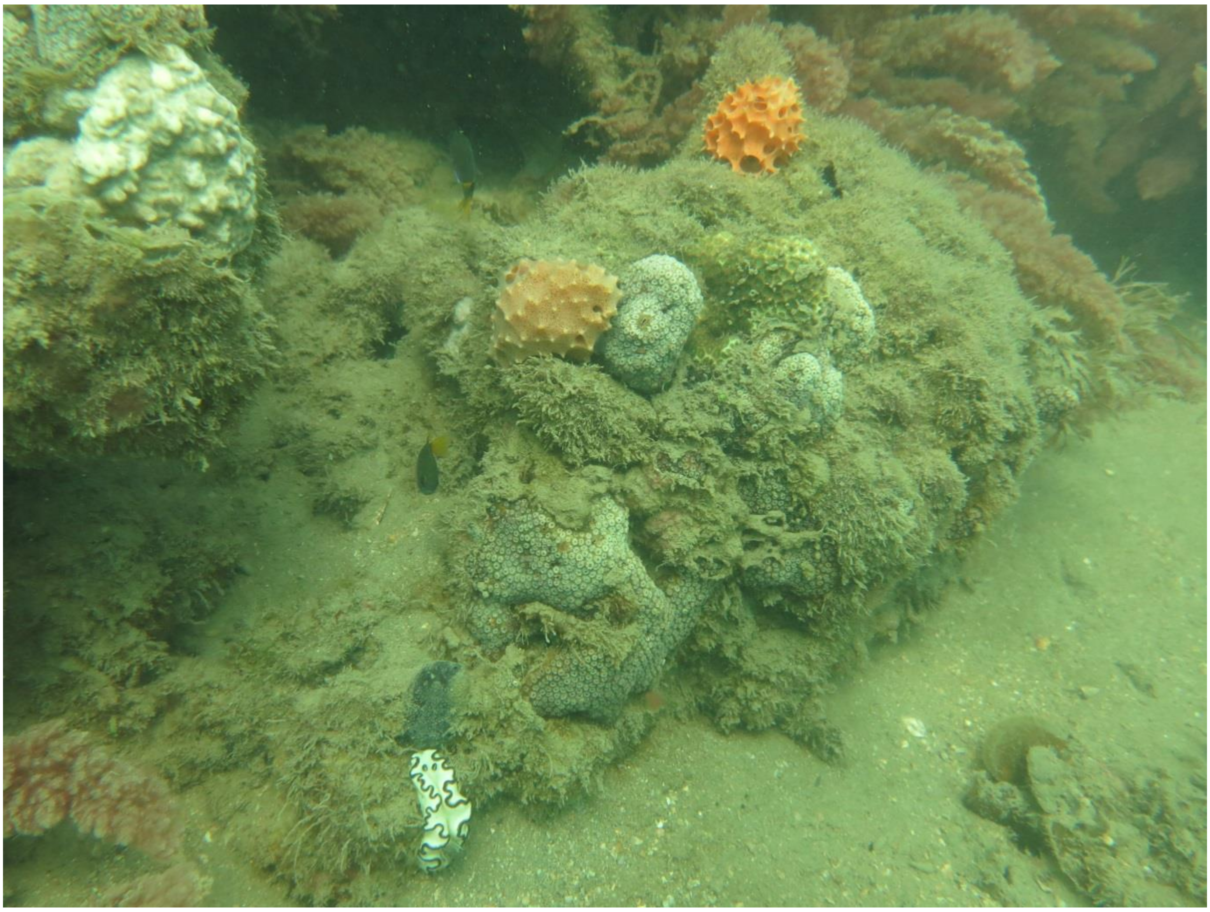
Coral Indicators for the 2016 Gladstone Harbour Report Card: ISP014

Report Prepared for the Gladstone Healthy Harbour Partnership



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1 EXECUTIVE SUMMARY

This report presents a detailed description of the benthic communities at coral monitoring locations within the Mid and Outer Harbour reporting zones that form the basis of the coral community component of the 2016 Gladstone Harbour Report Card.

In May 2016 the Australian Institute of Marine Science resurveyed benthic communities at permanent coral monitoring locations in the Mid (four locations) and Outer (two locations) Harbour. Overall the condition of these communities remains 'very poor' resulting in the continued Report Card grade of E (Table 1).

Report Card grades are based on the assessment of three indicators of coral condition: the proportion of the substrate occupied by living corals (Coral Cover), the proportion of the substrate occupied by large fleshy species of algae (Macroalgae Cover) and the density of juvenile hard corals (Juvenile Density). For each of these indicators observed levels were converted into scores based on thresholds developed for the 2015 Gladstone Harbour Report Card.

Table 1 Coral indicator scores and 2016 Report Card grade.

Juvenile Density	Coral Cover	Macroalgae Cover	Report Card	
			Score	Grade
0.33	0.07	0.04	0.15	E

The very poor condition of coral communities is heavily weighted by the very low cover of corals on most reefs. A strong contributing factor to the loss of corals in the Harbour was the extreme flooding that occurred in 2013 that almost certainly exposed corals to lethally low levels of salinity. Both the Macroalgae Cover and Juvenile Density indicators are included as representative of the recovery potential of coral communities from such acute events. The very high cover of macroalgae that have colonised the space made available by the loss of coral cover ensure the very poor assessment for this indicator. Macroalgae can limit coral recovery through a variety of pathways including direct completion with surviving colonies and suppression of the recruitment process. The 'poor' assessment of the Juvenile Density indicator is likely to reflect both the pressures imposed by high cover of macroalgae and regionally low availability of larvae as a result of low coral cover.

Consideration of the broad climatic drivers of coral condition: flooding, cyclones and temperature suggests that although anomalously high temperatures occurred in early 2016, it is not likely that these had a strong direct impact on corals in the year prior to sampling. It is possible, however, that the warmer autumn sea temperatures have supported the continued high cover of some macroalgae species that, along with the prevalence of bio-eroding sponges, have reduced the potential for coral communities to recover. Further, the photo-point intercept sampling method used for benthic cover estimates potentially biases coral cover as a result of macroalgae cover. Tall macroalgae have the capacity to over-top portions of coral colonies in the images resulting in reduced coral cover estimates. The higher proportion of macroalgae observed in 2016 (Harbour wide mean 41% cf. 31% in 2105) raises the potential that the small increase in coral cover (Harbour wide mean of 5.15 in 2015 cf. 5.8% in 2016) was a slight underestimate.

2 BACKGROUND

Coral communities around the world are under increasing pressure as intensifying land use, urbanisation and industrial development impinge on corals' ability to resist, or recover from, natural disturbances such as floods or storms. Along the Great Barrier Reef (GBR) coast it is well documented that loads of sediments, nutrients and other chemical pollutants carried to the sea in catchment runoff have increased since European settlement (Kroon *et al.* 2012, Waters *et al.* 2014).

Coral communities within Gladstone Harbour are subject to the same range of pressures as other inshore coral reefs in the GBR, though with the added potential impact of uniquely local pressures associated with the operations of the harbour and associated industries. It is for this reason that AIMS has co-invested with the Gladstone Healthy Harbour Partnership (GHHP) to monitor and report the condition of coral communities within the GHHP reporting area as part of the Gladstone Harbour Report Card.

The choice of indicators, sampling methodology and scoring system used to derive grades for the Gladstone Harbour Report Card were chosen to be as closely compatible as practicable to those used for the Great Barrier Reef Report Card (Queensland Government 2015). We note that recent revisions of the methods used to score coral community condition for the Great Barrier Reef Report Card (Thompson *et al.* 2016) mean that while indicators remain the same thresholds against which Report Card scores are derived do vary between these programs. Consideration should be given to a realignment of methodologies.

This report presents the first resurvey of the permanent coral monitoring transects constructed in 2015. The purpose of this report is to provide a detailed description of reef communities as observed in 2016 that expands on the necessarily succinct summary of condition presented by the 2016 Gladstone Harbour Report Card.

3 METHODS

3.1 Sampling design

The basis of the sampling design is the use of permanently marked transects to monitor the condition of coral communities. The selection of sites and construction of transects occurred in July 2015 as reported in detail in Thompson *et al.* (2015). In brief, suitable sites were identified at four locations within the Mid Harbour reporting zone and two locations in the Outer Harbour reporting zone (Figure 1). Within each site a series of five 20m long transects, each separated by a space of 5m, were constructed along a depth contour identified as the most suitable coral habitat; depths ranged between 0 and 1m below lowest astronomic tide (Table A 1) as dictated by the limited depth of hard coral communities within the harbour. To ensure accurate relocation of sampling, the start of each transect was marked with a steel star picket, with additional transect markers consisting of lengths of 10mm steel rod placed at the midpoint and end of each transect. The starting point of the 1st transect was recorded as a GPS location (WGS84 datum) and compass bearings recorded along each transect to aid future relocation (Table A 1). At each transect the following three types of surveys of the benthic communities were repeated on the 26th of May 2016.

3.1 Survey methods

3.1.1 Photo point intercept transects

Estimates of the composition of the benthic communities were derived from the identification of organisms on digital photographs taken along the permanently marked transects. The method followed closely Standard Operation Procedure Number 10 of the AIMS Long-Term Monitoring Program (LTMP, Jonker *et al.* 2008) and mirror those used by the Reef Plan Marine Monitoring Program (MMP). In short, digital photographs were taken at 50cm intervals along each transect. Estimations of cover of benthic community components are derived from the identification of the benthos lying beneath five fixed points digitally overlaid onto these images. A total of 32 images were analysed from each transect. For the majority of hard and soft corals, identification to at least genus level was achieved. 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 and checking of all identified points.

3.1.2 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.

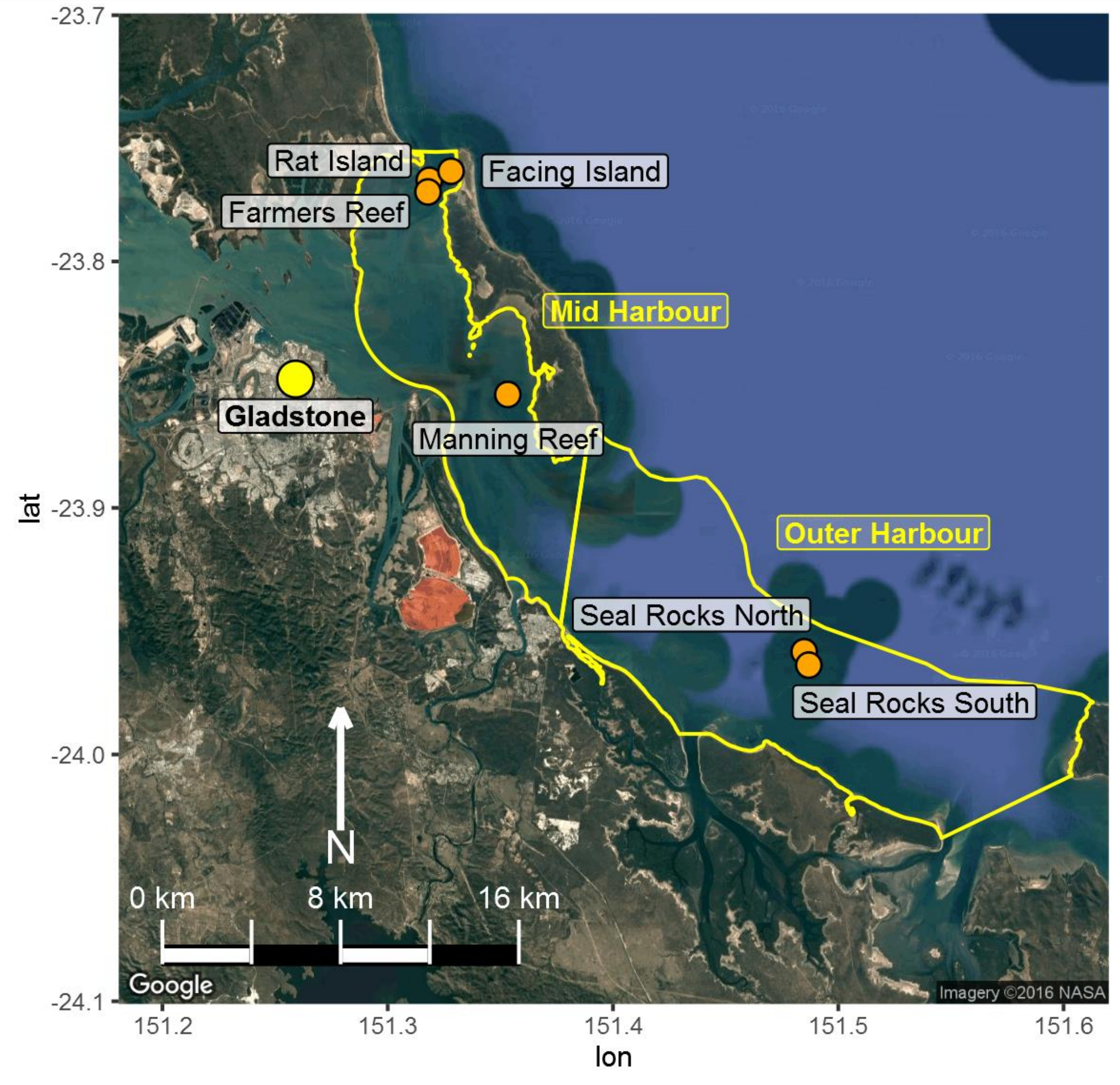

Figure 1 Coral monitoring sites.

3.1.3 Scuba search transects

Scuba search transects documented the incidence of disease and other agents of coral mortality 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.

3.2 Coral community Indicators

The indicators and methods used to derive report card scores for coral communities were the same as those used for the 2015 Gladstone Harbour Report Card (Thompson *et al.* 2015). This section provides an overview of the rationale for the selection of the three indicators used to assess coral community condition that, in combination, capture both the state and resilience of coral communities. A full excerpt from Thompson *et al.* (2015) is included as appendix 2.

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, temperature anomalies and, in coastal areas, flooding. The indicators Juvenile Density and Macroalgae Cover were included as they represent the potential for coral communities to recover from disturbances.

The density of juvenile corals is an indicator of the successful completion of early life history stages of corals form gametogenesis through fertilisation, larval survival in the plankton, 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 that was estimated as the proportion of benthos identified as algae along the co-located point intercept transects:

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

Where, J= count of juvenile colonies < 5cm in diameter, AS = area of transect occupied by algae.

High macroalgal abundance may suppress the recovery of coral communities through a variety of mechanisms including ranging from completion with surviving colonies though to suppression of the recruitment process (e.g., McCook *et al.* 2001, Hughes *et al.* 2007, Foster *et al.* 2008, Cheal *et al.* 2013, Hauri *et al.* 2010). The indicator Macroalgae Cover was estimated as the proportion of benthos along point intercept transects identified as macroalgae:

$Macroalgae\ Cover_{ij}$

Where, macroalgae include all algae larger than the filamentous turf or crustose coralline forms.

Two additional metrics included in the Great Barrier Reef Report Card are the rate of change in the cover of hard corals and change in community composition; both these metrics require a longer times series than is currently available from the Gladstone Harbour sites to be implemented. It is envisaged that inclusion of these metrics will occur once sufficient observations have been collected.

3.2.1 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 which were set based on expert opinion and knowledge gained from the time-series of coral community condition collected by the MMP and LTMP. The thresholds represent the boundary between Report Card grades of C and D (score =0.5) that would indicate the switch between a community in satisfactory condition and one displaying a lack of resilience (Table 2). In addition, 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).

Table 2 Thresholds and bounds for scoring of selected coral condition indicators.

Indicator	**Threshold**	**Upper bound (score=1)**	**Lower bound (score=0)**
Coral Cover	40%	90%	0%
Macroalgae Cover	14%	5%	20%
Juvenile Density	5.8 m^{-2}	16 m^{-2}	1 m^{-2}

3.2.2 Aggregation of indicator scores

The scaling of all scores to the common range of 0 to 1 allowed 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, individual indicators and Report Card scores for each reporting-zone and whole-of-harbour. For zone-level scores a mean score for each indicator was estimated as the mean of indicator scores for each reef within that zone, and Report Card scores as the mean of the three individual indicator mean scores. Similarly harbour-wide scores were taken as the mean of the zone-level means for each indicator and the Report Card score as the mean of these harbour-wide individual indicator scores.

It should be noted here that this integration of coral community scores into the Gladstone Harbour Report Card follows a slightly different aggregation method that accounts for the possibility of unbalanced sampling for the various indicators. For the coral data, the simple averaging described above will result in identical scores for this data set. For the Gladstone Harbour Report Card scores are derived though the aggregation of bootstrapped distributions of indicator scores, where bootstrapped distributions are produced by repeatedly sampling, with replacement, the observed distribution of indicators. This method of aggregating distributions ensures that each distribution has equal weighting on the aggregation.

In practice, to aggregate individual scores for the indicators at each reef to a mean score and estimate of variance for a zone requires that:

1. A bootstrap distribution of 10000 samples is constructed for each indicator within the zone.
2. The resulting bootstrap distributions are added together and the mean score for the zone along with variance extracted from this combined distribution.

Whole of Harbour scores were similarly generated by respectively aggregating the indicator distributions within zones, adding the aggregated distributions from each zone together to derive a harbour-level distribution from which mean and variance for individual indicators at the scale of the harbour were derived. Finally, adding the whole of harbour distributions for each indicator yields the distribution from which the whole of harbour score and variance were extracted.

Grades for coral community condition were derived from the scores estimated above according to the conversions described in Table 3.

Table 3 Conversion of aggregated indicator scores to Report Card grades.

Score	Condition description	Grade
≥ 0.85	Very good	A
≥ 0.65, < 0.85	Good	B
≥ 0.5, < 0.65	Satisfactory	C
≥ 0.25, < 0.5	Poor	D
0, < 0.25	Very poor	E

3.3 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 cause by tropical cyclones (Osborne *et al.* 2011, De'ath *et al.* 2012) , exposure to low salinity waters during flood events (van Woesik 1991, Jones & 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 accounted for that the potential impacts of chronic pressures such as elevated turbidity and nutrient levels can be inferred.

3.3.1 Thermal bleaching

Thermal stress, resulting in coral bleaching, is an increasing threat to coral communities in a warming world (Schleussner *et al.* 2016). During coral surveys in 2016 AIMS deployed temperature loggers to the star pickets marking transect 1 at each of Rat Island, Manning Reef, and Seal Rocks North. These loggers will provide an ongoing record of in-situ water temperature and begin the process of developing an accurate climatology for the coral communities in the harbour. Until this data series matures the likelihood of thermal stress to corals in the harbour can be interpreted from thermal anomalies presented as degree heating days DHD downloadable from ReefTemp (Garde *et al.* 2014) as published by the Bureau of Meteorology. For this report, annual summaries of DHD from 1 December to the 31 March and based on 14 Day IMOS climatology (Garde *et al.* 2014) were down loaded. In addition to further interrogate temperature anomalies monthly mean anomalies were also downloaded. Mean values of DHD and monthly anomalies for Gladstone Harbour were estimated as the average for all pixels falling within the Mid and Outer Harbour Reporting zones.

3.3.2 Runoff

Exposure to reduced salinity has proven lethal to coral communities in the inshore GBR (van Woesik 1991, Jones & Berkelmans 2014, Thompson *et al.* 2015) and highly likely to have been a key driver of the current very poor condition of coral communities in Gladstone Harbour (Thompson *et al.* 2015, Jones *et al.* 2015). 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 130005A-Ftitzroy River at the Gap
- Station 132001A-Calliope River at Castlehope

As the flow of the Boyne River is interrupted by Lake Awoonga Dam the time and magnitude of over flow of this Dam, as reported by the Gladstone Area Water Board, is also considered.

3.3.3 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/#).

4 DISCUSSION OF RESULTS

The Harbour wide Report Card score for coral communities in 2016 was 0.15, a slight decline from the 2015 score of 0.18 and resulting in the same grade of E (Table 5). A slight increase in mean score for the Juvenile Density indicator resulted in that indicator improving from a very poor (2015) to a poor categorisation in 2016. The improvement in Juvenile Density was however overshadowed by the substantial increase in Macroalgae Cover (Table 4 Figure 2). Overall Coral Cover remained stable at very low levels (Table 4).

Table 4 Indicator values for Gladstone Harbour.

	Year	Juvenile Density (m2)		Coral Cover (%)		Macroalgae Cover (%)	
		Mean	SD	Mean	SD	Mean	SD
Gladstone Harbour	2015	3.7	0.71	5.1	1.40	30.9	17.25
	2016	4.2	0.04	5.8	1.52	41.1	16.90

Table 5 Indicator scores for Gladstone Harbour.

	Year	Juvenile Density	Coral Cover	Macroalgae Cover	Report Card	
					Score	Grade
Gladstone Harbour	2015	0.28	0.06	0.19	0.18	E
	2016	0.33	0.07	0.04	0.15	E

4.1 Coral Cover

Extreme flooding of the Boyne River in 2013 caused Lake Awoonga to over flow and in combination with flows from the Calliope (Table 9) will almost certainly have resulted in the mortality of corals within the harbour (Thompson *et al.* 2015, Jones *et al.* 2015). In brief, monitoring of salinity within the Mid Harbour reporting zone by Vision Environment (2013a & b) confirmed modelling results (Jones *et al.* 2015) indicating the presence of water with salinity levels well below the threshold of 22 PSU for a period of 3 days lethal to *Acropora* corals (Berkelmans *et al.* 2004). Given the severity of the 2013 flood event it is not surprising that Coral Cover observed in 2015 was variously, low, or effectively absent, within the harbour. In 2016 mean Coral Cover had marginally increased (Table 4) though remained well within the levels categorised as very poor (Table 5).

The trajectory of Coral Cover within the Mid and Outer Harbour was noticeably different (Table 6). In the Outer Harbour Coral Cover increased a Seal Rocks South. At this reef the coral community is predominantly composed of the genus *Turbinaria* (Figure 2, Table A 4). Many of the *Turbinaria* colonies are sufficiently large so as to confidently assume they have survived the 2013 flood. It is the growth of these surviving colonies that has resulted in the observed increase in Coral Cover (Figure 2). In contrast, coral communities at Seal Rocks North appear to have been completely killed by the floods in 2013. Here, the remaining dead coral skeletons show the community to have included a high proportion of the genus *Acropora;* a group known to be sensitive to reduced salinity (van Woesik 1991, Berkelmans *et al.* 2012, Jones and Berkelmans 2014). No recovery of Coral Cover has occurred at Seal Rocks North where cover remains at 0% (Figure 2).

Table 6 Indicator values for reporting zones.

Zone	Year	Juvenile Density (m^2)		Coral Cover (%)		Macroalgae Cover (%)	
		Mean	SD	Mean	SD	Mean	SD
Mid Harbour	2015	3.2	1.36	6.1	5.44	18.7	12.24
	2016	4.2	0.62	4.7	3.13	29.2	8.71
Outer Harbour	2015	4.2	1.15	4.1	5.86	43.1	21.39
	2016	4.2	0.73	6.9	9.72	53.0	0.09

In the Mid Harbour mean Coral Cover has declined by half (13% in 2015 to 6% in 2016, Table 6). This reduction is due mostly to a loss of Porites cover at Facing Island (Figure 2). At both Rat Island and Famers Reef the coral communities are predominantly composed of species of Faviidae (Table A 4) and have remained relatively stable albeit at very low levels of cover (Figure 2). Cover of corals remained virtually absent from Manning Reef (Figure 2, Table A 4). Reductions in Coral Cover of the magnitude observed at Facing Island are typically associated with a distinct disturbance or pressure.

Table 7 Indicator scores and Report Card grade for reporting zones.

Zone	Year	Juvenile Density	Coral Cover	Macroalgae Cover	Report Card	
					Score	Grade
Mid Harbour	2015	0.23	0.08	0.37	0.23	E
	2016	0.33	0.06	0.07	0.16	E
Outer Harbour	2015	0.33	0.05	0	0.13	E
	2016	0.33	0.09	0	0.14	E

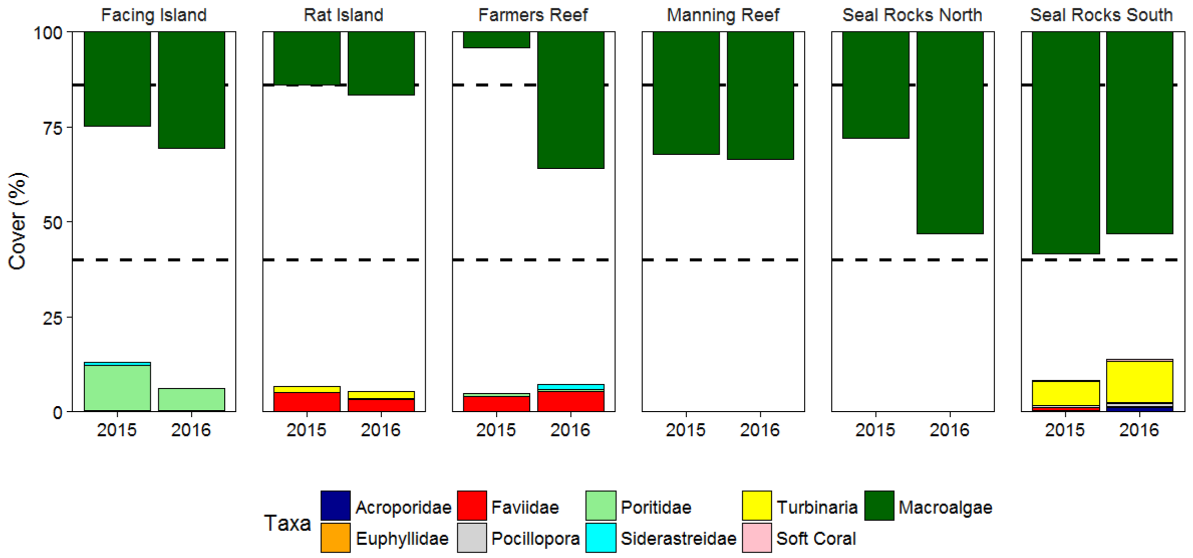

Figure 2 Composition of benthic cover at each location. Rising bars break down Coral Cover into major taxonomic groups (Families and Genera). Hanging bars represent Macroalgae Cover and are read in reverse (observed cover is read as 100 – y axis value, i.e. 10% cover will appear as a bar between 100 and 90% on the plot). White space is the remaining cover not occupied by indicators and will include: sand and silt substrate, turfing and crustose coralline algae along with other organisms such as sponges. Dashed reference lines indicate the boundary between the condition categories 'Poor' and 'Satisfactory'. Hanging Macroalgae Cover bars not extending to the upper reference line would be categorised as 'Satisfactory' or better. Rising bars for Coral Cover would have to extend to or beyond the lower reference line to receive a 'Satisfactory' or better categorisation.

Observations from scuba search surveys show the bio-eroding sponge *Cliona orientalis* to be the singular most common factor impacting corals during surveys in both 2015 and 2016 (Table A 6, Figure 3). At Facing Island 2 there was a notable increase in the cover of *Cliona orientalis* from 1% in 2015 to 3.5% in 2016. In combination these observations confirm that *Cliona orientalis* is limiting the recovery of Coral Cover in the Mid Harbour and contributing to the very poor condition of this indicator. Unfortunately little is currently known about the ecology of *C. orientalis*, observations from the MMP do however show the sponge to wide spread within the inshore GBR.

Over the 2015/2016 austral summer, high seawater temperatures caused severe coral bleaching to reefs in the northern Great Barrier Reef. One indicator of bleaching likelihood is the accumulated positive anomaly of summer sea-surface temperature compared with the historical climatology of the region; termed Degree Heating Days (DHD, Garde *et al.* 2014). DHD estimates for the summer period (December to March inclusive) for pixels within the Mid and Outer Harbour reporting zones were 87 for the 2014/2015 summer and 53 for the 2015/2016 summer. The DHD summary is, however, influenced by the cooler conditions observed in January 2016, and misses the high anomaly that occurred in April

2016 (Table 8) suggesting the influence of temperature could have played a role in cover declines. However, it is the authors' experience that when *Porites* are bleached they often do not die immediately and stay very pale for several months; observations that *Porites* were not bleached during surveys in May 2016 (Figure 3) detracts from thermally induced bleaching as the primary cause of coral mortality.

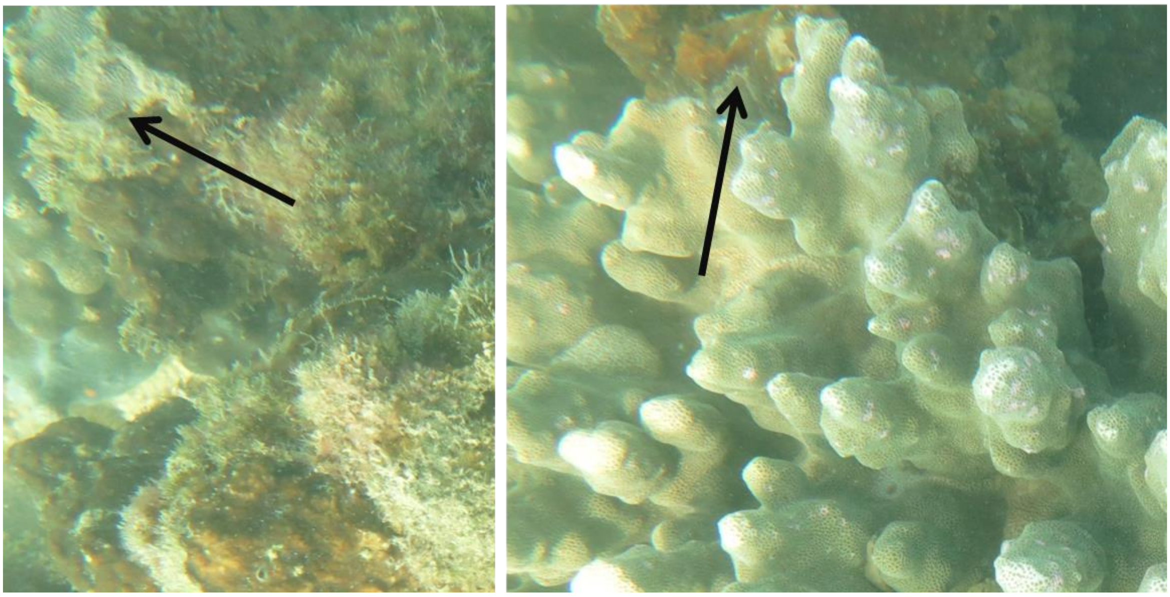

Figure 3 *Cliona orientalis* overgrowing *Porites* along transects at Facing Island.

Table 8 Mean monthly sea-surface temperature anomalies within Gladstone Harbour. Values were downloaded from eReef Marine Water Quality Dashboard. Colours are added as a visual guide only to enhance warmer (Red tones) and cooler (Blue tones) months

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2015	1.26	0.84	0.99	1.67	0.16	1.28	0.73	-0.18	-0.61	-1.49	-2.09	0.91
2016	-1.19	1.67	1.31	2.42	1.79							

A check of local river discharge for the wet season (December 2015-May 2016) reveals no evidence of major flooding in the region (Table 9) and most recent overflow of the Lake Awoonga dam to have occurred in January 2015. That the *Porites* at Facing Island survived the extreme flooding that occurred in 2013 negates flooding as a cause for the observed reductions.

In contrast to reduced Coral Cover, Macroalgae Cover increased at most reefs (Figure 2). This increase in macroalgae cannot be discounted as the cause for some reduction in Coral Cover as large erect algae species can overtop corals and exclude them from observation when using the photo point intercept method to estimate cover.

Table 9 River discharge. Values are annual wet season (December to May) discharge as a proportion of median wet season discharge for the period (1990-2010).

River	Median (ML)	2011	2012	2013	2014	2015	2016
Calliope	53309	10.7	2.9	17	2.8	5.2	1.2
Fitzroy	1447644	24.5	4.5	5.8	1	1.8	1.6

4.2 Macroalgae

Macroalgae Cover was high at all reefs (Table A 3, Figure 2) resulting in the assessment of condition for this indicator of 'very poor' (Table 5). The ubiquitously high Macroalgae Cover suggests the ongoing mismatch between rates of grazing and macroalgal production. Despite water quality generally within guideline values in the both Mid and Outer Harbour (Gladstone Healthy Harbour Partnership 2015) the availability nutrients within the harbour are clearly not limiting to macroalgae communities. Unfortunately we do not have any information relating to past or present populations of potential macroalgal grazers, limiting any interpretation of the cause for the current over production of algae compared to rates of grazing.

As for coral communities (Figure 2, Table A 4) differences in the taxonomic composition of the macroalgal communities (Table A 5) suggest fine scale differences in the combined physical and chemical environments at the monitoring locations.

The brown macroalgae *Sargassum* and *Lobophora* are most abundant at Facing Island and Seal Rocks (Figure 4a, c). During 2016 there was a bloom of *Colpomenia* and a mix of other fine brown macroalgae (including *Dictyota*) at Rat Island (Figure 4d). In contrast Farmers Reef and Manning Reef host a high cover of the red algae *Asparagopsis (*Figure 4*b)*. During surveys in both 2015 and 2016 turbidity at Manning Reef was consistently high; we did not observe more than 1m underwater visibility in either year during ebb or flow tides. The remaining Mid Harbour reefs receive a relatively clear inflow of water through North Passage during the flood tide followed by more turbid water flowing out from the harbour as the tide ebbs. Of the three reefs clustered around North Passage the turbidity and current at Farmers reefs increases most noticeably during the ebb tide. At Seal Rocks a similar pattern of low turbidity during the flood tide was observed and although turbidity does increase with the ebbing tide the change in conditions is not as apparent as that observed at Farmers Reef.

Monitoring undertaken by the MMP elsewhere on the GBR demonstrates that at reefs predisposed to high cover of macroalgae, cover is typically variable between years (Thompson *et al.* 2016). Many macroalgae species demonstrate seasonal patterns of abundance. We note that sampling in 2016 occurred on 26 of May which was seasonally earlier than the sampling in early July 2015. Potentially compounding any bias in estimates of Macroalgae Cover as a result of this difference in season was that the water temperatures in

April and May 2016 were substantially higher than those in 2015 (Table 8) potentially extending the growth period for these species. As such, although the increases observed between 2015 and 2016 are of concern, we cannot discount seasonal differences in temperature or timing of surveys as causes for this change. What is clear is that at the levels observed in both 2015 and 2016 macroalgae are likely to be contributing to the suppression of coral community recovery across the Harbour.

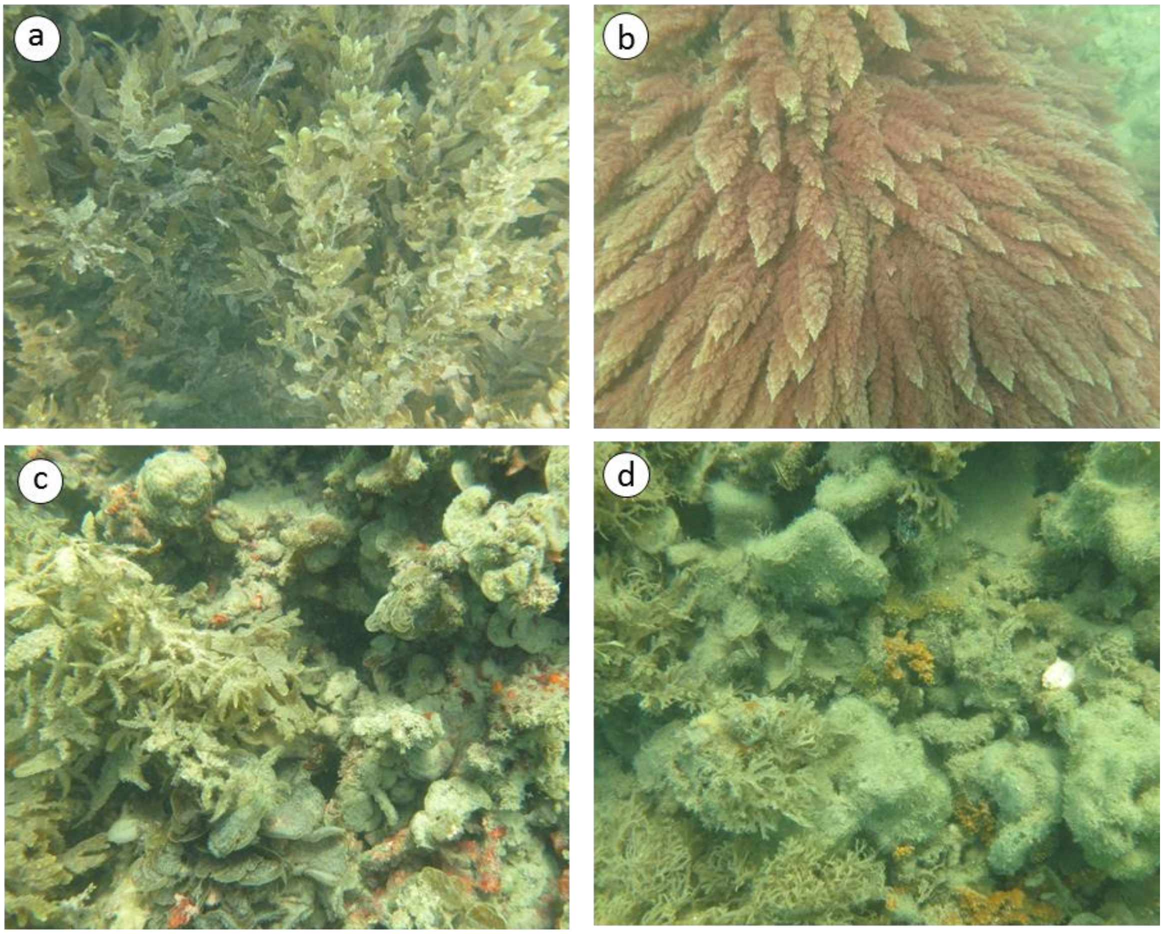

Figure 4 Representative images of dominant macroalgae genus at monitoring locations. a, *Sargassum* at Facing Island, b, *Asparagopsis* at Rat Farmers Reef, c, a mixture of *Sargassum* and *Lobophora* at Seal Rocks North and d, a mixture of *Dictyota* and *Colpomenia* at Rat Island.

4.3 Juvenile Density

The harbour wide mean density of juvenile corals increased marginally between 2015 and 2016, resulting in the continued classification of 'poor' (Table 4, Table 5). The increase in density was most evident in the Mid Harbour where the number of *Turbinaria* juveniles increased at all reefs, *Porites* increased at Rat Island and Facing Island and *Acropora* made an appearance at Manning Reef (Figure 5). The density of Juvenile *Acropora* also increased at both locations at Seal Rocks (Figure 5). The increase in *Acropora* and *Pocillopora* (Seal Rocks North, Figure 5) are important signs for the recovery of coral communities. Both these fast growing genus are effectively absent from the present adult communities (Figure 2, Table A

4) though they were present prior to the impacts of flooding in 2013 (Jones *et al.* 2015) and as evidenced by their remaining skeletons along the monitoring transects. In contrast, there has been a decline in Siderastreidae (predominantly *Psammocora*) juveniles at Facing Island and Seal rocks (Figure 5). This pattern of a pioneering recruitment pulse of *Psammocora* soon after major flooding and then subsequent decline has also been observed at Pelican Island in Keppel Bay (Thompson *et al.* 2016).

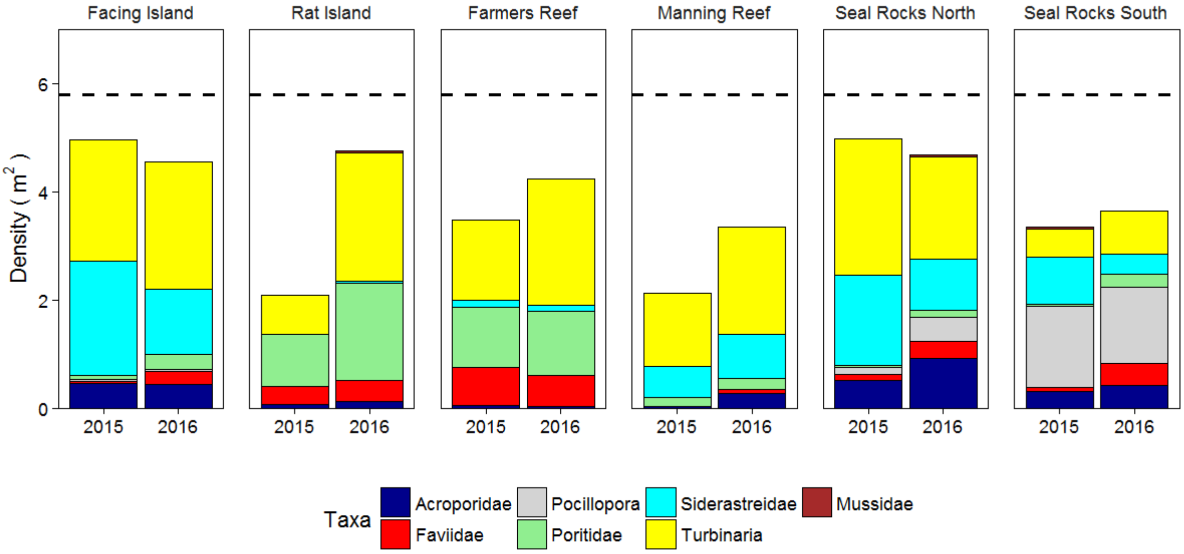

Figure 5 Composition of juvenile coral communities at each location. Bars break down juvenile density into major taxonomic groups (Families and Genera). Dashed reference line indicates the boundary between the condition categories 'Poor' and 'Satisfactory'. Juvenile density would have to extend to the reference line to receive a 'Satisfactory' categorisation.

Considering the size class distribution of juvenile corals (Table A 7) it can be seen that there has been an increase in the number of juvenile corals in the larger size classes of 2-5cm and 5-10cm indicating that juveniles are surviving and growing beyond their first year. This survival of juveniles is also an encouraging sign for the recovery of these communities.

5 CONCLUSION

The coral communities of the Mid and Outer Harbour exhibit a predictable response to the impact of severe flooding in 2013 when low salinity caused substantial mortality to the coral communities and the available space was rapidly colonised by algal groups (Jones *et al.* 2015, Thompson *et al.* 2015). The magnitude of coral loss that occurred as a result of the 2013 floods largely dictates the very low scores for the Coral Cover indicator that reports on the state of the coral community. It is the indicators: Macroalgae Cover, Juvenile Density, and the proposed future inclusion of an indicator for the rate of coral cover increase, which are most informative at this stage of the disturbance and recovery cycle as, collectively, these indicators report on the potential of coral communities to recover.

Given the very low cover of corals at all sites, and the dominance of slow-growing taxa (e.g. *Porites* and *Cyphastrea*) at most, the recovery of coral cover will be largely determined by the successful settlement, survival, and growth of juvenile corals. While turf algae are reported to have some inhibiting influence over coral recruitment (Birrell et al 2005), it is the larger fleshy macroalgae such as *Sargassum and Asparagopsis* and in particular the lower matt forming species such as *Lobophora* and *Dictyota* (Hauri et al. *2010*) that are most disruptive to coral community recovery. Macroalgae have been shown to reduce: gamete development in adult corals, and the settlement, survival and growth of juvenile corals (reviewed by Birrell *et al.* 2008, Foster *et al.* 2008, Diaz-Pulido *et al.* 2010). At the levels of Macroalgae Cover observed in 2016 it is reasonable to conclude that macroalgae have contributed to the poor scores for the Juvenile Density indicator.

The very low Coral Cover within the Harbour is also likely to be a contributing factor to the observed low Juvenile Density. While the connectivity between the Gladstone Harbour sites populations of corals elsewhere is unknown the dearth of coral cover within the Harbour is likely to be a limitation on larval supply and compound the negative influences of high macroalgae cover. It must be seen as positive, however, that although Juvenile Density is low there are a diversity of juveniles recruiting to all sites. That there has been a progression of juveniles into the larger 2-5cm and 5-10cm size classes demonstrates that despite the pressures offered by macroalgae conditions are conducive to the survival and growth of juvenile corals. Fundamental to the recovery of coral communities will be the reestablishment of the fast growing *Acropora* genus that was observed as a key component of the coral communities at most sites prior to the 2013 floods (BMT WBM 2013). Although in very low abundance, this genus was observed as juveniles at all sites in 2016.

Although the rate of change in coral cover indicator included in the Great Barrier Reef Report Card has not yet been included in the Gladstone Harbour Report Card the changes on coral cover observed between 2015 and 2016 are informative. In the Outer Harbour the increase in cover at Seal Rocks South indicates the ongoing recover of the coral community.

At Seal Rocks North coral cover in 2015 was 0%. From such a low point coral cover increase is expected to be low as any increase is restricted to the growth of very small juvenile corals that a generally unavailable to the point-intercept method. That there were increasing numbers of juveniles into the larger size classes suggest these colonies will begin to become more available to the point-intercept sampling method in the future. In contrast the declines in coral cover at Mid harbour sites at both Rat Island and Facing Island sites are a concern. These two sites had the highest incidence of coral colonies being impacted by the bio-eroding sponge *Cliona orientalis.* This ongoing loss of coral cover in the absence of any acute disturbance event in combination with high cover of macroalgae is a strong indication that chronic pressures imposed by the environmental conditions are limiting recovery of coral communities in the Mid Harbour.

Interpretation of the cause for the observed increase in Macroalgae Cover in 2016 were confounded by sampling earlier in the calendar year (26th May 2016 cf. early July 2015) and the warmer than usual autumn sea-surface temperatures. The effect of earlier sampling and higher temperatures may bias samples as a result of natural seasonal fluctuations in abundance. While year to year fluctuations in temperature will occur, setting a sampling period in the future with help to limit seasonal confounding. We suggest sampling in May is adopted into the future.

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7 APPENDICES

7.1 Appendix 1: Data Tables

Table A 1 Site location and transect directions. Minor corrections from those detailed in Thompson *et al.* 2015 are included. Required maintenance of transect markers is indicated. At each transect a steel star picket marks the start point, then there are 10 mm diameter sections of reinforcing bar at 10 m and at the end (20 m) of each transect. There is a 5 m gap between consecutive transects within each site.

Reef	Date	Depth	Latitude	Longitude	Transect directions	
Seal Rocks North	06-July-	1 m	23 57.500	151	1	295 then 270@10 m
					2	285 then 310@10 m
					3	300 then 320@10 m
					4	30 then 105@10 m
					5	50 then 60@10 m
Seal Rocks South	06-July-	1 m	23 57.825	151	1	0 then 30@10 m
					2	30 then 350@10 m
					3	260 then 250@10 m
					4	190
					5	230
Rat Island	07-July-	1 m	23 46.022	151	1	305 then 300@10 m
					2	300
					3	330 then 320@10 m
					4	330 then 290@10 m
					5	300 then 285@10 m
Facing Island	07-July-	0-1 m	23 45.801	151	1	220 then 210@10 m
					2	190 then 180@10 m
					3	180 then 210@10 m
					4	240 then 230@10 m
					5	180
Farmers Reef	07-July-	1 m	23 46.306	151	1	50
					2	40 then 50@10 m
					3	60
					4	60 then 75@10 m
					5	60 then 40@10 m (replace picket)
Manning Reef	08-July-	0-0.5	23 51.239	151	1	30 then 10@10 m, 50 to T2
					2	60 then 0@10 m, 80 to T3
					3	60 then 320@10 m, 300 to T4
					4	300 then 15@10 m, 350 to T5
					5	330 then 60@10 m (replace rods)

Table A 2 Indicator scores for individual reefs.

Zone	Reef	Year	Scores				Grade
			Juvenile	Coral	Macroalgae	Report	
Mid Harbour	Facing Island	2015	0.41	0.16	0	0.19	E
		2016	0.37	0.08	0	0.15	E
	Farmers Reef	2015	0.26	0.06	1	0.44	D
		2016	0.34	0.09	0	0.14	E
	Manning Reef	2015	0.12	0	0	0.04	E
		2016	0.25	0.00	0	0.08	E
	Rat Island	2015	0.11	0.08	0.50	0.23	E
		2016	0.39	0.07	0.29	0.25	D
Outer Harbour	Seal Rocks North	2015	0.42	0	0	0.14	E
		2016	0.38	0	0	0.13	E
	Seal Rocks South	2015	0.25	0.10	0	0.12	E
		2016	0.28	0.17	0	0.15	E

Table A 3 Indicator values for individual reefs.

Zone	Reef	Year	Juvenile Density (m^2)	Coral cover (%)	Macroalgae cover (%)
Mid Harbour	Facing Island	2015	4.98	13.1	24.8
		2016	4.57	6.1	30.6
	Farmers Reef	2015	3.48	4.8	4.13
		2016	4.24	7.1	35.9
	Manning Reef	2015	2.14	0	32.0
		2016	3.36	0.1	33.6
	Rat Island	2015	2.10	6.6	14
		2016	4.77	5.5	16.5
Outer Harbour	Seal Rocks North	2015	4.99	0	28
		2016	4.69	0	53
	Seal Rocks South	2015	3.36	8.3	58.2
		2016	3.65	13.8	53.1

Table A 4 Genus level coral cover and abundance of juvenile corals at reefs surveyed in 2016.

Sample type	Location	*Acropora* (Acroporidae)	*Montipora* (Acroporidae)	*Turbinaria* (Dendrophylliidae)	*Tubastrea* (Dendrophylliidae)	*Euphyllia* (Euphyllidae)	*Cyphastrea* (Faviidae)	*Favia* (Faviidae)	*Favites* (Faviidae)	*Goniastrea* (Faviidae)	*Leptastrea* (Faviidae)	*Platygyra* (Faviidae)	*Moseleya* (Faviidae)	*Acanthastrea* (Mussidae)	*Pocillopora* (Pocilloporidae)	*Goniopora* (Poritidae)	*Porites* (Poritidae)	*Coscinaraea* (Siderastreidae)	*Psammocora* (Siderastreidae)	*Pseudosiderastrea* (Siderastreidae)	*Cladiella* -Soft coral (Alcyoniidae)	*Sarcophyton* Soft coral (Alcyoniidae)
Cover (%)	Facing Island						0.38										5.75					
	Rat Island			1.88			2.75		0.50								0.38					
	Farmers Reef						4.88		0.50		0.13					0.13	0.25		1.25			
	Manning Reef	0.13																				
	Seal Rocks North																					
	Seal Rocks South	1.13		10.88		0.13	0.13								0.88	0.13					0.38	0.12
Juveniles (count)	Facing Island	12	1	68			1	1			2		3		1		8	3	32			
	Rat Island	2	1	50					2		5	1		1			38		1			
	Farmers Reef	1		44	1		2		2	1	6					5	18		1	1		
	Manning Reef	8		56			1						1				6		23			
	Seal Rocks North	24	3	55			2	1	4	2				1	13	2	2	1	26			
	Seal Rocks South	11		20			2	2	3	2		1			35	6		1	8			

Table A 5 Cover of Algae, Sponges and Sand & Silt

	Red macroalgae					Brown macroalgae								Green macroalgae	Coralline algae	Turf algae		Sand & Silt	Sponge
	Unidentified	*Asparagopsis*	*Peyssonnelia*	*Hypnea*	Calcareous Red Algae	Unidentified	*Colpomenia*	*Dictyota*	*Lobophora*	*Padina*	*Sargassum*	*Spatoglossum*	*Stypopodium*						
Facing Island	1			0.25	0.38	0.50			7.75		20.75				0.63	48.88		9.25	4.50
Rat Island	0.38					0.13	6.38	3.88	5.63	0.13					0.25	41.50		32.63	3.63
Farmers Reef		33.5						0.63	1.75						0.38	18.75		36.25	1.63
Manning Reef	0.25	28.38		0.13		0.13		2.13	2.63							48.13		17.50	0.38
Seal Rocks North	0.13		6.25			1.5	0.13		24.13		18.50	2.38			0.25	30.25		16.50	
Seal Rocks South			0.63			1.13		0.88	18.38	0.38	30.63	0.88	0.13	0.13	0.75	19.13		13.25	0.50

Table A 6 Causes of coral mortality at time of survey 2016. Area of survey 200 m2 at each reef. Data from both 2015 and 2016 included for comparison. No data are included for Manning Reef or Seal Rocks North where the very low coral cover ensured no colonies suffering mortality at the time of survey were observed.

Reef	**Year**	**Damage**	**Genus**	**Colonies affected**
Facing Island	2015	Bio-eroding sponge	*Porites*	13
			Turbinaria	1
	2016	Bio-eroding sponge	*Porites*	8
Farmers Reef	2015	Bio-eroding sponge	*Cyphastrea*	4
			Favia	1
	2016	Bio-eroding sponge	*Cyphastrea*	9
Rat Island	2015	Bleaching	*Favites*	1
		Bio-eroding sponge	*Cyphastrea*	6
			Turbinaria	5
	2016	Bio-eroding sponge	*Cyphastrea*	7
			Turbinaria	4
Seal Rocks South	2015	Bio-eroding sponge	*Turbinaria*	3
	2016	AN	*Turbinaria*	1
		Bleaching	*Pocillopora*	2
		Bio-eroding sponge	*Turbinaria*	4
		Unknown	*Turbinaria*	1

Table A 7 Size-class distribution of juvenile corals. Values are number of juveniles observed in 100m x 0.34m belt transects (34m2) at each reef. Data from both 2015 and 2016 included for comparison.

Reef	year	Size-class categories (cm)		
		< 2	2 to <5	5 to 10
Facing Island	2015	107	28	0
	2016	67	58	7
Farmers Reef	2015	32	17	5
	2016	37	26	9
Manning Reef	2015	52	6	2
	2016	55	40	0
Rat Island	2015	19	23	8
	2016	48	43	10
Seal Rocks North	2015	111	31	1
	2016	80	48	8
Seal Rocks South	2015	52	30	3
	2016	27	55	9

7.2 *Appendix 2: Rationale* for indicator selection and threshold setting.

This section is reproduced from Thompson *et al.* 2015.

7.2.1 Combined cover of hard corals and soft corals

For coral communities, the underlying assumption for resilience is that recruitment and subsequent growth of colonies is sufficient to compensate for losses resulting from the combination of acute disturbances and chronic adverse environmental conditions. High abundance of coral, expressed as proportional cover of the substratum, can be interpreted as an indication of resilience as the corals are clearly able to survive the ambient environmental conditions. In addition, high cover equates to a large broodstock, a necessary link to recruitment and an indication of the potential for recovery of communities in the local area. Corals also contribute to the structural complexity of a reef and as such support increased biodiversity and provide important ecosystem services such as the provision of habitat for fishes. Finally, high cover is the most tangible reflection of a healthy coral community and a desirable state from an aesthetic perspective. The consideration of both hard and soft corals in this indicator recognises that all corals have a place on coral reefs and that the cover of an area by any coral is effectively mutually exclusive of another.

The selection of critical values or thresholds for coral cover about which to base assessments of condition is difficult. From MMP observations since 2005 there are no strong indications that either hard or soft coral cover coral cover varies substantially along water quality gradients suggesting a common Great Barrier Reef (GBR) wide threshold for coral cover is appropriate. We do, however, acknowledge that differing disturbance histories in space and time are likely to confound any analysis attempting to quantify such a relationship. For the MMP, the setting of a threshold for coral cover is still under discussion however is likely to be based on an aspirational target of ~50% cover. This target is informed by two prior assessments of coral cover on nearshore reefs. A broad scale survey of nearshore reefs between Cape Tribulation and the Keppel Islands using the same sampling methods as used in Gladstone Harbour undertaken in 2004 returned a mean cover of hard corals of 33% and of soft coral of 5% (Sweatman *et al*. 2007). This total coral cover mean of 38% was observed following the severe loss of corals that occurred as result of thermal bleaching in 1998 and also 2002 (Berkelmans *et al*. 2004) and so is considered too low as a threshold that would indicate “good condition”. Secondly, a summary of surveys from over 100 sites between Cape Flattery and the Keppel Islands prior to 1996 returned a mean cover of hard corals of 62% (Ayling 1996). In this second study, soft coral cover was not reported and the surveys were based on a range of video and line intercept techniques. In-house analysis by AIMS of coral cover estimates using line intercept sampling along the same sites as photo point intercept (PIT) used by the MMP reveal a consistent bias with PIT being ~ 78% of that estimated by LIT (r^2 = 0.99). Correcting for technique puts the pre 1996 hard coral cover on inshore reefs at a mean of approximately 48%. Allowing some soft coral cover and rounding to an even percentage, the MMP is looking toward a threshold of 50% for the combined cover of hard and soft coral on inshore reefs. Finally, surveys conducted prior to 2009 in the mid harbour reporting zone of Gladstone Harbour had mean hard coral cover of 39% (BMT WBM 2013). Although the BMT WBM (2013) report did not provide a mean estimate for soft coral cover, Figure 4.4 of that report indicates soft coral cover in the middle harbour ranged between ~4% - 40%. These figures do not greatly deviate from the 50% combined cover of hard and soft corals likely to be used by the MMP in the future and so we suggest applying a 50% threshold for Gladstone also (Table A2-1). No prior data exist for the outer harbour reporting zone and so again we suggest a consistent use of the 50% threshold as this will allow comparison of condition across zones but also other regions of the GBR monitored by the MMP.

7.2.2 Cover of macroalgae

Macroalgal (MA) recruitment, growth and biomass are controlled by a number of environmental factors such as the availability of suitable substratum, sufficient nutrients and light, and rates of herbivory (Schaffelke *et al.* 2005). High macroalgal abundance may suppress reef resilience (e.g., Hughes *et al.* 2007, Foster *et al.* 2008, Cheal *et al.* 2013; but see Bruno *et al.* 2009) by increased competition for space or changing the microenvironment into which corals settle and grow (e.g. McCook *et al.* 2001a, Hauri *et al.* 2010). On the GBR, high macroalgal cover correlates with high concentrations of chlorophyll, a proxy for nutrient availability (De'ath and Fabricius 2010). Once established, macroalgae pre-empt or compete with corals for space that might otherwise be available for coral growth or recruitment (e.g. Box and Mumby 2007, Hughes *et al.* 2007). For the purpose of this indicator, macroalgae are considered as species of the phyla Rhodophyta (Red algae), Phaeophyta (Brown algae) and Chlorophyta (Green algae), excluding the encrusting coralline or short turf like species. The latter two groups are recorded as part of the assessments but are not aggregated into the MA indicator.

The interactions between corals and algae are complex, likely species-specific and, mostly, un-quantified (McCook *et al.* 2001a). Because of this it is difficult to determine realistic thresholds of macroalgal cover from which to infer information about the resilience of coral communities. Recent AIMS analysis of MMP data aimed at determining a threshold for the MA indicator gave a threshold of ~23% for communities in less than 3m depth below lowest astronomic tide (LAT), beyond which the density of juvenile corals declines. This direct influence on coral community replenishment could be used to define an upper bound for macroalgae cover. A further consideration is that within the MMP data set MA cover varies along environmental gradients with highest cover found in turbid areas and where wave or current action precludes the accumulation of fine sediments. As turbidity declines or the proportion of sediments with fine grainsizes increase then the cover of macroalgae also declines. This response to environmental conditions is a further constraint to the expectation of the level of MA cover at many locations. Current thinking within the MMP is to include the threshold mentioned above for an influence of juvenile corals as an upper threshold though reduce this to modelled estimates of cover based on observed relationships between MA cover, turbidity and sediment composition, in cases where these predictions are lower than the threshold for influence on juvenile corals. For the Gladstone Healthy Harbour Partnership monitoring, AIMS has collected sediment samples from each monitoring location and determined sediment grainsize composition. The depth of these samples was only 1-2m below LAT and so will not be directly comparable to grainsize compositions from MMP reefs that were sampled at the depth of 5m below LAT where wave driven resuspension is generally reduced. The results of the sediment analysis suggest that there is not a substantial accumulation of fine sediments at the coral sampling locations selected in Gladstone harbour and this along with the limited depth of the reefs suggest turbidity and sedimentation will not be limiting macroalgae cover.

In light of the above considerations an upper bound of 20% cover of macroalgae was adopted for the Gladstone Harbour reefs (Table A2-1) as this is below the threshold for impacts to juvenile settlement at shallow depths but also recognises that macroalgae cover is a natural component of shallow reef communities in nearshore areas of the southern GBR. The most comparable reef monitored by AIMS to those in Gladstone Harbour is Pelican Island in Keppel Bay. At Pelican Island MA cover declined to ~5% as the coral community at 2m below LAT recovered. The lower bound for cover of MA was set on Gladstone Harbour reefs was set at 5% as this is in line with cover at Pelican Island during a period that corals were showing strong recovery from past disturbance events but also allowing some natural occurrence of MA. We suggest the threshold for cover for MA be set midway between the lower and upper bounds at 12.5% (Table A2-1). We point out that the scoring of this indicator is the inverse to that used for coral cover or juvenile densities as high MA cover is considered a poor indication of coral community condition.

7.2.3 Density of juvenile hard corals

Common disturbances to inshore reefs include cyclones (often associated with flooding), thermal bleaching, and outbreaks of crown-of-thorns seastar, all of which can result in widespread mortality of corals (e.g. Sweatman *et al.* 2007, Osborne *et al.* 2011). Recovery from such events is reliant on both the recruitment of new colonies and regeneration of existing colonies from remaining tissue fragments (Smith 2008, Diaz-Pulido *et al.* 2009). Previous studies have shown that elevated concentrations of nutrients, agrichemicals, and turbidity can negatively affect reproduction in corals (reviewed by Fabricius 2005, van Dam *et al.* 2011 Erftemeijer *et al.* 2012) and increased organic carbon concentrations can promote coral diseases and mortality (Kline *et al*. 2006, Kuntz *et al*. 2005). Furthermore, high rates of sediment deposition and accumulation on reef surfaces can affect larval settlement (Babcock and Smith 2002, Baird *et al.* 2003, Fabricius *et al.* 2003) and smother juvenile corals (Harrison and Wallace 1990, Rogers 1990, Fabricius and Wolanski 2000). Any of these water quality-related pressures on the early life stages of corals have the potential to suppress the resilience of communities reliant on recruitment for recovery. For these reasons the density of juvenile corals is an important indicator of coral community resilience, especially in periods following severe disturbance events.

The number of juvenile colonies observed along fixed area transects may be biased due to the different proportions of substratum available for coral recruitment. For example, live coral cover effectively reduces the space available for settlement of coral larvae, as do sandy or silty substrata onto which corals are unlikely or unable to settle. To create a comparative estimate of the density of juvenile colonies between reefs and through time, the numbers of recruits observed along fixed transects are converted to densities per area of transect that is 'available' to settlement. This standardisation divides the number of juvenile corals observed along fixed transects by the area of those fixed transects that is not occupied by existing corals or deposits of loose sediments to which corals could not settle.

The setting of a threshold against which to assess observed densities of juvenile corals is problematic as detailed demographic studies that allow the estimation of adequate levels of recruitment that are likely to ensure coral community resilience have not been undertaken for the range of communities present in the turbid nearshore waters of the GBR. For the MMP, the thresholds used to date have been based on the distribution of densities observed over the years 2005-2009 as a baseline condition from which changes could be inferred as improvements or declines in condition. From MMP data, the mean density of juvenile corals (< 10 cm) at sites 2m below LAT is 7.5 per m^2 of available substrate, with the 10^{th} and 90^{th} percentiles of the distribution being 1 and 16 juveniles per m^2 (Table A2-1). These observations serve as a guide to the densities of juveniles that can be expected on inshore reefs.

One study that explicitly focused on estimating the density of juvenile corals (<10 cm) required for coral communities to recover rather than shift to an algal dominated following severe disturbance suggested a threshold of 6.2 juveniles per m^2 (Graham *et al.* 2015). Because this work was undertaken in the Seychelles the relevance to the inshore GBR is unknown. However, considering the similarity between the inshore GBR mean and the threshold of Graham *et al.* 2015, we adopted a value of 7 juvenile colonies per m^2 of available substrate for the Gladstone harbour threshold (Table A2-1).

7.2.4 References

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