Port of Abbot Point Ambient Coral Monitoring Program: Baseline Report 2016

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Cover photo: Corals at Holbourne Island, Paul Costello

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1 SUMMARY OR EXECUTIVE SUMMARY

The monitoring plan for the Port of Abbot Point Ambient Coral Monitoring Program (the program) was initiated in May 2016. This report outlines the results of baseline surveys conducted in May 2016 and a resurvey of sites in October 2016. The sampling methods used were selected to allow the estimation of integrated, overall coral condition index scores as used by the Reef Plan Reef Report Card. As at October 2016, the overall condition index score was 0.36, a slight decline from 0.40 observed in May 2016. In the context of the Reef Report Card these scores would translate into a report card grade of D representing communities in "poor" condition.

The overall score masks substantial differences in condition of benthic communities at the two islands included in the program. At Camp Island the coral index score was low ranging from 0.23 (grade D) in May down to 0.18 (grade E= "very poor") in October. These scores reflect the very high cover of large fleshy seaweeds, contrasting low cover of corals and low densities of juvenile corals. In contrast, the index score for Holbourne Island was substantially higher at 0.56 in May down slightly to 0.53 in October representing a report card grade of C, representing communities in "moderate" condition. The communities at this site were characterised by very low cover of macroalgae, moderate cover of corals, but also low density of juvenile corals.

This report presents the first baseline results, which means that it is difficult to accurately identify the pressures that have previously influenced the condition of these communities. However, the consideration of weather data, including wave height monitoring and river discharges presents a way to indicate pressures. For example, high waves associated with Tropical Cyclone Yasi in 2011 and the tropical low originating as Tropical Cyclone Ita in 2014 were probable disturbances to these communities. Above-median discharges from the Burdekin, Don and Elliot rivers in 2011 but also as short term flows 2012, 2013 and 2014 may also have affected the corals at Camp Island. Future monitoring will both help identify any such disturbance events but also document the recovery potential of these reefs from such events.

Sea surface temperatures in 2016 were anomalously high for the entire Great Barrier Reef. North of Port Douglas the summer temperatures resulted in widespread coral bleaching and subsequent mortality. Surveys in May recorded low levels of bleaching of the corals at the reefs included in this study. This stress event, together with ensuing above-average winter temperatures, are likely to have contributed to the slight declines in the index scores between May and October.

The results of this baseline assessment demonstrate differences in coral community composition and index scores between reefs, depths and aspects within reefs. This spatial variability is captured by the monitoring design selected for the program, which replicates sampling across each of these factors. However, the temporal replication that includes sampling in the late-wet and late-dry seasons potentially confounds seasonal changes with longer-term decline. For longer-term dynamics it is recommended that reporting of coral community condition is based on a single annual sample. To improve understanding of the seasonal dynamics of coral community condition within the region there is value in continuing to sample in the late-wet and late-dry. Repeat seasonal sampling will help to disentangle whether variability observed in between samples was due to environmental conditions particular to 2016 or reflects consistent seasonal patterns.

2 BACKGROUND

Coral communities are an iconic component of the marine ecosystems in Northern Australia. Inshore coral reefs of the Great Barrier Reef are impacted by multiple pressures including large scale disturbances such as cyclones, through to more localised issues such as elevated levels of nutrient or suspended sediments as a result of activities in the coastal zone and in adjacent catchments.

The successful management of activities with the potential to impact coral communities requires the ability to disentangle the impacts of local (manageable) pressures, from larger scale processes. To achieve this goal baseline information relating to the dynamics of communities exposed to ambient environmental conditions will provide valuable context to the variability that may be experienced during future local activities.

The Port of Abbot Point Ambient Coral Monitoring Program (the program) was initiated by the Australian Institute of Marine Science (AIMS) under contract to North Queensland Bulk Ports (NQBP). The overarching goal of this program is to develop an understanding of the condition of coral communities on fringing reefs in the vicinity of Abbot Point and of the key environmental factors influencing that condition. This understanding will benefit port master-planning and inform the management of future activities.

Specific objectives of the program are:

- To assess and report the condition of coral communities at Holbourne Island and Camp Island
- To identify key environmental factors influencing coral community condition

This report provides a summary of the condition of coral communities observed during late wet season and late dry season samples (May and October 2016 respectively). Differences in communities both between sites and seasons are discussed in terms of likely drivers of community condition but also in terms of the appropriate future sampling design.

3 METHODS

3.1 Sampling Design

The physical environment experienced by corals at a given location are described by a combination of depth, aspect of a reef relative to prevailing weather conditions, and the location of a reef along the steep gradient in water quality within the inshore Great Barrier Reef. Depth and exposure to wind-driven waves determine the exposure of corals to pressures associated with suspended particles (Wolanski et al. 2005). Light, required for coral's autotrophic acquisition of energy, attenuates exponentially with depth at a rate proportional to turbidity (Van Duin et al. 2001; Storlazzi et al. 2015), while sedimentation increases as a function of suspended sediment concentration, particle size, and turbulence (Storlazzi et al. 2015). Locational differences may also influence the risk of exposure to both acute disturbances such as cyclones or flooding as well as any pressures relating to port activities that may have either directional or depth stratified impacts.

In recognition of the importance of aspect and depth as determinants of coral community composition (e.g. Thompson et al. 2014), and exposure to potential acute and chronic pressures, sampling locations were selected on both the windward "Eastern" and leeward "Western" aspects of both Camp Island and Holbourne Island (Figure 1). At all locations at Holbourne Island transects were replicated at both 2m and 5m depths below lowest astronomic tide datum (LAT) as predicted by Navionics electronic charts on the day of site construction. At Camp Island East the reef slope transitioned to sand supporting seagrass at 1.5 to 2m below LAT and as such transects were set at 1.5m below LAT only. At Camp Island West the reef slope extended to 2-3m below LAT and transects were set at 2m LAT only (Table A1).

As coral communities are spatially heterogeneous two levels of replication were included within each combination of aspect and depth. Two replicate sites separated by at least 150m were selected haphazardly from the surface with the only limitations being that they were positioned on areas of substrate suitable for corals. At Holbourne West the sites are slightly closer together due to the limited extent of reef slope and a desire to keep the transect markers away from the beach, not only to avoid, as much as possible, potential damage to markers caused by anchoring but also to limit disruption of visual amenity at this popular recreational area. Within each site five 20 metre long transects were constructed to follow the depth contour of the site in a clockwise direction from the start point. Each transect was separated from the previous by a gap of 5 m and marked with a steel fence post "star-picket" at the start and a section of 10 mm steel rod at both the 10 m and end marks. A summary of the sampling design is presented as Table 1, additional details including the GPS waypoints marking the start of each site and depth combination along with compass directions along each transect are provided in Table A1.

Table 1Sampling design

Island	Zones	Sites per Zone	Depths per site	20m Transects per site and depth
Holbourne	East and West	2	2m and 5m	5
Camp	East and West	2	1.5-2m only	5

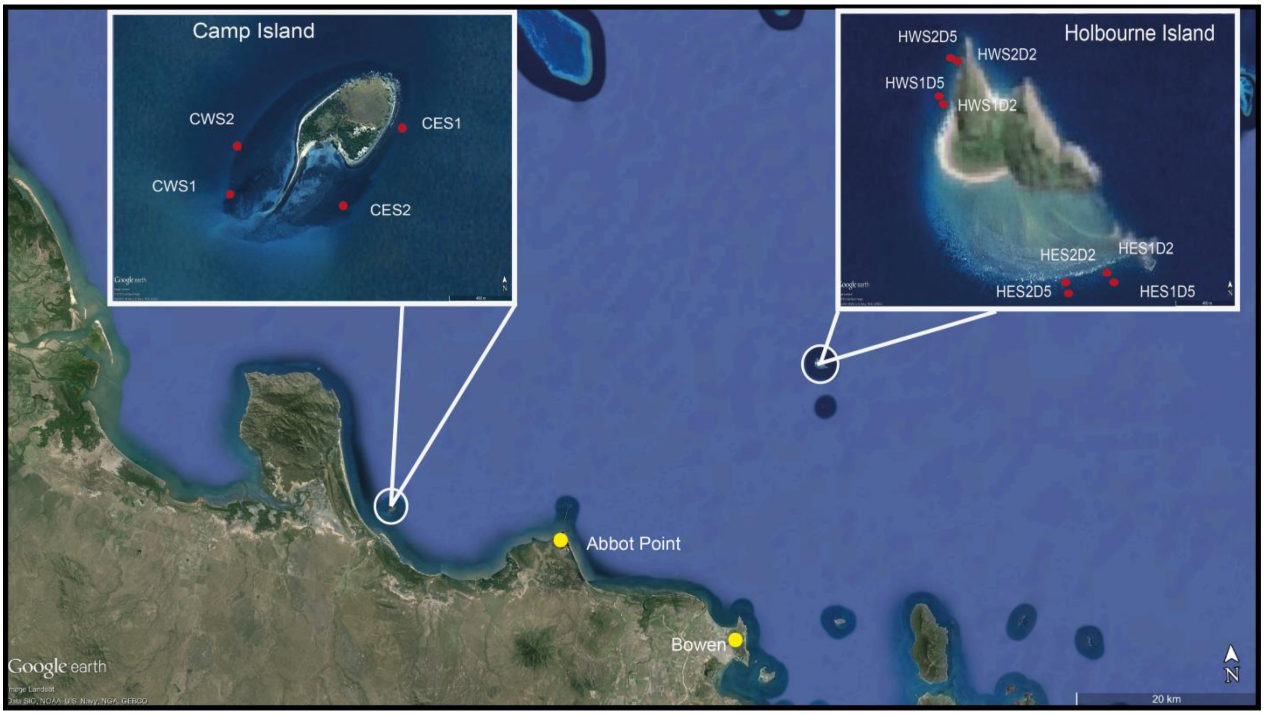

Figure 1 Coral monitoring locations. Site labels are abbreviated in the form; Reef –"H" for Holbourne Island and "C" for Camp Island, Aspect – "W" for West and "E" for East, Site number - S1 or S2 and Depth below low tide datum – "D2" for 2m and "D5" for 5m. No depths included at Camp Island as only 1 depth was sampled at each site.

3.2 Sampling methods

3.2.1 Photo point intercept transects

Benthic cover was estimated using photo point intercept transects (PPIT, Jonker et al. 2008). Along the upslope side of each transect line digital images of the substrate were taken at ~40cm elevation at 50cm intervals. Benthos beneath 5 evenly spaced points on each image was identified to the finest taxonomic resolution possible; typically genus level for corals and larger algae. A total of 32 images were analysed from each transect. Identifications for each point were entered directly into a data entry front-end to an Oracle® database, developed by AIMS. This system allows the recall of stored transect images. For data quality assurance all identified points were checked by a second observer.

3.2.2 Juvenile coral surveys

The number of juvenile coral colonies were counted *in situ* along the permanently marked transects. Corals in the size classes: 0-2cm, >2-5cm, and >5-10cm found within a strip 34cm wide (data slate length) positioned on the upslope side of the transect line were identified to genus level and recorded. Importantly, this method aimed to record only those small colonies assessed as juveniles, i.e. which result from the settlement and subsequent survival and growth of coral larvae, and so did not include small coral colonies considered to have resulted from the fragmentation or partial mortality of larger colonies.

3.2.3 Scuba search transects

Scuba search transects documented the incidence of disease and other agents of coral mortality and stress observed at the time of survey. This method followed closely the Standard Operation

Procedure Number 9 of the AIMS Long-Term Monitoring Program (Miller et al. 2009) and serves to help identify probable causes of any declines in coral community condition. For each 20m transect a search was conducted within a 2m wide belt transect centred on the marked transect line and the incidence of: coral disease, coral bleaching, coral predation by *Drupella* or crown-of-thorns seastars, overgrowth by sponges, smothering by sediments or physical damage to colonies was recorded.

3.3 Coral community Indicators

The indicators and methods used to derive report card scores for coral communities were a subset of those used for the 2015 Reef Report Card (Queensland Government 2016; Thompson et al. 2016). Of the five indicators included in the Reef Report Card two require multiple annual observations for estimation and as such were not estimated here. The rate of coral cover change indicator requires at least three annual visits. The change in community composition indicator is scored on the basis of deviation in community composition beyond baseline condition confidence intervals. The estimation of confidence intervals in community composition requires five observations. It is envisaged that both indicators for the rate of coral cover increase and changes in community composition will be incorporated as the time series of this program develops. This section provides an overview of the rationale for the selection of the three indicators used to assess coral community condition in 2016, a full description of these and the additional indicators can be found in Thompson et al. (2016).

3.3.1 Coral Cover

The most tangible and desirable indication of a healthy coral community is an abundance of coral. The Coral Cover indicator scored reefs based on the proportional area of substrate covered by either 'Hard' (order Scleractinia) or 'Soft' (subclass Octocorallia) corals.

$Coral\ Cover_{ij} = Hard\ Coral\ cover_{ij} + Soft\ Coral\ cover_{ij}$ where i = reef and j = time.

While high Coral Cover provides a good indication that environmental conditions are supportive of the growth and survival of corals, low cover does not necessarily indicate the opposite. Coral communities are naturally dynamic being impacted by acute disturbance events such as cyclones (Harmelin-Vivian 1994; Osborne et al. 2010), temperature anomalies (Berkelmans et al. 2004) and, in coastal areas, flooding (van Woesik 1991; Jones and Berkelmans 2014). The indicators Juvenile Density and Proportion of Macroalgae Cover were included as they represent the potential for coral communities to recover from disturbances.

3.3.2 Juvenile Density

The density of juvenile corals is an indicator of the successful completion of early life history stages of corals from gametogenesis through fertilisation, larval survival, settlement to the substrate and then early post settlement survival, all of which may be impacted by poor water quality (reviewed by Fabricius 2005; van Dam et al. 2011; Erftemeijer et al. 2012). The Juvenile Density indicator was derived from counts of juvenile corals along belt transects and converted to a density per area of potentially colonisable hard substrate estimated as the proportion of benthos identified as algae along the co-located point intercept transects.

$Juvenile\ Density_{ij} = J_{ij}\ /\ A_{ij}$

Where J= count of juvenile colonies < 5cm in diameter, A = area of transect occupied by algae (m^2).

3.3.3 Macroalgae Proportion

Macroalgae may suppress the recovery of coral communities through a variety of mechanisms ranging from direct competition with surviving colonies though to physical and chemical suppression of the recruitment process (McCook et al. 2001; Hughes et al. 2007; Foster et al. 2008; Hauri et al. 2010; Cheal et al. 2013). To ensure that the assessment of macroalgae cover was independent of the cover of corals, and that differences in available space for algal colonisation were considered, the indicator for macroalgae was estimated as the proportion of the total cover of algae made up of large fleshy species, collectively macroalgae.

$$Macroalgae\ Proportion_{ij} = Macroalgae\ cover_{ij}\ /Total\ algae\ cover_{ij}$$

3.3.4 Scoring of indicators

To facilitate the reporting of coral community condition, the observed values for each indicator were converted to scores on a common scale of 0 to 1. For each indicator, observed levels were scaled against thresholds used by the MMP. These thresholds were set based on expert opinion and knowledge gained from the time-series of coral community condition collected by the MMP and LTMP. Upper bounds were set that represent values of indicators that were considered to represent communities in as good a condition as could be expected in the local environment. Conversely, lower bounds were set to represent minimal resilience (Table 2). While observations may exceed these limits, any such values will be capped at the minimum or maximum score (0 or 1 respectively). For the Macroalgae Proportion indicator upper and lower bounds were set individually for each reef and depth to account for natural variation in macroalgal abundance across the steep gradient in water quality that exists in the inshore GBR. Selection of the reef-level thresholds were based on predictions of Macroalgae Proportion based on gradient boosted models (Ridgeway 2007). The models predict Macroalgae Proportion based on mean chlorophyll *a* and non-algal particulate (turbidity) concentrations for each reef derived from MODIS Aqua data sourced from the Bureau of Meteorology[1]

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[1] *Marine water quality indices produced by the Australian Bureau of Meteorology as a contribution to eReefs - a collaboration between the Great Barrier Reef Foundation, Australian Government, Bureau of Meteorology, Commonwealth Scientific and Industrial Research Organisation, Australian Institute of Marine Science and the Queensland Government. Data are acquired from NASA spacecraft by the Bureau, Australian Institute of Marine Science, and the Commonwealth Scientific and Industrial Research Organisation.*

Table 2 Indicator score thresholds

Indicator	**Location**	**Upper bound (score=1)**	**Lower bound (score=0)**
Coral Cover	All	75%	0%
Macroalgae Proportion	Camp East	9%	23%
	Camp West	6%	23%
	Holbourne East 2m	5.9%	10.2%
	Holbourne East 5m	0.6%	9.9%
	Holbourne West 2m	3.7%	8.8%
	Holbourne West 5m	0.5%	9.8%
Juvenile Density		13 m^{-2}	0 m^{-2}

3.3.5 Aggregation of indicator scores

The scaling of all scores to the common range of 0 to 1 allows the aggregation of scores across indicators at a hierarchy of spatial scales. Within this report scores are presented at the scale of individual indicators at each reef and depth, individual indicators and Report Card scores for each island, and the whole of area. For island-level scores each indicator score was estimated as the mean of indicator scores for each combination of aspect and depth, and Report Card scores as the mean of the three individual indicator mean scores. Similarly the whole of region scores were taken as the mean of island level means for each indicator and the Report Card score as the mean of these region-wide individual indicator scores. Grades for coral community condition were derived from the scores estimated above, according to the conversions described in Table 3.

Table 3 Indicator scores, condition descriptions and report card grade conversions.

Score	Condition description	Grade
> 0.8	Very good	A
> 0.6 ≤ 0.8	Good	B
> 0.4 ≤ 0.6	Satisfactory	C
> 0.2 ≤ 0.4	Poor	D
0 ≤ 0.2	Very poor	E

3.4 Key pressures

Coral communities are susceptible to a range of pressures. Identifying these pressures and the associated drivers is essential in determining the likely cause of impacts to coral community condition. For inshore reefs of the GBR common disturbances to coral communities include, physical damage caused by tropical cyclones (Osborne et al. 2011; De'ath et al. 2012), exposure to low salinity waters during flood events (van Woesik 1991; Jones and Berkelmans 2014), and anomalously high summer temperatures resulting in coral bleaching (Berkelmans et al. 2004; Sweatman et al. 2007). It is only once the influences of acute pressures have been accounted for that the potential impacts of chronic pressures such as elevated turbidity and nutrient levels can be inferred.

3.4.1 Thermal bleaching

Thermal stress, resulting in coral bleaching is an increasing threat to coral communities in a warming world (Schleussner et al. 2016). During initial surveys in May 2016 temperature loggers were deployed to star pickets marking site 1, transect 1 at each of Holbourne East 2m, Holbourne East 5m and Camp East. These loggers were retrieved and replaced during October 2016 and have begun the process of recording an accurate in-situ climatology experienced by coral communities at each island. Once climatology has been described (3 to 5 years) deviations during summer will indicate the likelihood of thermal stress. In the interim, thermal anomalies expressed as degree hearting days (DHD) downloadable from ReefTemp (Garde et al. 2014) as published by the Bureau of Meteorology do allow the identification of atypically warm periods likely to lead to coral bleaching. For each combination of island and aspect, waypoints were selected in open water approximately 2 km out from the reefs (Table 4). These waypoints served as the central locations for a set of nine pixels from which the 2015/16 annual summary of DHD and a time-series of monthly anomalies were downloaded. DHD are the sum of daily temperature anomalies from long term monthly averages across the period 1 December to the 31 March, whereas monthly anomalies are the mean daily anomaly for a given month; both estimates were based on the 14 Day IMOS climatology (Garde et al. 2014). Mean values of DHD and monthly anomalies were estimated as the average of the values from the nine pixels at each location. Thresholds at which moderate and severe bleaching are expected have been approximated as 60 and 100 DHD respectively (Maynard et al. 2008; Garde et al. 2014), though the pattern of warming and individual tolerances of species will add variability to these thresholds.

Table 4 Location of satellite derived environmental information

Location	Latitude	Longitude
Camp East	-19.829	147.896
Camp West	-19.829	147.896
Holbourne East	-19.751	148.371
Holbourne West	-19.711	148.34

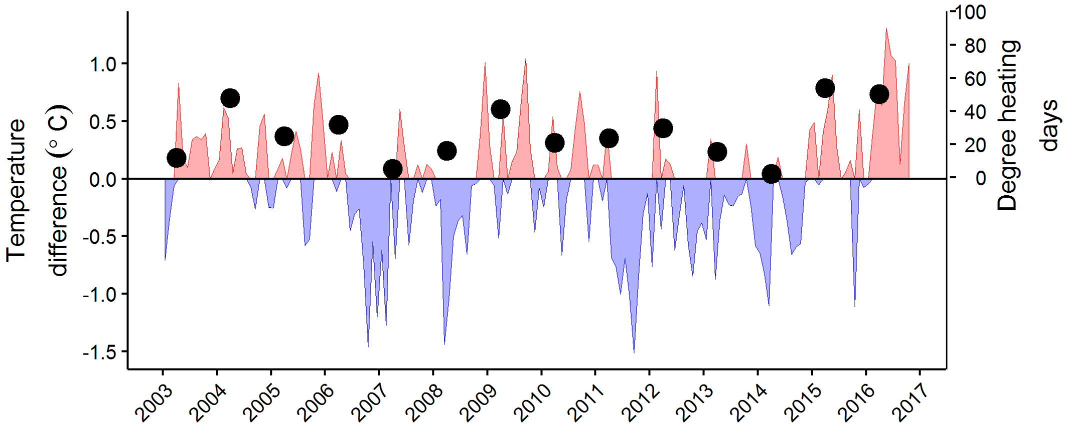

Figure 2 Temperature anomalies. Red and blue bars indicate mean monthly deviations. Black dots indicate annual degree heating days accumulated December 01 – March 31. All values are relative to IMOS 14 day climatology for the points listed in Table 2

3.4.2 Runoff

Exposure to reduced salinity has proven lethal to coral communities in the inshore GBR (van Woesik 1991; Jones and Berkelmans 2014; Thompson et al. 2016). As a generalisation, the presence of coral communities can be interpreted as direct evidence that ‘typical’ salinity levels do not pose a threat to coral communities; it is deviations to levels below 28ppt that begin to cause coral mortality (Berkelmans et al. 2012). As a first step in assessing the likelihood that floods may have led to a direct salinity-related stress to corals, the seasonal discharge of local rivers is compared to long term median flows. Median discharge for the “wet season” defined here as December-May are calculated from available data 1990-2010 and compared to the current year. Discharge data were sourced from the Queensland Government water monitoring portal for:

- Station 121001A-Don River at Ida Creek
- Station 121002A – Elliot River at Guthalungra
- Station 120006B-Burdekin River at Clare

River discharge data highlights a period of well above median flows including 2008, 2009 and then very high discharge in 2011 (Table 5).

Table 5 Annual discharge form local rivers. Values expressed as proportion of median discharge over the period 1980-2010. Colour heat used to define level of exceedance of the median: yellow=2-3 times median, orange=3-5 times median, red=5-10 times median and dark red >10 time median.

River	Median discharge (ML)	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Burdekin	4593112	2.1	6.0	6.4	1.7	7.6	3.4	0.8	0.3	0.2	0.4
Don	39986	2.5	7.2	3.9	2.4	14.5	2.0	2.0	0.7	0.7	0.3
Elliot	23568	3.1	6.2	6.0	2.2	8.7	4.1	2.3	1.3	0.4	0.5

Obscured in annual flow summaries are the magnitude of individual flow peaks. Since record flooding in 1991 the highest single day discharges from both the Don and Elliot Rivers occurred on the 12th Feb 2008 with single day discharge exceeding the annual medians presented in Table 5. Single day exceedance of the Elliot River annual median also occurred in each of 2012, 2013 and 2014. The proximity of Camp within 3km of the mouth of the Elliot River along with the shallow nature of the sites may expose the coral communities here to low salinity waters during flood events.

3.4.3 Cyclones and storms

Significant impacts to coral reefs in the GBR have been attributed to cyclone and storm damage (Osborne et al. 2011; De’ath et al. 2012). Due to the physical nature of damage associated with cyclones, impacts are readily identifiable by surveys the following winter. In addition cyclones are well publicised and highly unlikely to go unnoticed. Verification of the potential impacts of cyclones was assessed based on viewing seasonal cyclone tracks published online by the Cooperative Institute for Meteorological Satellite Studies (http://cimss.ssec.wisc.edu/tropic2/#). In addition, wave height data from the Abbot Point buoy (https://www.qld.gov.au/environment/coasts-waterways/beach/waves-sites/abbot-point/) was accessed to verify exposure to extreme wave heights associated with cyclones. These two sources of information identify the highest recorded wave height of 10.1m as occurring on the 3rd February 2011 during the passage Tropical Cyclones Yasi. This will have almost certainly caused substantial damage to coral communities at the study locations. Subsequently the third highest waves on record (6.5m) occurred on the 14th April 2014 as the tropical low remnant of Tropical Cyclone Ita passed between Camp and Holbourne; again, it is likely this event will have also reduced coral cover in the study area.

3.5 Spatial and temporal analysis

A series of generalised linear mixed effects models (Bolker 2009; McCulloch and Neuhaus 2013; Bates et al. 2015) were applied to the coral community response variables: juvenile density, macroalgae proportion, hard coral cover and soft coral cover. These models allowed the accommodation of non-normal response distributions including the binomial distribution of cover-based responses and the Poisson distribution for juvenile density. Further, juvenile density was modelled using juvenile abundance as the response and including an offset term of the log of the area available to juveniles within the sampled transects. Random components were included in each model to account for the correlations included by the repeated measures sampling design. Finally for each response linear contrasts were computed based on the estimated models to explicitly inform the questions:

- Did the response differ between Islands?
- Did the response differ between the eastern and western aspects of each combination of Island and depth?
- Did the response differ between 2m and 5m depths at either Holbourne Island East or West?
- Did the response differ between May and October samples within each combination of Island, aspect and depth?

Differences in benthic community composition were explored using unconstrained principle coordinates analysis (Gower 1966) based on Bray-Curtis dissimilarities (Beals 1984) estimated from square-root transformed percent cover estimates of corals and identifiable algae genera.
All statistical analyses were done using R software (Core Team 2016) and the packages lme4 (Bates et al. 2015), multicomp (Hothorn et al. 2008) and vegan (Oksanen et al. 2015).

3.6 Environmental setting of reefs

3.6.1 Ambient Water Quality

Turbidity and nutrient levels are critical components of the aquatic environment and are fundamental determinants of benthic community composition. For the reporting of coral community condition in inshore areas, nutrient availability in particular determines the level of macroalgae cover that can be expected, influencing the thresholds set for scoring macroalgae on a site specific basis (Thompson et al. 2016). Relative to other reefs of the inshore GBR, levels of chlorophyll *a* (Chl) and Total Suspended Solids (TSS) at Holbourne Island show the ambient conditions here to be some of the highest quality for reefs monitored by the Marine Monitoring Program (Figure 3) reflecting the distance of this reef from the coast. In contrast Chl levels at Camp Island were double that at Holbourne Island whilst TSS was ~70% greater (Table 6). At higher than 0.45ugL^{-1} the concentration of Chl at Camp Island predisposes that location to a high proportion of macroalgae and subsequent detrimental impacts to coral communities.

That the ambient water quality conditions at the two monitoring locations are within the range observed at other reefs monitored by AIMS (Figure 3) ensures the dynamics of communities observed can be validly compared to those occurring elsewhere in the inshore GBR and monitored as part of the AIMS LTMP and Reef Plan MMP.

Table 6 Ambient water quality conditions. Values represent the 10 year mean for each water quality parameter derived from satellite data; CDOM (m-1): Spatial distribution of mean of observed absorption due to coloured dissolved organic matter at 440 nm; Chl (mg/ m3): observed chlorophyll-*a* concentration, TSS (g/m^3): Spatial distribution of mean of observed total suspended solids.

Reef	**CDOM**	**Chl**	**TSS**
Camp Island	0.048	0.475	0.903
Holbourne Island	0.031	0.236	0.507

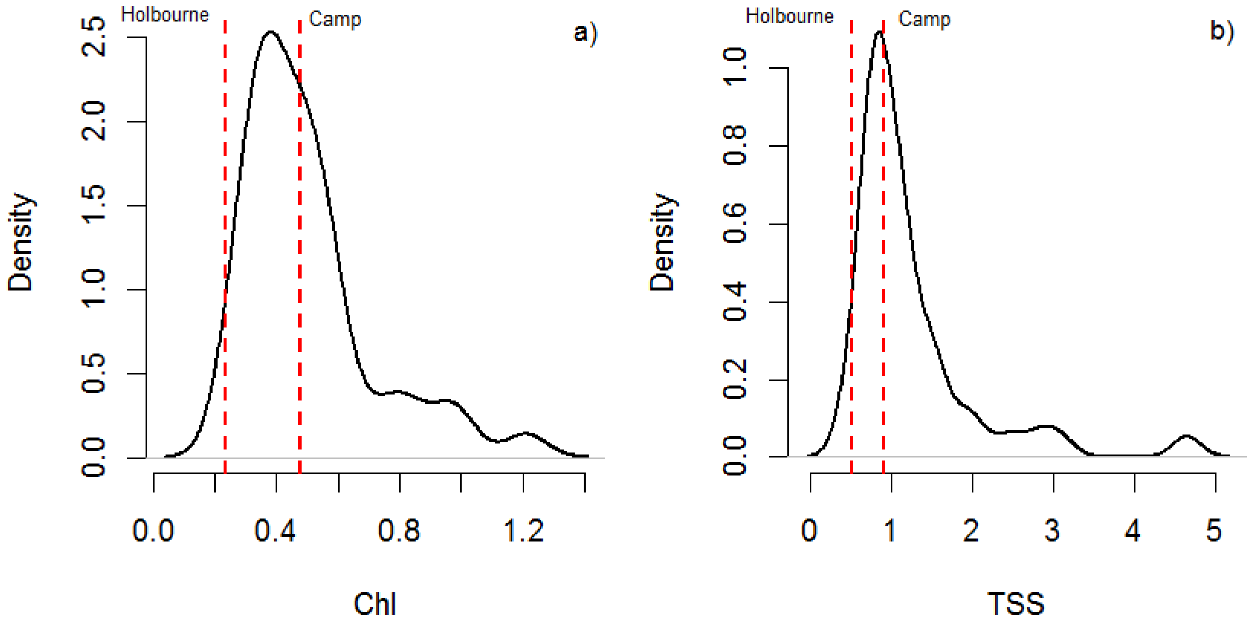

Figure 3 Ambient water quality conditions a) Chlorophyll *a* and b) Total Suspended Solids. Black lines show the distribution of satellite derived water quality conditions averaged over 10 years for nearshore reefs of the GBR included in AIMS LTMP and MMP. Red lines indicate the relative position of Camp and Holbourne Island's within each distribution.

3.6.2 Sediment characteristics – Hydrodynamic setting

As a proxy for the hydrodynamic setting of a site (Wolanski et al. 2005) the composition of sediments is a useful covariate to consider in terms of coral community dynamics. Higher proportions of fine clay and silt sized particles in the sediment identify sites more prone to sediment accumulation than those with course grained sediments.

At each site six small samples of surface sediments were collected. Sampling was conducted using a 100mm syringe tube that had had the restricted end removed. The open tube was plunged into deposits of sediment > 20mm deep encountered along the benthic transects and plugged to capture an undisturbed core of sediment. The top 10mm fraction from each core was kept and combined into a single sample from each site. These samples were then sieved through a 63µm sieve and the proportion of clay and silt sized particles in the sample determined by dry weight of the portions retained and passed through the sieve. At Holbourne Island samples were collected at the 5m sites, conforming to the sampling design for inshore reefs monitored under the MMP. As 5m sites were not present at Camp Island samples were taken from the shallower sites. Samples from the two islands are not directly comparable; those from Camp Island are assumed to have a lower proportion of clay and silt sized particles than would have been sampled at 5m should depth have permitted. As such, although the grainsize distributions are similar between the two islands (Table 7), accounting for the shallower depth of sampling at Camp, the results should be interpreted as the coral communities at Camp being more sheltered from wave exposure than those at Holbourne.

Table 7 Sediment composition at monitoring locations. Values indicate the percentage of total weight of sample with grainsizes <64 microns.

Reef	Site	Depth	Proportion of sample with grainsize < 64um (Clay/Silt %)		
			May 2016	October 2016	Mean[2]
Holbourne East	1	5	1.7	3.6	2.5
Holbourne East	2	5	2.6	2.3	
Holbourne West	1	5	9.5	10.6	9.0
Holbourne West	2	5	8.8	7.0	
Camp Island East	1	2	2.3	3.0	2.7
Camp Island East	2	2	3.5		
Camp Island West	1	2	9.3	6.7	8.0
Camp Island West	2	2	6.1		

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[2] Means are not directly comparable between Islands due to difference in depth of sampling, see accompanying text for interpretation.

4 DISSCUSSION OF RESULTS

4.1 Coral community condition assessment

The overall coral index score for coral communities at Camp and Holbourne Islands declined from 0.40 in May 2016 to 0.36 in October to be graded as D and categorised as poor condition (Table 8 & Table 9). This overall index score does however mask the substantial differences in the condition of coral communities between reefs and, to a lesser degree, between eastern and western aspects of the Islands and between 2m and 5m depths at Holbourne (Table 10). The index scores were lowest at Camp East where an index score of 0.10 in October (Grade E) contrasted scores of 0.56 and 0.57 (Grade C) at the 5m sites of Holbourne East and West respectively.

Table 8 Indicator values for Abbot Point Region.

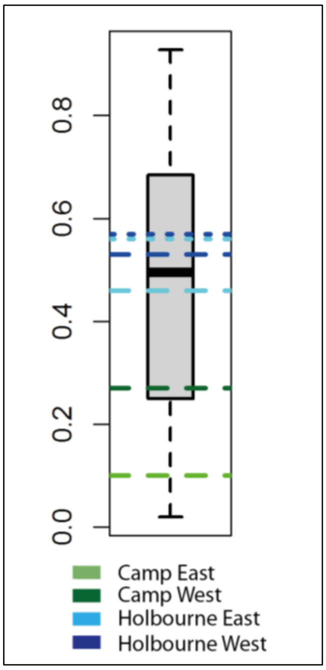
	Year	Juvenile Density (m2)		Coral Cover (%)		Macroalgae Cover (%)	
		Mean	SD	Mean	SD	Mean	SD
Regional summary	May	3.66	1.68	27.69	10.17	28.58	40.17
	October	2.88	1.30	26.12	14.31	38.14	52.50

Table 9 Indicator scores for Abbot Point Region.

	Year	Juvenile Density	Coral Cover	Macroalgae Cover	Report Card	
					Score	Grade
Regional Scores	May	0.32	0.37	0.50	0.40	D
	October	0.26	0.35	0.47	0.36	D

Table 10 Index grade and scores at each reef and depth combination. Figure to the right indicates illustrates indicator scores from this study (horizontal lines) relative to the distribution of scores observed in inshore waters of the GBR in 2015 (Thompson et al. 2016). Line style indicates depth: 2m (dashed) and 5m (dotted).

REEF	Month	Grade	index
Camp East	May	E	0.13
	October	E	0.10
Camp West	May	D	0.33
	October	D	0.27
Holbourne East 2m	May	C	0.48
	October	C	0.46
Holbourne East 5m	May	B	0.64
	October	C	0.56
Holbourne West 2m	May	C	0.53
	October	C	0.53
Holbourne West 5m	May	C	0.60
	October	C	0.57



Comparing the October scores from each aspect and depth of Camp and Holbourne Islands to the 2015 scores estimated for 71 sites monitored by AIMS within the inshore area of the GBR demonstrate that the Holbourne Island communities are clustered around the median index scores for inshore GBR reefs (Table 10). In contrast, the condition of the coral community at Camp East is in the lower 10% of inshore reefs (Table 10). To more fully interpret these results and link condition to likely pressures each of the three indicators are considered separately.

4.2 Coral Cover

The Coral Cover indicator is scored on the combined cover of hard and soft corals to account for differences in community composition that occur along environmental gradients within the GBR.
The lowest scores for the Coral Cover indicator were observed at Camp East where hard coral cover was lower than at any other location and soft corals absent (Table 11). Camp East was also the only location at which either hard or soft coral cover showed a statistical decline; hard coral cover declined from 11.2% in May to 4.2% in October (Table 11, Table 12). This loss of cover reflects the infection of *Montipora* colonies by coral disease that was observed to increase between May and October suggesting that the loss of cover was ongoing at the time of survey (Table A 6). An increase in the cover of the macroalgae *Sargassum* (Figure A 3, discussed below) is also likely to have contributed to the observed reduction in coral cover as corals were overtopped by algae and so excluded from sampling. Many of the colonies listed as having "unknown" cause of mortality in October (Table A 6) were over topped by *Sargassum* demonstrating the stress increased macroalgae cover can have on the corals below (Hauri et al. 2010). At Camp East, soft coral cover was again very low (Table 11) and hard coral cover remained significantly higher than at Camp West (Table 12). Although coral cover did declined slightly at Camp West, where disease to *Montipora* colonies (Table A 6) and increased cover of macroalgae as common pressures (Table 13), this decline was not statistically significant (Table 12) with a slight increase in cover of *Acropora* partially offsetting reduced cover of *Montipora* (Table A 2). Increased levels of disease to *Montipora* (Jones et al. 2004) and corals in general (Bruno et al. 2007) have been previously linked to high temperatures within the GBR pointing to the anomalously high temperatures during 2016 as contributing to the declines in cover observed.

At Holbourne Island the inclusion of 5m deep sites revealed the influence of depth on the Coral Cover indicator with cover higher at 5m at both East and West locations (Table 11, Table 12). This difference in coral communities between depths was most marked at Holbourne East where coral cover at 5m was the highest of all sites surveyed (rising to 38% in October, Table 11) compared to the 2m sites where hard coral cover was lowest of the four Holbourne depth and aspect combination (down to 11% in October, Table 11). The differences in cover at Holbourne East were also reflected in differences in community composition as interpreted from the separation between 2m and 5m communities evident in ordination analysis (Figure 5, note the strong separation between Holbourne East 2m (red squares), and 5m (blue squares)). The primary difference in hard coral communities between 2m and 5m at Holbourne East was that extensive stands of branching and bottlebrush forms of the genus *Acropora* and moderate cover of the soft coral *Sinularia* present at 5m that did not extend to the 2m (Figure A 4)sites where the substrate appeared scoured, presumably by wave action. These growth forms of *Acropora,* along with *Montipora* (Family Acroporidae), were also present at both the 2m and 5m depths at Holbourne West (Figure A 4).

Table 11 Coral cover and indicator scores for each location. Figure to the right indicates Coral Cover indicator scores from this study (horizontal lines) relative to the distribution of scores observed in inshore waters of the GBR in 2015 (Thompson et al. 2016). Line style indicates depth: 2m (dashed) and 5m (dotted).

REEF	Month	Hard Coral cover	Soft Coral cover	Coral cover	Coral cover Score
Camp East	May	11.2	0	11.2	0.15
	October	4.2	0	4.2	0.06
Camp West	May	29.4	0.4	29.8	0.40
	October	27.6	0.2	27.8	0.37
Holbourne East 2m	May	13.3	9.1	22.4	0.30
	October	11	10.1	21.1	0.28
Holbourne East 5m	May	34.7	16.2	50.9	0.68
	October	38	19.1	57.1	0.76
Holbourne West 2m	May	15	13.8	28.8	0.38
	October	16.7	14.4	31.1	0.42
Holbourne West 5m	May	19.3	18.2	37.5	0.50
	October	20.2	15.4	35.6	0.48

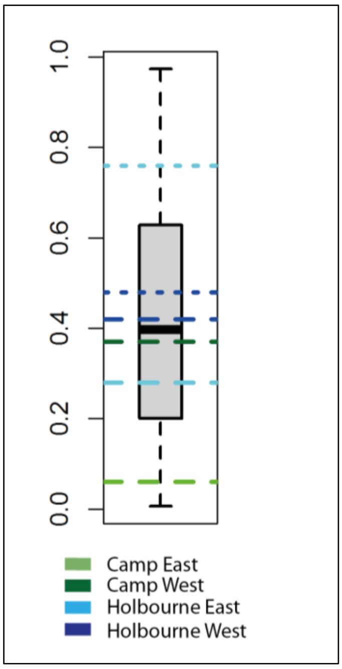


Table 12 Spatial and temporal differences in coral cover. Results of contrasts based on generalised linear mixed models applied to hard coral cover and soft coral cover. Statistical probability of no difference are indicated as > 5% (ns), < 5% (*), less than 1% (**) and less than 0.1% (***)

	Depth	Reef	Aspect	Change
Hard Coral	Higher at 5m at both Holbourne East (***) and West (***)	Higher at Camp (*)	5m depth - higher at Holbourne East (***) 2m depth – Holbourne (ns), higher at Camp West(*)	Decrease Camp East (***)
Soft Coral	Higher at 5m at Holbourne East (***) and West (*)	Higher at Holbourne (***)	5m depth (ns) 2m depth- higher at Holbourne West (*), no difference at Camp (ns)	No changes

4.3 Macroalgae proportion

Despite higher threshold values (Table 2) the proportion of macroalgae in the algal community at Camp was well above thresholds resulting in consistent minimum scores for this indicator at both Camp East and Camp West (Table 13). At the observed levels, macroalgae are almost certainly inhibiting coral communities at these reefs as the maximum threshold of 23% was set based on observed negative impacts to juvenile densities, coral cover and the rate of coral cover increase on inshore reefs (Thompson et al. 2016). That increases were observed between surveys (Table 13, Table 14, Figure A 3) are particularly concerning for the future recovery of these coral communities. The macroalgae community at both Camp East and Camp West includes a high proportion of brown algae (Family Phaeophyta, Figure 4) and in particular the genera *Sargassum* and *Dictyota* (Table A 4). In May a high proportion of macroalgae were identified as “Other” brown macroalgae (Table A 4).

These points represent algae impossible to differentiate on photo images due to a high epiphyte loads in addition to the aggregation of rare groups. It is highly likely that much of the unidentifiable algae were indeed *Sargassum* that can become heavily colonised by epiphytic growth at the end of the summer growing period. *Sargassum* is of particular concern as this genus tends to form persistent stands (lasting years) resulting in long-term completion with corals. In comparison *Dictyota* blooms are more ephemeral, with observed blooms often disappearing between annual samples undertaken by the MMP (authors pers. obs.).

In contrast to Camp macroalgae are almost absent from Holbourne as reflected in the maximum scores for this indicator for all but the October sample at Holbourne East 5m (Table 13) when a low cover of “Other” brown macroalgae was observed (Table A 4). In this case the “Other” category included very small plants of encrusting species that were at the boundary between classification of macroalgae and the general category of “Turf” that is used to classify a range of small algae unlikely to have substantial negative impacts of coral communities.

Table 13 Macroalgae cover and indicator scores for each location. Figure to the right indicates macroalgae indicator scores from this study (horizontal lines) relative to the distribution of scores observed in inshore waters of the GBR in 2015 (Thompson et al. 2016). Only Holbourne East 5m depth shown, all other reefs score either 0 or 1.

REEF	Month	Macroalgae cover	Macroalgae proportion	Macroalgae score
Camp East	May	56.5	67.75	0
	October	87.94	93.8	0
Camp West	May	35.94	46.2	0
	October	42.25	56.7	0
Holbourne East 2m	May	0.25	0.4	1
	October	0.06	0.1	1
Holbourne East 5m	May	0.06	0.2	1
	October	1.19	3.2	0.72
Holbourne West 2m	May	0	0	1
	October	0.25	0.5	1
Holbourne West 5m	May	0.06	0.1	1
	October	0.12	0.2	1

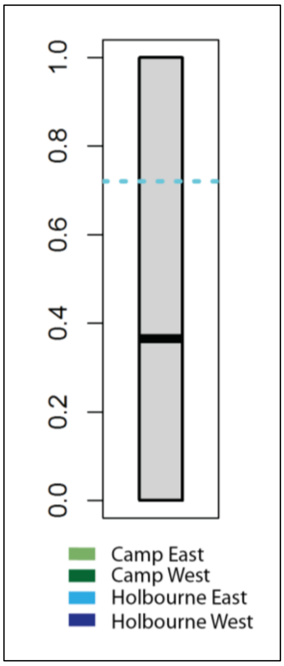


Table 14 Spatial differences in proportion of macroalgae in the algal community. Statistical support for differences in cover based on generalised linear mixed models. Statistical probability of no difference are indicated as >5% (ns) <5% *, less than 1% ** and less than 0.1% ***

	Depth	Reef	Aspect	Change
MA proportion	Insufficient cover to model	Higher at Camp (***)	5m – insufficient cover to model 2m – no difference with aspect (ns)	Increase at both Camp East (***) and West (***) Insufficient cover to model at Holbourne

4.4 Pressures and disturbance

Benthic communities on coral reefs are naturally dynamic, existing in a cycle of disturbance and subsequent recovery requiring consideration of past acute disturbances and any ongoing pressures to appropriately assess community condition.

The high cover of both brown (Phaeophyta) and Red (Rhodophyta) macroalgae clearly differentiate the benthic communities at Camp Island from those at Holbourne (Figure 4) and point to differing pressures imposed by water quality at the two locations. The high availability of nutrients at Camp, as indicated by chlorophyll *a* levels (Table 6), predisposes this location to the potential for high macroalgae cover. Where chlorophyll *a* concentrations exceed 0.4ugL^{-1} macroalgae is more abundant and potentially detrimental to coral communities through reduced levels of coral cover, juvenile densities and coral growth rates, suggesting that water quality is a limiting factor in the recovery of this reef (Thompson et al. 2016). In addition, high nutrient levels are chronic stressors reported to increase the susceptibility of corals to disease (Vega Thurber et al. 2013), a point supported by the high levels of disease observed at Camp compared Holbourne (Table A 6).

The baseline data presented in this report allows suggests past disturbances likely to that have shaped the benthic communities in the region. At Camp East and site 2 of Camp West coral cover was low and consisted primarily of *Acropora* and *Montipora;* both are genera capable of rapid growth. Although colony size was not recorded it was observed during surveys that colonies were exclusively small (< 50cm diameter). The exception was a large stand of *Montipora digitata,* at site 2 Camp East. This species is common to reef flats around inshore islands and so presumably tolerant of exposure to low salinity. The coral community at site 1 Camp West was in stark contrast to the other sites. Here, cover was higher (42% in May cf. a maximum of 17.5% at the other sites), included larger colonies and higher diversity of *Acropora*, and a higher diversity of corals in general; of particular note was a stand of large (>2m diameter) colonies of *Pavona decussata* (Figure A 3). From these observations it was clear that the disturbances shaping coral communities at Camp Island had differentially impacted the sites. The high waves and local flooding recorded during 2011 could explain the depauperate coral communities with small size-class colonies at Camp East and Camp West site 2, as both occurred in the time frame consistent with the subsequent settlement and growth of colonies to the size observed in 2016. Islands can protect corals in the lee of both cyclone driven waves and flood plumes potentially, explaining the lesser impact to communities at Camp West site 1. There is also evidence that Cyclone Yasi may have impacted the coral communities at Holbourne. Although there are large colonies present, irregular colony outlines suggest past physical damage (Figure A 4). At Holbourne East 2m the substrate is heavily scoured between bommies, and at the remaining sites broken *Acropora* rubble is clearly evident with the majority of colonies of fragile species such as *Acropora* being small (Figure A 4).

While these observations are necessarily speculative they serve the purpose of illustrating the importance of recording disturbances to help interpret monitoring data. With ongoing monitoring the timing of future disturbances can be pinpointed and so pressures more accurately ascribed.
The most recent pressure for coral communities was high water temperature observed over the 2015/2016 summer and into winter 2016 (Figure 2). In response to this anomaly coral bleaching was observed at both Islands (Table A 6). At Camp Island bleaching was restricted to just individual colonies of *Montipora* along some transects at Camp East with no bleaching observed at Camp West. By October bleaching had abated though there were elevated levels of disease particularly amongst

Montipora a genus previously reported as suffering disease coinciding with heat stress (Jones et al. 2004). Bleaching was more evident at Holbourne Island with up to 5-10% of colonies from a range of genera showing signs of bleaching especially at 2m sites (Table A 6). In addition to bleaching, moderate numbers of lesions recorded as "unknown" on *Acropora* colonies at Holbourne East consisted of small areas at the bases of branching and bottlebrush growth forms and are typical for these species of coral. Minor physical damage consistent with anchor damage was observed at both Holbourne West and East. Predation by the coralivorous snail *Drupella* and crown-of-thorns starfish were observed. Although numbers of crown-of-thorns were low (Table A 6), the destructive capacity of these starfish warrants ongoing tracking of their abundance.

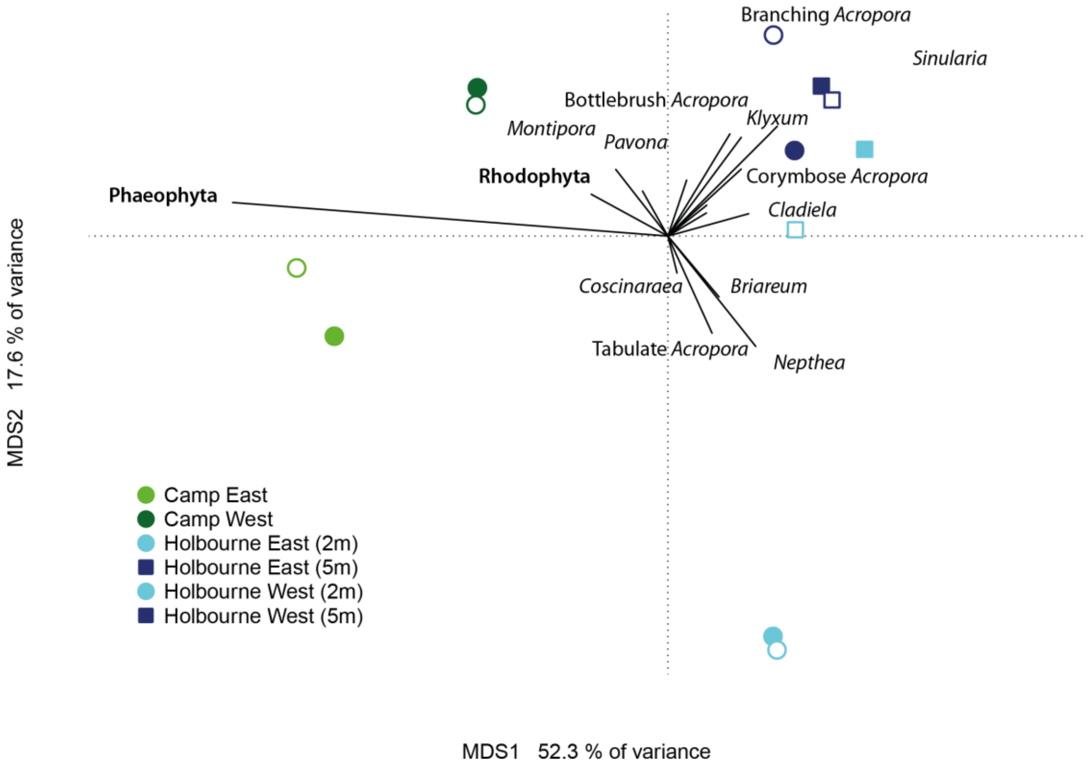


Figure 4 Benthic community composition PCoA. Location of communities along the two dimensions explaining the most variability in ecological distance (dissimilarity) between communities are presented. Symbol colour defines island and aspect, while round (2m) and square (5m) shapes define community depth. Filled symbols indicate samples from May and open symbols samples from October. Lines (eigenvectors) represent the relative abundance of genera (Corals) or major groups (macroalgae, in bold type). Eigenvectors begin at the plot origin and extend in the direction of increasing abundance of a given taxa, for example, Camp Eest has higher cover of the brown algae family (Phaeophyta) than all locations to the right of the plot. The length of the eigenvectors indicates the relative magnitude of cover differences among locations. Only those taxa varying most among sites are labelled.

4.5 Juvenile Density

Despite the pressures imposed by a high proportion of macroalgae occupying the substrate available to coral settlement the density of juvenile hard corals was higher at Camp than at 2m depths at Holbourne (Table 15, Table 16). Within Camp the density of juvenile hard corals was higher at

Camp West and this was the only location with a sufficient density of juvenile corals to be classified as being in moderate condition - grade C, for this indicator (Table 15); though the density was still below the median observed within inshore reefs elsewhere in the GBR (Table 15). Bolstering the density on both aspects of Camp was a high representation of the genus *Turbinaria* (Family Dendrophylliidae, Figure A 2, Table A 5). Within the inshore GBR high densities of *Turbinaria* are commonly observed on close-inshore reefs (Thompson et al. 2016). As with other inshore reefs monitored by the MMP a high proportion of *Turbinaria* in the juvenile community is not reflected in composition of coral cover (compare family Dendrophylliidae in Figure A 1 and Figure A 2) suggesting that these juveniles may suffer high rates of mortality and not contribute greatly to recovery of coral cover. Excluding *Turbinaria,* the density of juvenile hard corals at Camp East would be very low (Figure A 2).

At Holbourne the density of juveniles was higher at the western location and at 5m depths (Table 15, Table 16). The highest density, at Holbourne West 5m was however low compared to the median for inshore reefs of the GBR (Table 15). The reason for a low density of juvenile corals at Holbourne is unknown although the low turbidity and Chlorophyll levels (Figure 3) detract from poor water quality as a likely cause. Both Holbourne and Camp are quite distant from other coral reefs raising the potential that isolation from brood-stock may be limiting larval supply; a situation that can limit the recovery potential of coral communities (Underwood et al. 2009). It is only ongoing monitoring of juvenile densities that will help to gain a clearer understanding of recruitment dynamics over the longer term. The composition of juvenile communities is broadly similar to that of the surviving adult community and consistent with what would be expected of communities in relatively shallow and clear waters (Figure A 1, Figure A 2). The presence of Acroporidae in the juvenile community, although low in density, is encouraging as this family of fast growing species critical for rapid recovery of coral cover.

Analysis of change in juvenile density between the May and October samples was not appropriate due to the low sample size as a result of juvenile density being estimated at the site rather than transect level. It is notable however that the density of juvenile hard corals declined slightly at all locations other than Camp East (Table 15). The cause of this decline is uncertain as the juvenile density aggregates corals that may be variable in age. As most corals have a single summer spawning period samples taken annually at the same time of year can be assumed to be sampling corals of roughly similar ages each year, though the number of cohorts may vary between genera due to variable growth rates. Sampling juvenile density in different seasons confounds the ability to interpret change as differing proportions of cohorts may be available to sampling. It is possible that the observed decline reflects: real loss of juvenile abundance as a result of mortality or the growth of corals to sizes beyond those included in estimation of juvenile abundance without the next year's cohort yet to settle.

Table 15 Juvenile hard coral abundance, density and indicator scores for each location. Figure to the right indicates Juvenile indicator scores from this study (horizontal lines) relative to the distribution of scores observed in inshore waters of the GBR in 2015 (Thompson et al. 2016). Line style indicates depth: 2m (dashed) and 5m (dotted).

REEF	Month	Juvenile abundance	Juvenile density	Juvenile score
Camp East	May	75.5	2.7	0.24
	October	90	2.8	0.25
Camp West	May	116	7.0	0.58
	October	71	4.8	0.43
Holbourne East 2m	May	28.5	1.4	0.13
	October	20	1.0	0.09
Holbourne East 5m	May	41	2.6	0.24
	October	28.5	2.3	0.21
Holbourne West 2m	May	48	2.4	0.22
	October	38.5	2.0	0.18
Holbourne West 5m	May	62.5	3.5	0.31
	October	46.5	2.5	0.23

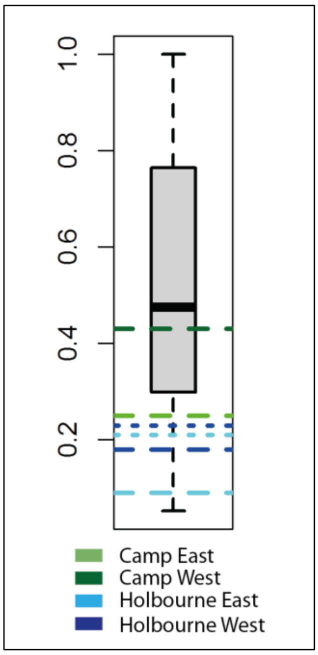


Table 16 Spatial differences in density of juvenile hard corals. Statistical support for differences in cover based on generalised linear mixed models. Statistical probability of no difference are indicated as >5% (ns), <5% *, less than 1% ** and less than 0.1% ***

	Depth	Reef	Aspect
Juvenile density	Higher at 5m at both Holbourne East (***) and West (**)	Higher at Camp (***)	5m- no effect (ns) 2m- higher on the western sites at both Holbourne (***) and Camp (***)

5 CONCLUSIONS

The initial surveys of benthic communities at Camp Island and Holbourne Island allowed for a baseline condition assessment. The overall grade of D averaged over the relatively poor condition of coral communities at Camp Island compared to Holbourne, where condition was similar to the median condition reported for other reefs in the inshore GBR (Thompson et al. 2016). Included in this report are a suite of environmental variables that assist in identifying key disturbances or pressures likely to have contributed to the observed condition of communities. Ideally these variables are assessed in parallel with the monitoring of coral communities as this allows matching of timing of changes in communities with known events. For this initial assessment we have identified storm driven waves associated with Tropical Cyclone Yasi in 2011 as likely to have reduced coral cover at both Camp Island and Holbourne Island. At Camp Island local flooding may also have impacted coral communities. It must be noted however that without a time-series of coral community data these assessments remain speculative.

While it is important to identify the response of communities to acute disturbance events it is the identification of chronic pressures limiting coral community recovery from such events that is important in terms of understanding community dynamics that may influence management options. The very high representation of macroalgae in the benthic communities at Camp Island were a strong contributor to low condition scores and can be reasonably interpreted as indicting water quality as a pressure impacting coral communities. Further, the low density of juvenile corals at Camp East is also likely linked to the detrimental influence of macroalgae at that site (McCook et al. 2001; Hauri et al. 2010). That juvenile density at Holbourne was even lower than at Camp however suggest that macroalgae is not the only pressure limiting the recruitment process in the region. A speculative explanation founded on the relative isolation of Holbourne Island from the mid-shelf reefs, offshore, or inshore fringing reefs may reduce the availability of larvae at the reef. Ongoing monitoring will be required to determine the consistency of low recruitment and help to further define possible causes.

High water temperatures over the 2015/2016 summer and 2016 autumn are very likely to have contributed to the slight declines in the coral index between May and October. The cover of the macroalgae *Sargassum* on coral reefs at Magnetic Island has been observed to vary seasonally; growing through the warmer months before shedding their thallus and persisting as holdfasts through winter (Vuki and Price 1994). The increase in cover over winter is then unexpected and was potentially facilitated by high winter temperatures allowing an early onset of typically summer growth. Certainly the plants in October were noticeably less fouled with epiphytic organisms supporting the interpretation that this was fresh growth. The increase of the coral disease Atramentos necrosis will have contributed to the loss of coral cover at Camp Island and again has been observed to have links to increased water temperatures (Jones et al. 2007).

The spatial hierarchy from islands, to aspects within islands and then depths within aspects - at Holbourne Island, is supported by the observed differences in the composition and condition of the benthic communities at these scales. That variability was observed at these scales indicates the differing selective pressures that have been imposed on the communities in each environmental setting and suggests there is limited predictability from one level to the next, requiring ongoing observations at the full spatial design to develop a detailed understanding of the dynamics of these communities.

The dynamics of coral communities can be generalised as following a cycle of disturbance and subsequent recovery. Major disturbances such as cyclones, floods and bleaching events typically occur over summer meaning that a single post summer observation will largely capture the impact of any such events. Following disturbance, recovery of coral communities is relatively slow (decades) with the rate of recovery potentially influenced by chronic pressures. The rate of recovery of coral cover can be estimated by comparing sequential annual observations, and is an indicator used in the Reef Report Card that is intended to be added to the indicators for this program once the time-series allow. Importantly, shorter period resampling does not improve this indicator as the rate of recovery is slow; meaning that estimation of rate is improved with longer periods between samples. Further, for most corals the reproductive cycle on the GBR is focused on an annual spawning event following full moons in November and December. As the juvenile density indicator includes corals likely to fall into more than a single cohort (this will vary from species to species based on growth rates), samples at different times of year will not be as comparable as those from a single season because the proportion of various cohorts within the size class of the sample may vary. For the above reasons the reporting of long-term trends in the condition of communities should focus on results from a single and consistently timed annual samples.

That variation in community attributes between May and October was observed implies that additional pressures impacted coral communities over the winter months. As such, there is value repeating the biannual sampling so as to gain insight into whether the observed changes represent consistent seasonality in coral community condition attributes or were the result environmental conditions particular to 2016.

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7 APPENDICES

Table A 1 Waypoints and detailed compass directions for monitoring sites.

Reef	Latitude S	Longitude E	Depth	Site	Tran	Compass directions
Holbourne East	19.7332	148.3644	2	1	1	300
Holbourne East			2	1	2	205, 270@10m
Holbourne East			2	1	3	220, 280@10m
Holbourne East			2	1	4	280, 240@12m
Holbourne East			2	1	5	270, 230@7m
Holbourne East	19.7338	148.3647	5	1	1	215, 150@13m
Holbourne East			5	1	2	240, 210@15m
Holbourne East			5	1	3	270, 260@10m
Holbourne East			5	1	4	270, 315@6m
Holbourne East			5	1	5	300
Holbourne East	19.7336	148.3618	2	2	1	265, 300@5m, 230@15m
Holbourne East			2	2	2	260
Holbourne East			2	2	3	260, 250@reo
Holbourne East			2	2	4	270, 220@15m
Holbourne East			2	2	5	240, 330@4m, 270@ 10m, 280@14m
Holbourne East	19.734	148.3618	5	2	1	210, 200@10m
Holbourne East			5	2	2	270, 255@10m
Holbourne East			5	2	3	240, 290@2m
Holbourne East			5	2	4	320, 0 toT5
Holbourne East			5	2	5	320, 290@10m
Holbourne West	19.7252	148.3547	2	1	1	10, 50@6m, 30@10m
Holbourne West			2	1	2	10, 0@8m, 30@14m
Holbourne West			2	1	3	340
Holbourne West			2	1	4	20
Holbourne West			2	1	5	10, 340@5m
Holbourne West	19.7249	148.3545	5	1	1	40, 320@reo, 50 to T2
Holbourne West			5	1	2	350, 0@8m, 300@15m
Holbourne West			5	1	3	30, 330@5m, 40@10m
Holbourne West			5	1	4	60, 40@3m, 300@5m, continue around bommie
Holbourne West			5	1	5	340, 15@6m, 25@10m
Holbourne West	19.7233	148.3556	2	2	1	345, 0@10m
Holbourne West			2	2	2	25, 75@10m
Holbourne West			2	2	3	10, 20@10m
Holbourne West			2	2	4	330, 20@5m, 100@15m
Holbourne West			2	2	5	50, 340@8m

Reef	Latitude S	Longitude E	Depth	Site	Tran	Compass directions
Holbourne West	19.7232	148.3553	5	2	1	30
Holbourne West			5	2	2	350, 10@9m, 60@16m
Holbourne West			5	2	3	30, 20@7m
Holbourne West			5	2	4	15
Holbourne West			5	2	5	40, 140@5m, 110@8m, 170@11m
Camp East	19.8508	147.9052	1.5	1	1	170
Camp East			1.5	1	2	270
Camp East			1.5	1	3	225, 230@10m
Camp East			1.5	1	4	210, 220@10m
Camp East			1.5	1	5	200
Camp East	19.8541	147.9012	1.5	2	1	230
Camp East			1.5	2	2	270
Camp East			1.5	2	3	235
Camp East			1.5	2	4	240
Camp East			1.5	2	5	170, 155@7m
Camp West	19.8533	147.8942	2	1	1	340, 0@10m
Camp West			2	1	2	0
Camp West			2	1	3	0, 35@11m
Camp West			2	1	4	345, 300@8m, 340@11m
Camp West			2	1	5	20, 10@7m
Camp West	19.8512	147.8950	2	2	1	20, 30@10m
Camp West			2	2	2	345, 30@8m
Camp West			2	2	3	30
Camp West			2	2	4	130
Camp West			2	2	5	20

Table A 2 Cover of hard coral genera. Genus with a minimum cover of 1% at any reef are included. All less abundant genera are grouped as Other HC

Reef	Month	*Acropora*	*Merulina*	*Montipora*	*Pavona*	*Pocillopora*	*Porites*	*Stylophora*	Other HC
Camp East	May	1.13		8.19			0.31		1.63
	October	0.81		3.25		0.06			0.06
Camp West	May	14.13		9.06	2.44	0.50	1.63		1.63
	October	14.63		7.75	2.50	0.06	0.75		1.94
Holbourne East 2m	May	7.56		1.69		0.44	0.81	0.25	2.56
	October	7.63		1.25		0.06	0.88	0.06	1.13
Holbourne East 5m	May	27.10	0.81	0.75		2.38	0.38	1.40	1.88
	October	27.51	1.69	2.17		2.52	1.45	1.34	1.34
Holbourne West 2m	May	6.50		6.69		0.38	0.56	0.13	0.75
	October	7.56		7.56		0.31	0.25		1.06
Holbourne West 5m	May	10.00		3.25	0.38	0.56	1.88		3.25
	October	10.75	0.06	2.63	0.06	0.63	2.31	0.19	3.63

Table A 3 Cover of soft coral genera. Genus with a cover of at least1% at any reef are included. All less abundant genera are grouped as Other SC

Reef	Month	*Briareum*	*Cladiella*	*Klyxum*	*Lobophytum*	*Nephthea*	*Rhystima*	*Sinularia*	*Xenia*	Other SC
Camp East	May									
	October									
Camp West	May	0.25		0.06				0.06		
	October	0.06		0.13						
Holbourne East 2m	May	2.19	0.94		0.25	5.69	0.06			
	October	1.88	1.31			6.76		0.13		
Holbourne East 5m	May	4.78	0.63		0.19	2.88	0.75	5.82	0.69	0.44
	October	3.89	1.08	0.25	0.13	3.71	1.50	6.84	1.38	0.31
Holbourne West 2m	May		3.88	2.25	1.00	0.19	0.06	6.38		
	October		5.50	2.44	0.81	0.19		5.19		0.25
Holbourne West 5m	May	0.06	2.31	7.06	1.19	2.13		4.63		0.81
	October	0.13	2.13	6.75	0.75	1.13		3.75		0.75

Table A 4 Cover of Algae. Identified macroalgae genera with a cover of at least 1% at any reef are separated. All less abundant genera and smaller algae are grouped.

Reef	Month	Brown							Red		Green Macro	*Chrysoscystis*	Turf	Blue-green	Coralline
		Dictyopteris	*Dictyota*	*Lobophora*	*Padina*	*Sargassum*	*Spatoglossum*	Other	*Hypnea*	Other					
Camp East	May	0.19	19.44	1.88	4.06	21.13	1.19	6.06	0.06	2.00			25.94	0.31	0.75
	October	4.75	0.56	0.38	0.06	75.56	2.69	3.50		0.44			5.31		0.44
Camp West	May		7.13	0.44	1.13	12.50		10.56	0.38	2.94			22.94	0.13	0.69
	October	0.06	5.19	1.94	1.50	26.25	0.56	0.13	2.56	3.75			15.75		0.75
Holbourne East 2m	May		0.19								0.06		57.81	0.50	0.81
	October									0.06			54.97		1.50
Holbourne East 5m	May									0.06			40.71	1.88	0.63
	October							0.94		0.25			34.31	0.13	0.50
Holbourne West 2m	May											0.44	49.94	7.69	0.56
	October									0.13	0.13		55.94	1.94	0.31
Holbourne West 5m	May									0.06			51.81	0.31	0.63
	October									0.06	0.06		50.44	3.44	0.06

Table A 5 Abundance of juvenile hard corals by genus. Mean abundance per site for genera with at least 2 corals per site at any reef separated. All less abundance genus grouped as Other.

REEF	Month	*Acropora*	*Cyphastrea*	*Favia*	*Favites*	*Fungia*	*Galaxea*	*Goniastrea*	*Leptastrea*	*Lobophyllia*	*Montipora*	*Moseleya*	*Pavona*	*Platygyra*	*Pocillopora*	*Porites*	*Psammocora*	*Scolymia*	*Stylophora*	*Turbinaria*	Other genera
Camp East	May	13	2	1.5	1.5	10	1	1	0	0.5	10.5	5	0	0.5	2	1.5	0.5	0	0	32.5	2.5
	October	7	2	0.5	2.5	3.5	0	0	0	0	9	2	0	0	0.5	2.5	0.5	0	0	62.5	1
Camp West	May	40	4.5	2	1.5	18	0	0	2.5	0.5	17	5.5	1.5	0.5	5	7.5	2	0	0	22.5	3.5
	October	26	1	2	2.5	4.5	0.5	0	2	0	5.5	4.5	2	0	3	3	1	0	0	16.5	1.5
Holbourne East 2m	May	14.5	0	0.5	0	0	0.5	2	0.5	0	1	0	0	0.5	1	2	0	0	3.5	0	2.5
	October	8	0	0.5	1	0	0	2	0	0.5	0	0	0	0	2.5	3	0	0	2.5	0	0
Holbourne East 5m	May	7.5	0	1	0	0	0	1	1	0	11.5	0	0	0	2.5	2	1	0	9.5	0	4
	October	2	0.5	0	0.5	0.5	0	0	0	0	2	0	0	0.5	2.5	10	1	0	6.5	0	3
Holbourne West 2m	May	16.5	0.5	0.5	1	1.5	0.5	0.5	0	1	7.5	0	0	0.5	3	13	0.5	0.5	1	0	1.5
	October	11	0	0.5	2	2	2	0.5	0.5	0.5	4.5	0	0	2	4	6	0.5	0	1.5	0	3
Holbourne West 5m	May	16.5	1	3	4.5	0	0	1.5	1	4	11	0	0	1	4.5	5	1	2	2	0	4.5
	October	11	0	1	2	0	2.5	1	1	3.5	9.5	0	0	0.5	2.5	6.5	0.5	0	2	0	3

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Table A 6 Coral health survey results

		Camp East		Camp West		Holbourne East				Holbourne West			
						2m		5m		2m		5m	
DAMAGE	GENUS	May	Oct	May	Oct	May	Oct	May	Oct	May	Oct	May	Oct
Disease (colonies)	*Montipora*	5	18	4	24						1		
	Acropora		1		1				1				
	Pavona										1		
Unknown cause (colonies)	*Acropora*	1	6	1		1	1	13	11			2	5
	Montipora	4	4							2			
	Stylophora						1						
crown-of-thorns (number of seastars)									1				1
crown-of-thorns scar (colonies)	*Acropora*								3				2
Drupella (number of snails)	*Acropora*			2				22	68	18	15		1
	Montipora									12	1		
	Stylophora							3					
Sponge - *Cliona orientalis* (on coral colonies)	*Cyphastrea*	1											
	Favites	1											
	Montipora						1	1	1	1		1	
	Porites			1		1	1						
	Isopora								1				
Anchoring (proportion of colonies)					<1%				<5%	<5%			
Bleaching (proportion of colonies)		<1%				<1%		5-10%		<5%		5-10%	

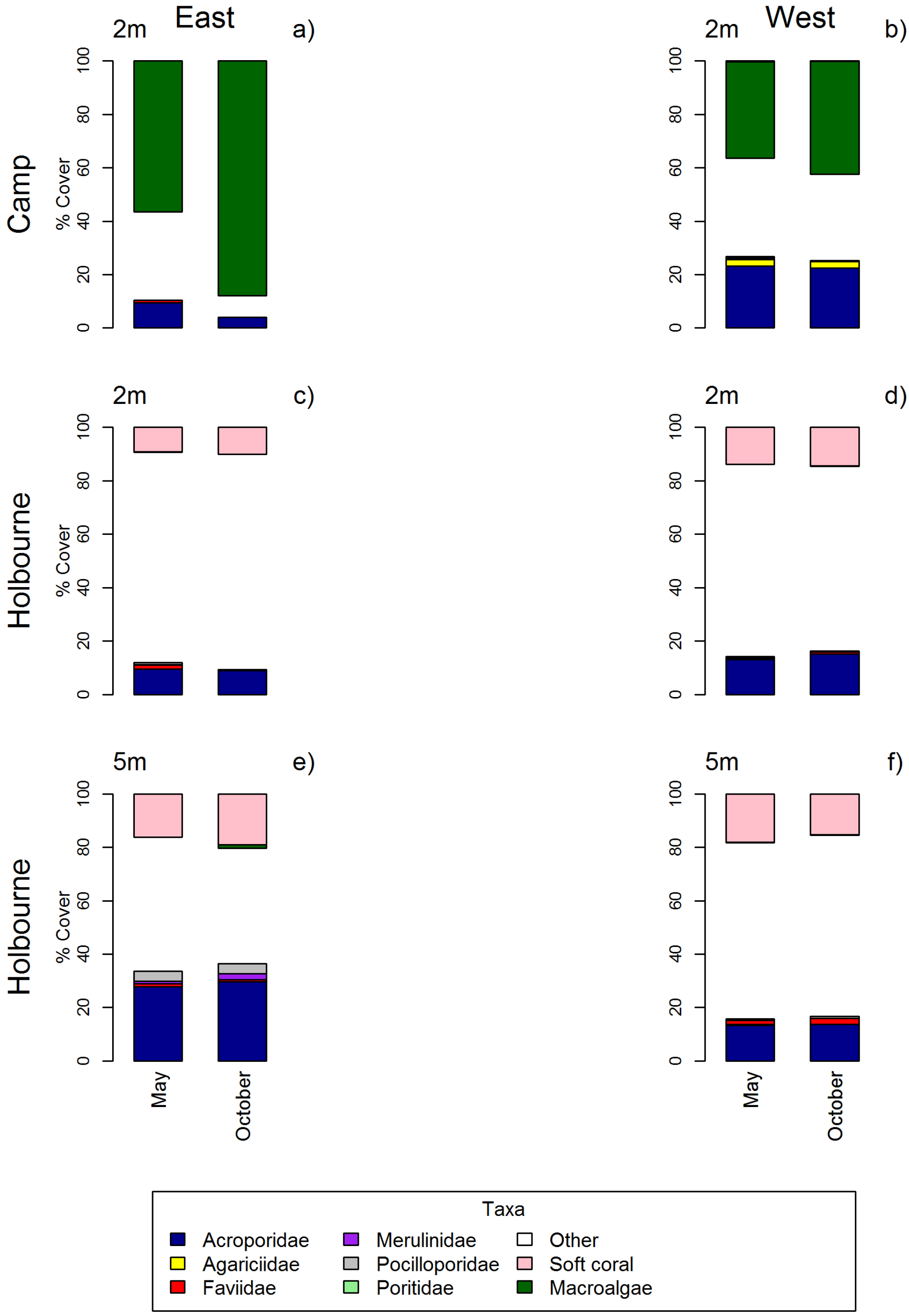

Figure A 1Cover hard coral families, soft coral (hanging) and macroalgae (hanging).

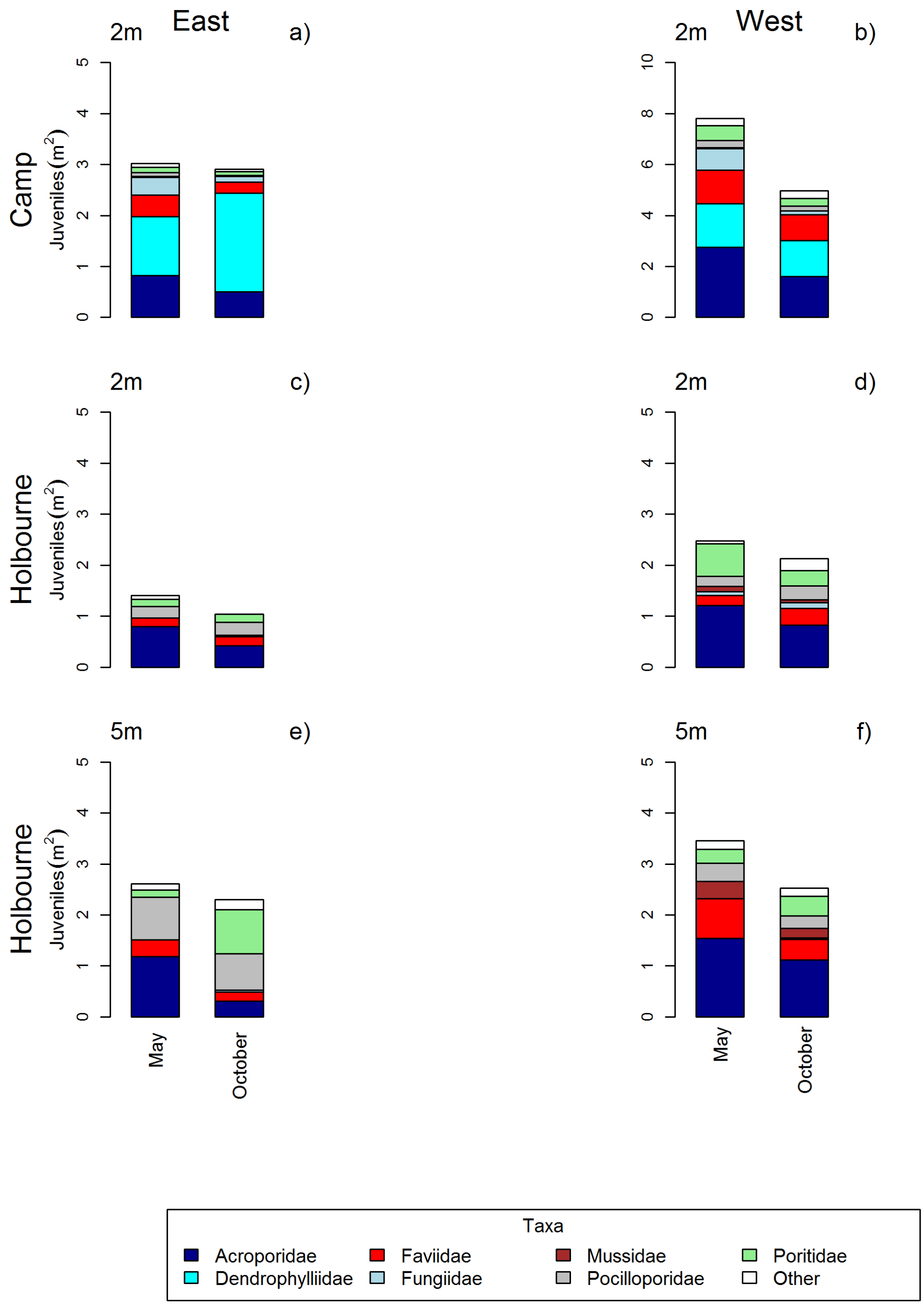

Figure A 2 Density of hard coral juveniles by family.

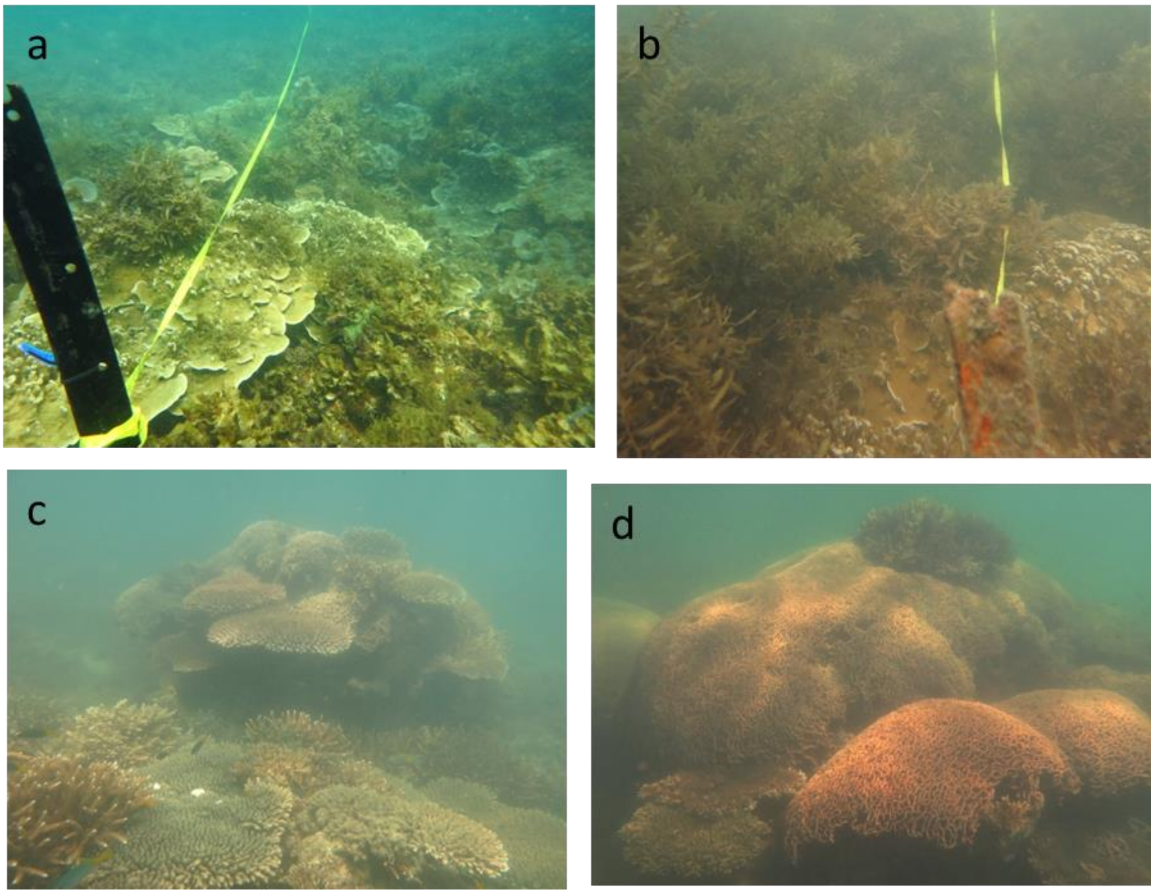

Figure A 3 Benthic community photos at Camp Island. Increase in macroalgae cover at Camp East site 2 from a) May to b) October, photos are in the same location. Camp West site 1 mixed *Acropora* community c), and d) large *Pavona decussata* colonies

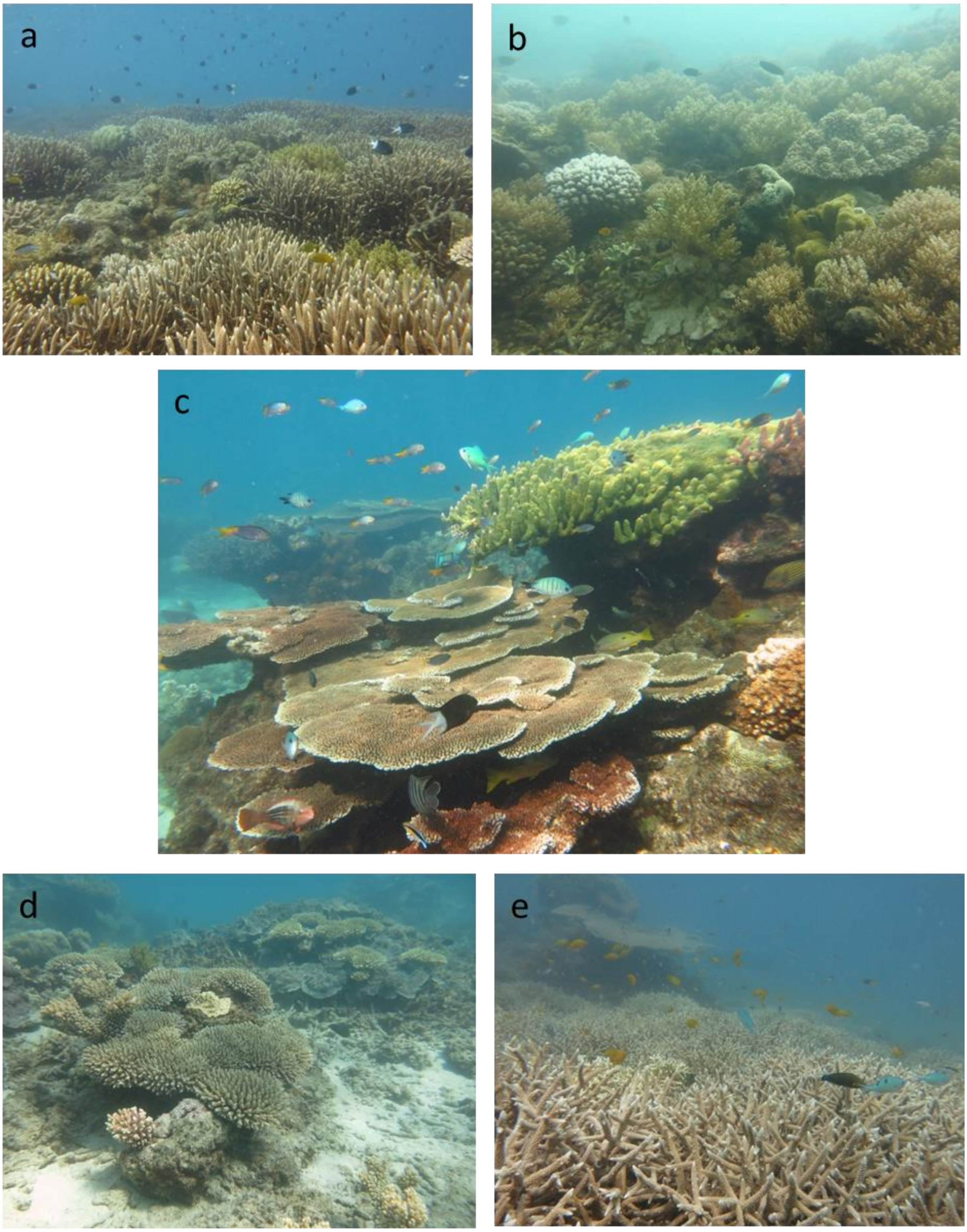

Figure A 4 Coral community photos at Holbourne Island. East 5m depth: a) small colonies of branching *Acropora* and b) mixed hard and soft corals. East 2m, c)Tabulate *Acropora* colonies irregular outlines suggest past physical damage. West 5m, d) Small *Acropora* colonies, and e) extensive stands of branching *Acropora* made up of multiple small colonies