Australian Government

Australian Institute of Marine Science

Development of Coral Indicators for the Gladstone Harbour Report Card, ISP014: Coral

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AIMS: Australia's tropical marine research agency

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Executive Summary

The Australian Institute of Marine Science has developed a variety of methods to assess and report the condition of coral communities that have been adapted for use in Gladstone Harbour to allow the inclusion of coral community condition into the Gladstone Healthy Harbour Partnership (GHHP) 2015 Report Card.

In July of 2015 surveys were undertaken within the Inner, Mid and Outer Harbour reporting zones aimed at locating suitable areas of coral habitat for the establishment, and baseline survey of permanent long-term coral monitoring sites. The methods used to monitor coral communities are consistent with those used by the Great Barrier Reef Report Card.

In the Mid Harbour four monitoring sites were located with an additional two sites located and at Seal Rocks in the Outer Harbour. At all six sites permanent coral monitoring sites were established and baseline surveys of coral communities completed. From these surveys coral community condition was scored against three indicators:

- The percent cover of the substrate occupied by coral, as a direct indicator of the condition of corals.
- The percent cover of the substrate occupied by large fleshy seaweeds (macroalgae), as in indicator of poor water quality that may be limiting the recovery potential of coral communities.
- The density of juvenile corals, also as an indicator of the recovery potential of coral communities.

A fourth indicator identified for future use in the Report Card is the rate at which coral cover changes from year to year. As this indicator requires prior observations against which to compare cover increase it could not be included in this baseline report.

Each indicator is assessed against a threshold specific for the Gladstone Harbour. The thresholds decided upon were selected based on AIMS expert knowledge relating to the dynamics of inshore coral reef communities and the desire to ensure thresholds were broadly consistent with those used by the GBR Report Card. Coral community condition is measured relative the threshold values and converted to a score between 0 (worst condition) and 1 (best condition). The average of these scores for each indicator is then converted into a report card grade ranging from A to E.

Based on the results of surveys in 2015 the coral communities in both the Mid and Outer Harbour received a grade of E (Table 1). The poor assessment of coral condition was based on very low coral cover at all reefs, and the high cover of macroalgae and low densities of juvenile corals at most reefs.

Table 1 Coral condition indicator scores and report card grades

<table>
<tr><th>Harbour Reporting Zone</th><th>Macroalgae cover</th><th>Coral cover</th><th>Juvenile coral density</th><th>Zone (Grade)</th><th>Harbour (Grade)</th></tr>
<tr><td>Mid Harbour 8</td><td>0.37</td><td>0.08</td><td>0.23</td><td>E</td><td rowspan="2">E</td></tr>
<tr><td>Outer Harbour 11</td><td>0.00</td><td>0.05</td><td>0.33</td><td>E</td></tr>
</table>

Flooding in January 2013 substantially reduced the salinity within the Harbour and this will almost certainly have severely influenced the current condition of coral communities. Given the severity of this event it is difficult to determine the contribution of activities within the harbour or adjacent catchments to the condition of coral communities in 2015. The combination of ongoing coral community and water quality monitoring will enable the recovery trajectory of coral communities to be assessed and any potential limitations imposed by environmental conditions identified. Although still low, the density and diversity of juvenile corals recorded in this 2015 survey indicates that recovery of coral communities is underway.

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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 sediment, 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). Concerns surrounding the negative effects of land runoff on the ecosystems of the GBR triggered the formulation by the Australian and Queensland governments of the Reef Water Quality Protection Plan (Reef Plan) for catchments adjacent to the GBR World Heritage Area (Anon. 2003; 2009). The coral component of the Reef Plan Marine Monitoring project (MMP) was implemented in 2005 to provide an assessment of condition of coral communities in inshore areas of the GBR, reported in the Great Barrier Reef Report Card[1]. The Australian Institute of Marine Science (AIMS) has been responsible for the development of an indicator scoring system that provides the report card summary of coral community conditions. Importantly the indicator system developed recognises that coral communities are naturally dynamic; they are intermittently impacted by acute disturbance events such as cyclones or floods, generally followed by recovery. This is done by including indicators that allow inference about the recovery potential as well as current condition of coral communities.

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 develop a monitoring program and report card scoring system for the coral communities within the GHHP reporting area. The choice of indicators, sampling methodology and report card scoring system used to derive report card grades for the Gladstone Harbour report card were chosen to be as closely compatible as practicable to those used for the GBR report card.

Purpose

This report includes three separate sections of work:

- The body of the report provides an overview of the monitoring undertaken and the basis for the report card grade assigned to coral communities in the 2015 Gladstone Harbour report card. Included in this section is a comprehensive presentation and interpretation of the data on which the report card score is based.
- The first Appendix to the report provides a more detailed description of the reconnaissance surveys of potential coral habitat within the harbour that preceded the selection of monitoring sites. Included in this section are observational notes relating to the benthic communities found at a range of sites that were not included as long-term monitoring sites.
- The second Appendix provides a detailed rationale for the selection and scoring of indicators used to assess coral community condition for use in the GHHP report card.

[1] Most recent Reef Report Card: http://www.reefplan.qld.gov.au/measuring-success/report-cards/2014/

Selection of coral monitoring locations

The first task in developing this coral monitoring program was to select appropriate locations at which to establish permanent monitoring sites. The primary selection criterion for a coral monitoring site is that the location can be considered as suitable coral habitat. Pragmatically, an area can be assessed as being suitable coral habitat by either; the observation of living coral communities, or the presence of dead coral skeletons, that in lieu of living corals, provide evidence that the location had at supported coral communities in the past. An additional consideration for this program was the desire to include sites in several of the GHHP reporting zones.

Within the GHHP reporting zones BMT WBM (2013) provide a summary of coral survey data that gave approximate locations and summaries of coral communities in both the Inner and Mid Harbour Reporting Zones. No published information could be found for coral communities in the Outer Harbour Reporting Zone. However, there was a general understanding, based on unpublished observations, that Seal Rocks supported coral communities. These sources of information informed the GHHP in their selection of potential monitoring locations in each of the Inner, Mid and Outer Harbour reporting zones. Over the period 6 – 8 July AIMS undertook a reconnaissance survey of the proposed monitoring locations that resulted in the selection of six long-term coral monitoring sites (Figure 1).

Key observations from the reconnaissance of potential coral monitoring sites are summarised below from the more detailed report of activities and observations (see Appendix 1).

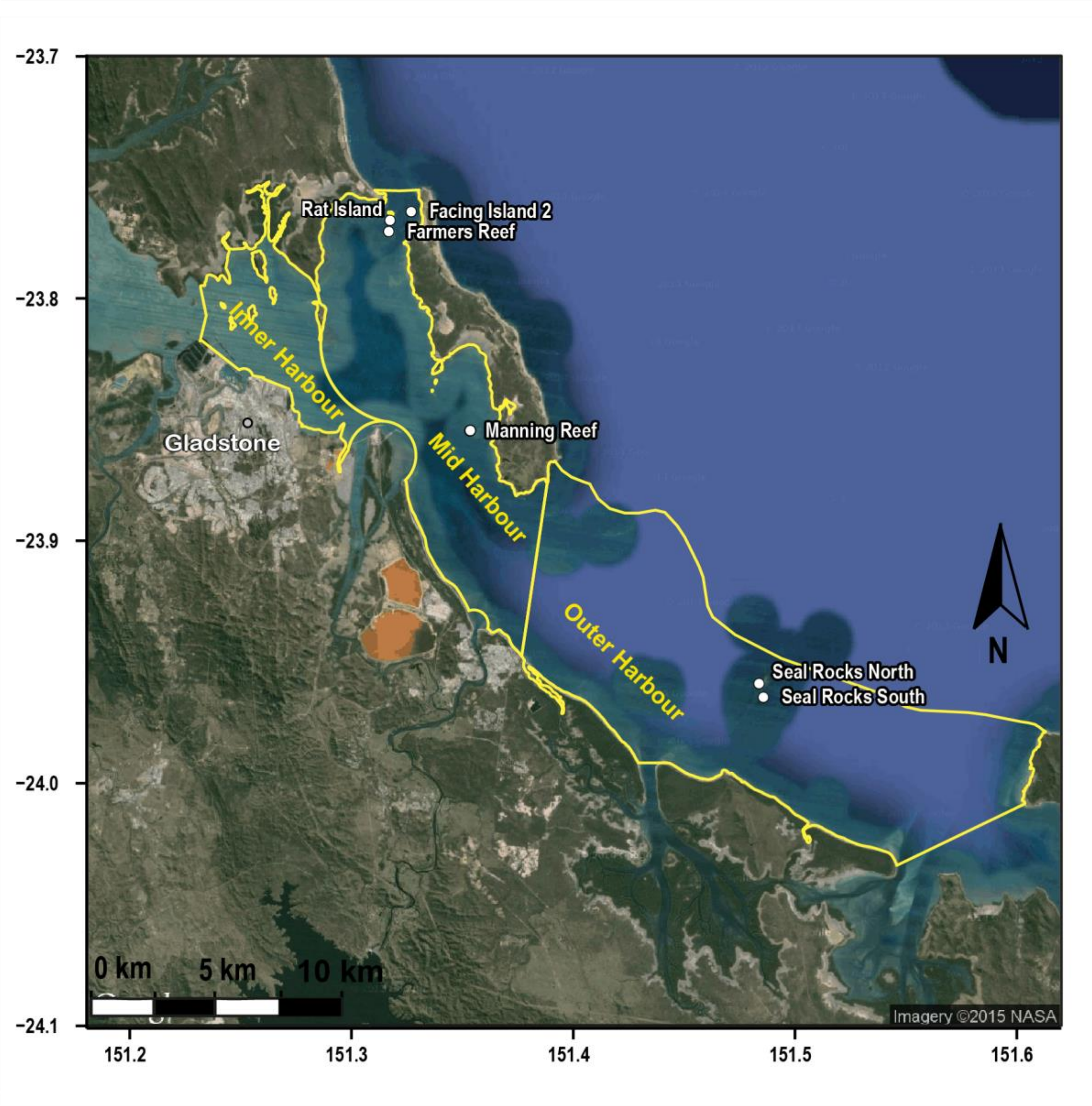

Figure 1 Selected coral monitoring locations in Gladstone Harbour.

Inner Harbour site search

Within the Inner Harbour extensive searching around Quoin Island, Turtle Island and Diamantina Island revealed no areas of coral habitat suitable for selection as long-term coral monitoring locations (Appendix 1, Table A1-1). Much of the substrate surrounding the islands of the Inner Harbour was comprised of soft sediments unsuitable for coral communities. Where hard substrate was located it consisted primarily of broken rock and occasional small dead coral colonies colonised by a mixed community of macroalgae and small heterotrophic soft corals (Figure 2). During the time AIMS spent in the Inner Harbour the underwater visibility remained in the range of 0.1 to 0.3m. These conditions effectively precluded the possibility of selecting and surveying benthic monitoring sites, even if suitable areas had been located. It is possible that live corals existed. However, the very limited underwater visibility severely limited the ability to detect what would, in all likelihood, be very patchily distributed small coral colonies.

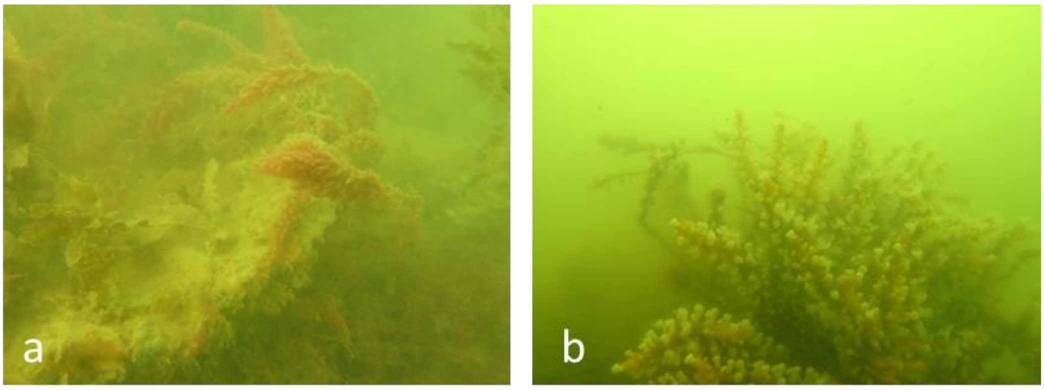

Figure 2 Benthos at Inner Harbour spot check sites, a) a dead *Turbinaria* coral supporting macroalgae and, b) a heterotrophic soft coral.

Middle Harbour site search and selection

Suitable locations for coral monitoring were identified at Rat Island, Facing Island Reef #2, and Manning Reef (Figure 1, Table A1-1, A1-2). At each of these locations coral monitoring sites were established and baseline surveys of the coral communities completed. At each location, sites were selected where living and dead coral communities suggested suitable coral habitat. As such, the coral communities reported may be considered as approximating the best condition of coral communities within the reporting zone. Due to the presently low cover of living corals, the selection of sites was highly influenced by the observation of stands of dead coral skeletons that demonstrated the sites' potential to support higher cover and diversity of corals than currently observed (e.g. Figure 3). The monitoring sites selected were in depths of less than 2m below lowest astronomical tide, with coral communities and hard substrate changing to sand below this depth.

From a practical perspective it is important to note that all four monitoring sites experience very strong currents on a falling tide that precludes diving during this phase of the tidal cycle.

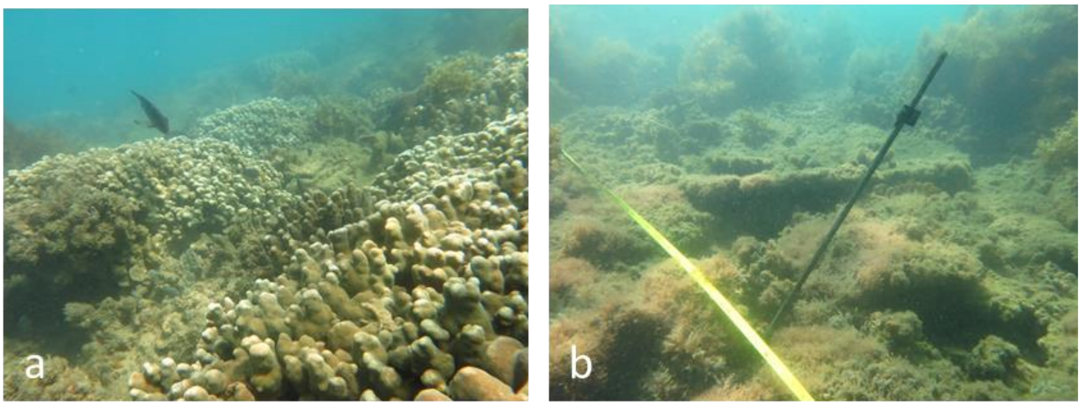

Figure 3 Benthos at Facing Island Reef 2, a) living *Porites* corals and b) dead *Acropora* corals.

Outer Harbour site search and selection

Two suitable locations for the long-term coral monitoring sites were identified at Seal Rocks (Figure 1). At both Seal Rocks North and Seal Rocks South long-term monitoring sites were established (Table A1-2) and baseline surveys of the benthic communities completed. At both, sites the presence of dead coral colonies clearly indicated higher cover and diversity of corals than presently observed (Figure 4). At East Banks, searches for potential coral monitoring locations revealed no areas of hard substrate, rather, all areas searched were found to be sand banks (Appendix 1). The monitoring sites were located in 1-2m depth below lowest astronomical tide with the substrate changing to sand at deeper depths.

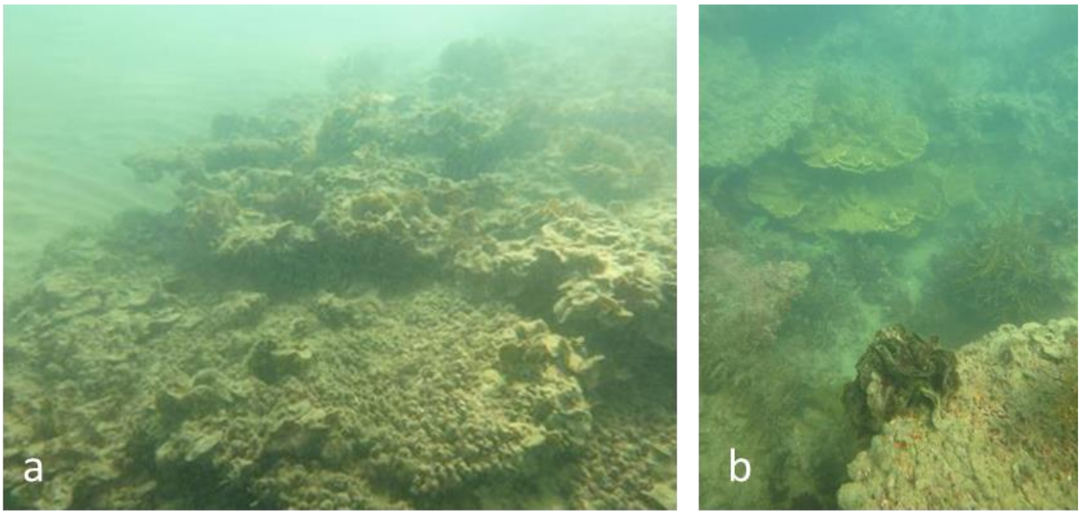

Figure 4 Benthos at Seal Rocks, a) North monitoring site, and b) South monitoring site.

Coral monitoring methodology

Sampling design

At each coral monitoring location a 120m long site was constructed along the depth contour consistent with the most suitable coral habitat. For the Gladstone Harbour locations this was between 0 and 1m below lowest astronomic tide (Table A1). This 120m long site was divided into five, 20m long, transects each separated by a space of 5m. 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 and compass bearings recorded along each transect to aid future relocation (Table A2). At each transect the following three types of surveys of the benthic communities were completed.

Survey methods

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 (Jonker *et al.* 2008). 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. At total of 32 images are 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 frontend to an Oracle-database, developed by AIMS. This system allows the recall of stored transect images and checking of any identified points.

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 are identified to genus level and recorded. Importantly, this method aims 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 does not include small coral colonies considered to have resulted from the fragmentation or partial mortality of larger colonies.

Scuba search transects

Scuba search transects document the incidence of disease and other agents of coral mortality and damage. This method follows 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 strip 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 or smothering by sediments or physical damage to colonies was recorded.

Coral community Indicators

Data from photo point intercept transects and juvenile surveys are used to derive three indicators of coral community condition: the combined cover of hard and soft corals, the cover of macroalgae and the density of juvenile hard corals. These indicators are broadly consistent with those used to report coral condition throughout the inshore areas of the GBR and form the basis of the coral condition score reported by the Great Barrier Reef Report Card (Anon, 2011). An additional metric included in the GBR Report Card is the rate of change in hard coral cover. This metric requires baseline data against which current cover can be compared and so could not be estimated here—future Gladstone Harbour Report Cards would include this additional metric. A detailed description and rationale for each of these indicators is included as Appendix 2 of this report. The conceptual context of these indicators is that coral communities are naturally dynamic and exist in a cycle of disturbance and recovery. In combination, the indicators aim to assess the condition of communities on the basis of the endpoint of good condition that is high coral cover and demonstrating resilience, which is the ability to recover from disturbance events as indicated by strong recruitment of juvenile corals and low abundance of macroalgae.

Scoring of indicators

For each indicator, observed levels were scored against thresholds which were set based on expert opinion and knowledge from the MMP long-term coral inshore monitoring program. The thresholds represent the boundary between report card grades of C and D that would indicate the switch between a community in good condition and one displaying a lack of resilience (Table 2). In addition, upper bounds are set that represent values of indicators that are considered to represent communities in as good a condition as could be expected in the local environment; conversely, lower bounds are set to represent minimum 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). Again, the rationale for the selection of these critical limits to indicator values can be found in Appendix 2. The scaling of all scores to the common range of 0 to 1 allows the aggregation of scores across indicators.

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}

Aggregation of indicator scores

To maximize information retention throughout a series of aggregations, it is better to aggregate distributions rather than single properties of those distributions (such as a mean). Furthermore, bootstrapping (a process by which distributions are repeatedly sampled with replacement so as to reconstruct a distribution comprising a set number of items) the source distributions prior to aggregation 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 are 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 can be derived. Finally, adding the whole of harbour distributions for each indicator yields the distribution from which the whole of harbour score and variance can be extracted.

Grades are derived from the score 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**

Discussion of Results

The report card grade of E assigned to the coral communities within Gladstone Harbour reflects the current low cover of living corals, low abundance of juvenile corals and high cover of macroalgae at most reefs (Tables 4 and 5, Figure 5). It is only the low cover of macroalgae at Farmers Reef (resulting in a grade of "A" for this indicator, Table 4) that is the outlier in the otherwise poor or very poor grades for coral communities across the harbour.

Table 4 Individual Indicator scores and Grades within zones

	Macroalgae cover			Coral cover			Juvenile density		
Reef	**Value**	**Score**	**Grade**	**Value**	**Score**	**Grade**	**Value**	**Score**	**Grade**
Facing Island 2	24.8	0.00	E	13.1	0.16	E	5	0.41	D
Farmers Reef	4.1	1.00	A	4.8	0.06	E	3.5	0.26	E
Manning Reef	32.0	0.00	E	0	0.00	E	2.1	0.12	E
Rat Island	14	0.50	C	6.6	0.08	E	2.1	0.11	E
Seal Rocks North	28	0.00	E	0	0.00	E	5	0.42	D
Seal Rocks South	58.2	0.00	E	8.3	0.10	E	3.4	0.25	D

Table 5 Individual Indicator scores and Grades within zones

	Macroalgae cover			Coral cover			Juvenile density		
Zone	**Mean**	**Variance**	**Grade**	**Mean**	**Variance**	**Grade**	**Mean**	**Variance**	**Grade**
8	0.37	0.17	D	0.08	0.00	E	0.23	0.02	E
11	0.00	0.00	E	0.05	0.00	E	0.33	0.01	D

Table 6 Aggregated Indicator scores for zones and Harbour

	Mean	Variance	Grade
Zone 8	0.23	0.08	E
Zone 11	0.13	0.02	E
Harbour	0.18	0.06	E

At all locations the proportion of the substrate occupied by corals was very low and substantially below the 40% threshold that would equate to grade of C (Figure 5a). In the Mid Harbour (reporting zone 8) this low cover is in contrast to a mean cover 39% for hard corals alone during surveys in 2009 (BMT WBM 2013). Similarly, although no previous data of coral cover have been reported for the Outer Harbour (Reporting Zone 11) locations at Seal Rocks, visual estimates of cover in the vicinity of Seal Rocks North in December 2012 put cover there in the order of 50%, including corals of the genus *Acropora* (Russ Babcock: Gas Industry Social & Environmental Research Alliance, pers. comm.). This genus was not recorded in the present 2015 surveys (see Appendix, Table A3-1), though clearly present in the dead coral community.

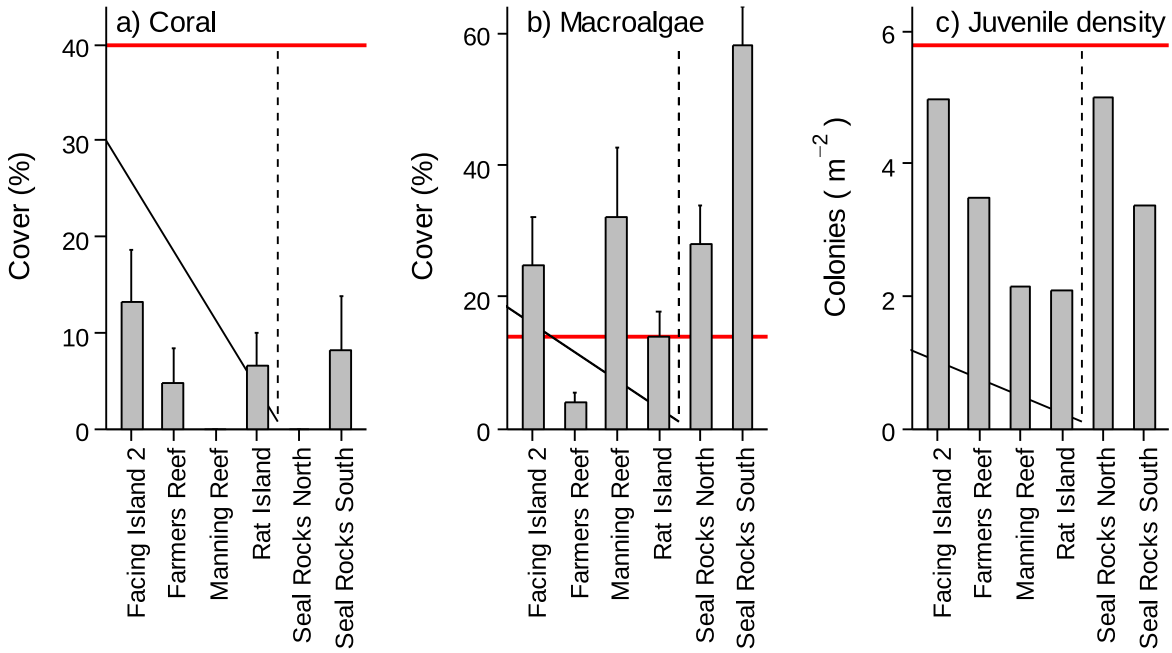

Figure 5 Observations for each report card indicator, a) the proportional cover of the substrate occupied by corals, b) the proportion of the substrate occupied by macroalgae, and c) the density of corals <10cm in diameter standardised for available settlement substrate. In each case the thresholds limit set at the C to D grade boundary is represented as a red horizontal line, noting that for coral cover and juvenile density values below the threshold are in worse condition while values of macroalgal cover higher than the threshold are considered to be in worse condition.

Slightly biasing estimates of the coral cover and macroalgae indicators is the high proportion of sand among patches of hard substrate at some reefs: ranging from 7% at Facing Island 2 to 50% at Farmers Reef (see Appendix, Table A3-2). The thresholds of these indicators were selected to be broadly similar to those used to assess coral community condition on inshore reefs for the Great Barrier Reef Report Card. At the majority of reefs monitored for the GBR Report Card the sites are located on areas with lower proportions of sand and so a case could be made to adjust estimates of cover for the Gladstone context in future assessments. For the current levels of cover of both coral and macroalgae such an adjustment to consider only the percent cover of non-sand areas would not have altered the grades for either coral cover or macroalgae at any of the reefs. Should coral communities begin to recover in the future, not correcting for the sandy areas of sites will however limit the sensitivity of coral cover indicator.

Not correcting for the proportion of sand results in a conservative estimate of the cover of macroalgae, only reinforcing the poor score for this indicator at most reefs (Table 4). Differences in the composition of the algae communities reinforce the differing environmental conditions influencing benthic communities at the different monitoring sites. At both Seal Rocks sites and also Facing Island 2 the high cover of macroalgae (Figure 5b) is dominated by large brown algae species of *Sargassum* and *Lobophora* (Table 3-2). Both taxa have been observed in other areas of the inshore GBR to form persistent communities following declines in coral cover (pes. obs.). At Manning Reef there is a high cover of the red algae genus *Asparagopsis* (Table 3-2) consistent with the higher turbidity and more sheltered setting of this reef. How persistent these communities prove to be over coming years will be informative as to the influence that water quality may be having on affecting coral community recovery within the harbour.

The estimation of density of juvenile corals does correct for the areas of 'non-habitable space' (sand and living corals). Although the densities observed in 2015 were all below the grade C threshold (Table 4-6, Figure 5c) an investigation of the size distribution of juveniles suggests this may be under-representing the resilience of coral communities that can be inferred from these data. Many corals spawn in the days following full moons in November or December (Baird *et al*. 2009). The size-classes into which juvenile corals are aggregated can be broadly considered to represent corals that have settled following the previous spawning event (0 to 2cm), the corals between 1 and 2 years old (2 to 5cm) and corals greater than 2 years old (5 to 10cm). The very low number of juveniles in 5 to 10cm size-class (Table 7) indicates that one of the three cohorts targeted by this indicator is effectively missing from the community. Even a moderate representation of this size class would have increased densities of juveniles at some reefs to a satisfactory grade.

The absence of the 5 to 10cm size-class of juvenile corals further defines the timing of what has clearly been a severe disturbance to coral communities in Gladstone Harbour. The high proportion of juveniles in the 0 to 2cm size-class suggests a successful settlement and subsequent survival of larvae following spawning in late 2014. Similarly the moderate numbers of juveniles in the 2 to 5cm size-class suggest settlement and survival of corals spawned in late 2013. Conversely, the almost complete absence of corals in the 5 to 10cm size-class strongly implies a lack of settlement or survival of juveniles spawned in late 2012. In combination, the loss of corals from Seal Rocks, that occurred post December 2012 and the observation of a juvenile coral cohort likely to have settled in late 2013 places the timing of a severe disturbance to coral communities between December 2012 and November 2013.

Table 7 Proportion of juvenile hard corals in each size class.

Reef	<2cm (%)	2 - 5cm (%)	5 - 10cm (%)
Facing Island 2	79.3	20.7	0.0
Farmers Reef	59.3	31.5	9.3
Manning Reef	86.7	10.0	3.3
Rat Island	38.0	46.0	16.0
Seal Rocks North	77.6	21.7	0.7
Seal Rocks South	61.2	35.3	3.5
Overall Average	**67.0**	**27.5**	**5.5**

In late January 2013 the Boyne River experienced a major flood event as a result of extreme rainfall associated with Tropical Cyclone Oswald. Based on conversion of temperature and conductivity data reported by Vision Environment (2013a, b) the salinity at 0.75m depth in the Mid Harbour reached minimum levels of below 5 practical salinity units (psu) and, sustained levels of less than 12 psu on 28 January 2013 and remained below 20 psu for approximately three days from 27 to 29 January. These salinities are likely to have been sufficiently low to cause mortality among the coral communities within the harbour. Berkelmans *et al*. (2012) published a salinity threshold for *Acropora* of 22 (psu) for three days. As described by Berkelmans *et al*. (2012) the effect of salinity follows a dose/time relationship meaning that progressively shorter exposures are required as salinity levels decline to cause equally lethal effects.

The loss of coral cover as a result of exposure to low salinity in recent years is not limited to the corals of Gladstone Harbour. In 1991, flooding of the Fitzroy River was observed to cause severe mortality of corals down to a depth of 1-2m at reefs in Keppel Bay (van Woesik 1991). In 2011 corals in Keppel Bay were again affected by low salinity waters that caused widespread mortality among coral communities exposed to low salinity (Thompson *et al.*, 2011; Jones and Berkelmans 2014). Further

South, Butler *et al*. (2013, 2015) document a 56% loss of corals over consecutive flood events attributed to a combination of low salinity and increased turbidity and nutrients in Hervey Bay.

The studies mentioned above also document the variable susceptibility of coral species to low salinity. In Keppel Bay, van Woesik (1991) lists species in the families Faviidae, Siderastreidae and Dendrophylliidae as least influenced by low salinity, the genus *Porites* as being bleached though surviving and the Acroporidae and Pocilloporidae as the most susceptible. More recent observations by Berkelmans *et al.* (2012) and Thompson *et al.* (2011) confirm this pattern of susceptibility as do observations from Hawaii where *Cyphastrea* and *Porites* where noted as tolerant to short term exposure to salinities as low as 15 psu (Jokiel *et al*. 1993). There is clearly a strong correspondence between the surviving coral species in Gladstone Harbour (Figure 6, Table A3-1) and those reported as being tolerant of low salinity - reinforcing the evidence for the floods of January 2013 as a primary driver of the current very poor condition of coral communities.

The severity of disturbance to the coral communities, that appears to have coincided with the flooding of January 2013, has effectively reset coral communities to an early post-disturbance state. This makes it difficult to infer any impact of pressures associated with the development of the harbour, industry or land use within the catchments draining to the Harbour. Following a severe disturbance, it is typical for coral reefs in nearshore GBR to have low coral cover and become dominated by macroalgae. This means that the present very low condition grade is not unexpected. It will be informative for assessing the future health of coral communities within the harbour to document how persistent the high cover of macroalgae proves to be and how rapidly the recovery toward previously observed levels of coral cover progresses.

The comparison between the composition of coral cover and the composition of juvenile corals indicates that the diversity of corals is already increasing with corals of the genera *Acropora* and *Pocillopora*, which are sensitive to disturbances such as low salinity, observed to be recruiting to most reefs (Figure 6, Table A3-1). These taxa were clearly evident in the dead coral communities at most sites and so this observation appears to indicate the beginning of the recovery process.

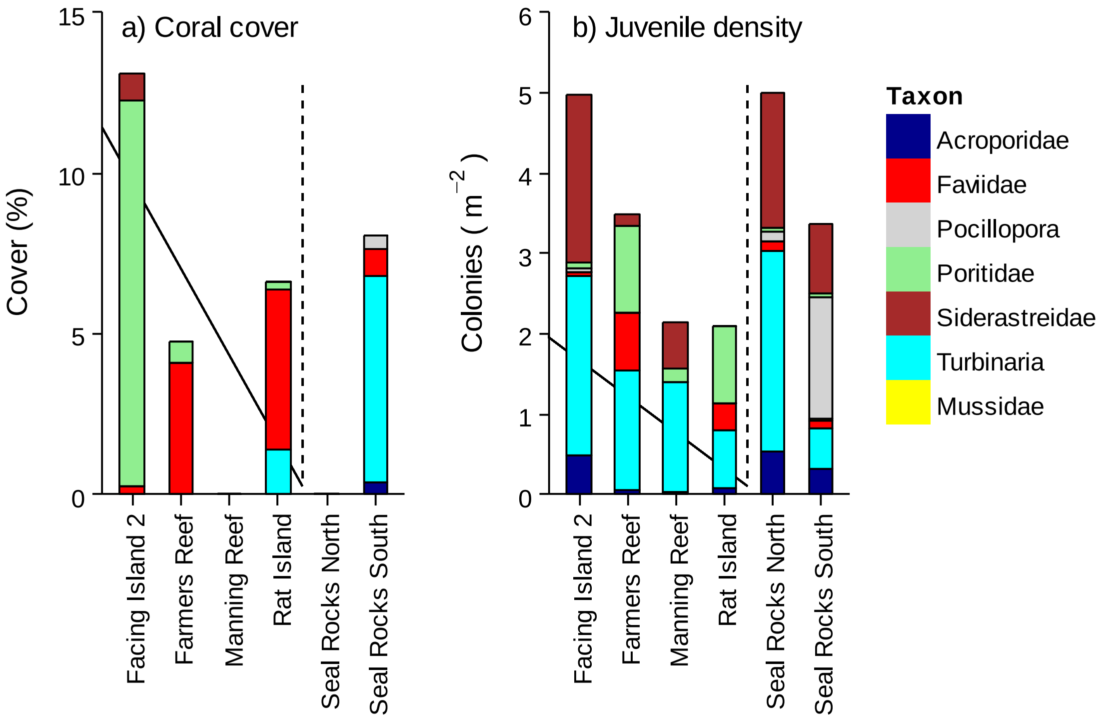

Figure 6 Taxonomic composition of coral communities at monitoring locations represented by a) proportional cover of the substrate, and b) numbers of colonies < 10cm in diameter.

Conclusion

The coral communities in the Gladstone Harbour are currently in very poor condition. The evidence available strongly points to low salinity associated with the floods of 2013 as having strongly impacted the coral communities in both the Mid and Outer Harbour. This does not preclude the possibility that conditions experienced prior to January 2013, or in the months following the flood, did not additionally influence the current condition, such impacts may include: low salinity and high turbidity associated with flooding in December 2010-January 2011, or exposure to contaminants including high turbidity associated with development and operation of the harbour. While anecdotal evidence (Russ Babcock: Gas Industry Social & Environmental Research Alliance, pers. comm.), along with observations of recently dead corals at all monitoring sites suggest a higher cover of living corals prior to the 2013 floods, without systematic observations it is not possible to comment on the extent of any decline in coral communities that may have occurred between the baseline surveys of reefs in the mid harbour in 2009 (BMT WBM 2013) and the severe flood event of 2013.

The monitoring program now in place will enable the tracking of the recovery of coral communities toward the baseline condition observed in 2009 (BMT WBM 2013). Scores for each indicator over coming years will help to track any recovery of the harbour's coral communities. The rate that recovery occurs will provide the basis for inferring the ongoing influence of cumulative stressors acting on these communities. Given the intensity of the 2013 flood the presence of moderate numbers of juvenile corals is a positive sign that early recovery of coral communities is underway.

References

Anon (2003) Reef Water Quality Protection Plan for catchments adjacent to the Great Barrier Reef World Heritage Area. The State of Queensland and Commonwealth of Australia. Queensland Department of Premier and Cabinet, Brisbane. 43 pp

Anon (2009) Reef Water Quality Protection Plan 2009. For the Great Barrier Reef World Heritage Area and adjacent catchments. The State of Queensland and Commonwealth of Australia. Queensland Department of the Premier and Cabinet, Brisbane. 30 pp.

Anon (2011) Reef Water Quality Protection Plan. First Report 2009 Baseline. The State of Queensland and Commonwealth of Australia. Queensland Department of Premier and Cabinet, Brisbane. 140 pp. Available at www.reefplan.qld.gov.au

Baird AH, Guest JR, Willis BL (2009) Systematic and Biogeographical Patterns in the Reproductive Biology of Scleractinian Corals. Annual Review of Ecology, Evolution, and Systematics 40 (2009): 551-571

Berkelmans R, Jones AM, Schaffelke B (2012) Salinity thresholds of Acropora spp. on the Great Barrier Reef. *Coral Reefs 31*(4):1103-1110

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

Butler IR, Sommer B, Zann M, Zhao J-X, Pandolfi JM (2015) The cumulative impacts of repeated heavy rainfall, flooding and altered water quality on the high-latitude coral reefs of Hervey Bay, Queensland, Australia. Marine Pollution Bulletin 96:356-367

Butler IR, Sommer B, Zann M, Zhao J-X, Pandolfi JM (2013) The impacts of flooding on the high-latitude, terrigenoclastic influenced coral reefs of Hervey Bay, Queensland, Australia. Coral Reefs 32(4):1149-1163

Jokiel PL, Hunter CL, Taguchi S, Watarai L (1993) Ecological impact of a fresh-water “reef kill” in Kaneohe Bay, Oahu, Hawaii. Coral reefs 12:177-184

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. doi:10.1371/journal.pone.0084739

Jonker M, Johns K, Osborne K (2008) Surveys of benthic reef communities using underwater digital photography and counts of juvenile corals. Long-term Monitoring of the Great Barrier Reef, Standard Operational Procedure Number 10, Australian Institute of Marine Science, Townsville

Kroon FJ, Kuhnert PM, Henderson BL, Wilkinson SN, Kinsey-Henderson A, Abbott B, Brodie JE, Turner RDR (2012) River loads of suspended solids, nitrogen, phosphorus and herbicides delivered to the Great Barrier Reef lagoon. Marine Pollution Bulletin 65:167–181

Miller IR, Jonker M, Coleman G (2009) Crown-of-thorns seastars and coral surveys using the manta tow and SCUBA Search techniques. Long-term Monitoring of the Great Barrier Reef Standard Operational Procedure Number 9, Edition 3. Australian Institute of Marine Science, Townsville

Thompson A, Costello P, Davidson J, Uthicke S, Schaffelke B, Takahashi M (2011) Reef Rescue Marine Monitoring Program. Report of AIMS Activities – Inshore coral reef monitoring 2010/11. Report for Great Barrier Reef Marine Park Authority. Australian Institute of Marine Science, Townsville. (123 pp.)

van Woesik (1991) Immediate impact of the January 1991 floods on the coral assemblages of the Keppel Islands. Research Publication 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

Waters, DK, Carroll, C, Ellis, R, Hateley, L, McCloskey, GL, Packett, R, Dougall, C, Fentie, 2014, Modelling reductions of pollutant loads due to improved management practices in the Great Barrier Reef catchments – Whole of GBR, Technical Report, Volume 1, Queensland Department of Natural Resources and Mines, Toowoomba, Queensland (ISBN: 978-1-7423-0999)

WBPD (2015) Environmental reports, viewed 31-August-2015, http://www.westernbasinportdevelopment.com.au/environmental_reports

Appendix 1: Selection of coral monitoring locations

An initial list of potential locations for the selection of long-term coral monitoring sites was agreed to by AIMS and the GHHP (Figure A1-1). This list was informed firstly by the desire to include coral monitoring sites in each of the; Inner Harbour, Mid Harbour and Outer Harbour reporting zones and secondly, on observations of coral community presence documented by previous surveys (BMT WBM 2013). Reconnaissance of the proposed locations over the period 6 to 8 July resulted in the selection, construction and survey of four coral monitoring locations in the Mid Harbour (Reporting Zone 8) and two locations in the Outer Harbour (Reporting Zone 11) (Figure A1-1).

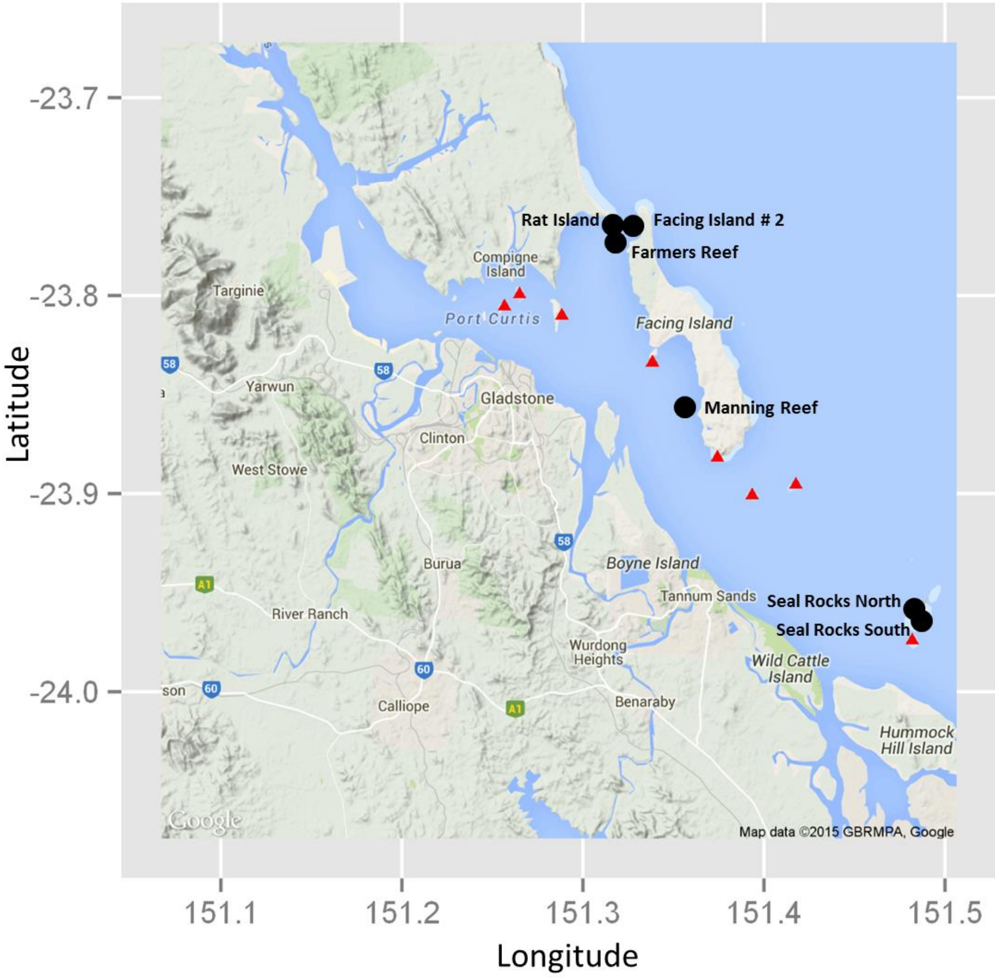

Figure A1-1 Potential (red triangles) and selected (black circles) locations for coral monitoring sites.

Inner Harbour site search

Within the Inner Harbour extensive searching around Quoin Island, Turtle Island and Diamantina Island revealed no areas of coral habitat suitable for selection as long-term coral monitoring locations. AIMS visited this region of the Harbour on the falling tide on 7 July and again on the low and rising tide on 8 July 2015. The locations and observations of benthic communities on areas of hard substrate that were located are summarised in Figure A1-2 and Table A1-1. During the time AIMS spent in the Inner Harbour the underwater visibility remained in the range of 0.1 to 0.3m. These conditions effectively precluded the possibility of selecting and surveying benthic monitoring sites, even had suitable areas been located. It is possible that live corals existed. However, the very limited underwater visibility experienced severely limited the ability to detect what would, in all likelihood, be very patchily distributed and small colonies.

Observations from Max Allen, a long term operator of the Quoin Island Ferry (John Kirkwood pers. comm.), suggest that the turbidity in the Inner Harbour declines in August and September under conditions of light south westerly winds. Any future efforts to locate and monitor coral communities in the Inner Harbour and also parts of the Mid Harbour should therefore target such conditions. Max Allen also identified a deep pool adjacent to the spit off the northern end of Quoin Island as an area that had supported coral communities in the past and this area could be searched in the future.

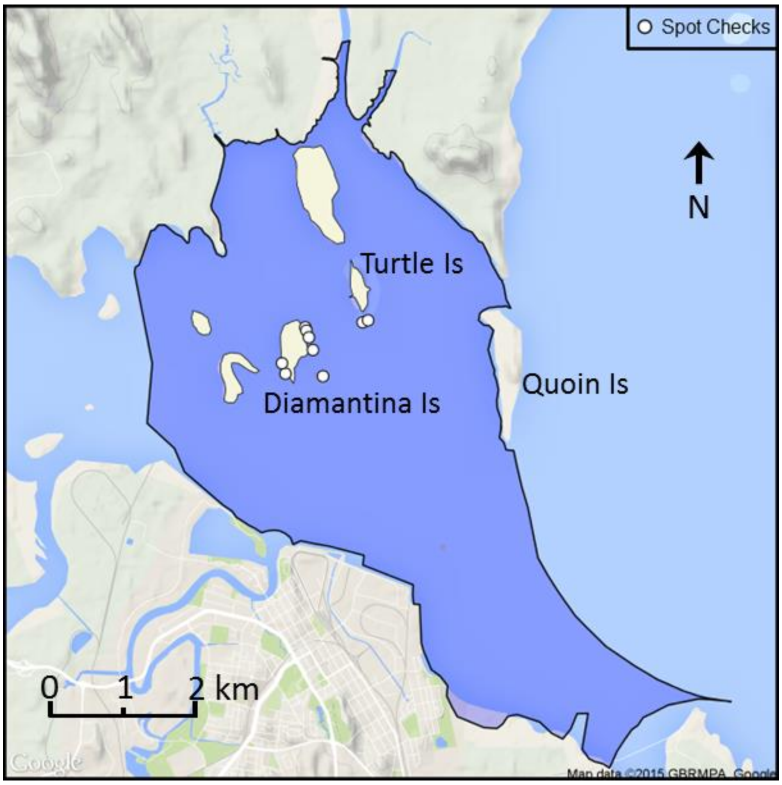

Figure A1-2 Location of spot checks of the benthos within the Inner Harbour reporting zone.

Quoin Island

Only the western side of Quoin Island lies within the Inner Harbour reporting zone. The full length of the Western side of Quoin Island was searched using a side scanning depth sounder. This search followed the approximate contour of the lowest astronomic tide (LAT). This search revealed only soft sediments with no evidence of corals or the hard substrates that are required to support coral communities.

Diamantina Island

At low tide, exposed rocky substrate was observed in the intertidal zone at the southern point of the island. This extended for a short distance along the western side and along most of the eastern side of the island. Side scanning revealed this substrate extended into the sub-tidal zone. A series of five spot checks along the eastern side of the island (Figure A1-2, Table A1-1) revealed no live hard corals and a very few small dead colonies (<20cm diameter) of the hard coral genus *Turbinaria* (Figure A1-

33a, Table A1-1). The substrate was predominantly small rocks interspersed by deposits of silt. The rocks supported a community of algae with the genus *Asparagopsis* and *Lobophora* common. The coral community observed was limited to small heterotrophic Gorgonian like soft corals (Figure A1-3b). A further two spot checks along the south western face revealed a substrate and communities largely consistent with those observed on the eastern face (Figure A1-2, Table A1-1).

Turtle Island

The low tide revealed hard substrate in the intertidal zone along the south, south west and south east sides of the island. Side scanning showed this substrate to extend into the subtidal zone. Scanning targeting the level of the LAT around the rest of the island revealed no additional areas of hard substrate. Snorkel check swims of approximately 100m along both the south western and south eastern flanks of the island (Figure A1-2, Table A1-1) revealed similar substrate and communities to those described above for Diamantina Island. Again, as no evidence of substantial dead or live coral communities could be found and due to the very limited underwater visibility experienced, no long-term monitoring site could be selected.

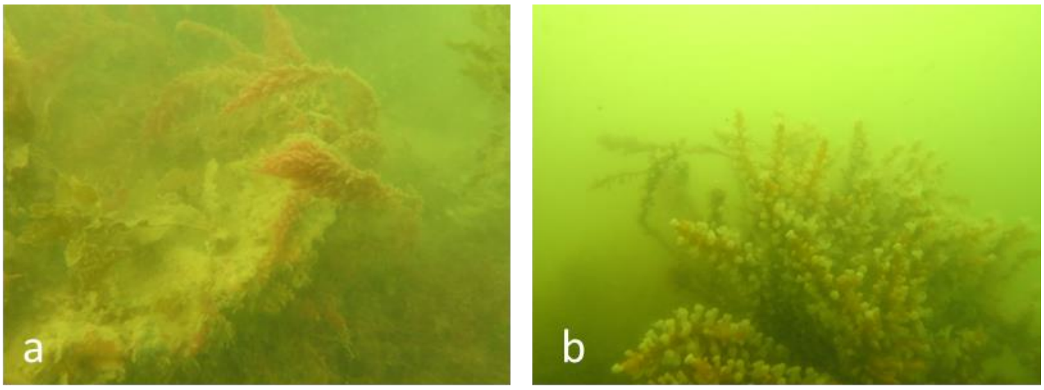

Figure A1-3 Benthos at Inner Harbour spot check sites, a) a dead Turbinaria coral supporting macroalgae and, b) a heterotrophic soft coral.

Middle Harbour site search and selection

There were three locations identified as priority areas for coral monitoring in the Middle Harbour reporting zone: Rat Island, Facing Island Reef #2, and Manning Reef (Figure A1-1). At each priority location suitable coral habitat was located, permanent sites constructed and baseline surveys completed on 7 July 2015 (Figure A1-4, Table A1-2). In addition, and in compensation for the lack of sites in the Inner Harbour reporting zone a site was also constructed and surveyed at Farmers Reef (Figure A1-4, Table A1-2). A spot check of a small area of hard substrate located by side scan at Bushy Island identified a narrow fringe of dead standing coral with some remaining live *Porites* colonies. The area of this patch of coral habitat was too small to be considered for a long-term monitoring site.

From a practical perspective it is important to note that all four monitoring sites experience very strong currents on a falling tide that precludes diving during this phase of the tidal cycle.

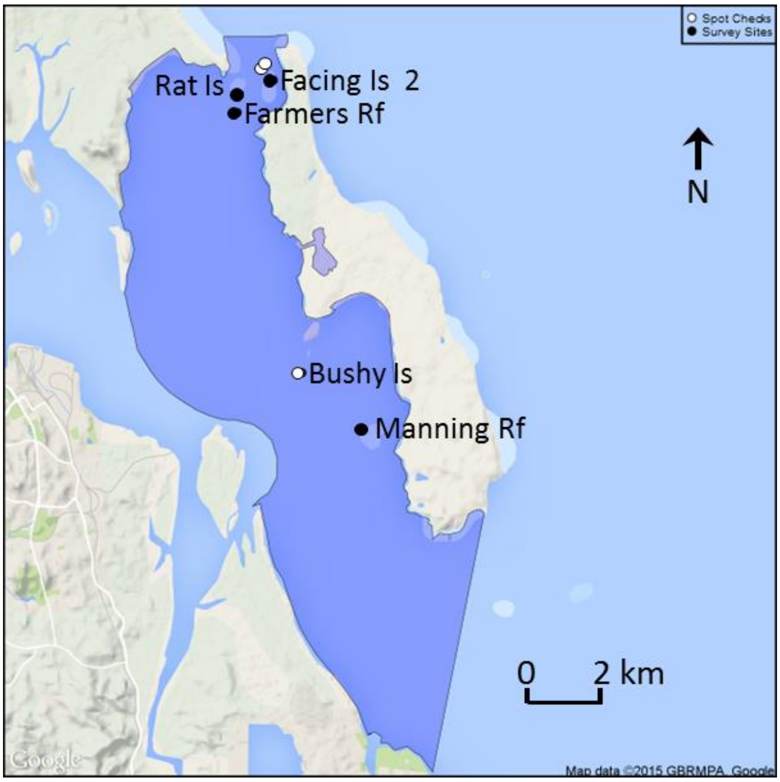

Figure A1-4 Location of long-term monitoring sites and additional spot checks within the Middle Harbour reporting zone.

Rat Island

On the rising tide the shallow waters surrounding Rat Island were sufficiently clear to identify the narrow fringing reef on the southern side of the island as having the highest density of both living and dead standing corals. The coral community here ran from the depth of LAT to approximately 1m below LAT before fading into a sandy substrate. A long-term monitoring site was constructed (Table A1-2) and baseline coral community monitoring undertaken (Figure A1-5). The eastern and northern aspects of the island were scoured hard rocky substrate interspersed with sand patches that supported a lower cover of live and dead coral than the site selected. The western face was rubbly and shallow with strong current. On a rising tide the monitoring site was current-free. The dead coral community included mostly the genera *Acropora* and *Turbinaria*.

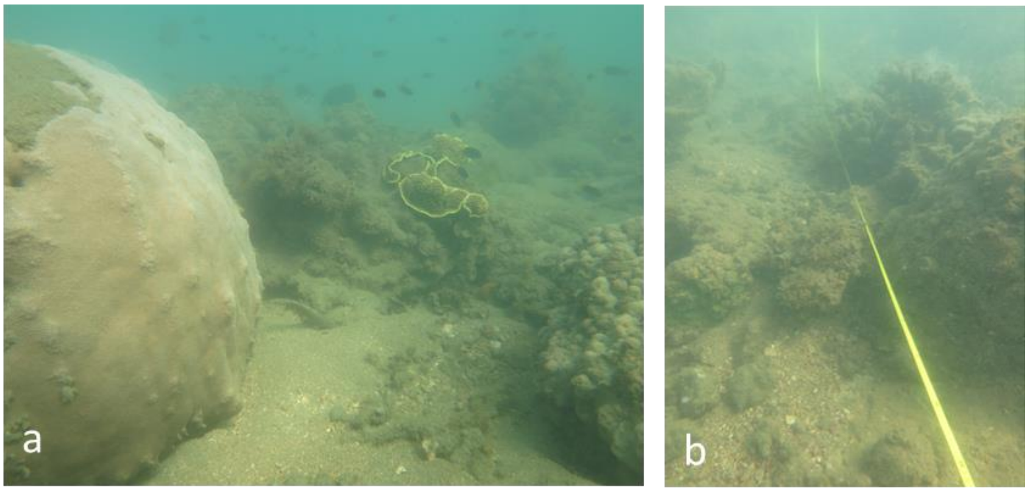

Figure A1-5 Benthos at Rat Island, a) Cyphastrea and Turbinaria coral among dead corals and b) a section of a monitoring transect over dead corals.

Farmers Reef

Here again the water was sufficiently shallow and clear to identify the northern aspect of the reef as the best location for a long-term monitoring site. The eastern aspect runs through a channel and was largely scoured to bed rock though did support some live and dead corals. The south and west aspects were shallow and sandy. A long-term monitoring site was constructed at ~1m below LAT (Table A1-2) and included live and dead corals on areas of hard substrate patchily distributed in a sandy area (Figure A1-6). Dead corals were mostly of the genus *Porites* and *Turbinaria* and the family Faviidae. As the tide began to ebb this site had a strong current and reduced visibility.

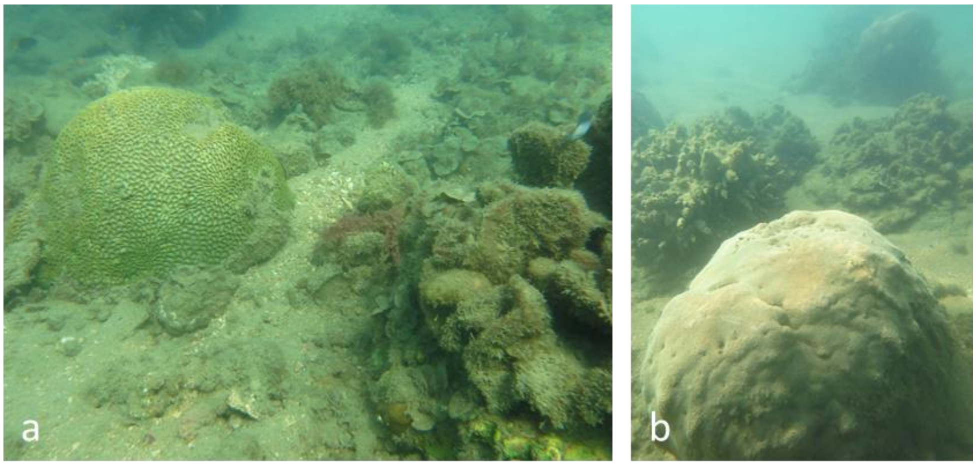

Figure A1-6 Benthos at Farmers Reef, a) Favities coral and b) Cyphastrea coral among a patchy sand and dead coral substrate.

Facing Island Reef #2

Visually surveying the western aspect of the reef from the surface suggested the substrate was scoured and rocky rather than coral based. Spot checks on snorkel at two points on the northern aspect confirmed a patchy rocky and sandy substrate with low cover of live and dead corals (Table A1-1). Along the south eastern face of the reef an area of mixed dead and live coral community was identified during a snorkel spot check (Figure A1-7). This area was selected, a long-term monitoring site constructed (Table A1-2) and baseline survey completed. The depth of this site was between 0m to 1m below LAT. The dead community was predominantly composed of branching and corymbose forms of the genus *Acropora* and also the genera *Turbinaria* and *Porites*. Diving on a rising to high tide was current-free.

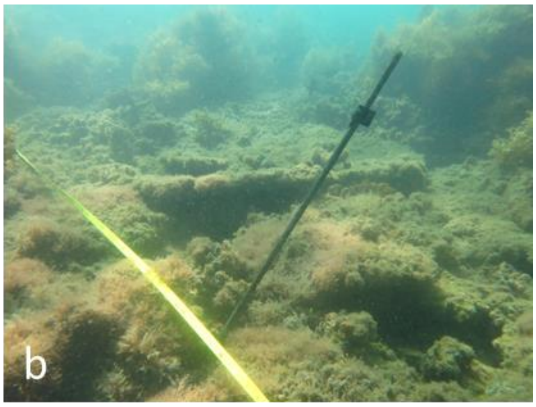

Figure A1-7 Benthos at Facing Island Reef 2, a) living Porites corals and b) a transect marker among dead Acropora corals.

Manning Reef

The majority of the depth contour of 0m to 1m below LAT of Manning Reef was side scanned and this identified an area of hard substrate on the northern side. On a rising tide a spot check was undertaken and revealed an expanse of dead coral colonies, mostly of the genus *Acropora*. A long-term monitoring site was constructed (Figure A1-4, Table A1-2) and baseline survey completed. The visibility during this survey was poor at 0.5m for the majority of the survey though current was minimal on a rising tide. The site is set at 0m to 0.5m below LAT at which point the dead corals run to a silty/sandy substrate. The presence of dead *Acropora* colonies along the entire site suggests recent presence of a high coral cover (Figure A1-8).

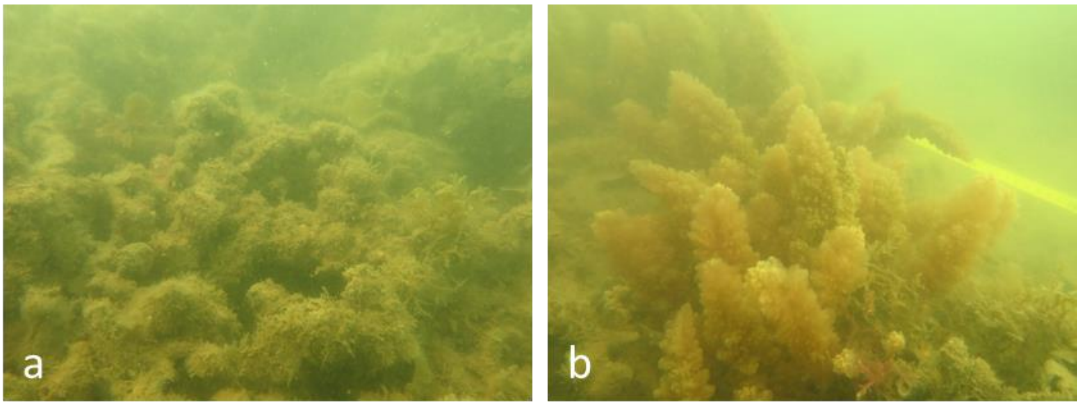

Figure A1-8 Benthos at Manning Reef, a) dead Acropora corals and, b) Asparagopsis macroalgae on dead coral.

Bushy Island

The majority of the depth contour of 0 -1m below LAT of Bushy Island was search using side scan. A small area of hard substrate was located on the south western side where two spot checks revealed a scattering of dead corals over a very narrow band of substrate between the intertidal and muddy sub-tidal area (Figure A1-4, Table A1-1). Dead standing corals included the genus *Turbinaria*, *Porites* and branching forms of *Acropora* and *Porites*. One small (~20cm) living colony of *Porites* was observed. The extent of this stand of corals appeared too limited to accommodate a 120m long monitoring site. In addition the visibility on the falling tide was <0.4m and so no further work attempted.

Outer Harbour site search and selection

Two locations at each of East Banks and Seal Rocks were identified for potential monitoring sites (Figure A1-1). Of the identified locations only Seal Rocks 2 was found to have suitable substrate for coral communities and supported both living and recently dead stands of coral. Two long-term monitoring sites were constructed and surveyed at Seal Rocks 2 (Figure A1-9).

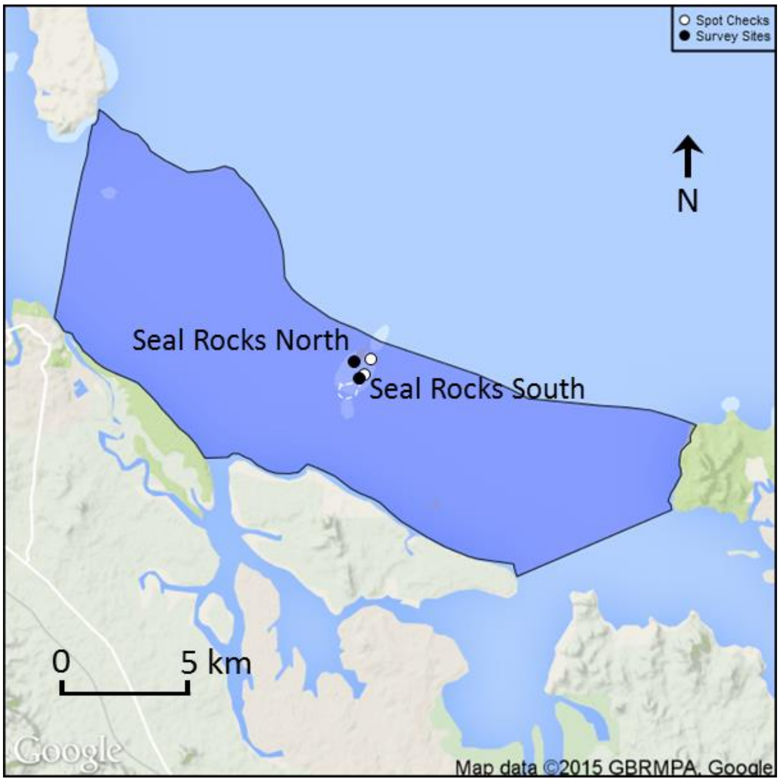

Figure A1-9 Location of long-term coral monitoring sites and additional areas searched in the Outer Harbour reporting zone.

Seal Rocks

The three sections of Seal Rocks as indicated on GBRMPA maps and also on maps supplied by the GHHP were not clearly distinguishable. The major rocky section that is exposed at low tide is consistent with the location of Seal Rocks 2 and an additional area of rocky ground to the east was consistent with the location of Seal Rocks 1. A shallow area on the marine charts close to the location of Seal Rocks 3 was found to be primarily a sand bank.

At Seal Rocks 2 the water clarity allowed easy scanning of the northern side of the reef from the surface and an area of suitable substrate was identified, a long-term monitoring site constructed (Figure A1-9, Table A1-2), and survey of coral communities completed. This site was at 1m to 2m below LAT and comprised of dead standing corals with moderate cover of macroalgae interspersed by patches of sand (Figure A1-10a). Almost all corals were dead though the site had clearly recently supported high living coral cover composed mostly of branching, corymbose and tabulate forms of the genus *Acropora* and also *Turbinaria*. Below the depth of this site the substrate was sand though scattered patches of hard substrate did extend to 2m to 3m below LAT.

Two spot checks on the south eastern side of the main rocky area (Table A1-1) revealed a rocky substrate with lower cover of live and dead corals and very high cover of the macroalgae *Sargassum* and *Lobophora*. The Rocky substrate ran to sand at ~2m below LAT. A third spot check on the south western aspect of the main rocky area revealed an area of living corals mostly of the genus *Turbinaria* and a substrate comprised of dead standing coral and patches of sand (Figure A1-10b). A second long-term monitoring site was constructed in the area of this third spot check (Figure A1-9, Table A1-2) and survey of the coral community completed.

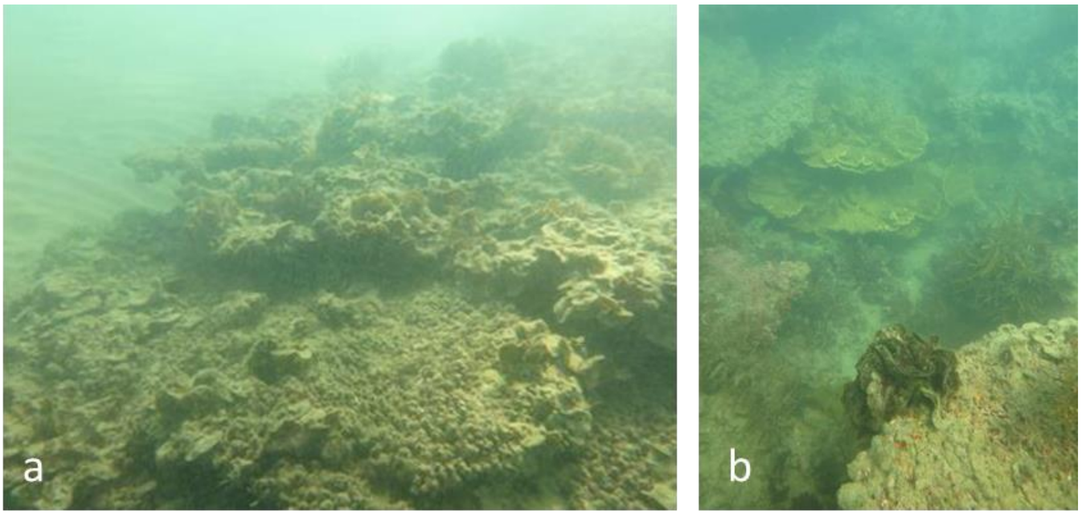

Figure A1-10 Benthos at Seal Rocks, a) north monitoring site, and b) south monitoring site.

East Banks

The marine chart of East Banks is very different to the GBRMPA maps. There really are not two patches as shown; rather, there is a large area of sand banks that are washed by very strong currents on both falling and rising tides. AIMS twice ventured into the East Banks area and targeted shallow areas showing on electronic charts to search for reef both from the surface and using the side scan. We did not locate any sign of hard substrate that would serve as coral habitat. Further, the currents running over these banks would preclude diving surveys even if coral communities do exist. No sites were located and no spot checks conducted.

Table A1-1 Location of spot checks and summary of benthos

Reef	Depth below LAT	Latitude South	Longitude East	Comments
Seal Rocks 2	1-2 m	23 57.428	15 29.452	Rocky substrate with patchy dead coral, high cover of macroalgae *Sargassum*, Hard Coral cover estimated at 5%.
Seal Rocks 2	1-2 m	23 57.492	151 29.423	Patchy rocky and sand substrate with some dead coral. High cover macroalgae *Sargassum*. Hard Coral cover estimated at 10%. Most common coral *Turbinaria.*
Seal Rocks 3				Traversed shallowest area, substrate visible from surface, predominantly a sand bank.
Bushy Island	0-1 m	23 50.362	151 20.172	Circumnavigation with scan. Hard substrate below intertidal on SW face. Spot check revealed very narrow fringe of deal corals between intertidal and sand/silt substrate. Area too small for monitoring site.
Facing Island 2	1 m	23 45.610	151 19.507	Patchy Rocky and sand substrate. Low cover of dead and live corals. Most common corals *Turbinaria* and *Psammocora*.
Facing Island 2	1 m	23 45.553	151 19.574	Patchy Rocky and sand substrate. Low cover of dead and live corals. Most common corals *Turbinaria* and *Psammocora.*
Quoin Island	0-1 m			Full scan of Western side of Island. No areas of hard substrate located.
Diamantina Island	0-1 m	23 48.208	151 15.396	Patchy rock and mud substrate. One small (<20cm) dead hard coral (*Turbinaria*) and unidentified dead massive coral. Visibility too poor for further work (~0.3 m).
Diamantina Island	0-1 m	23 48.233	151 15.406	Small rocks and mud. Macroalgae and some small gorgonian soft corals, no hard coral.
Diamantina Island	0-1 m	23 48.286	151 15.427	Small rocks and mud. Macroalgae and some small gorgonian soft corals, no hard coral.

Diamantina Island	0-1 m	23 48.384	151 15.461	Mud.
Diamantina Island	0-1 m	23 48.588	151 15.547	Small rocks and mud. Macroalgae and some small gorgonian soft corals, no hard coral.
Diamantina Island	0-1 m	23 48.568	151 15.228	Small rocks and gravel supporting macroalgae, no hard coral.
Diamantina Island	0-1 m	23 48.487	151 15.199	Small rocks and mud supporting macroalgae, no hard coral.
Turtle Island West	0-1 m	23 48.208	151 15.899	Snorkel swim between points. Substrate, small rocks and mud supporting macroalgae and some small gorgonian soft corals, no hard coral.
		23 48.137	151 15.868	
Turtle Island East	0-1 m	23 48.179	151 15.929	Snorkel swim between points. Substrate, small rocks, gravel and mud supporting macroalgae. No hard coral.
		23 48.130	151 15.929	

Table A1-2 Construction details for coral monitoring sites. 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-15	1 m	23 57.500	151 29.092	1	295 then 270@10 m
					2	250 then 310@10 m
					3	300 then 320@10 m
					4	15 then 100@10 m
					5	50 then 60@10 m
Seal Rocks South	06-July-15	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	~260 follows sand reef interface
					5	~300 follows sand reef interface
Rat Island	07-July-15	1 m	23 46.022	151 19.107	1	305 then 300@10 m
					2	300
					3	330 then 320@10 m
					4	320 then 300@10 m
					5	295 then 285@10 m
Facing Reef 2	07-July-15	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	180 then 210@15 m
Farmers Reef	07-July-15	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-15	0-0.5 m	23 51.239	151 21.199	1	30 then 10@10 m, 50 from end to T2
					2	60 then 0@10 m, 80 from end to T3
					3	60 then 320@10 m, 300 from end to T4
					4	300 then 15@10 m, 330 from end to T5
					5	330 then 60@10 m

Appendix 2: Rationale for Indicator selection

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 Coast it is well documented that loads of sediment, nutrients and other chemical pollutants carried to the sea in runoff have increased since European settlement (Kroon *et al.* 2012; Waters *et al.* 2014). For corals in the Gladstone Harbour report card zone any impacts associated with land use in the catchment may be compounded by dredging and other port related activities (BMT WBM 2013). The purpose of coral community monitoring undertaken within the Gladstone Harbour report card zones is to document change in coral community condition that can be assessed as a response to either natural or anthropogenic pressures or the success of management actions aimed at improving the health of Gladstone Harbour (GHHP 2015). This is broadly analogous to the purpose of the Queensland State-produced GBR report card, which reports coral condition data from the Reef 2050 Plan Marine Monitoring Program (MMP). That program was implemented to provide an assessment of the condition of key inshore habitats and environmental parameters as an assessment of the success of Reef Plan (Anon. 2013). It is the similarity of purpose of the Gladstone Harbour and GBR report cards that justifies the transfer of both sampling methods and approach to synthesise results used to monitor and report coral community condition by the MMP to the Gladstone context.

Underlying the assessment of coral community condition is the conceptual understanding that coral communities are naturally dynamic and exist in a cycle of disturbance, as a result of acute events, followed by periods of recovery. The coral community report card scores developed under the MMP are the aggregation several separate indicators of coral community condition into a multimetric index. Importantly, each of the indicators was selected to represent different aspects of the disturbance recovery cycle and the indicators collectively provide a broad basis for the assessment of biological integrity while also producing a single "score" or "grade" for reporting purposes (Bradley *et al.* 2010).

Due to the inference ascribed to report card scores, it is important that each indicator included be carefully selected and tested to ensure it is both relevant to the purpose of the assessment and can be feasibly implemented in a manner able to detect relevant differences in the response (Jameson *et al*. 2001). In the coral reef context the purpose of biological assessments are generally to assess the integrity of communities influenced by human pressures such as local increases in nutrients and sediments (Jameson *et al*. 2001, Fisher *et al* 2008, Cooper *et al*. 2009, Fabricius *et al*. 2012) or the resilience to global climate change (McClanahan *et al* 2012). In each of the studies listed above, the authors have tested a range of biological attributes and identified those most relevant as potential indicators to be used in multimetric indices. While these studies were considered in the selection of indictors for the GBR and also Gladstone Harbour report cards, many of the indicators suggested in the literature are not considered to be suitable due to incompatibilities between the sampling methods and the sampling design used for the GHHP coral condition monitoring (and the MMP) that intentionally focuses on long-term changes in coral community condition. In the sections below, each selected indicator underlying the coral condition grade in the GHHP report card is discussed in detail.

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.

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.* 2010; 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 so turbidity and thus light reduction will be the primary physical limitation on the development of high macroalgal cover on these reefs.

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. Here 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.

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 and 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).

Potential indicators to be included in the future

Rate of increase in cover of hard corals

In addition to the three indicators described above, the MMP includes an indicator based on the rate that coral cover increases. While high coral cover can justifiably be considered a positive indicator of community condition, the reverse is not necessarily true of low cover. 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 (as above) we also assess the rate at which coral cover increases as a direct measure of recovery potential. This indicator is estimated by comparing the observed rate of change in hard coral cover at a given reef to that predicted by a coral cover rate of increase model parameterised from time series of coral cover from reefs monitored by the AIMS Long-term monitoring program and the MMP. The formulation of this model and setting of thresholds is currently under revision within the MMP though in practice follows the following procedure: annual change in benthic cover derived from inshore reefs sampled over the period 1987-2007 are used to parameterise a multi-species Gompertz growth equation (Dennis and Taper 1994; Ives *et al.* 2003). This model returns estimates of growth rates for hard corals of the family Acroporidae and hard corals of all other families. Importantly, growth rate estimates for each coral group are dependent on the existing cover of each group along with the cover of soft corals and macroalgae which, in combination, represent potential space competitors. Assessments of the observed rate of increase in coral cover are scored relative to the magnitude of departure from model predictions. Importantly, this metric is not used for a given location in the instances where disturbance events occurred as there is no logical expectation of an increase in cover in these instances.

As this indicator requires comparison to data from previous observations to be able to estimate the rate of change in coral cover, it is not possible to include it in the first year of reporting for the Gladstone Harbour report card. The revision of analysis and scripting for this indicator for the MMP is underway and should be completed prior to any 2016 monitoring and reporting. It is suggested that a decision as to the inclusion or not of this indicator be deferred until 2016.

Changes in community composition of hard corals

There are two additional indicators being considered for the MMP that will assess any change in the composition of coral communities observed as cover and as juveniles. As for the indicator 'rate of cover change' these indicators require observations of previous communities to which current observations are compared. This means this indicator cannot be included in the Gladstone assessment in the short term. The underlying concept for these indicators is that the environmental conditions of a location impose selective pressure on the coral communities. Changes in community composition through time can be assessed whether they reflect a shift toward communities that are typical of changed environmental, especially water quality, conditions. This assessment is made possible by the use of constrained analyses of principal coordinates applied to existing MMP genus-level estimates of cover and juvenile abundance matched to water quality gradients. We do, however, caution that our preliminary observations from 2015 surveys of the coral communities in Gladstone Harbour may preclude the use of this indicator in the medium term due to the high level of disturbance that has clearly impacted these reefs and resulted in such low coral cover that the initial baseline composition of communities is difficult to estimate and may not reflect a typical composition under the prevailing environmental conditions.

Determination thresholds and calculation of coral index scores

For each indicator the estimation of thresholds has been described above. There are many different ways for scoring relative to these thresholds that variously weight deviations from threshold values. Past MMP scoring has set an upper and lower boundary around thresholds and scored indicators categorically as either, falling within that threshold range, exceeding the threshold range in a favourable direction or exceeding the threshold range in an unfavourable direction. The problem with the categorical approach is that scores can change dramatically with very small changes in observed values of an indicator when these values span the threshold bounds. Furthermore, the magnitude of exceedance of the threshold is not considered. In the revision of the MMP report card, we are moving to scoring indicators based on the magnitude of deviations from threshold values. In the simplest form, the range of observations around a threshold are scaled to scores of between 0 (when indicator value is at a minimum) and 1 (when indicator value is at a maximum). There are a multiple options for scoring deviations that can alter the sensitivity of scoring around threshold values. By applying non-linear relationships (such as logit or log ratios) to the magnitudes of deviation prior to scaling, such approaches will require some form of justification and inevitably add complexity to the scoring system. The simplest form of relationship is to linearly increase (or decrease) scores with the magnitude of deviation from a threshold. This approach can, however, be modified to impose upper and lower boundaries to the indicator values beyond which any value is considered as either scoring the maximum (1) or minimum (0) score (“modified amplitude scaling”, Figure A2-1). This is the approach adopted for the scoring of Gladstone Harbour water quality indicators. We suggest that this approach is also applied to the scoring of the coral condition indicators for the GHHP report card.

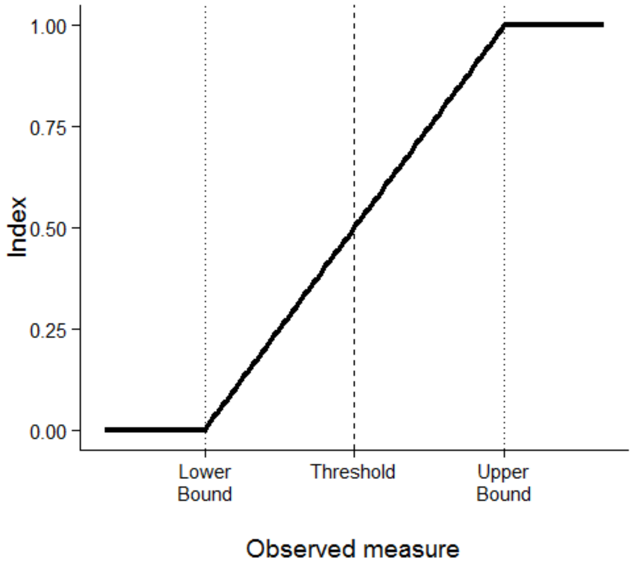

Figure A2-1 Generic scoring of indicators.

It is our understanding that scores for indicators in the report card will be categorised in to a five point scale from best condition “A” through to “E” for worst condition. Further, that the threshold values should be at the C-D boundary. This placement of the threshold differs slightly from the MMP categorisation for coral indicators that sets the threshold in the centre of the C categorisation and is the basis of the thresholds discussed above. To account for this slight difference in grading of scaled scores, Table A2-1 presents the suggested thresholds for Gladstone that have been adjusted to place the threshold on the C and D grade boundary along with upper or lower bounds to be used in scaling of indicator observations.

Table A2-1 Thresholds and bounds for scoring selected indicators

Indicator	Gladstone Threshold	Upper bound (score=1)	Lower bound (score=0)
Coral Cover	40%	90% Reduced from 100% cover rarely attains 100% due to areas of un-colonisable substrate and ongoing population dynamics turnover.	0%
Macroalgae Cover	14%	5%	20% (of none soft substrate area)
Juvenile Density	5.8 m^{-2}	16 m^{-2}	1 m^{-2}

Indicators not advocated for the long-term assessment of coral communities.

Corals respond to changes in environmental conditions in a number of ways along a continuum from short-term molecular or physiological responses to mortality of colonies when conditions exceed tolerance thresholds. There are many potential indicators of environmental stress, that respond over temporal scales of minutes, such as the up or down regulation of genes, though to months or years, such as community composition changes in response to selective pressures (Cooper *et al*. 2009). For a monitoring program it is important to select indicators that are likely to be responsive on time scales that are matched to the objectives and sampling limitations of the project. For impact assessment work during a defined activity, such as dredging, rapidly responding indicators are ideal as stress associated with the activity can be determined and, ideally, mitigated prior to any long-term impact being realised. Indictors such as genes expression, RNA/DNA ratios and the density and photo-physiology of coral symbionts are indicators that could prove useful in these situations (Cooper *et al*. 2009). For longer-term studies such as the coral condition monitoring proposed for Gladstone Harbour and used elsewhere on the GBR, rapidly responsive indicators should be avoided. These may respond as much to short term environmental variability associated with weather conditions as they do to long term stress. In addition, the spatial and temporal scale of monitoring can and does incur limitations to sampling design and methodologies that again further dictate the indicators that can be considered.

In the GBR context, Cooper *et al.* (2009) and Fabricius *et al.* (2012) provide reviews of potential indicators to be used in in long term monitoring programs aimed at assessing the cumulative impacts of environmental conditions and propose a set of 11 and 12 indicators respectively. These indicators along with our considerations leading to the recommendation to not include these in the Gladstone Harbour context are presented in Table A2-2.

Table A2-2 Published indicators of water quality for coral reefs. Relevance to Gladstone Harbour report card discussed. Shaded rows are indicators suggested for inclusion and detailed in body of report.

Cooper *et al.* 2009	Fabricius *et al.* 2012	Considerations relevant to Gladstone Harbour report card
Coral Brightness	Porites colour brightness	In combination these indicators are all derived from work that focused on changes to massive corals along a steep water quality gradient in the inshore Great Barrier Reef. While all correlate to changes in water quality it is not clear how these changes relate to coral community resilience or if sufficient changes can be expected within a location to illicit a detectible response over time. Problematic for the Gladstone Harbour monitoring is the lack of massive corals at some locations that effectively precludes some indicators.
Tissue thickness massive corals		
Rugosities of massive corals		
skeletal elemental composition		
skeletal isotopic composition		
Macro-bioeroders	*Porites* Macro-bioeroders	The skeletal composition indicators require damaging sampling and additional post sampling laboratory analysis of samples that would add cost to the project. These skeletal compositions may be more appropriate for a one off hindcasting of conditions rather than an ongoing monitoring tool.
FORAM Index	FORAM Index	The FORAM index compares the relative abundances of Foraminifera classified by their mode of energy acquisition; some like corals derive energy from the photosynthesis of symbiotic algae while others at heterotrophic and feed on biofilms. With short life cycles compared to corals changes in Foraminifera communities have proven sensitive to changes in environmental conditions. This indicator has been used in the MMP though was discontinued due to budgetary constraints. Sampling requires only the collection of a small volume of surface sediment. This is a relatively cheap and easy method could be added to the monitoring program and would allow sampling in the inner harbour reporting zone that is relevant to corals.
Macroalgal cover	Macroalgae cover	Included
depth of coral-reef development		The depth of reef development is limited by turbidity as a result of light attenuation. There is no scope for an increase in the depth of reef development at the Gladstone harbour reefs due to shallow sandy surrounding substrates
	Coralline algae cover	Coralline Algae is understood to promote coral settlement. The inclusion of juvenile coral densities implicitly includes any influence of Coralline Algae is having on coral recruitment. Estimation of CA abundance from photo transects is difficult as it often forms an understory obscured by other algae or corals.
Taxonomic richness of corals	*Acropora* cover	Taxonomic richness, *Acropora* cover and *Turbinaria* cover are focusing on specific aspects of coral community composition. These data are available within those sampled by the photo transect method used to monitor coral communities in the Gladstone Harbour. However, we believe community composition is better assessed based on the multivariate analysis of the entire community as any such analysis will include trends in these and any other corals responding to environmental conditions.
	Turbinaria cover	
	HC juvenile density	Included
	SC juvenile density	Experience has shown that SC juvenile abundance is problematic due to the small size of many soft coral colonies and the propensity of some species spread by budding-off new colonies that are no considered juveniles
	HC juvenile richness SC juvenile richness	We could consider richness of juvenile corals though as for cover consider a multivariate approach to assessing change in community composition will be more appropriate.

References

Anon. (2013) Reef Water Quality Protection Plan 2013.Securing the health and resilience of the Great Barrier Reef World Heritage Area and adjacent catchments. The State of Queensland. Reef Water Quality Protection Plan Secretariat, Brisbane. 34 p. Available at www.reefplan.qld.gov.au

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.

Bradley P, Fore LS, Fisher W, Davis W (2010) Coral reef biological criteria: using the Clean Water Act to protect a national treasure. US Environmental Protection Agency

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

Cooper TF, Gilmour JP, Fabricius KE (2009) Bioindicators of changes in water quality on coral reefs: review and recommendations for monitoring programmes. Coral Reefs 28:589-606

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

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, Cooper TF, Humphrey C, Uthicke S, De'ath G, Davidson J, LeGrand H, Thompson A, Schaffelke B (2012) A bioindicator system for water quality on inshore coral reefs of the Great Barrier Reef. Marine Pollution Bulletin 65:320-332

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

Fisher WS, Fore LS, Hutchins A, Quarles RL, Campbell JG, LoBue C, Davies WS (2008) Evaluation of stony coral indicators for coral reef management. Marine Pollution Bulletin 65:320-332

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.

Gladstone Healthy Harbour Partnership (2015) Gladstone Healthy Harbour Partnership: Scope of Works for Project ISP014: Developing the coral indicators for the Gladstone Harbour Report Card.

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

Jameson SC, Erdmann MV, Karr JR, Potts WK (2001) Charting a course toward diagnostic monitoring: A continuing review of coral reef attributes and research strategy for creating coral reef indexes of biotic integrity. Bulletin of Marine Science, 69:701-744

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

Kroon FJ, Kuhnert PM, Henderson BL, Wilkinson SN, Kinsey-Henderson A, Abbott B, Brodie JE, Turner RDR (2012) River loads of suspended solids, nitrogen, phosphorus and herbicides delivered to the Great Barrier Reef lagoon. Marine Pollution Bulletin 65:167–181

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

McClanahan TR, Donner SD, Maynard JA, MacNeil MA, Graham NA, Maina J, Baker AC, Alemu JB, Beger M, Campbell SJ, Darling ES, Eakin CM, Heron SF, Jupiter SD, Lundquist CJ, McLeod E, Mumby PJ, Paddack MJ, Selig ER, van Woesik, R (2012) Prioritizing key resilience indicators to support coral reef management in a changing climate. *PloS One*, *7*(8), e42884. doi:10.1371/journal.pone.0042884

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

Miller IR, Jonker M, Coleman G (2009) Crown-of-thorns seastars and coral surveys using the manta tow and SCUBA Search techniques. Long-term Monitoring of the Great Barrier Reef Standard Operational Procedure Number 9, Edition 3. Australian Institute of Marine Science, Townsville

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.

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.

Waters, DK, Carroll, C, Ellis, R, Hateley, L, McCloskey, GL, Packett, R, Dougall, C, Fentie, 2014, Modelling reductions of pollutant loads due to improved management practices in the Great Barrier Reef catchments – Whole of GBR, Technical Report, Volume 1, Queensland Department of Natural Resources and Mines, Toowoomba, Queensland (ISBN: 978-1-7423-0999).

Appendix 3: Additional Information

Table A3-1 Cover and juvenile abundance for coral genera observed at monitoring locations

Sample type	Location	*Acropora* (*Acroporidae*)	*Montipora* (*Acroporidae*)	*Turbinaria* (*Dendrophylliidae*)	*Cyphastrea* (*Faviidae*)	*Favia* (*Faviidae*)	*Favites* (*Faviidae*)	*Goniastrea* (*Faviidae*)	*Leptastrea* (*Faviidae*)	*Platygyra* (*Faviidae*)	*Plesiastrea* (*Faviidae*)	*Acanthastrea* (*Mussidae*)	*Pocillopora* (*Pocilloporidae*)	*Goniopora* (*Poritidae*)	*Porites* (*Poritidae*)	*Coscinaraea* (*Siderastreidae*)	*Psammocora* (*Siderastreidae*)	*Pseudosiderastrea* (*Siderastreidae*)	*Cladiella* -Soft coral (Alcyoniidae)
Cover (%)	Facing Island 2				0.25										12		0.88		
	Farmers Reef				4					0.13				0.38	0.25				
	Manning Reef																		
	Rat Island			1.38	2.63		1.25	0.25			0.88			0.13	0.13				
	Seal Rocks North																		
	Seal Rocks South	0.38		6.40	0.13		0.13			0.63			0.38						0.25
Juveniles (Number)	Facing Island 2	12	1	61	1								1		2	3	54		
	Farmers Reef	1		23	2	1	1	1	5		1			3	14		0	2	
	Manning Reef	1		38											5		16		
	Rat Island	2		17	3		3	1			1			2	21				
	Seal Rocks North	13	2	72		1	1			1			4		1	1	47		
	Seal Rocks South	8		13	1					1		1	38		1		22		

Table A3-2 Cover of Algae, Sponges and Sand & Silt

Location	Red Macroalgae			Brown Macroalgae								Green Macroalgae	Coralline algae	Turf algae		Sand & Silt	Sponge
	Unidentified	*Asparagopsis*	*Peyssonnelia*	Unidentified	*Colpomenia*	*Dictyota*	*Lobophora*	*Padina*	*Sargassum*	*Spatoglossum*	*Stypopodium*						
Facing Island 2	3	0.13		0.13	0.13		10.2		11.1				0.13	53		7.12	1.75
Farmers Reef	0.13	0.75		0.13			3.13							38.9		50.1	2.13
Manning Reef	1.50	27.7		0.63		1.63	0.63							49.7		18.3	
Rat Island	0.5			0.75		2.5	10		0.13			0.12	0.38	52.9		23.4	2.75
Seal Rocks North	0.38		2.25				23.6		1.38	0.38			0.13	53		18.9	
Seal Rocks South	0.13		0.76	1.25		0.63	27.9	0.63	24.2	1.75	0.5	0.5		15.4		17.6	0.25