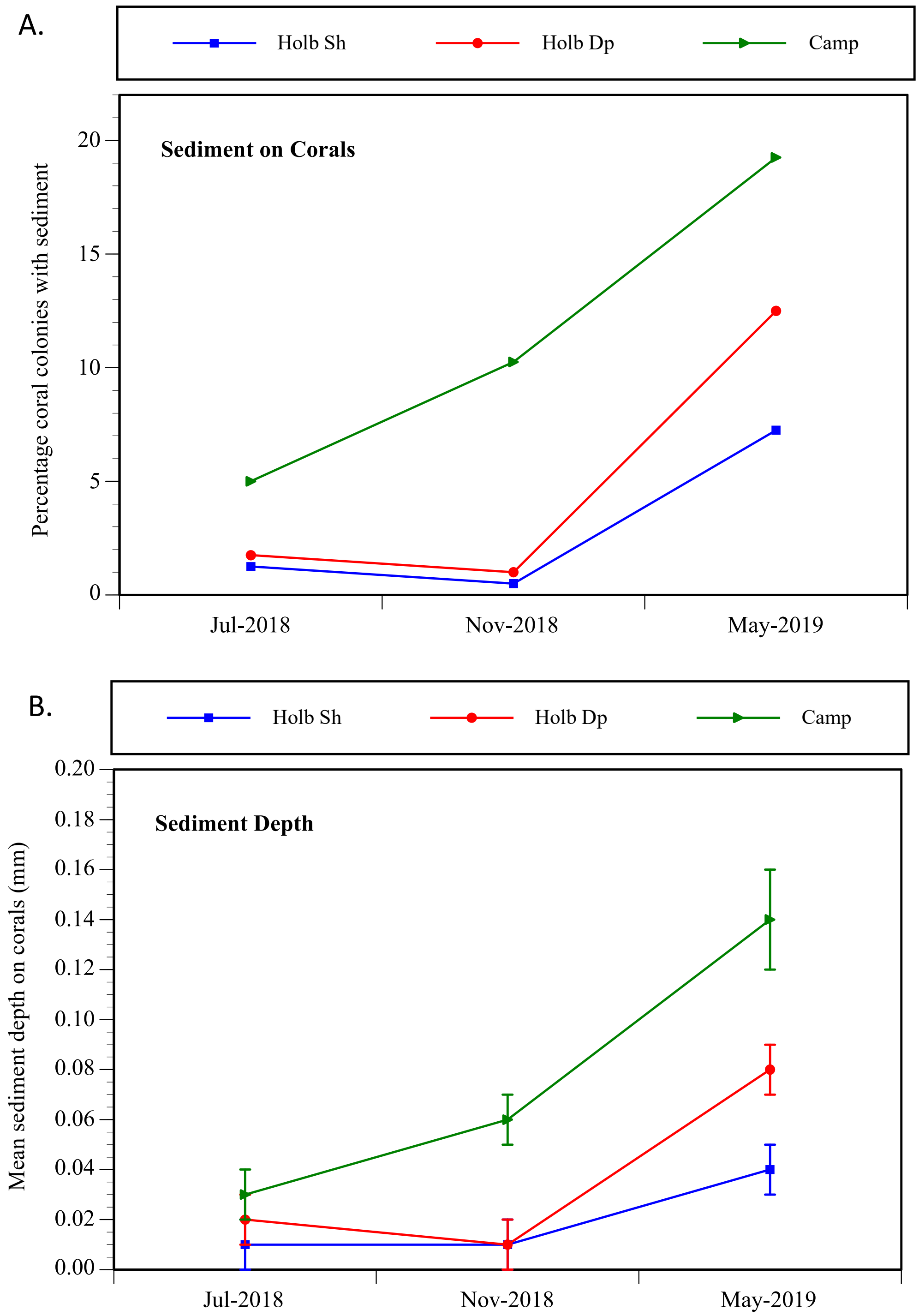


Figure 17. Changes in Number of Corals with Sediment Load and Sediment Depth. Graphs show percentage of the 400 coral colonies examined in each location that had measurable sediment on part of the surface during each survey and the mean depth in mm of that sediment for the last three ambient surveys. Error bars where appropriate are standard errors. Holb Sh = Holbourne Island shallow stratum; Holb Dp = Holbourne Island deep stratum.

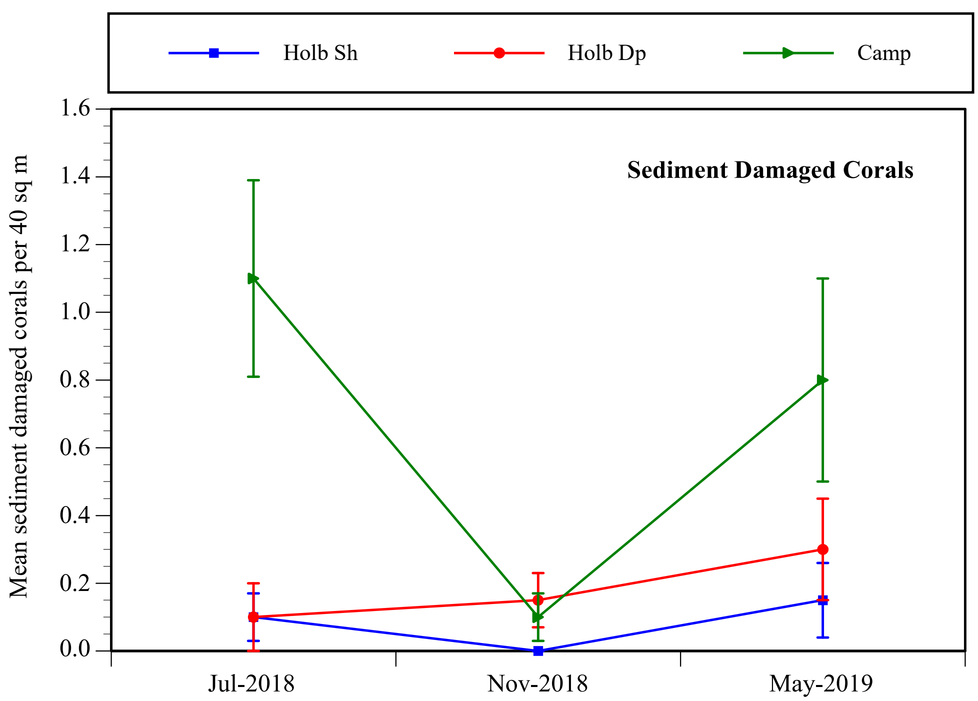
3.6 Sediment Damage and Disease in Coral Colonies

Heavy sediment deposition on living coral can cause patches of mortality on the coral surface. With the low sediment levels in both Holbourne Island locations the number of sediment damaged coral colonies was also low (Table 5, Figure 18). The number of sediment damaged corals was significantly higher on Camp Island (Table 6), but fluctuated significantly giving significant Time and Time x Location factors (Figure 18, Table 6). The fluctuations in levels of coral sediment damage on Camp Island did not relate to the measures of coral sediment load. 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.

A small number of diseased corals are present in most coral reef communities. The coral groups most often affected by disease in the Abbot Point region were *Acropora* and *Montipora*, but pocilloporid corals were also sometimes damaged by disease. Disease levels were low during these ambient surveys with a grand mean of 0.4 diseased corals per 40 sq m (Table 5). There were significantly more diseased corals in the Camp location than in the Holbourne locations during these ambient surveys (Table 5). These were no significant Time or Location x Time effects (Table 6).

Although there have been significantly more health issues recorded on Camp Island than in the Holbourne locations this does not take account of the different abundance of corals in the three locations. Mean coral cover was only about 2% in the shallow Holbourne stratum and 8% in the deep Holbourne stratum but was about 25% on Camp Island. Overall health issues relative to coral abundance were actually about two times higher in both Holbourne locations than on Camp Island.

A.



B.

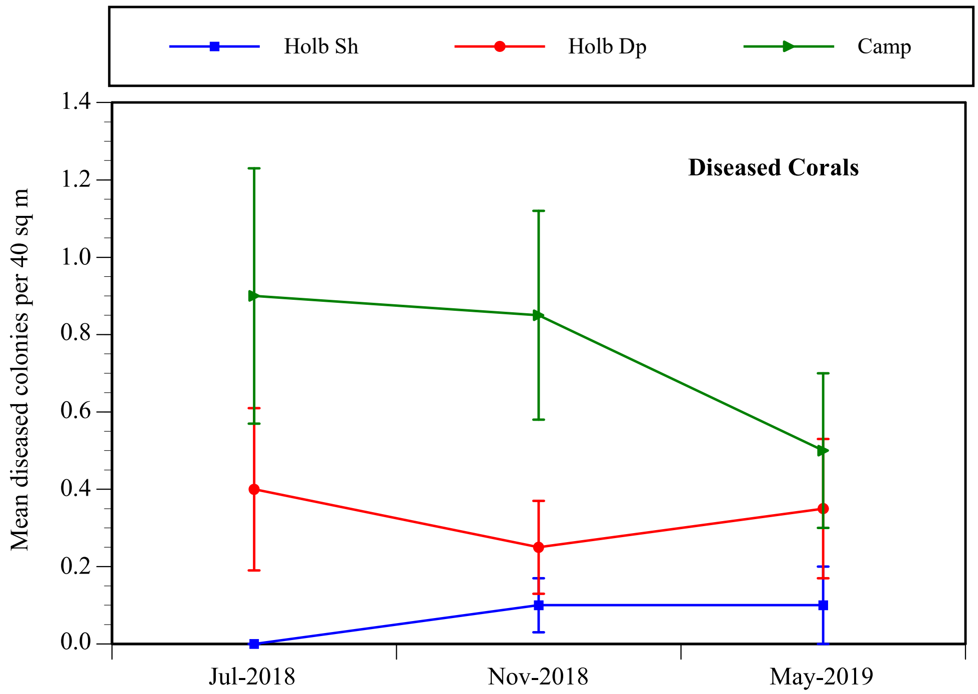


Figure 18. Changes in density of sediment damaged and diseased coral colonies. Graphs show grand mean density of diseased coral colonies and sediment damaged corals per 40sq m from four sites of five 20 x 2m transects in each location from the last three ambient surveys. Error bars are standard errors. Holb Sh = Holbourne Island shallow stratum; Holb Dp = Holbourne Island deep stratum.

3.7 Other Coral Health Issues

Several other coral health issues were also recorded during these ambient surveys. A small number of coral colonies were recorded as damaged due to grazing by the coralivorous *Drupella* snails (Figure 19). This damage was at a very low level with only 1-2 damaged colonies recorded in total for the three 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.

Physical damage was also recorded at several of the locations during these surveys. One of the Camp Island east sites is shallow and exposed to the SE winds. There are usually some broken branching coral colonies at this location during each survey (Figure 19). The broken branches are still living and eventually regrow into new colonies or fuse with the parent colonies. During the May 2019 survey damage from a large anchor had affected one of the west Holbourne deep sites (Figure 19) but had caused minimal change to coral cover.

During the May 2019 survey a small aggregation of very large crown-of-thorns sea stars had moved into the West 2 Deep Holbourne site. More than ten individuals were seen in the area with four recorded in the five 20 x 2m coral health transects. The animals were all very large adults ranging in size from 50-60cm diameter and had damaged a mean of 6.4 coral colonies per 40 sqm at that site (Figure 19).

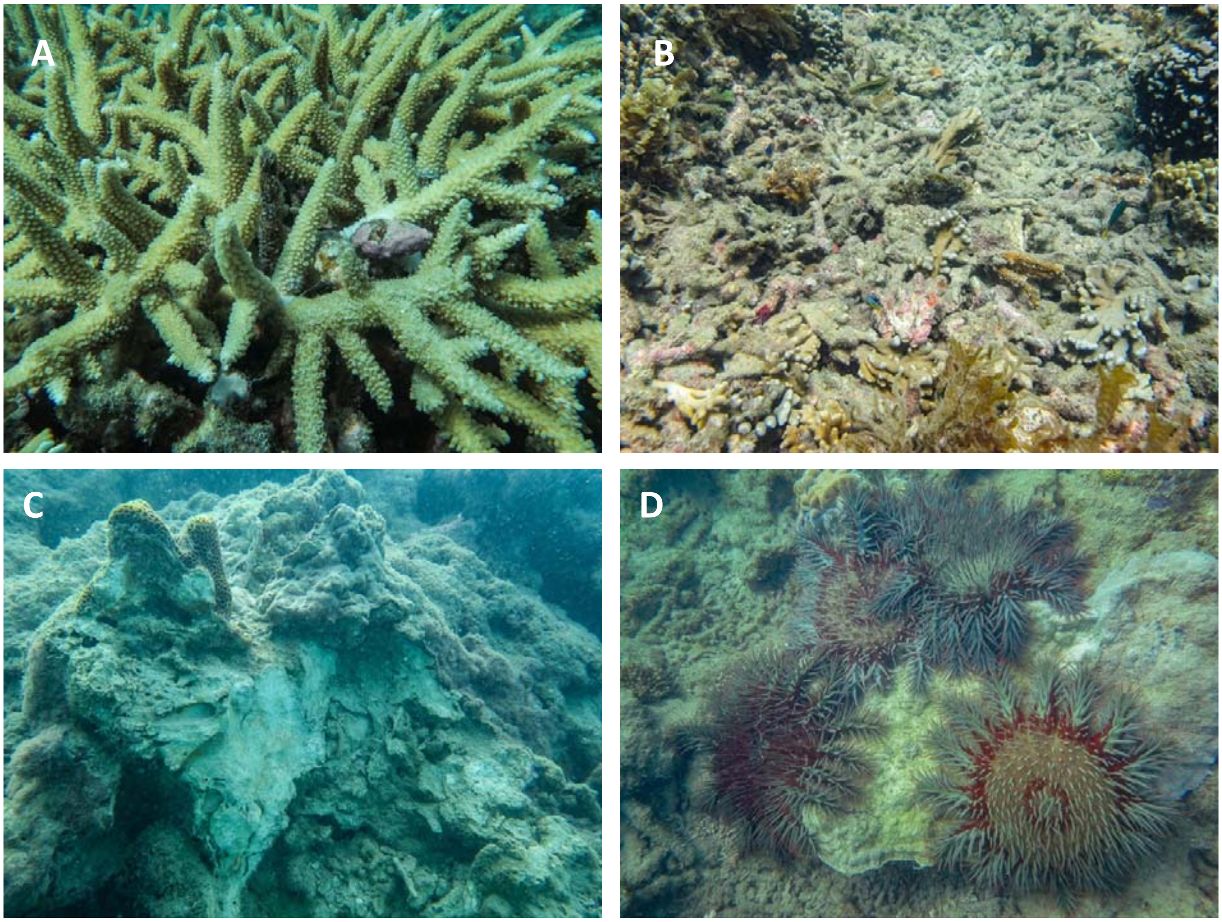


Figure 19. Coral health issues: A. Two *Drupella* snails grazing on an *Acropora* staghorn colony in the Holbourne deep location. B. Rubble and broken coral fragments caused by wave action in the Camp Island east 2 site. C. Broken section of reef caused by a large anchor at the Holbourne deep location. D. Cluster of *Acanthaster* sea stars in the Holbourne deep location in May 2019.

3.8 Coral Recruitment Patterns

Numbers of hard coral recruits less than 10 cm in diameter were higher on Camp Island reefs than in the two Holbourne locations during these ambient surveys (Figure 20, Table 9). Grand mean recruit densities were about 1.7 per sq m on Camp Island, 0.9 per sq m in the Holbourne deep location and a low 0.5 per sq m on Holbourne shallow. 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). Although there is lots of free space in the Holbourne shallow location as a result of Cyclone Debbie damage that appears suitable for coral settlement recruit numbers have remained very low in this location. Recruit numbers did not change significantly over the eleven months covered by these three surveys (Table 9). The apparent nominal dip in recruit numbers on Camp Island in November 2018 was probably due to dense algal growth making accurate assessment of recruits unreliable at several of the sites.

The dominant coral groups represented in the recruit population for the shallow Holbourne Island location were *Acropora* species, faviids and poritids while most coral groups were well represented in the Holbourne deep recruit population. On Camp Island *Acropora* corals and *Turbinaria* were the dominant recruit groups with *Montipora* and faviids also well represented (Figure 21). No one coral group dominated the recruit population at any of the three locations. Proportions of the dominant Acroporid and *Turbinaria* recruits during these surveys were 42% and 29% respectively of total recruits. This compares to approximately 33% and 27% 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 Three Ambient Surveys: ANOVA Results

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

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

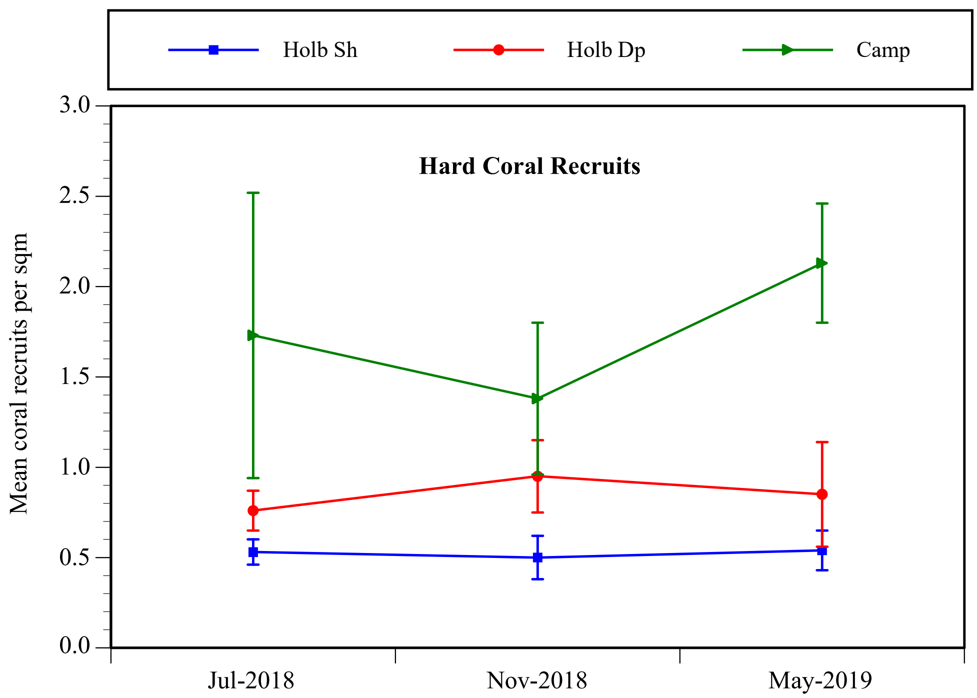


Figure 20. Changes in density of hard coral recruits over the ambient surveys. Graphs show mean density of hard coral recruits per m^{-2} from four sites in each location for the past three ambient surveys. Error bars are standard errors. Holb Sh = Holbourne Island shallow stratum; Holb Dp = Holbourne Island deep stratum.

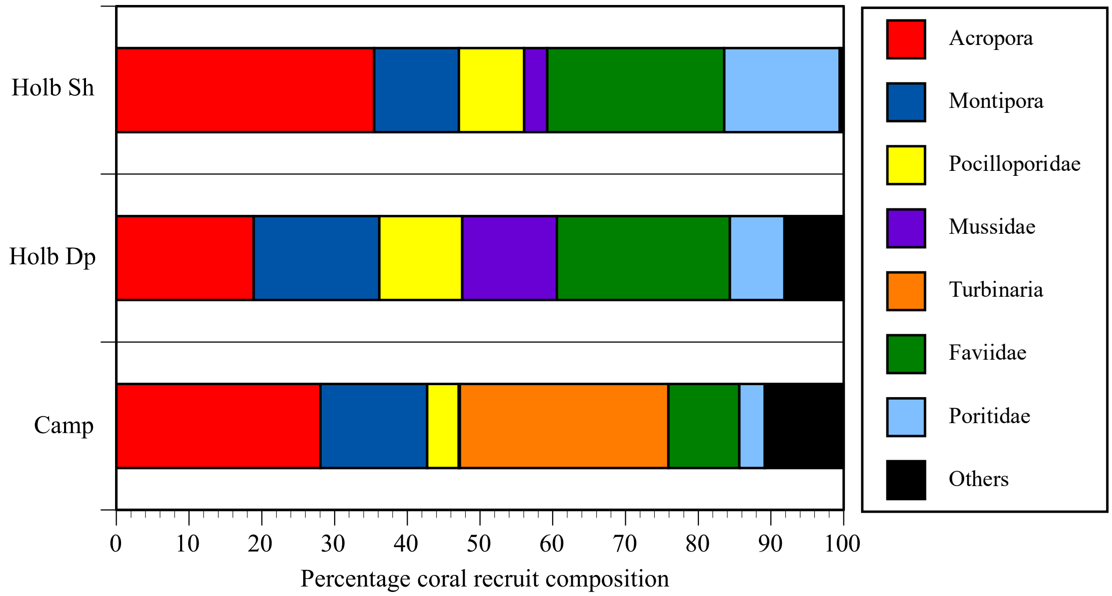


Figure 21. Composition of the hard coral recruit population in the three locations over the ambient surveys. Graphs show mean percentage composition of the major groups of coral recruits from the three locations. Composition is averaged across the last three ambient surveys

3.9 Benthic Community Images

Examples of the benthic community structure at each location and examples of coral health impacts are provided in Figure 21 to Figure 37.

Figure 22. Consolidated rubble from Cyclone Debbie damage in the shallow Holbourne Island location.

Figure 23. *Coscinarea* (left), *Platygyra* (centre) and *Favia* (right) coral colonies at the East 1 shallow Holbourne Island site. Hard coral cover was only 4% at this site.

Figure 24. Bare substratum suitable for new coral recruitment in the shallow Holbourne location still has low numbers of new coral recruits more than 2 years after Cyclone Debbie.

Figure 25. Small patch of healthy hard and soft corals (orange) in the deep East Holbourne location.

Figure 26. Patch of dead staghorn *Acropora* corals resulting from Cyclone Debbie in the deep East Holbourne location.

Figure 27. Scattered hard and soft corals in the deep West Holbourne location. Hard coral cover was about 9% in this location.

Figure 28. Extensive field of healthy bottlebrush *Acropora* a few metres below the survey transects at the deep Holbourne stratum.

Figure 29. Dense forest of *Sargassum* macroalgae at the East 1 Camp Island site. Hard coral cover was only 7% at this site.

Figure 30. Dense macroalgal cover with scattered hard corals at the West 2 Camp Island site. Hard coral cover was 24% at this site.

Figure 31. *Sargassum* macroalgae caught amongst otherwise healthy hard corals at the West 1 Camp Island site in November 2018.

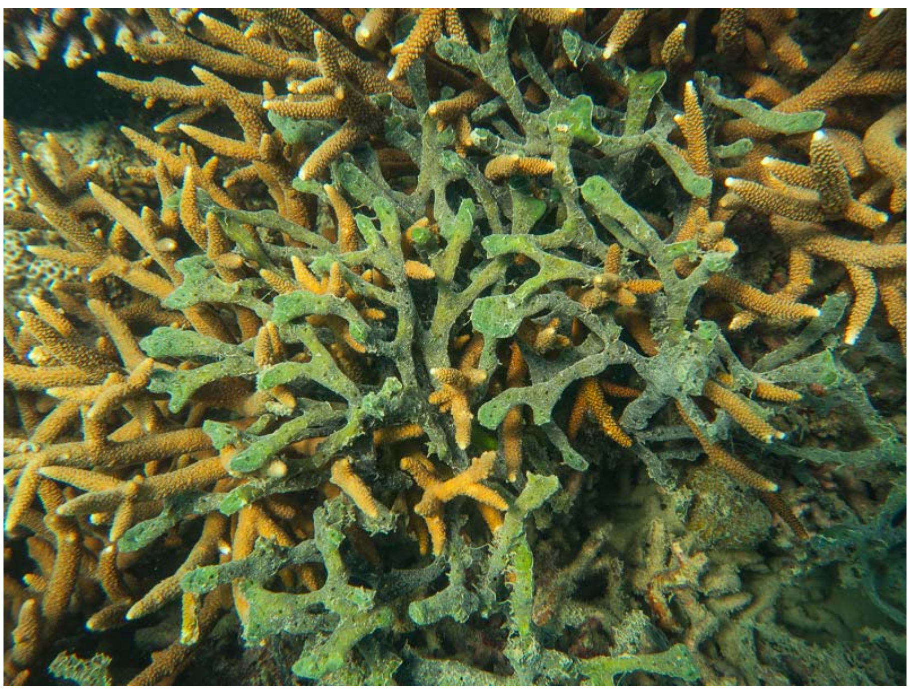


Figure 32. The green sponge *Haliclona cymaeformis* amongst staghorn *Acropora* at the West 1 Camp Island site.

Figure 33. Encrusting *Montipora* corals, *Acropora* corals and macroalgae at the East 2 Camp Island site.

Figure 34. Extensive colonies of staghorn *Acropora* at the West 1 Camp Island site. Hard coral cover was almost 55% at this site.

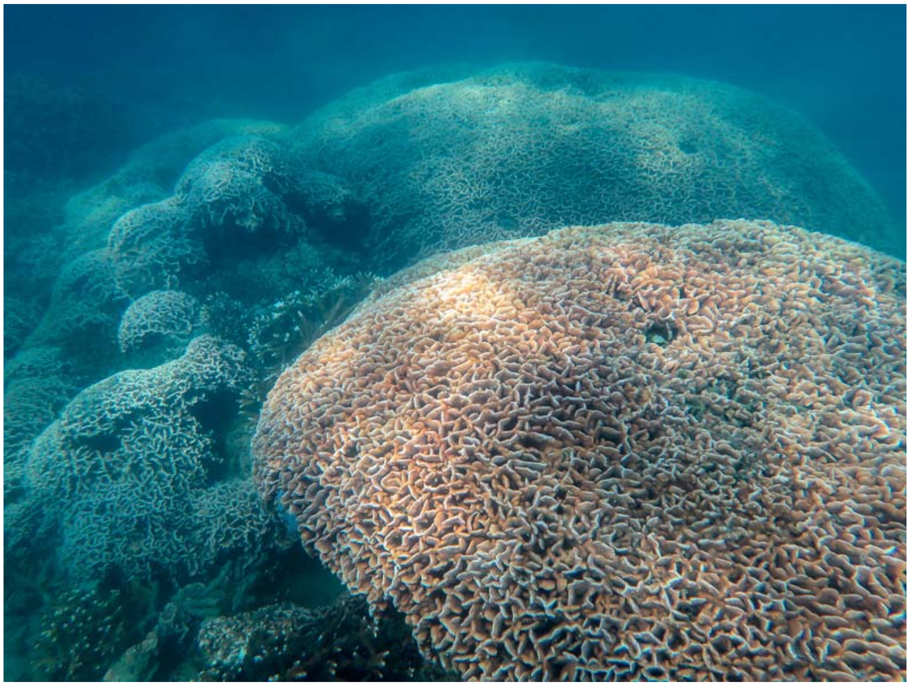


Figure 35. Large colonies of *Pavona decussata* at the West 1 Camp Island site.

Figure 36. Several large *Porites* colonies surrounded by other corals at the West 1 Camp Island site.

Figure 37. Dense cover of *Acropora* and *Montipora* corals at the East 2 Camp Island site.

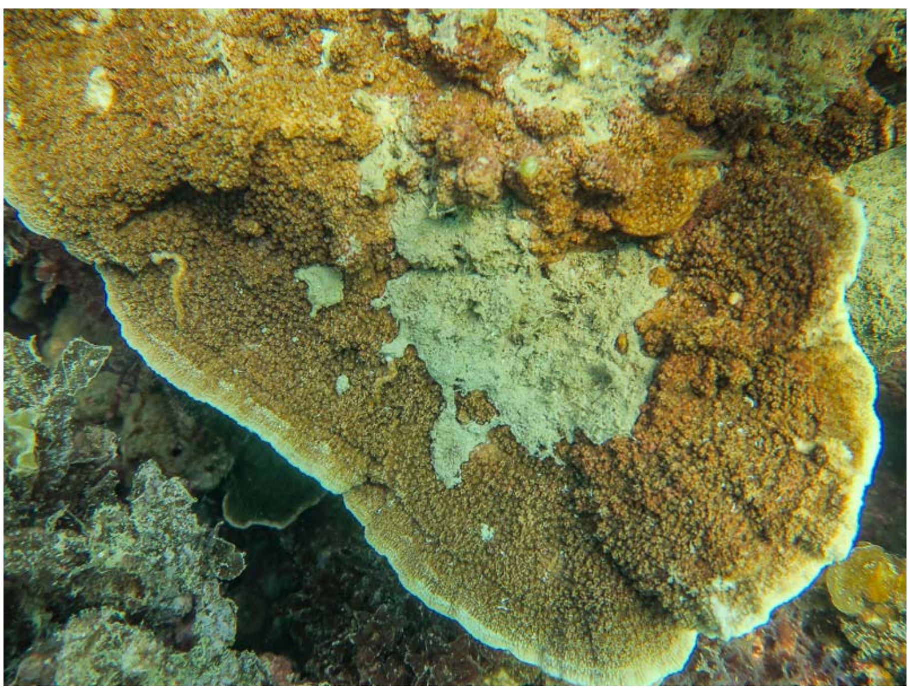


Figure 38. Thick patch of sediment on the surface of a *Montipora* coral on the West 2 Camp Island site.

4 DISCUSSION

4.1 Benthic Cover during the last three Ambient Surveys

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 wold have been 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 (Figure 28) and a deeper stratum would have documented this. Another issue with site selection around Holbourne Island is that all the present sites are on the SW facing side of the island with no sites on the NE face. As a result all eight sites were severely impacted by Cyclone Debbie whereas sites on the NE face of the island would have been far less impacted and hence give more balance to the overall reef community condition monitoring. It is therefore recommended that the Holbourne sites be changed moving forward with 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 face of the island. In order to maintain capacity to integrate monitoring data into the broader regional report cards PSD should be measured during the first new site survey event. These data will be beneficial in interpretation of the new sites sediment hydrodynamics.

The four sites at Camp Island were each very different in terms of macroalgal and coral cover, with mean macroalgal cover ranging from less than 1% at the West 1 site to almost 55% at the East 1 site. Hard coral cover was equally variable with less than 7% cover at the East 1 site to almost 55% at the West 1 site. Sites were selected by AIMS haphazardly at windward and leeward aspects of the island 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 to hard coral dominated, it is future trajectories of coral dominated sites that most aligns with the objectives of this ambient program.

Benthic communities were very stable on both Holbourne Island locations. Coral communities at all survey sites around this island had been decimated in by Cyclone Debbie (AIMS 2018) and recovery was very slow with just a nominal increase in hard coral cover over these three ambient 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. Similar slow recovery was noted by AIMS during the decade after COT 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).

The major change recorded during the 2018/2019 ambient surveys covered in this report was the steady decrease in macroalgal cover at the Camp Island location and a slight increase in hard coral cover at the same location. 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 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 were healthy and growing during these ambient surveys.

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 actively to remove surface sediment unless rates remain very high for long periods. It takes extreme events like cyclones or prolonged rough weather to overwhelm coral colonies natural sediment removal mechanisms. 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 also has 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 four visits to the location. This clear water mass appears to be restricted to the immediate vicinity of Camp Island with normal turbid inshore water encountered only 500 m east of the island on most visits. The reasons for this are not clear but may relate to the shallow depths around the island. The percentage of fine particles (<64 microns) in the sediment at the Camp Island sites was only around 8% (AIMS 2018) roughly equivalent to measurements from the 5 m depth stratum at the more offshore Holbourne Island.

In spite of the less turbid water at the Abbot Point monitoring locations the level of sedimentation and sediment damage to hard coral colonies was only slightly less than in the Mackay/Hay Point survey locations (TropWATER 2019 report). Grand mean sediment depth on coral colonies was 0.09mm for Abbot Point and 0.12mm for Hay Point with densities of sediment damaged corals 0.53 per 40 sqm compared to 0.64. This suggests that movement of fine bottom sediments by wave actions onto nearby coral colonies is more important than settlement of suspended sediment from the water mass.

4.3 Other Sources of Coral Mortality

Levels of coral disease during these ambient surveys were in line with levels recorded over the thirteen years spanned by the long-term surveys at the Mackay/Hay Point locations, with a grand mean of 0.32 diseased colonies per 40 sqm. Corals usually affected by disease during these surveys were acroporids and a small number of pocilloporids. On Camp Island all recorded disease was atramentous necrosis of *Montipora* colonies at densities of 0.5-1.0 diseased colony per 40 sqm. AIMS also recorded atramentous necrosis of *Montipora* corals at Camp Island with high numbers in November 2017 (3.3 colonies diseased per 40 sqm). Coral disease is usually more prevalent when water temperatures and nutrient levels are higher (AIMS 2018). 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).

Three juvenile *Acanthaster* sea stars (COTs) were recorded by AIMS damaging a few corals at one of the deep Holbourne East sites in Oct 2017 after Cyclone Debbie. No COTs were recorded at any of the Holbourne East sites during the surveys reported here but a small cluster of very large adult COTs were present in the West Holbourne deep location in May 2019. At least 10 COTs were seen in the West 2 deep site with over 6 corals per 40 sqm transect damaged by COT grazing. This is further damaging coral communities that are struggling to recover from Cyclone Debbie damage and will slow recovery.

Large numbers of coral grazing *Drupella* snails were recorded by AIMS in the Holbourne East deep sites in October 2017 but only a few of these snails were recorded during the three 2018/2019 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 Implications of Coral Assessment

Recent natural cyclonic impacts have reduced coral cover significantly on the Holbourne Island locations. The slow rate of recovery of hard coral communities on these fringing reefs in the 30 months since Cyclone Debbie is a cause for concern but is in line with the decadal long recovery times reported by AIMS following COT grazing damage to Holbourne coral communities in 1987. Further damage caused by COT grazing is now exacerbating this slow recovery. The present 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. Observations by A.M. and A.L. Ayling on the northeast face of the island suggest that corals were not as badly impacted by Cyclone Debbie on those reefs. A more balanced view of coral recovery on Holbourne as a whole may be available if surveys are confined to the deep stratum in future and extended to include reefs on the northeast face of the island.

Coral communities on Camp Island appear to be healthy and growing significantly but smothering by algal growth may be a seasonal problem at this location. There is no evidence at this stage 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.

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