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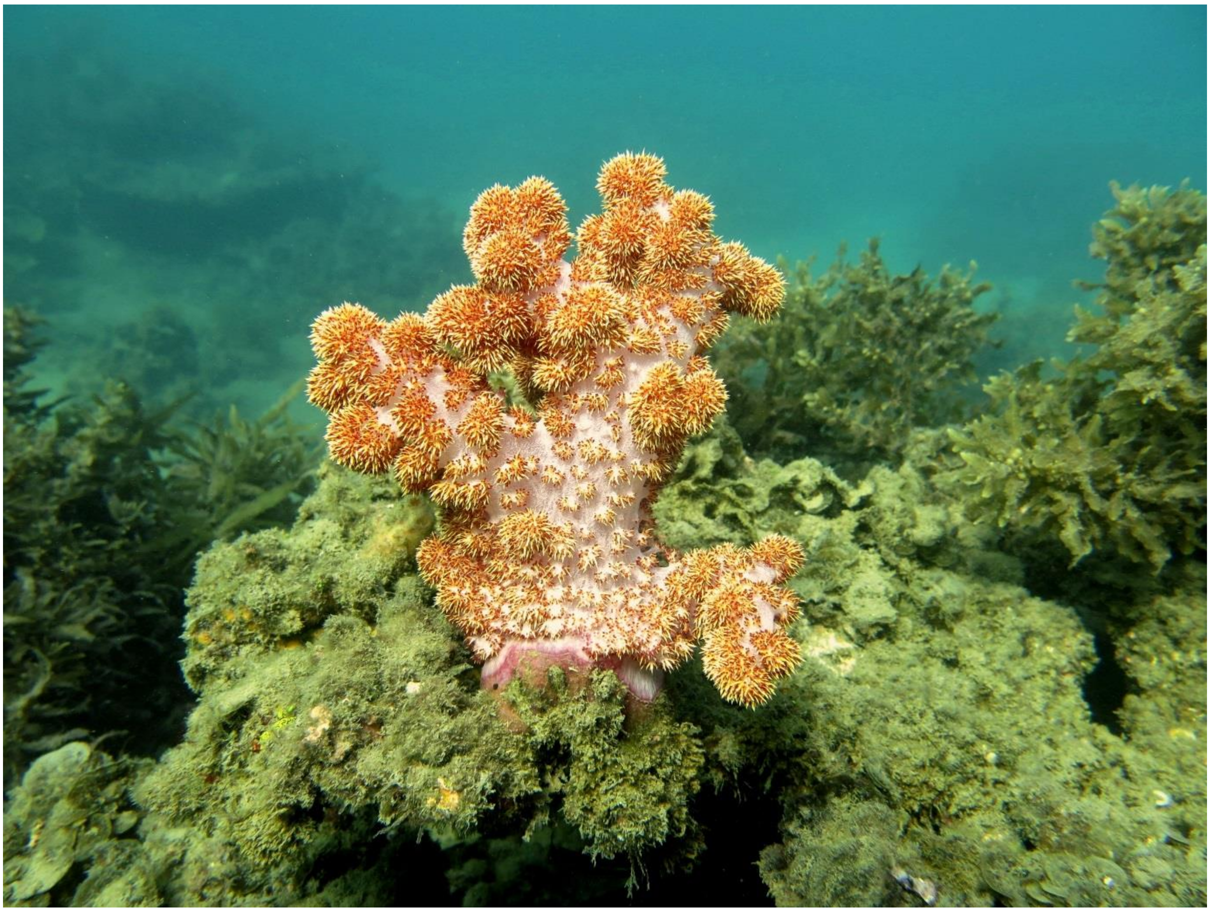
Coral Indicators for the 2017 Gladstone Harbour Report Card: ISP014

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 2017 Gladstone Harbour Report Card.

In May 2017, the Australian Institute of Marine Science resurveyed benthic communities at permanent coral monitoring locations in the Mid Harbour (four locations) and Outer Harbour (two locations). Overall the condition of these communities has improved from 'Very poor' (E) in 2016 to 'Poor' (D) in 2017 (Table 1).

Report Card grades prior to 2017 were 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). With three years of data now available it is possible to include a fourth indicator of coral condition; Change in Hard Coral Cover. For each of the established indicators, observed levels were converted to scores based on thresholds developed for the 2015 Gladstone Harbour Report Card. The methods for converting observed levels of coral change into scores are outlined in this report.

Table 1 Coral indicator scores and 2017 Report Card grade.

Juvenile Density	Coral Cover	Macroalgae Cover	Change in Hard Coral Cover	Report Card	
				Score	Grade
0.38	0.07	0.24	0.40	0.28	D

The 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, which almost certainly exposed corals to lethally low levels of salinity. The remaining three indicators, Macroalgae Cover, Juvenile Density and Change in Hard Coral, are included as representative of the recovery potential of coral communities from such acute events.

High macroalgae cover continues to ensure the 'Very poor' assessment of this indicator. Macroalgae can limit coral recovery through a variety of pathways including direct competition 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 levels of macroalgae cover 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 2017, as well as flooding in the region associated with ex-Tropical Cyclone Debbie, it was not apparent that these had a strong direct impact on corals in the year prior to sampling. It is however reasonable to consider that some mortality may have occurred due to thermal bleaching, but was not detectable by the time surveys were conducted. Localised pressures of high macroalgae cover and the prevalence of bio-eroding sponges appear to be the strongest factors contributing to the suppression of recovery at these reefs.

The addition of the fourth indicator Change in Hard Coral Cover has shown that recovery is occurring with the majority of reefs achieving a ‘Satisfactory’ assessment. Although changes in cover are small this is to be expected given the low cover and predominance of slow growing species.

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, 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 the Australian Institute of Marine Science (AIMS) has co-invested with the Gladstone Healthy Harbour Partnership (GHHP) to monitor and report on the condition of coral communities within the GHHP reporting area as part of the Gladstone Harbour Report Card.

The indicators, sampling methodology and scoring system used to derive grades for the Gladstone Harbour Report Card were chosen to be as 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 state level as well as regional Report Card scores are derived now vary between these programs. Consideration should be given to realignment of methodologies.

This report presents the third 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 2017 which expands on the necessarily succinct summary of condition presented by the 2017 Gladstone Harbour Report Card.

3 METHODS

3.1 Sampling design

The basis of the sampling design is permanently marked transects used 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 20 metre (m) 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 10 millimetre (mm) steel rod placed at the midpoint and end of each transect. The starting point of the first 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 benthic community surveys were repeated on the 16th of May 2017.

3.1 Survey methods

3.1.1 Photo point intercept transects

Estimates of the composition of benthic communities were derived from the identification of organisms on digital photographs taken along the permanently marked transects. The method closely followed Standard Operation Procedure Number 10 of the AIMS Long-Term Monitoring Program (LTMP) (Jonker *et al.* 2008) and mirrors that used by the Reef Plan Marine Monitoring Program (MMP). In short, digital photographs were taken at 50 centimetre (cm) intervals along each transect. Estimations of cover of benthic community components were 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 of 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, within a strip (34 cm wide, or data slate length) along the upslope side of the transect line. Corals were assigned to one of three size classes (0-2cm, greater than 2-5cm, and greater than 5-10cm), identified to genus level and recorded. Importantly, this method aimed to record only those small colonies assessed as juveniles, i.e. those which result from the settlement and subsequent survival and growth of coral larvae. Small coral colonies considered to have resulted from the fragmentation or partial mortality of larger colonies were excluded from the survey.

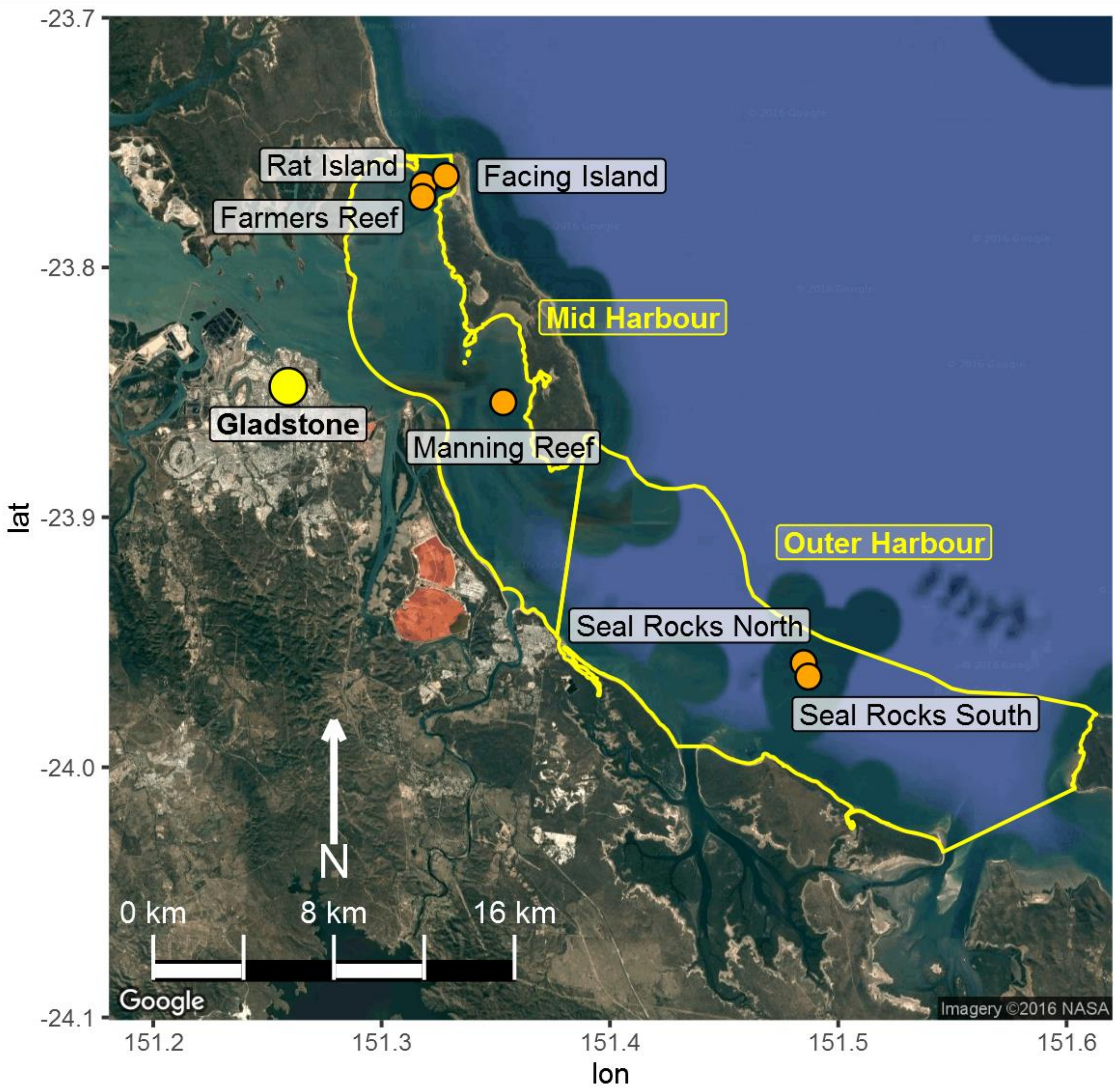

Figure 1 Coral monitoring sites.

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 closely followed 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 include those used for the 2015 Gladstone Harbour Report Card (Thompson *et al.* 2015) and the 2016 report card. In addition the 2017 Gladstone Harbour Report Card includes a fourth indicator, Change in Hard Coral Cover. This section provides an overview of the methods used to estimate and score each indicator used to assess coral community condition that, in combination, capture both the state and resilience of coral communities. A full description for the rationale behind the selection and scoring of each indicator is included in Appendix 2.

3.2.1 Coral Cover indicator

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, Macroalgae Cover and Change in Hard Coral Cover were included as they represent the potential for coral communities to recover from disturbances.

3.2.2 Juvenile indicator

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.

3.2.3 Macroalgae indicator

High macroalgal abundance may suppress the recovery of coral communities through a variety of mechanisms ranging from competition 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.

3.2.4 Cover Change indicator

While high coral cover can justifiably be considered a positive indicator of community condition, the reverse is not necessarily true. Low cover may occur following acute disturbance and, hence, may not be a direct reflection of the community's resilience to underlying environmental conditions. For this reason, in addition to considering the actual level of coral cover we also assess the rate at which hard coral cover increases as a direct measure of recovery potential. The assessment of rates of cover increase is possible as rates of change in hard coral cover on inshore reefs have been modelled (Thompson *et al* 2016); allowing estimations of expected increases in cover for communities of varying composition to be compared against observed changes.

A Bayesian framework was used to permit propagation of uncertainty through predictions of expected hard coral cover increase from separate models applied to fast growing Acroporidae, and the combined cover of all other hard corals. Noting, that the example presented below for Acroporidae (*Acr*), has the same form as that applied for Other Corals (*OthC*) if these terms are exchanged where they appear in the equations.

$$\ln(Acr_{it}) \sim \mathcal{N}(\mu_{it}, \sigma^2)$$

$$\mu_{it} = vAcr_i + \ln(Acr_{it-1}) + \left(-\frac{vAcr_i}{\ln(estK_i)}\right) * \ln(Acr_{it-1} + OthC_{it-1} + Sc_{it-1})$$

$$vAcr_i = \alpha + \sum_{j=0}^{J} \beta_j Reef_i$$

$$\alpha \sim \mathcal{N}(0, 10^6)$$

$$\beta_j \sim \mathcal{N}(0, \sigma^2_{Reef})$$

$$\sigma^2, \sigma^2_{Reef} = \mathcal{U}(0,100)$$

$$rAcr = v\bar{A}cr_i$$

Where, $Acr_{it}, OthC_{it}$ and Sc_{it} are the cover of Acroporidae coral, other hard coral and soft coral respectively at a given reef at time (t). $eskK$ is the community size at equilibrium (100-proportion of area comprised of unconsolidated substrates) and $rAcr$ is the rate of increase (growth rate) in percent cover of Acroporidae coral. Varying effects of Reef (β_j) is also incorporated to account for spatial autocorrelation. Model coefficients associated with the intercept, and Reef (α_i and β_j) all had weekly informative Gaussion priors, the latter two with model standard deviation). The overall rate of coral growth parameters ($rAcr$ or alternatively $rOthC$) constituted the mean of the individual posterior rates of increase ($vAcr_i$ or alternatively $vOthC_i$).

This indicator metric is based on the rate at which coral cover increases.

3.2.5 *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 the LTMP. Details of the rationale for setting thresholds and relevance to reefs in Gladstone Harbour are provided in Appendix 2. 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}
Change in Hard Coral Cover	Lower 95% CI	2* upper 95% CI	Below 2* lower 95% CI

3.2.6 *Aggregation of indicator scores*

The scaling of all scores to the common range of 0 to 1 allowed 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 four 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 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 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 been 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 the first transect 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 1st December to the 31st March and based on 14 Day IMOS climatology (Garde *et al.* 2014) were downloaded on the 25th July 2017. 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 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 28 parts per thousand (ppt) 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 undertaken in 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 2017 was 0.28, elevating the harbour-wide condition grade to 'D' (Table 5). The Juvenile Density indicator continued to improve, a consistent trend since the commencement of monitoring. Macroalgae cover has decreased slightly, but the score for this indicator remains poor. (Table 4, Table 5, Figure 2). Overall Coral Cover remained stable at very low levels, further contributing to the "Poor" grading (Table 4, Table 5). The Change in Hard Coral Cover metric for Gladstone Harbour scored a "Poor" grading, in this, the first year of assessment (Table 5).

Table 4 Indicator values for Gladstone Harbour. For the Change in hard coral cover indicator the tabulated values are the mean of the changes in cover from the previous year, scores for this indicator are based on the mean of these changes and consider also the composition of the communities at each reef.

	Year	Juvenile density (m2)		Coral cover (%)		Change in hard coral cover (%)		Macroalgae cover (%)	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD
Gladstone Harbour	2015	3.7	0.71	5.1	1.40	NA	NA	30.9	17.25
	2016	4.2	0.04	5.8	1.52	0.8	3.0	41.1	16.90
	2017	4.7	0.72	5.4	0.71	-0.35	2.2	36.6	26.34

Table 5 Indicator scores for Gladstone Harbour.

	Year	Juvenile Density	Coral Cover	Change in Hard Coral Cover	Macroalgae Cover	Report Card	
						Score	Grade
Gladstone Harbour	2015	0.28	0.06	NA	0.19	0.18	E
	2016	0.33	0.07	NA	0.04	0.15	E
	2017	0.38	0.07	0.40	0.24	0.28	D

4.1 Environmental Pressures

Over the 2016/2017 austral summer, high seawater temperatures caused severe coral bleaching on reefs across a large area of the 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 147 for the 2016/2017 summer, more than double the previous estimate of 70 for the 2015/2016 summer.

The DHD summary for the 2015/2016 summer was heavily influenced by the cooler conditions observed in January 2016 which did not occur again in 2017. It should be noted that, as in 2016, April 2017 again showed a high anomaly which the DHD summary does not take into account (Table 6). Despite this strong potential for coral bleaching across Gladstone Harbour, corals exhibited very little evidence of bleaching impacts, with only two colonies of *Montipora* recorded as bleached in the scuba search data (Table A 5). The lack of a clear response to high temperatures was similarly noted at reefs in Keppel Bay, during annual MMP surveys (AIMS unpublished data). It is possible that some sensitive corals had died prior to the surveys in May and were not detected due to overgrowth by algae.

Table 6 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	1.63	1.18	1.38	1.80	0.28	1.48	0.87	-0.06	-0.49	-1.33	-1.92	1.16
2016	-0.79	2.0	1.53	2.46	1.83	2.67	0.84	0.59	-1.42	1.59	0.66	-0.03
2017	0.83	1.18	1.57	2.46	1.08							

River discharge for the wet season (December 2016-May 2017) revealed that flooding in the Fitzroy River (as a result of rainfall associated with ex-Tropical Cyclone Debbie) contributed to 3.9 times the median flow (Table 7). This system also led to overflow of the Lake Awoonga dam on the 30th March 2017. Despite this, surveys conducted in May 2017 found clear evidence that exposure to low salinity had not impacted the coral communities in Gladstone Harbour, and sensitive Acropora colonies were surviving in shallow waters at most sites. Further inspection of satellite imagery confirms no significant plumes affected Gladstone Harbour.

Table 7 River discharge

River	Median (ML)	2011	2012	2013	2014	2015	2016	2017
Calliope	53309	10.7	2.9	17	2.8	5.2	1.2	0.5
Fitzroy	1447644	24.5	4.5	5.8	1	1.8	1.6	3.9

Note: Values are annual wet season (December to May) discharge as a multiple of the long-term median wet season discharge for the period (1990-2010).

4.2 Coral Cover

Extreme flooding of the Boyne River in 2013 caused Lake Awoonga to overflow and, in combination with flows from the Calliope River (Table 7) would have almost certainly 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 that water with salinity levels well below the threshold of 22 Practical Salinity Units (PSU) (lethal to *Acropora* corals) (Berkelmans *et al.* 2004), had been present for a period of three days. Given the severity of the 2013 flood event, it is not surprising that coral cover observed in 2015 was either low or effectively absent within the harbour. In 2017, mean coral cover was marginally higher than that observed in 2015. Despite a slight decrease from that observed in 2016, these minor fluctuations have all remained well within the levels categorised as 'Very poor' (Table 5).

It is important not to over-interpret the minor changes in coral cover observed since 2015. All sampling incurs some degree of sampling error. The use of fixed transects does minimise this error, however some variability in estimates should be expected. In particular, fluctuating abundance of large erect species of macroalgae, can overtop corals, excluding them from observation. The result of this increase in macroalgae cover is that there is likely to be a slight underestimate of coral cover compared to when macroalgae cover is low. Given the variability in macroalgae between years and the small changes in coral cover, there is little evidence that cover has shown significant recovery. Therefore the following descriptions of changes in coral cover should be considered with sampling error in mind.

In 2017, coral cover had increased within the Mid Harbour, driven by increased cover at all reefs in the zone, with the exception of Farmers Reef where cover remained stable (Figure 2, Table A 2). In contrast, cover at Seal Rocks South had decreased since 2016, whilst Seal Rocks North showed a very slight increase (Figure 2). Of note for 2017 was that coral cover was observed at Manning Reef for the first time in the three years of surveys (Figure 2).

Improved coral cover in the Mid Harbour zone was primarily driven by increases at Facing Island and Rat Island (Figure 2). Coral communities at these reefs are primarily comprised of species in the families Poritidae and Faviidae, both of which are slow growing. In contrast to increases in coral cover, macroalgae cover decreased at most reefs in the Mid Harbour (Figure 2), suggesting the likelihood that some of the observed increase in coral cover resulted from increased availability of corals to observation.

Table 8 Indicator values for reporting zones.

Zone	Year	Juvenile density (m^2)		Combined cover of hard and soft coral (%)		Change in hard coral cover (%)		Macroalgae cover (%)	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD
Mid Harbour	2015	3.2	1.36	6.1	5.44	NA	NA	18.7	12.24
	2016	4.2	0.62	4.7	3.13	-1.33	4.10	29.2	8.71
	2017	4.2	1.54	5.9	3.83	1.22	1.59	18.0	16.48
Outer Harbour	2015	4.2	1.15	4.1	5.86	NA	NA	43.1	21.39
	2016	4.2	0.73	6.9	9.72	2.92	4.14	53.0	0.09
	2017	5.2	1.10	4.9	6.10	-1.93	3.46	55.2	8.46

The decrease in coral cover observed at Seal Rocks South (Figure 2) coincided with a decrease in macroalgae cover, adding confidence that this observation was not the result of sampling error. Scuba search data indicates an increase in the prevalence of the bio-eroding sponge *Cliona orientalis*, with notable impacts on colonies of *Turbinaria,* the predominant genus at this reef. The impact of this bio-eroding sponge remains the singular most common factor affecting corals during all three years of surveys to date (Table A 5, Figure 3). In addition, impacts from coral disease remain evident at Seal Rocks South. It is possible that stress associated with high summer temperatures has contributed to the levels of disease observed (Jones *et al.* 2004). It should be noted that although the levels of coral cover lost at this site are relatively low (4.5%), this still accounts for one third of the coral cover at this reef. Given the already low levels, any loss in coral cover, especially in the absence of a direct disturbance, questions the resilience of these reefs.

Table 9 Indicator scores and Report Card grade for reporting zones.

Zone	Year	Juvenile Density	Coral Cover	Change in Hard 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
	2017	0.33	0.08	0.44	0.5	0.34	D
Outer Harbour	2015	0.33	0.05		0	0.13	E
	2016	0.33	0.09		0	0.14	E
	2017	0.44	0.06	0.37	0	0.23	E

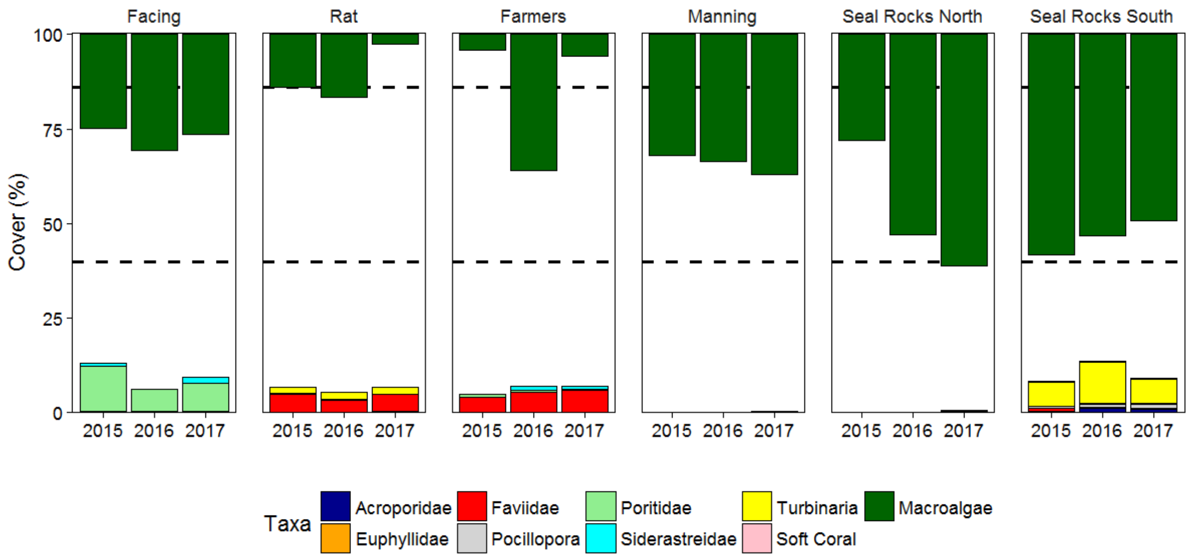

Figure 2 Composition of benthic cover at each location. Rising bars break down coral cover into major taxonomic groups (Families and Genera). Hanging bars represent macroalgae cover and are read in reverse (observed cover is read as 100 – y axis value, i.e. 10% cover will appear as a bar between 100 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.

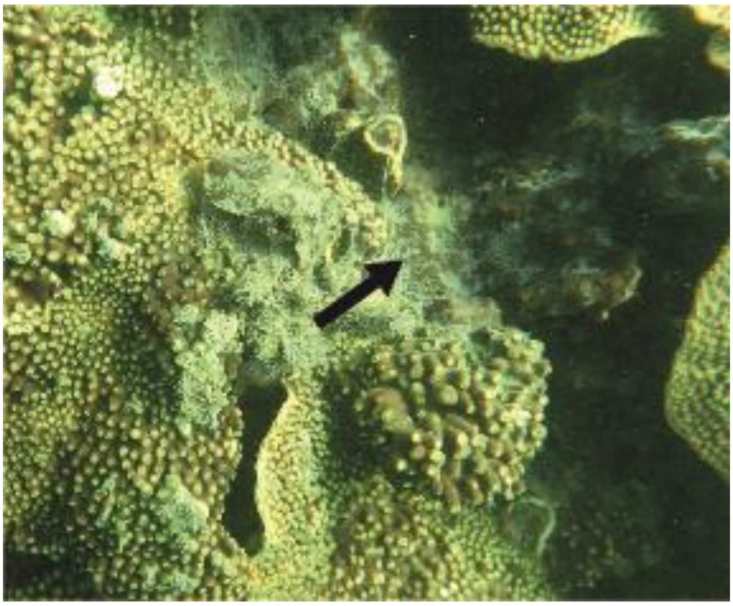

Figure 3 *Cliona orientalis* overgrowing *Turbinaria* at Seal Rocks South.

Table 10 Indicator scores for individual reefs.

Zone	Reef	Year	Scores					Grade
			Juvenile Density	Coral Cover	Change in Hard Coral Cover	Macroalgae Cover	Report card	
Mid Harbour	Facing Island	2015	0.41	0.16		0.00	0.19	E
		2016	0.37	0.08		0.00	0.15	E
		2017	0.25	0.12	0.50	0.00	0.22	E
	Farmers Reef	2015	0.26	0.06		1.00	0.44	D
		2016	0.34	0.09		0	0.14	E
		2017	0.53	0.09	0.50	0.95	0.52	C
	Manning Reef	2015	0.12	0		0.00	0.04	E
		2016	0.25	0.00		0.00	0.08	E
		2017	0.22	0.01	0.54	0	0.19	E
	Rat Island	2015	0.11	0.08		0.50	0.23	E
		2016	0.39	0.07		0.29	0.25	D
		2017	0.31	0.08	0.28	1	0.42	D
Outer Harbour	Seal Rocks North	2015	0.42	0		0.00	0.14	E
		2016	0.38	0		0.00	0.13	E
		2017	0.36	0.01	0.40	0.00	0.19	E
	Seal Rocks South	2015	0.25	0.10		0.00	0.12	E
		2016	0.28	0.17		0.00	0.15	E
		2017	0.51	0.12	0.50	0.00	0.28	D

4.3 Macroalgae

Macroalgae cover remains high across Gladstone Harbour (Table 4, Figure 2), resulting in the continued 'Very poor' assessment for this indicator (Table 5). At a reef level, however, there were notable reductions of macroalgae cover at both Rat Island and Farmers Reef, resulting in improved indicator scores to within the 'Very good' category at those reefs (Figure 2, Table A 2). The most notable contribution to the decreased cover of macroalgae was the absence of the brown macroalgae *Colpomenia* at Rat Island (Figure 4). During 2016 there was a bloom of *Colpomenia* and a mix of other fine brown macroalgae (including *Dictyota*) at this site that were not observed in 2017. Given the timing of surveys between years was aligned, and temperature profiles were similar over March and April in both 2016 and 2017 (Table 6), the primary cause of the reduction remains unclear.

Although there were reductions in the cover of macroalgae in 2017, the generally high cover across the harbour suggests that, despite water quality being generally within guideline values in the both Mid and Outer Harbour (Gladstone Healthy Harbour Partnership 2015), the availability of nutrients within the harbour is clearly not limiting macroalgae communities. The continued high cover of macroalgae indicates that the algal communities are contributing to the suppression of coral community recovery across the harbour.

As with coral communities (Figure 2, Table A 3), differences in the taxonomic composition of macroalgal communities (Table A 4) suggest fine scale differences in the combined physical and chemical environments at the monitoring locations. Further, changes in taxonomic composition over time suggest these fine scale differences may be influenced by larger scale processes.

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). Based on the data for Gladstone Harbour to date, variability is especially evident at reefs in the Mid Harbour zone both in the overall density and composition of the macroalgae communities (Figure 2, Figure 4, Table A 4). In contrast, although there is some variability in the overall cover of macroalgae, the community composition at reefs in the Outer Harbour appears relatively stable. At these two sites the macroalgae community is consistently dominated by the two brown macroalgae genera, *Sargassum* and *Lobophora* (Table A 4, Figure 4).

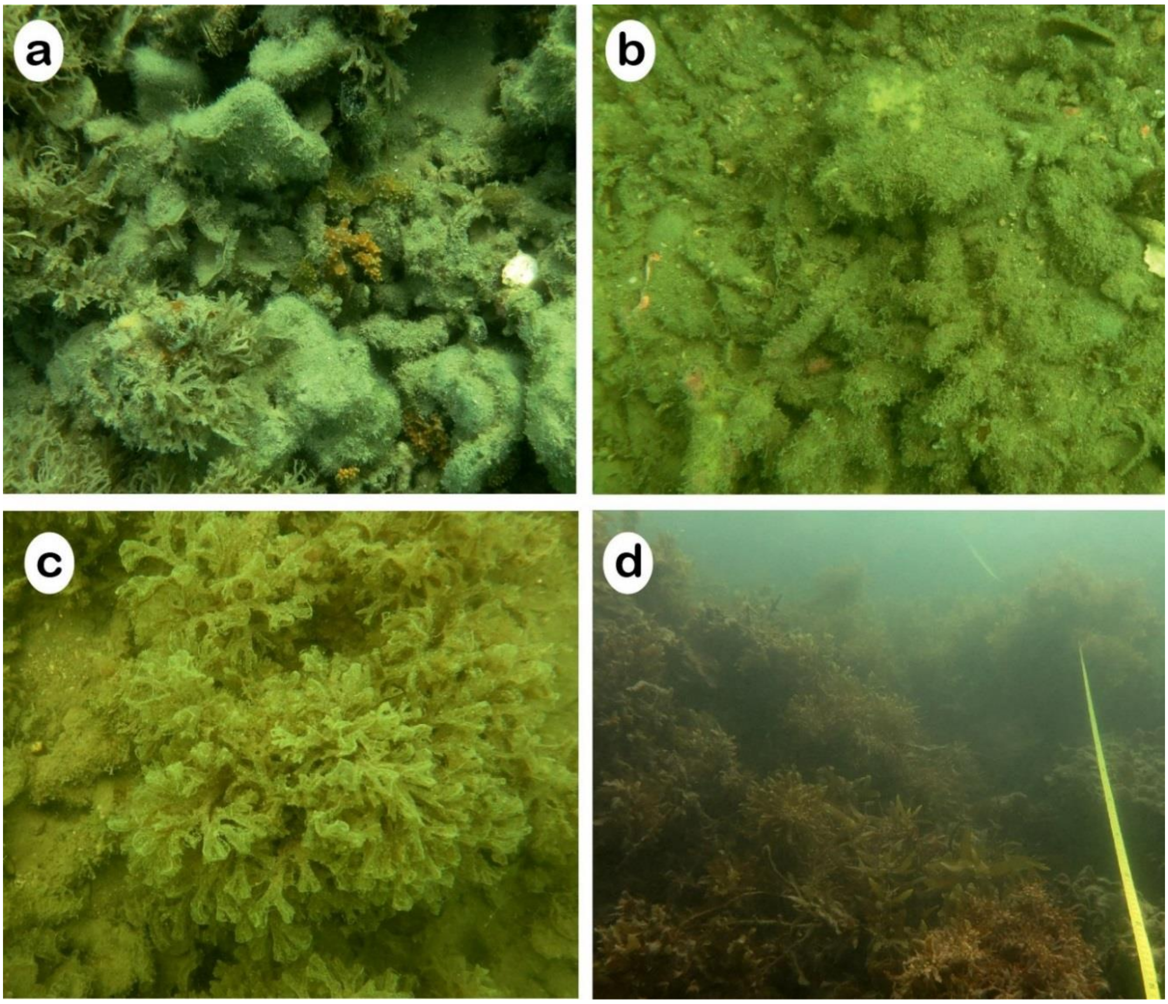

Figure 4 Representative images of variability in the taxonomic composition and presence of macroalgae at monitoring locations. a, *Colpomenia* bloom at Rat Island in 2016, b, substrate at Rat Island 2017 completely absent of *Colpomenia*, c, noticeable increase in *Dictyota* at Manning Reef and d, the persistent dominance of *Sargassum* and *Lobophora* at Seal Rocks North.

4.4 Juvenile Density

The harbour-wide mean density of juvenile corals increased marginally between 2016 and 2017, although this indicator is still classified as 'Poor' (Table 4, Table 5). This slight improvement was primarily a result of a marked increases in juvenile densities at Farmers Reef (Mid Harbour) and Seal Rocks South (Outer Harbour), both of which exceeded the threshold of 'Satisfactory' for the first time. (Figure 5, Table A 2). At both locations, these higher densities were driven primarily by an increase in the number of *Turbinaria* juveniles (Figure 5).

Consideration of the size class distribution of juvenile corals remains encouraging. Overall there has been a continued increase in the number of juvenile corals in the larger size classes of 2-5cm and 5-10cm, particularly the latter which has consistently increased at all reefs (Table A 6). This trend indicates that juvenile corals are surviving, a promising sign of the recovery of these communities.

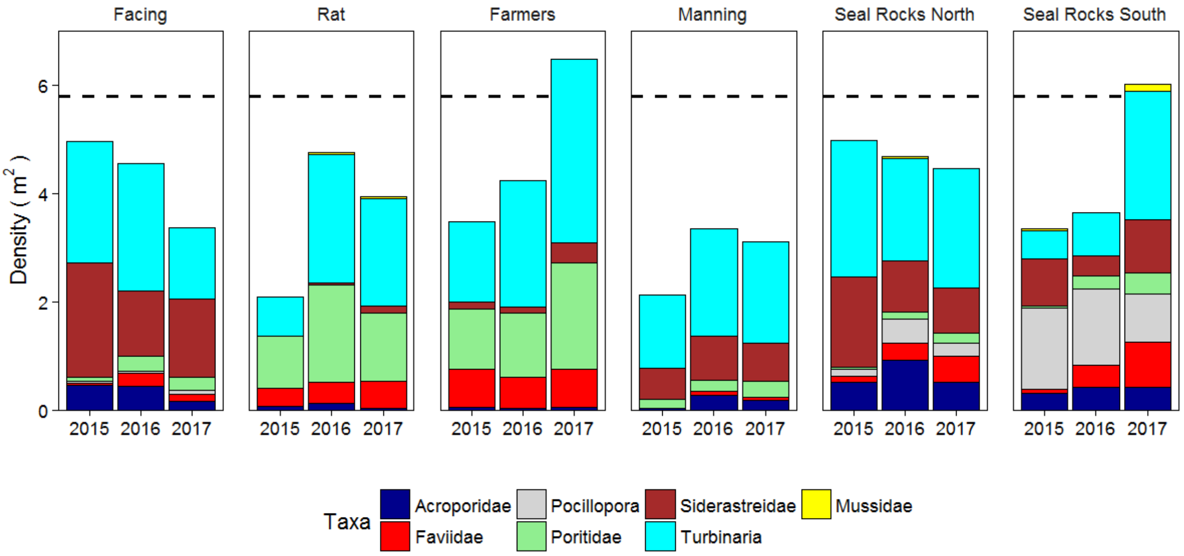

Figure 5 Composition of juvenile coral communities at each location. Bars break down juvenile density into major taxonomic groups (Families and Genera). Dashed reference line indicates the boundary between the condition categories 'Poor' and 'Satisfactory'. Juvenile density would have to extend to the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

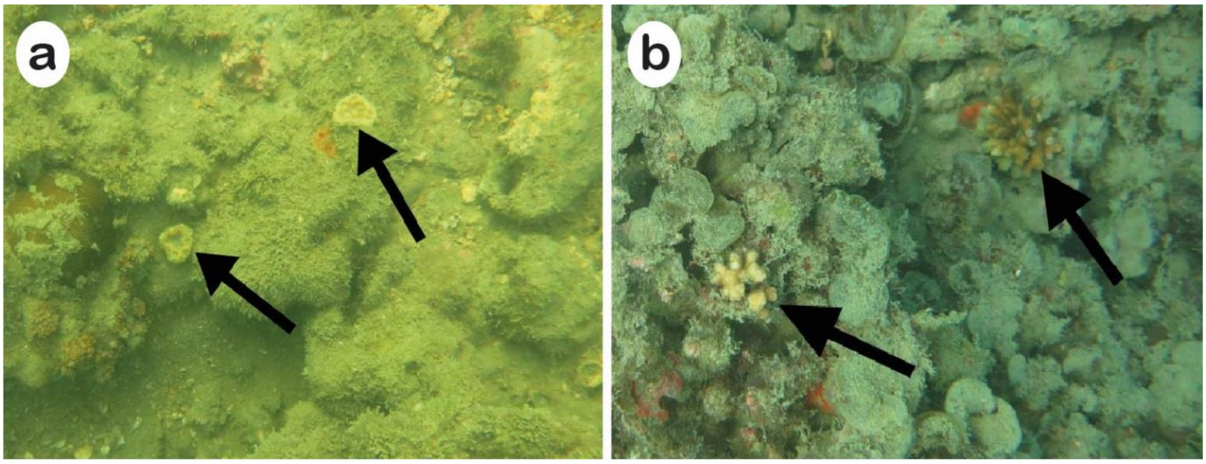

Figure 6 Juvenile corals at a, Farmers Reef and b, Seal Rocks South.

4.5 Change in Hard Coral Cover

The first assessment of the Change in Hard Coral Cover indicator classifies the rate of coral cover increase as 'Poor' (Table 1). Of the six reefs surveyed, only two, Rat Island and Seal Rocks North, fell below 'Satisfactory' scores at the reef level (Table A 2). The low scores at these reefs were, however, sufficient to prevent a "Satisfactory" grade at both the Harbour-wide and zone level (Table 1, Table 5, Table 8). Satisfactory scores at most reefs highlight the importance of the inclusion of this indicator as a direct measure of recovery potential, as opposed to the current condition indicated by the Coral Cover metric. Whilst the observed levels of change in coral cover are small (as expected when coral cover is low), by meeting the expectations of the model they provide a good indication that recovery is occurring. An important point to note is that the scores for this indicator are averaged over up to three years (only two changes are available currently, 2015 to 2016 and 2016 to 2017) in part to compensate for sampling error when observed changes are small.

As an example, despite a decline in coral cover in 2017 at Seal Rocks South, the Change in Hard Coral Cover indicator achieved a 'Satisfactory' score (Table 10) as the increase in cover between 2015 and 2016 outweighed the reduction observed this year (Figure 2). At both Seal Rocks North and Manning Reef it is apparent that recovery, whilst slow, is indeed occurring. The zero levels of coral cover observed in 2015 (and 2016 for Manning Reef) provide indication that recovery at these reefs is most likely due to the ongoing survival, and growth, of juvenile corals, as seen in the increasing densities of juveniles in the larger size classes (Table A 6). The small size of juvenile corals limits their contribution to cover estimates done using the photo transect technique. This explains the seeming discrepancy between presence of juvenile corals and zero estimates of coral cover.

5 CONCLUSION

The coral communities of the Mid and Outer Harbour exhibited a predictable response to the past 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. It is the indicators: Macroalgae Cover, Juvenile Density, and Change in Hard Coral Cover, 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 levels of coral cover across Gladstone Harbour, coupled with the dominance of slow-growing taxa within the communities, it is evident that recovery of these reefs will not be a rapid process. Rather, recovery will be largely dependent on the successful settlement, survival, and growth of juvenile corals. The observed increase in coral cover (albeit minor at both Manning Reef and Seal Rocks North) from 0% at the commencement of surveys to 0.5% in 2017 provides evidence that recovery is occurring. The Change in Coral Cover indicator is a valuable addition to the assessment of Gladstone Harbour coral communities and adds a positive interpretation to the subtle changes in coral cover observed since 2013. That the majority of reefs are achieving satisfactory rates of increase in coral cover given their low starting point and community composition is a promising sign of recovery.

Whilst levels remain low, juvenile densities continue to increase within both the Mid and Outer Harbour zones. The progression of juveniles into larger size classes remains evident, demonstrating that conditions remain favourable for the continued survival and growth of juvenile corals. Further, the relatively high diversity of coral genera recorded as juveniles, compared to the lower diversity in adult communities, suggests in-flow of larvae from beyond the harbour. This potential connectivity to a larger brood-stock is a promising sign for the resilience of these communities, although the ongoing low density of juveniles suggests the current low cover within the harbour represents general a limitation to larval supply. The continued presence of *Acropora* juveniles across all sites is an additional positive sign for recovery. *Acropora* were a key component of the coral communities at most sites prior to the 2013 floods (BMT WBM 2013), and the reestablishment of the fast growing *Acropora* genus will be fundamental to the recovery of these communities.

High cover of macroalgae is, however, likely to be significantly retarding the recovery of coral communities. Large fleshy macroalgae such as *Sargassum and Asparagopsis* and, in particular, the lower matt forming species such as *Lobophora* and *Dictyota,* have been shown to be highly disruptive to coral community recovery (Hauri *et al.* 2010) (reviewed by Birrell *et al.* 2008, Foster *et al.* 2008, Diaz-Pulido *et al.* 2010). Despite macroalgae cover declining at the majority of sites, the levels observed in 2017 are still likely to be affecting coral recruitment processes and contributing to the ‘Poor’ score for the Juvenile Density indicator.

The high temporal variability in both cover and composition of macroalgae communities especially within the Mid Harbour remain unexplained. Previously, disparity between the timing of surveys in 2015 and 2016 confounded any interpretation of changes observed in 2016 owing to possible seasonal effects. In 2017, however, surveys were conducted in the same month as the 2016 surveys, providing some indication that the observed variability is not purely seasonal. Whatever the processes, rapid fluctuations in macroalgae cover raise the prospect that occasional blooms may be occurring between annual survey events, putting additional pressure on coral recovery processes.

Impacts from bleaching were not evident during the 2017 survey, with only two bleached colonies observed. The Bio-eroding sponge *Cliona orientalis* continues to be the most significant contributor to coral mortality within the harbour. Coral disease also remains present however levels are not of concern at this stage.

The report card indicates the overall condition of coral communities within Gladstone Harbour has improved from ‘Very poor’ to ‘Poor’. While some of the indicators are driving small improvements in overall condition, the very low coral cover and continued high levels of macroalgae remain considerable factors limiting recovery.

6 REFERENCES

Berkelmans R, Jones AM, Schaffelke B (2012) Salinity thresholds of Acropora spp. On the Great Barrier Reef. *Coral Reefs* 31:1103-1110

Berkelmans R, De'ath G, Kininmonth S, Skirving WJ (2004) A comparison of the 1998 and 2002 coral bleaching events on the Great Barrier Reef: spatial correlation, patterns and predictions. *Coral Reefs* 23:74-83

Birrell CL, McCook LJ, Willis BL, Diaz-Pulido GA (2008) Effects of benthic algae on the replenishments of corals and the implications for the resilience of coral reefs. *Oceanography and Marine Biology: An Annual Review* 46:25-64

BMT WBM (2013) Central Queensland corals and associated benthos: Monitoring review and gap analysis. April 2013. Prepared for the Gladstone Ports Corporation.

Cheal AJ, Emslie M, MacNeil MA, Miller I, Sweatman H (2013) Spatial variation in the functional characteristics of herbivorous fish communities and the resilience of coral reefs. *Ecological Applications* 23:174–188

De'ath G, Fabricius KE, Sweatman H, Puotinen M (2012) The 27-year decline of coral cover on the Great Barrier Reef and its causes. *Proceedings of the National Academy of Sciences* 190(44):17995-17999

Diaz-Pulido G, Harii S, McCook LJ, Hoegh-Guldberg O (2010) The impact of benthic algae on the settlement of a reef-building coral. *Coral Reefs* 29:203-208

Erftemeijer PLA, Reigl B, Hoeksema BW, Todd PA (2012) Environmental impacts of dredging and other sediment disturbances on corals: A review. *Marine Pollution Bulletin* 64:1737-1765

Fabricius KE (2005) Effects of terrestrial runoff on the ecology of corals and coral reefs: Review and synthesis. *Marine Pollution Bulletin* 50:125-146

Foster NL, Box SJ, Mumby PJ (2008) Competitive effects of macroalgae on the fecundity of the reef-building coral *Montastrea annularis*. *Marine Ecology Progress Series* 367: 143-152

Garde LA, Spillman CM, Heron S, Beeden R (2014) ReefTemp Next Generation: A new operational system for monitoring reef thermal stress. *Journal of Operational Oceanography* 7:21-33

Gladstone Healthy Harbour Partnership (2015) *Technical Report, Gladstone Harbour Report Card 2015*, GHHP Technical Report No.2. Gladstone Healthy Harbour Partnership, Gladstone.

Hauri C, Fabricius K, Schaffelke B, Humphrey C (2010) Chemical and physical environmental conditions underneath mat- and canopy-forming macroalgae, and there effects on understory corals, *PloS ONE* 5(9):e12685

Hughes TP, Rodrigues MJ, Bellwood DR, Ceccarelli D, Hoegh-Guldberg O, McCook L, Moltschaniwskyj N, Pratchett Ms, Steneck RS, Willis B (2007) Phase shifts, herbivory, and the resilience of coral reefs to climate change. *Current Biology* 17:360-365

Jones, R., Bowyer, J., Hoegh-Guldberg, O., & Blackall, L. (2004). Dynamics of a temperature-related coral disease outbreak. *Marine Ecology Progress Series* 281, 63-77.

Jones AM, Berkelmans R (2014) Flood impacts in Keppel Bay, Southern Great Barrier Reef in the aftermath of cyclonic rainfall. *PLoS ONE* 9(1): e84739

Jones C.M., Richardson D.L., Baheerathan R., Guard P.A., Ettema S. (2015). Prioritisation of reef restoration and enhancement sites – Phase 2 and 3 report. Report produced for Gladstone Ports Corporation's Biodiversity Offset Strategy. 130pp

McCook LJ, Jompa J, Diaz-Pulido G (2001) Competition between corals and algae on coral reefs: a review of evidence and mechanisms. *Coral Reefs* 19:400-417

Osborne K, Dolman AM, Burgess SC, Johns KA (2011) Disturbance and the dynamics of coral cover on the Great Barrier Reef (1995–2009). *PLoS ONE* 6:e17516

Queensland Government (2015) Report Cards, http://www.reefplan.qld.gov.au/measuring-success/report-cards/

Schleussner CF, Lissner TK, Fischer EM, Wohland J, Perrette M, Golly A, Rogelj J, Childers K, Schewe J, Frieler K, Mengel M, Hare W, Schaeffer M (2016) Differential climate impacts for policy-relevant limits to global warming: the case of 1.5°C and 2°C. *Earth System Dynamics* 7:327-352

Sweatman H, Thompson A, Delean S, Davidson J, Neale S (2007) Status of near-shore reefs of the Great Barrier Reef 2004. Marine and Tropical Sciences Research Facility Research Report Series. Reef and Rainforest Research Centre Limited, Cairns 168pp

Thompson A, Costello P, Davidson J (2015) Gladstone Healthy Harbour Partnership 2015 Report Card, ISP014: Coral. Australian Institute of Marine Science, Townsville. 41pp

Thompson A, Costello P, Davidson j, Logan M, Gunn K, Schaffelke B (2016) Annual report for coral reef monitoring: 2014-2015. Report for the Great Barrier Reef Marine Park Authority. Australian Institute of Marine Science, Townsville. 133pp

Van Dam JW, Negri AP, Uthicke S, Muller JF (2011) Chemical pollution on coral reefs: exposure and ecological effects. In: Sanchez-Bayo F, van den Brink PJ, Mann RM (Eds.), *Ecological Impact of Toxic Chemicals*. Bentham Science Publishers Ltd.

Van Woesik R (1991) Immediate impact of the January 1991 floods on the coral assemblages of the Keppel Islands. Research Publication No. 23, Great Barrier Reef Marine Park Authority, Townsville

Vision Environment (2013a) WBDDP 2013 Event Sampling –March 2013. Gladstone, QLD

Vision Environment (2013b) WBDDP Water Quality Monitoring –April 2013. Gladstone, QLD

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 10mm diameter sections of reinforcing bar at 10m and at the end (20m) of each transect. There is a 5m 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 29.092	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 29.215	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 19.107	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 19.687	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	170
Farmers Reef	07-July-	1 m	23 46.306	151 19.073	1	50
					2	40 then 50@10 m
					3	60
					4	60 then 75@10 m
					5	60 then 40@10 m
Manning Reef	08-July-	0-0.5	23 51.239	151 21.199	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 values for individual reefs.

Zone	Reef	Year	Juvenile density (m^2)	Coral cover (%)	Change in hard coral cover (%)	Macroalgae cover (%)
Mid Harbour	Facing Island	2015	4.98	13.1	NA	24.8
		2016	4.57	6.1	-7	30.6
		2017	3.37	9.5	3.47	26.5
	Farmers Reef	2015	3.48	4.8	NA	4.13
		2016	4.24	7.13	2.68	35.9
		2017	6.49	7.0	-0.13	5.9
	Manning Reef	2015	2.14	0	NA	32.0
		2016	3.36	0.1	0.14	33.6
		2017	3.12	0.5	0.39	37
	Rat Island	2015	2.10	6.6	NA	14
		2016	4.77	5.5	-1.13	16.5
		2017	3.96	6.6	1.16	2.6
Outer Harbour	Seal Rocks North	2015	4.99	0	NA	28
		2016	4.69	0	0	53
		2017	4.47	0.6	0.51	61.2
	Seal Rocks South	2015	3.36	8.3	NA	58.2
		2016	3.65	13.8	5.85	53.1
		2017	6.03	9.3	-4.38	49.3

Table A 3 Genus level coral cover and abundance of juvenile corals at reefs surveyed in 2017

Sample type	Location	*Acropora* (Acroporidae)	*Montipora* (Acroporidae)	*Turbinaria* (Dendrophylliidae)	*Cyphastrea* (Faviidae)	*Favia* (Faviidae)	*Favites* (Faviidae)	*Goniastrea* (Faviidae)	*Leptastrea* (Faviidae)	*Plesiastrea* (Faviidae)	*Acanthastrea* (Mussidae)	*Pocillopora* (Pocilloporidae)	*Goniopora* (Poritidae)	*Porites* (Poritidae)	*Coscinaraea* (Siderastreidae)	*Psammocora* (Siderastreidae)	*Pseudosiderastrea* (Siderastreidae)	*Cladiella* -Soft coral (Alcyoniidae)	*Sinularia* -Soft coral (Alcyoniidae)	*Lobophytum* -Soft coral (Alcyoniidae)	*Erythropodium* -Soft coral (Anthothelidae)
Cover (%)	Facing Island	0.12			0.37									7.5		1.75					
	Rat Island	0.25		1.6	3.5	0.12	0.75						0.12	0.12							
	Farmers Reef				5.5		0.5							0.37		0.75					0.1
	Manning Reef	0.12												0.12							
	Seal Rocks		0.13									0.12									
	Seal Rocks	0.87		6.5	0.25							1.12	0.12			0.12		0.12	0.1	0.1	
Juveniles (count)	Facing Island	5		38	3			1				2		7		42					
	Rat Island	1		44	2		2	1	5	1	1		2	26		3					
	Farmers Reef	1		62	3	1	2	1	6				5	31		3	4				
	Manning Reef	5		51	1				1					8		19					
	Seal Rocks	13	2	63	4	3	2	5				7	4	1		24					
	Seal Rocks	9	1	54	1	4	7	7			3	20	9		1	21					

Table A 4 Cover of algae, sponges and sand and silt

Location	Red macroalgae					Brown macroalgae					Coralline algae	Turf algae		Sand & Silt	Sponge
	Unidentified	*Asparagopsis*	*Peyssonnelia*	Unidentified	*Dictyopteris*	*Dictyota*	*Lobophora*	*Sargassum*	*Spatoglossum*	*Stypopodium*					
Facing Island	1.25	0.13		0.25		0.13	7.00	18.88				50.75		5	4.63
Rat Island				0.13		0.75	1.63	0.00			0.38	57.13		39.25	2.5
Farmers Reef		5.25				0.13	0.38	0.00				40.25		21.07	1.25
Manning Reef	0.13	18.54	0.13	0.38		7.89	7.90	0.00				43.09		28.5	0.63
Seal Rocks North	0.38		7.76	1.50	0.25		20.78	27.06	0.38	0.13	0.75	26.03		15.87	
Seal Rocks South	0.38		2.63	1			24.00	18.63		0.88	0.38	19.88		24.25	0.63

Table A 5 Causes of coral mortality at time of survey 2016. Area of survey 200 m2 at each reef. Data from both 2016 and 2017 included for comparison. No data are included for Manning Reef. First record of ongoing mortality included for Seal Rocks North. Bio-eroding sponge is primarily *Cliona orientalis.*

Reef	Year	Damage	Genus	Colonies affected
Facing Island	2016	Bio-eroding sponge	*Porites*	8
	2017	Bio-eroding sponge	*Porites*	12
Farmers Reef	2016	Bio-eroding sponge	*Cyphastrea*	9
	2017	Bio-eroding sponge	*Cyphastrea*	9
			Favites	1
Rat Island	2016	Bio-eroding sponge	*Cyphastrea*	7
			Turbinaria	4
	2017	Bio-eroding sponge	*Cyphastrea*	8
Seal Rocks South	2016	*Atramentous necrosis* (coral disease)	*Turbinaria*	1
		Bleaching	*Pocillopora*	2
		Bio-eroding sponge	*Turbinaria*	4
		Unknown	*Turbinaria*	1
	2017	White syndrome	*Turbinaria*	1
			Psammocora	1
		Bio-eroding sponge	*Turbinaria*	6
		Bleaching	*Montipora*	1
Seal Rocks North	2017	Bleaching	*Montipora*	1

Table A 6 Size-class distribution of juvenile corals. Values are number of juveniles observed in 100m x 0.34m belt transects (34m^2) at each reef. Data from all three years of surveys 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
	2017	32	58	8
Farmers Reef	2015	32	17	5
	2016	47	26	9
	2017	64	39	16
Manning Reef	2015	52	6	2
	2016	55	40	0
	2017	49	29	7
Rat Island	2015	19	23	8
	2016	48	43	10
	2017	44	28	16
Seal Rocks North	2015	111	31	1
	2016	80	48	8
	2017	55	64	9
Seal Rocks South	2015	52	30	3
	2016	27	55	9
	2017	58	58	21

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

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 brood-stock, 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 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. AIMS in-house analysis of coral cover estimates using line intercept (LIT) 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 Mid Harbour ranged between ~4% - 40%. Based on this information, a realistic threshold of 40% was set (Table 2). No prior data exist for the Outer Harbour reporting zone and so again we suggest a consistent use of the 40% threshold as this will allow comparison of condition across zones.

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 increasing 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 grain sizes 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 grain size composition. The depth of these samples was only 1-2m below LAT and so will not be directly comparable to grain size 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 2) 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. Following, the threshold for cover for MA was set midway between the lower and upper bounds at 14% (Table 2). 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’ for 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 10th and 90th percentiles of the distribution being 1 and 16 juveniles per m^2 (Table 2). 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 state 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 5.8 juvenile colonies per m^2 of available substrate for the Gladstone Harbour threshold (Table 2).

7.2.4 Change in hard coral cover

This indicator metric is based on the rate at which coral cover increases. While high coral cover can justifiably be considered a positive indicator of community condition, the reverse is not necessarily true. Low cover may occur following acute disturbance and, hence, may not be a direct reflection of the community's resilience to underlying environmental conditions. For this reason, in addition to considering the actual level of coral cover we also assess the rate at which hard coral cover increases as a direct measure of recovery potential. This indicator reflects the coral growth performance on a per reef basis by comparing observed increase in coral growth (in the absence of acute disturbance) to expected coral growth. Estimates are derived by comparing the observed rate of change in hard coral cover at a given reef to that predicted by a multi-species form of the Gompertz growth equation (Dennis & Taper 1994, Ives *et al.* 2003). The equations used were parameterised from the time-series of coral cover from reefs monitored by the LTMP and the MMP over the period 1987-2007.

The growth models used are parameterised in a Bayesian framework to permit propagation of uncertainty from the two models onto the overall growth expected. Observations of annual change in benthic cover derived from 47 near-shore reefs sampled over the period 1987-2007 were used to parameterise two multi-species Gompertz growth equations. These models returned estimates of growth rates for corals of the family Acroporidae and the combined grouping of all other hard corals. These two groups were modelled separately as the growth rate of Acroporidae is substantially higher than most other corals. Within these models growth rate estimates are dependent on the cover of each of these hard coral groups along with the cover of soft coral which in combination represent space competitors and so limit the area available for coral cover increase. It is important to note here that the calculation of this metric considers both the level of cover and the composition of communities. As such, the thresholds have been derived to be relevant to inshore reefs on the GBR and are considered appropriate for the Gladstone Harbour threshold.

Model projections of future coral cover on GBR inshore reefs based on the growth rates estimated by these models coupled with the observed disturbance history for inshore reefs of the GBR over the period 1987-2002 indicated a long-term decline in coral cover (Thompson & Dolman 2010). For this reason the positive score of 1 was reserved for only those reefs at which the observed rate of change in cover exceeded twice the upper 95% confidence interval of the change predicted. Observations falling within the upper and lower confidence intervals of the change in predicted cover were scored as neutral (indicator score 0.5) and those not meeting the lower confidence interval of the predicted change received an indicator score of 0 (Table 2). The rate of change is averaged over three years of observations. As implemented in 2017 only two years of change were used (2015-2016 and 2017-2017), future applications will be based on a rolling mean of three years of observed changes. Years in which disturbance events occurred at particular reefs were not included as there is no logical expectation for an increase in cover in such situations.

7.2.5 References

Ayling A (1997) The biological status of fringing reefs in the Great Barrier Reef world heritage area. Proceedings of the State of the Great Barrier Reef World Heritage Area Workshop pp. 109-113

Babcock RC, Smith L (2002) Effects of sedimentation on coral settlement and survivorship. In: Proceedings of the 9th International Coral Reef Symposium, Bali, Indonesia, 245–248

Baird AH, Babcock RC, Mundy CP (2003) Habitat selection by larvae influences the depth distribution of six common coral species. *Marine Ecology Progress Series* 252:289-293

Berkelmans R, De'ath G, Kininmonth S, Skirving WJ (2004) A comparison of the 1998 and 2002 coral bleaching events on the Great Barrier Reef: spatial correlation, patterns and predictions. *Coral Reefs* 23:74-83

BMT WBM (2013). Central Queensland corals and associated benthos: Monitoring review and gap analysis. April 2013. Prepared for the Gladstone Ports Corporation.

Box SJ, Mumby PJ (2007) Effect of macroalgal competition on growth and survival of juvenile Caribbean corals. *Marine Ecology Progress Series 342*, 139-149.

Bruno JF, Sweatman H, Precht WF, Selig ER, Schutte VGW (2009) Assessing evidence of phase shifts from coral to macroalgal dominance on coral reefs. *Ecology* 90:1478-1484

Cheal AJ, Emslie M, MacNeil MA, Miller I, Sweatman H (2013) Spatial variation in the functional characteristics of herbivorous fish communities and the resilience of coral reefs. *Ecological Applications*, 23:174–188

De'ath G, Fabricius KE (2010) Water quality as a regional driver of coral biodiversity and macroalgae on the Great Barrier Reef. *Ecological Applications* 20:840–850

Dennis B, Taper ML (1994) Density dependence in time series observations of natural populations: estimation and testing. *Ecological Monographs* 64:205-224

Diaz-Pulido G, McCook LJ, Dove S, Berkelmans R, Roff G, Kline DI, Weeks S, Evans RD, Williamson DH, Hoegh-Guldberg O (2009) Doom and boom on a resilient reef: Climate change, algal overgrowth and coral recovery. *PLoS ONE* 4(4): e5239

Erftemeijer PLA, Reigl B, Hoeksema BW, Todd PA (2012) Environmental impacts of dredging and other sediment disturbances on corals: A review. *Marine Pollution Bulletin* 64:1737-1765

Fabricius KE (2005) Effects of terrestrial runoff on the ecology of corals and coral reefs: Review and synthesis. *Marine Pollution Bulletin* 50:125-146

Fabricius KE, Wild C, Wolanski E, Abele D (2003) Effects of transparent exopolymer particles and muddy terrigenous sediments on survival of hard coral recruits. *Estuarine, Costal and Shelf Science* 57:613-621

Fabricius KE, Wolanski E (2000) Rapid smothering of coral reef organisms by muddy marine snow. *Estuarine, Costal and Shelf Science* 50:115-120

Foster NL, Box SJ, Mumby PJ (2008) Competitive effects of macroalgae on the fecundity of the reef-building coral *Montastrea annularis*. *Marine Ecology Progress Series* 367:143-152

Graham NAJ, Jennings S, MacNeil MA, Mouillot D, Wilson S (2015) Predicting climate-driven regime shifts versus rebound potential in coral reefs. *Nature* 518:94-97.

Harrison PL, Wallace CC (1990) Reproduction, dispersal and recruitment of Scleractinian corals. In Dubinsky Z (ed) Ecosystems of the world 25: Coral Reefs. Elsevier, New York, pp 133-202

Hauri C, Fabricius K, Schaffelke B, Humphrey C (2010) Chemical and physical environmental conditions underneath mat- and canopy-forming macroalgae, and the effects on understory corals. *PLoS ONE* 5(9): e12685

Hughes TP, Rodrigues MJ, Bellwood DR, Ceccarelli D, Hoegh-Guldberg O, McCook L, Moltschaniwskyj N, Pratchett Ms, Steneck RS, Willis B (2007) Phase shifts, herbivory, and the resilience of coral reefs to climate change, *Current Biology* 17:360-365

Ives AR, Dennis B, Cottingham KL, Carpenter SR (2003) Estimating community stability and ecological interactions from time series data. *Ecological Monographs* 73:301-330

Kline DL, Kuntz NM, Breitbart M, Knowlton N, Rohwer F (2006) Role of elevated organic carbon levels and microbial activity in coral mortality. *Marine Ecology Progress Series* 314: 119–125

Kuntz N, Kline D, Sandin S, Rohwer F (2005) Pathologies and mortality rates caused by organic carbon and nutrient stressors in three Caribbean coral species. *Marine Ecology Progress Series* 294:173–180

McCook LJ, Jompa J, Diaz-Pulido G (2001) Competition between corals and algae on coral reefs: a review of evidence and mechanisms. *Coral Reefs* 19:400-417

Osborne K, Dolman AM, Burgess SC, Johns KA (2011) Disturbance and the Dynamics of Coral Cover on the Great Barrier Reef (1995–2009). *PLoS ONE* 6:e17516

Rogers CS (1990) Responses of coral reefs and reef organisms to sedimentation. *Marine Ecology progress Series* 62:185-202

Schaffelke B, Mellors J, Duke NC (2005) Water quality in the Great Barrier Reef region: responses of mangrove, seagrass and macroalgal communities. *Marine Pollution Bulletin* 51:279-296

Sweatman H, Thompson A, Delean S, Davidson J, Neale S (2007) Status of near-shore reefs of the Great Barrier Reef 2004. Marine and Tropical Sciences Research Facility Research Report Series. Reef and Rainforest Research Centre Limited, Cairns 168pp.

Thompson A, Dolman A (2010) Coral bleaching: one disturbance too many for inshore reefs of the Great Barrier Reef. *Coral Reefs* 29:637-648

Van Dam JW, Negri AP, Uthicke S, Muller JF (2011) Chemical pollution on coral reefs: exposure and ecological effects. In: Sanchez-Bayo F, van den Brink PJ, Mann RM (Eds.), Ecological Impact of Toxic Chemicals. Bentham Science Publishers Ltd.