Gladstone Healthy Harbour Partnership

TECHNICAL REPORT

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GLADSTONE HARBOUR REPORT CARD 2017

Authorship statement

This Gladstone Healthy Harbour Partnership (GHHP) Technical Report was written based on material from a number of separate project reports. Authorship of this GHHP Technical Report is shared by the authors of each of those project reports and the GHHP Science Team. The team summarised the project reports and supplied additional material. The authors of the project reports contributed to the final product. They are listed here by the section/s of the report to which they contributed.

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Gladstone Healthy Harbour Partnership partners

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Executive summary

Context

The 2017 Gladstone Harbour Report Card reports on the environmental health of 13 reporting zones in and around Gladstone Harbour and the overall environmental, social, cultural and economic health of the harbour. This report card covers monitoring undertaken in the period 1 July 2016 to 30 June 2017. Indicator scores range between 0.00 and 1.00 and are converted into grades (Figure 1).

A **Very good** (0.85 – 1.00)

B **Good** (0.65 – 0.84)

C **Satisfactory** (0.50 – 0.64)

D **Poor** (0.25 – 0.49)

E **Very poor** (0.00 – 0.24)

Figure 1: Grading scheme used to convert scores to grades in the 2017 Gladstone Harbour Report Card for each component of harbour health.

Overall component scores

The overall component scores and grades for the 2017 report card were: Environmental 0.60 (C), Social 0.66 (B), Cultural 0.62 (C) and Economic 0.74 (B). Compared to the 2016 report card, the Social and Cultural grade has remained the same and the Economic and Social component scores are similar to the 2016 score (Figure 2). Direct comparison with the 2016 results for Environment are not possible owing to the addition of an indicator for mud crabs and a new sub-indicator for coral 'coral cover change' in the Environmental component.

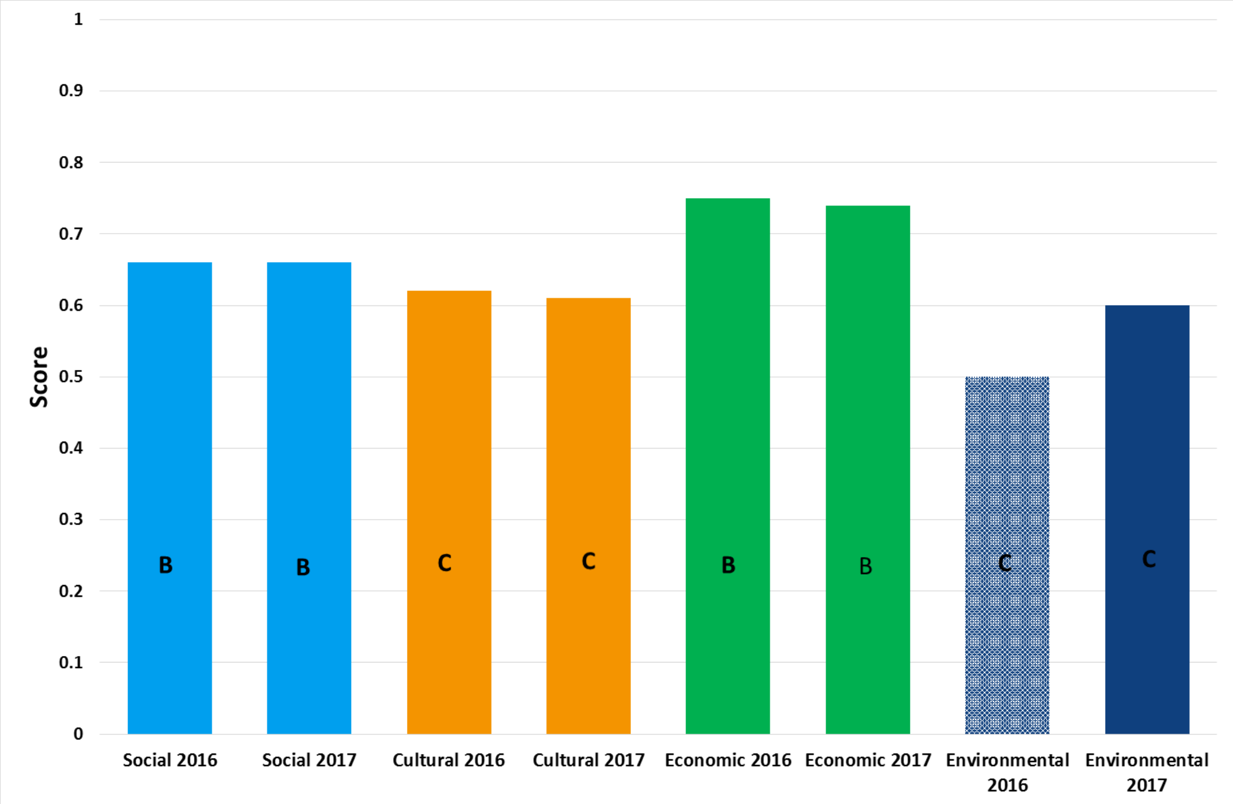


Figure 2: Overall scores for each of the four components of Gladstone Harbour health in 2017. The 2016 component results have been included for comparison. Direct comparison with the 2016 (hashed column) results for the Environmental component is not possible owing to the incorporation of additional indicators in 2017.

Environmental health

Within the Environmental component, the water and sediment quality indicator group received a score of 0.87 (A), habitats 0.33 (D), and fish and crabs 0.63 (C). Overall scores in 2016 were water and sediment quality 0.84 (B), and habitats 0.25 (D). Environmental indicator group zone scores are presented in Table 1. Within the Habitats indicator group, scores were not available for each indicator in each zone, for example five of the habitat scores were based on the seagrass scores only.

Table 1: Environmental indicator group scores for the 13 harbour zones and the overall harbour scores.

Zone	Indicator groups		
	Water and sediment quality	Habitats (seagrass and corals)[3]	Fish and crabs[3]
1. The Narrows	0.81	0.59[1]	0.70
2. Graham Creek	0.90		0.59
3. Western Basin	0.87	0.50[1]	0.78
4. Boat Creek	0.78		0.57
5. Inner Harbour	0.86	0.00[1]	0.75
6. Calliope Estuary	0.85		0.62
7. Auckland Inlet	0.83		0.57
8. Mid Harbour	0.87	0.34	0.71
9. South Trees Inlet	0.91	0.75[1]	0.71
10. Boyne Estuary	0.90		0.74
11. Outer Harbour	0.93	0.21[2]	
12. Colosseum Inlet	0.92		0.71
13. Rodds Bay	0.85	0.19[1]	0.55
Harbour score	**0.87**	**0.33**	**0.63**

1. Habitat score based on seagrass only
2. Habitat score based on coral only
3. Blank cells in grey represent no assessment

Water and sediment quality

The water quality indicator group received a score of 0.78 (B) and sediment quality a score of 0.95 (A). These are comparable to the 2016 results of 0.72 (B) and 0.96 (A) respectively.

Water quality

Water quality was relatively uniform across the harbour and all zones received good or very good scores except for Boat Creek which received a satisfactory score (Table 2). Similar to 2016, water quality received a B, although the overall score (0.78) improved slightly from 2016. The scores for nutrients improved in 10 of the 13 harbour zones. The scores for dissolved metals remained very good in all zones.

Table 2: Overall water quality indicator scores for Gladstone Harbour zones (2015–2017).

Water quality	Physico-chemical score	Nutrients score	Dissolved metals score	Zone score 2017	*Zone score 2016*	*Zone score 2015*
1. The Narrows	0.76	0.44	0.93	0.71	*0.68*	*0.82*
2. Graham Creek	0.99	0.69	0.94	0.88	*0.75*	*0.86*
3. Western Basin	0.74	0.64	0.93	0.77	*0.70*	*0.82*
4. Boat Creek	0.58	0.32	0.89	0.59	*0.58*	*0.70*
5. Inner Harbour	0.76	0.69	0.95	0.79	*0.78*	*0.88*
6. Calliope Estuary	0.68	0.70	0.94	0.77	*0.71*	*0.86*
7. Auckland Inlet	0.83	0.60	0.94	0.79	*0.71*	*0.77*
8. Mid Harbour	0.85	0.59	0.95	0.79	*0.77*	*0.80*
9. South Trees Inlet	0.91	0.68	0.95	0.84	*0.79*	*0.85*
10. Boyne Estuary	1.00	0.53	0.95	0.83	*0.71*	*0.70*
11. Outer Harbour	1.00	0.74	0.95	0.90	*0.72*	*0.84*
12. Colosseum Inlet	1.00	0.55	0.95	0.83	*0.73*	*0.78*
13. Rodds Bay	0.80	0.50	0.95	0.75	*0.73*	*0.80*

Sediment quality

Similar to 2016 and 2015, sediment quality scores were uniformly very good (A) across all Gladstone Harbour reporting zones. This is a result of low concentrations of all measures (arsenic, cadmium, copper, lead, nickel, mercury and zinc) (Table 3). Sediment mercury levels were assessed for the first time in 2017.

Table 3: Sediment quality indicator scores for Gladstone Harbour zones in 2017, 2016 and 2015.

Sediment quality	Zone score 2017	*Zone score 2016*	*Zone score 2015*
1. The Narrows	0.92	*0.92*	*0.94*
2. Graham Creek	0.92	*0.96*	*0.98*
3. Western Basin	0.97	*0.98*	*0.99*
4. Boat Creek	0.98	*0.90*	*0.96*
5. Inner Harbour	0.93	*0.94*	*0.98*
6. Calliope Estuary	0.94	*0.99*	*0.98*
7. Auckland Inlet	0.87	*0.94*	*0.94*
8. Mid Harbour	0.95	*0.97*	*0.99*
9. South Trees Inlet	0.98	*0.95*	*0.96*
10. Boyne Estuary	0.97	*0.98*	*1.00*
11. Outer Harbour	0.97	*0.96*	*0.96*
12. Colosseum Inlet	0.99	*1.00*	*1.00*
13. Rodds Bay	0.95	*0.99*	*0.98*

Habitats

The overall score for habitats was poor (0.33, D) with seagrass having a poor score of 0.39 (D) and coral a poor score of 0.28 (D). The coral score improved from very poor (0.15, E) in 2016 to poor in 2017, in part because of the addition of a new coral sub-indicator. The seagrass grade remained poor despite a slight improvement in the score from 0.35 to 0.39.

Seagrass

Three seagrass sub-indicators—biomass, area and species composition—were assessed in six reporting zones. Unlike other indicators in the report card, the scores for seagrass meadows were based on the lowest score for those sub-indicators rather than the average score. This is because if one of the sub-indicators was in a poor condition, then irrespective of the other two sub-indicator scores, the overall health of the seagrass meadow is deemed to be poor.

In 2017, South Trees Inlet received a good score (0.75), and The Narrows (0.59) and Western Basin (0.50) were in satisfactory condition. The Mid Harbour (0.34) received a poor score. The Inner Harbour (0.00) and Rodds Bay (0.19) were in very poor condition (Table 4). These very poor scores were due to low area scores in Rodds Bay and a low species composition score in the Inner Harbour (only one species of seagrass was present).

The overall seagrass score in 2017 of 0.39 (D) was similar to that recorded in 2016 of 0.35 (D) indicating a poor overall condition for seagrass. At the zone level, seagrass condition has improved in two zones—The Narrows and South Trees Inlet (Table 4).

Multiple years of high rainfall and cyclone activity in the Gladstone region may have reduced the resilience and capacity for recovery of seagrass communities in Gladstone as it has in other locations in Queensland. In the 2016–17 reporting year, the seed banks that assist recovery remained in key meadows and some seagrass was observed across most of the historical seagrass distribution.

Table 4: Scores for seagrass indicators (biomass, area and species composition) and overall meadow, zone and harbour scores for the 2017 reporting year and overall zone scores from 2015 and 2016.

Zone	Meadow	Biomass score	Area score	Species Composition score	Overall meadow score	Zone score 2017	*Zone score 2016*	*Zone score 2015*
1. The Narrows	21	0.60	0.59	0.63	0.59	0.59	*0.33*	*0.15*
3. Western Basin	4	1.00	0.66	0.73	0.66	0.50	*0.55*	*0.51*
	5	0.70	0.69	0.52	0.52			
	6	0.78	0.76	0.54	0.54			
	7	0.68	0.36	1.00	0.36			
	8	0.87	0.29	0.18	0.18			
	52–57	0.97	0.77	0.98	0.77			
5. Inner Harbour	58	0.73	0.87	0.00	0.00	0.00	*0.14*	*0.41*
8. Mid Harbour	43	0.14	0.66	0.60	0.14	0.34	*0.35*	*0.56*
	48	0.75	0.54	0.58	0.54			
9. South Trees Inlet	60	0.75	0.96	0.98	0.75	0.75	*0.48*	*0.52*
13. Rodds Bay	94	0.17	0.06	1.00	0.06	0.19	*0.25*	*0.45*
	96	0.42	0.65	0.57	0.42			
	104	0.13	0.07	0.28	0.07			
Harbour score						**0.39**	***0.35***	***0.43***

Corals

Four coral sub-indicators—coral cover, change in hard coral cover, macroalgal cover and juvenile density—were assessed at four reefs in the Mid Harbour and two reefs in the Outer Harbour (Table 5). In 2017, coral cover change was included for the first time to provide a measure of the rate of coral recovery in Gladstone Harbour. As with the other three sub-indicators, this sub-indicator is consistent with those used in the Australian Institute of Marine Science's Reef Plan Marine Monitoring Program. With the addition of the change in hard coral cover indicator, the overall grade for corals improved from E (0.15) in 2016 to D (0.28) in 2017. The improved score is largely attributable to the addition of the new sub-indicator, as scores for coral cover, juvenile density and macroalgal cover have remained similar to those recorded in previous years, although there has been a slight decline in juvenile density and a slight increase in coral cover.

Table 5: Coral indicator scores for the two surveyed harbour zones from 2015 to 2017.

Zone	Coral cover	Change in hard coral cover	Macroalgal cover	Juvenile density	Zone score 2017	*Zone score 2016*	*Zone score 2015*
8. Mid Harbour	0.08	0.44	0.50	0.33	0.33	*0.15*	*0.23*
11. Outer Harbour	0.06	0.37	0.00	0.44	0.21	*0.14*	*0.15*
Harbour score					**0.28**	***0.15***	***0.18***

Fish and crabs

For the first time, the 2017 Gladstone Harbour Report Card provides grades and scores for mud crab health and abundance indicators. Fish recruitment (bream species) is included for the second time and indicators for fish health are being developed and will be included in future report cards.

Fish

The overall score for fish recruitment in 2017 was 0.71 (B) compared to 0.40 (D) in 2016. This was measured in two species: yellow-finned bream *Acanthopagrus australis* and pikey bream *Acanthopagrus pacificus*. The final scores (Table 6) were measured against a five-year baseline (2011–12 to 2015–16). The 2017 score for fish recruitment indicates a season with a higher recruitment rate (increased catch rate) relative to the median reference level determined over the baseline period. However, statistical analysis identified large differences in fish recruitment between years (seasons) over this short time period. Hence this result is regarded as provisional at this stage as it may incorporate natural variability. Confidence in this indicator will improve as the dataset (number of years sampled) grows.

Table 6: Bream recruitment score for 13 harbour zones and the overall harbour score.

Zone	2017	*2016*	*2015**
1. The Narrows	0.75	*0.30*	*0.86*
2. Graham Creek	0.58	*0.44*	*0.72*
3. Western Basin	0.78	*0.36*	*Not surveyed*
4. Boat Creek	0.47	*0.36*	*0.80*
5. Inner Harbour	0.64	*0.33*	*0.80*
6. Calliope Estuary	0.79	*0.43*	*0.70*
7. Auckland Inlet	0.91	*0.53*	*0.80*
8. Mid Harbour	0.71	*0.29*	*Not surveyed*
9. South Trees Inlet	0.71	*0.43*	*0.72*
10. Boyne Estuary	0.74	*0.54*	*0.69*
11. Outer Harbour	Not surveyed	*Not surveyed*	*Not surveyed*
12. Colosseum Inlet	0.71	*0.45*	*Not surveyed*
13. Rodds Bay	0.74	*0.58*	*Not surveyed*
Harbour average	**0.71**	***0.40***	***0.80***

*The 2015 results are shown for comparison only as they were not included in the 2015 report card.

Mud crabs

Three mud crab measures were assessed in 2017: abundance, prevalence of rust lesions and size (sex ratio). A fourth measure, biomass, will be included in the future when sufficient data are accumulated to determine a biomass baseline.

The overall mud crab score, 0.55 (C), was calculated from monitoring in 7 of the 13 environmental monitoring zones (Table 7). Three of those seven zones received very good scores for abundance, three zones received very poor scores and one zone had a satisfactory score. Owing to the variability that can occur in abundance data which are sensitive to local pressures, this measure has low reliability. Confidence in this measure will improve as the dataset (number of years sampled) increases.

In Queensland mud crab fisheries, it is illegal to take female crabs. Therefore, changes in the ratio of male to female crabs can indicate changes in fishing pressures. This measure assesses the ratio of legal-size male crabs (>15cm spine width) to female crabs (>15cm spine width). Scores for this measure were generally poor to very poor. Rust spots (shell lesions) were first reported in Gladstone Harbour by commercial fishers in 1994.

In the report card, visual inspection is used to monitor rust spots. In 2017, five zones received very good scores for this measure and the remaining two zones had a good and a satisfactory score indicating low levels of rust spots across the harbour.

Table 7: Mud crab score for seven harbour zones and the overall harbour score.

Zone	Abundance (CPUE*)	Prevalence of rust lesions	Size (sex ratio)	Zone score 2017
1. The Narrows	1.00	1.00	0.00	0.66
2. Graham Creek	0.52	0.95	0.36	0.61
4. Boat Creek	1.00	1.00	0.11	0.70
5. Inner Harbour	1.00	0.89	0.71	0.87
6. Calliope Estuary	0.14	0.90	0.36	0.47
7. Auckland Inlet	0.12	0.63	0.00	0.25
13. Rodds Bay	0.03	0.67	0.39	0.36
Harbour score				**0.55**

*catch per unit effort

Social health

The overall score for social health in 2017 was 0.66 (B) which is identical to the score received in 2016. This score was based on three indicators of social health: harbour usability (0.62, C), harbour access (0.66, B) and liveability and wellbeing (0.66, B) (Table 8).

All scores were similar to the 2016 scores, although the grade for harbour usability declined from good (B) to satisfactory (C) as a result in changes to 'perceptions of harbour safety for human use' which declined from 0.76 (B) to 0.60 (C).

The overall social health of the harbour has remained stable since 2015 suggesting people living in the Gladstone region feel that Gladstone Harbour provides them with a positive living experience and quality of life.

Table 8: Scores for social indicator groups and indicators from 2015 to 2017.

Indicator groups	2017 Score	*2016 Score*	*2015 Score*	Social indicators	2017 Score
Harbour usability	0.62	*0.66*	*0.65*	Satisfaction with harbour recreational activities	0.69
				Perceptions of air and water quality	0.56
				Perceptions of harbour safety for human use	0.60
Harbour access	0.66	*0.65*	*0.62*	Satisfaction with access to the harbour	0.72
				Satisfaction with boat ramps and public spaces	0.65
				Perceptions of harbour health	0.63
				Perceptions of barriers to access	0.65
Liveability and wellbeing	0.66	*0.66*	*0.64*	Liveability and wellbeing	0.66

Cultural health

The overall score for the cultural health of Gladstone Harbour was 0.62 (C). Two indicator groups for cultural health were assessed: 'sense of place' 0.65 (B) (Table 9) and Indigenous cultural heritage 0.55 (C) (Table 10). Traditional Owners were consulted in the development of the Indigenous Cultural Heritage indicator and participated in field surveys. The overall score for 'sense of place' was similar to that scored in 2016 and 2015 (Table 8). Indigenous cultural heritage was assessed for the second time and gave a similar score to that recorded in 2016.

Table 9: Scores for the 2016 and 2015 'sense of place' indicator group.

Indicator group	2017 Score	*2016 Score*	*2015 Score*	Indicators	2017 Score
'Sense of place'	0.65	*0.66*	*0.65*	Distinctiveness	0.57
				Continuity	0.54
				Self-esteem	0.72
				Self-efficacy	0.58
				Attitudes to harbour	0.81
				Values of harbour	0.66

Table 10: Scores for Indigenous cultural heritage indicators and overall harbour score for the 2017 report card.

Zone	Cultural health			Management strategies			Zone score 2017	*Zone score 2016*
	Spiritual & social values	Scientific values	Physical condition	Protection	Land use	Cultural maintenance		
The Narrows	0.73	0.57	0.53	0.70	0.45	0.38	0.56	*0.53*
Facing Island	0.57	0.65	0.66	0.70	0.50	0.25	0.55	*0.57*
Wild Cattle Creek	0.39	0.54	0.64	0.65	0.55	0.25	0.50	*0.44*
Gladstone Central	0.84	0.67	0.50	0.50	0.80	0.40	0.60	*0.59*
Harbour score for Indigenous cultural heritage							**0.55**	***0.53***

Economic health

The overall score for the Economic component of the 2017 report card of 0.74 (B), which is similar to the 2016 score of 0.75 (B). The 2017 score was determined by the scores from three indicator groups: economic performance (0.90, A), economic stimulus (0.67, B) and economic value (0.73, B) (Table 11).

The economic performance indicator group comprises three indicators: shipping activity, tourism and commercial fishing. These reflect the key industries using the harbour and were weighted according to economic activity and a survey of local industry and community leaders.

The overall score for the economic performance indicator group was 0.90 (A) up from 0.87 (A) in 2016, a result of increased scores for shipping activity and tourism. Commercial fishing remained poor although the score declined from 0.43 in 2016 to 0.35 in 2017.

The economic stimulus indicator group comprises two indicators: employment and socio-economic status. The overall score for economic stimulus was 0.67 (B), which is a result of lower scores for both indicators. Employment was 0.53 (C) in 2017 compared to 0.62 (C) in 2016, and socio-economic status was 0.70 (B) in 2017 compared to 0.80 (B) in 2016.

The score for economic value 0.73 (B) was identical to the score received in 2016.

Table 11: Scores for the economic indicator groups and scores from 2015 to 2017.

Indicator group	2017 Score	2016 Score	2015 Score	Indicators	2017 Score
Economic performance	0.90	0.87	0.79	Shipping activity	0.90
				Tourism	0.90
				Commercial fishing	0.35
Economic stimulus	0.67	0.74	0.82	Employment	0.53
				Socio-economic status	0.70
Economic value (recreational)	0.73	0.73	0.72	Land-based recreation	0.76
				Recreational fishing	0.65
				Beach recreation	0.74

1. Introduction

1.1. The Gladstone Healthy Harbour Partnership

1.1.1. Overview

The Gladstone Healthy Harbour Partnership (GHHP) is a forum that brings together numerous parties to maintain and, where necessary, improve the health of Gladstone Harbour. The GHHP vision is that 'Gladstone has a healthy, accessible, working harbour'. The guiding principles of the partnership are open, honest and accountable management, annual reporting of the health of Gladstone Harbour and management advice. Actions are based on rigorous science and strong stakeholder engagement to ensure the ongoing and continuous improvement of the health of Gladstone Harbour.

AN ENVIRONMENTALLY HEALTHY HARBOUR
… has functioning and interconnected key ecosystems and ecosystem services, supports sustainable populations of marine species and has natural tidal and seasonal variations of water and sediment quality parameters.

A SOCIALLY HEALTHY HARBOUR
… is a place in which the community has civic and community pride and continues to support a sense of community (e.g. friendliness, easy access, personal relationships and lifestyle) and has infrastructure that allows citizens to easily and safely use, access and enjoy the harbour and foreshore for recreation.

A CULTURALLY HEALTHY HARBOUR
… is a place in which the cultural heritage and cultural heritage sites (such as stone quarries and middens) are preserved and in which the community has a sense of identity and satisfaction with its condition.

AN ECONOMICALLY HEALTHY HARBOUR
… is a working harbour that contributes to a positive diverse economic future, supports existing and new industries and returns economic benefit to the whole community.

The GHHP partnership has 26 partners comprising 13 industry representatives; 6 research and monitoring agencies; local, state and federal government representatives and 4 community groups including Traditional Owners. The GHHP was formally launched on 6 November 2013 when partner representatives agreed to work together to achieve the GHHP vision that 'Gladstone has a healthy, accessible, working harbour'.

The Independent Science Panel (ISP) provides independent scientific advice, review and direction. Its role is to ensure that the environmental, social, cultural and economic challenges of policy, planning and actions as they relate to achieving the GHHP vision are supported by credible science.

1.1.2. Moving from a vision to objectives and indicators of harbour health

The GHHP vision was developed in a series of interactive workshops held with the local Gladstone and regional community (including Traditional Owner groups – Gooreng Gooreng, Taribelang Bunda, Bailai and Gurang tribal groups), industry (including commercial fishers), government representatives, research organisations, conservation groups and recreational fishers.

The ISP developed a set of 'report card objectives' from the GHHP vision that were accepted by the GHHP Management Committee on behalf of the partnership. The objectives are the measurable goals that underpin the GHHP monitoring and reporting program. In consultation with the GHHP partners, the ISP grouped the objectives into the identified Environmental, Cultural, Social and Economic components and used them to select the specific indicators to be measured and reported against (Figure 1.1).

The ISP commissioned a review of the international and national use of report cards (Connolly et al., 2013), a review of the available data relevant to Gladstone (Llewellyn et al., 2013) and reports to assist in selecting social, cultural and economic indicators (Greer & Kabir, 2013), and environmental indicators (Dambacher et al., 2013). The ISP used the recommendations from these reports and local issues to guide the final selection of indicators. These reports are available on the GHHP website.

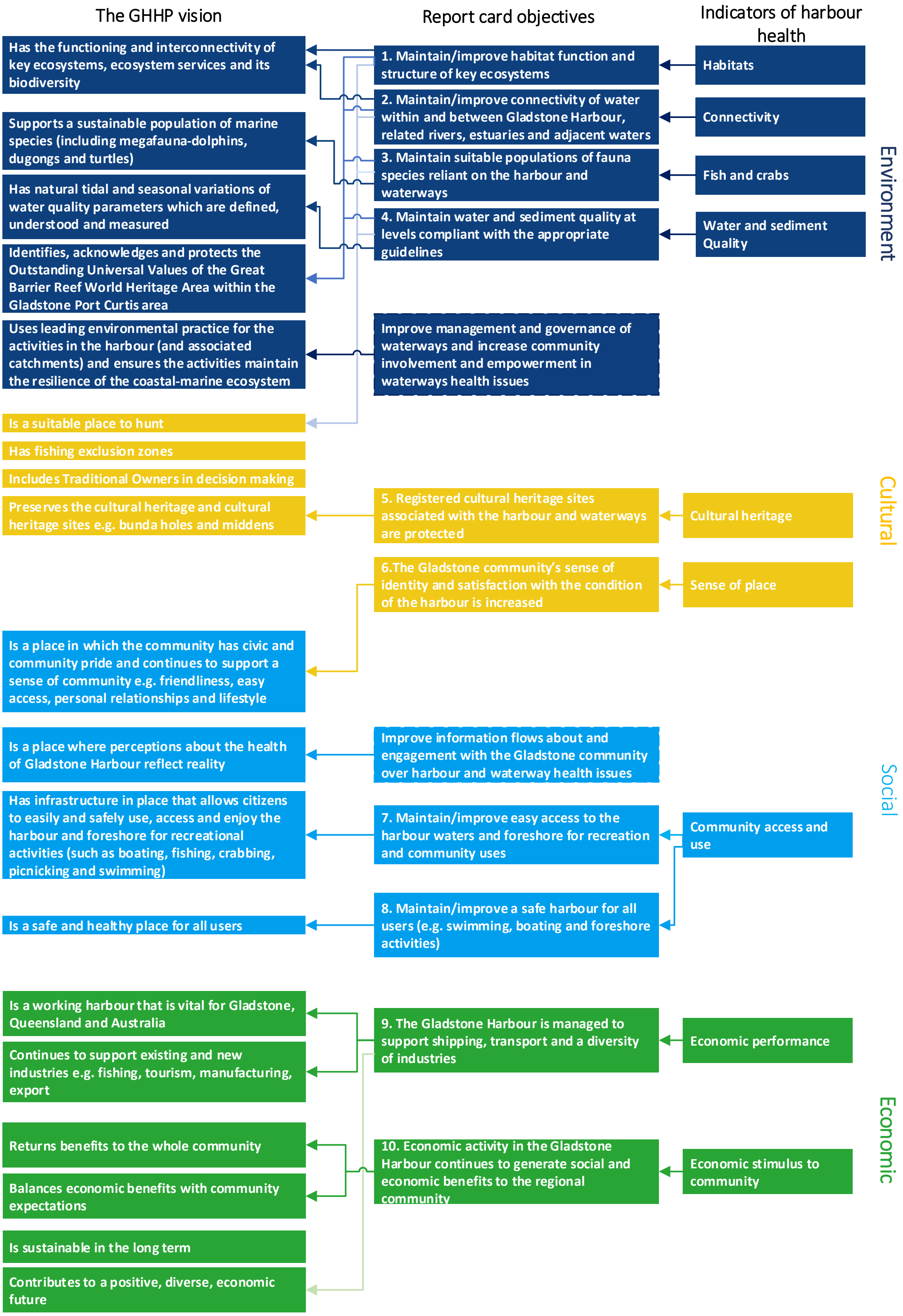


Figure 1.1: The Gladstone Harbour Report Card objectives and harbour health indicators were developed from the GHHP vision statements for the Environmental, Cultural, Social and Economic components of Gladstone Harbour health.

1.1.3 *The four components of harbour health*

The 2015 Gladstone Harbour Report Card is one of the first report cards in Australia to report on environmental, social, cultural and economic health (Figure 1.2). Stakeholder and community consultation identified these four components as important to the community.

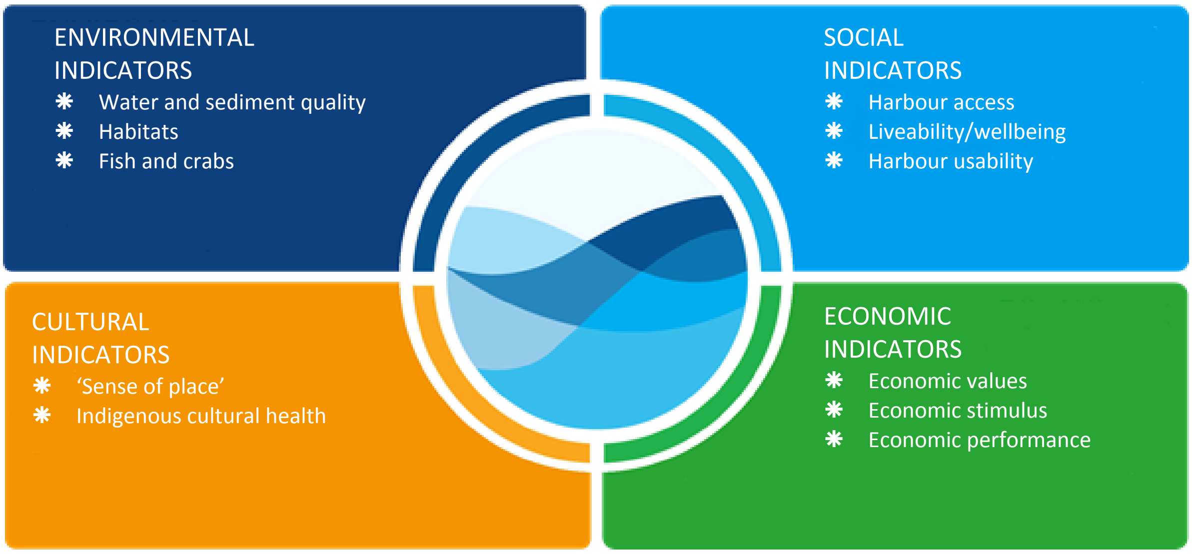


Figure 1.2: The four components of harbour health.

1.2. The science program

The GHHP science program commenced in 2013 and is now in its fourth year. It has passed through three key phases, the design phase (in 2013) and the pilot phase (in 2014); and an operational phase has been ongoing since 2015 (Figure 1.3). The science program includes many projects that inform the report card indicators. The ISP, with the agreement of the GHHP Management Committee, develops these projects to help design and implement the Gladstone Harbour Report Card and its ongoing improvement. When completed, the final reports from each of these projects will be available on the GHHP website. Refer to Appendix 1 for a list of GHHP projects.

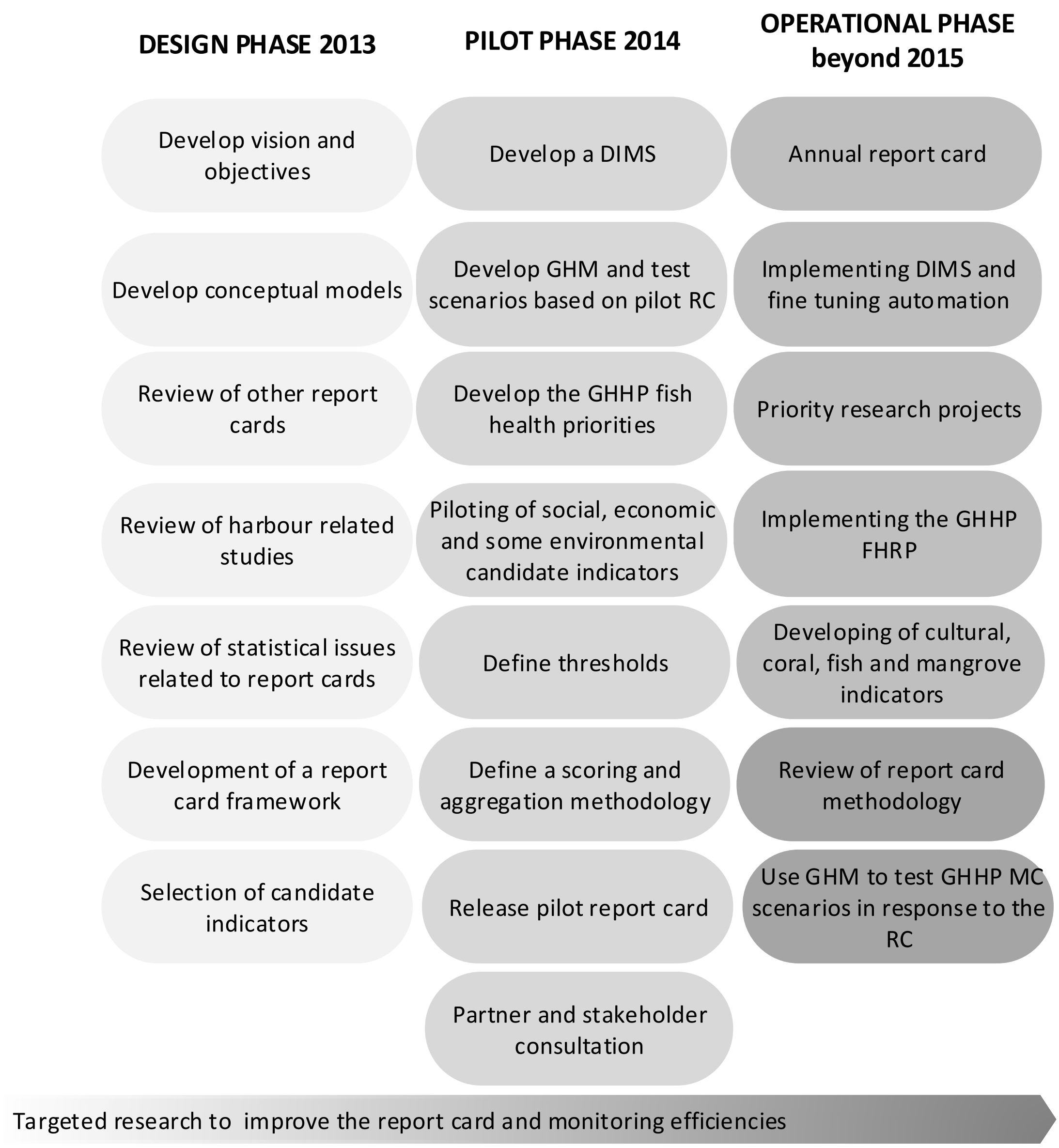


Figure 1.3: The three phases of the GHHP science program. DIMS = Data Information Management System, GHM = Gladstone Harbour Model; RC = Report Card; MC = Management Committee, FHRP = Fish Health Research Program.

1.3. Reporting periods

The reporting period for the 2017 Gladstone Harbour Report Card was 1 July 2016 to 30 June 2017. This allows the significant environmental changes that occur in the wetter summer months to be captured in the annual data. However, some data collected prior to the 2016–17 financial year for the Social and Economic components were used as they were the most up-to-date available.

2. From indicators to report card grades

2.1. Structure and indicators

Terminology has been developed to describe the hierarchy of scores for each component of harbour health. This can include up to five levels of aggregation: component, indicator group, indicator, sub-indicator and measure (Table 2.1). This structure derives component scores from raw data collected through field sampling, community surveys and publicly available sources.

Table 2.1: The five levels of aggregation employed to determine the grades and scores in the 2015 Gladstone Harbour Report Card.

Name	Explanation
Level 1: Component	The Gladstone Harbour Report Card reports on the condition of four components of harbour health: Environmental, Social, Cultural and Economic.
Level 2: Indicator group	Group of several related indicators – for instance, the indicator group 'habitats' comprises the indicators seagrass and corals; the indicator group 'economic performance' comprises the indicators shipping activity, tourism and fishing.
Level 3: Indicator	An aspect of a system that may be used to indicate the state or condition of that system – for instance, 'water quality and seagrass' may be used to indicate the environmental condition of Gladstone Harbour; 'shipping activity' may be used to indicate the economic state of the Gladstone Harbour.
Level 4: Sub-indicator	Group of several related measures – for instance, the 'nutrients sub-indicator' (within water quality) comprises the measures total nitrogen and total phosphorus.
Level 5: Measure	A numerical value assigned to an individual parameter used to assess harbour health. It may be based on a single measurement or combination of measurements for each parameter (e.g. an annual average).

Each indicator has a baseline and five ranges (A to E) that determine the grade for each measurement type. The methods used to determine baselines for each indicator are described in detail in the relevant sections of this report. Each threshold is a decimal value between 0.00 and 1.00 (Figure 2.1). Scores are assigned to measurements that are then aggregated upwards towards a component.

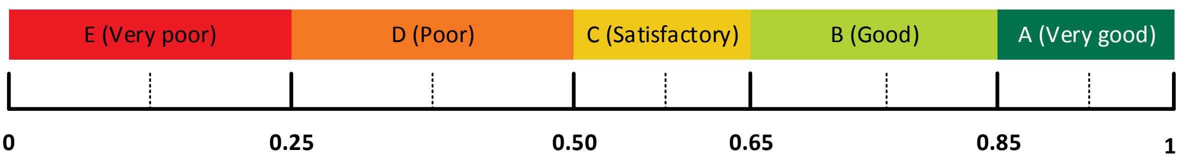


Figure 2.1: Grade ranges used in the 2017 Gladstone Harbour Report Card.

Aggregation of report card grades and scores

A number of methods have been used to calculate an index value for the smallest geographic unit of reporting (e.g. 'site' for water and sediment quality, 'reef' for coral indicators and 'meadow' for seagrass indicators) for the 2016–17 reporting period.

For example, the starting point for water quality index calculation was the annual mean value for a measure per site. This was calculated by averaging the field data collected on four occasions in the 2016–17 reporting year. The annual site means were used to develop indexed scores between 0 and 1 compared with relevant guidelines (DEHP water quality objectives or ANZECC/ARMCANZ guidelines as appropriate). This yielded final indexed scores at site level which could be aggregated to higher levels of reporting (Figures 2.2a–d). References have been provided on the methods used to calculate the indexed values for coral, seagrass, and fish and crabs indicators in their respective sections in this report.

Aggregation used a hierarchical approach so that scores for a range of reporting levels (e.g. indicator, indicator group and component) could be generated for individual zones and for the whole harbour for reporting. The lowest level of reporting (e.g. measures such as aluminium, copper, lead, manganese, nickel and zinc for a site) was aggregated to the next level (e.g. metals in water) using bootstrapped distributions rather than direct means of each measure. The bootstrapping method resamples the original data many times to yield multiple means which are used to develop a series of distributions for measures, sub-indicators, indicators and indicator groups. By aggregating distributions (rather than individual means), the rich distributional properties could be preserved, sample bias could be avoided, and means (the report card score) and variances could be calculated for reporting (Figure 2.3).

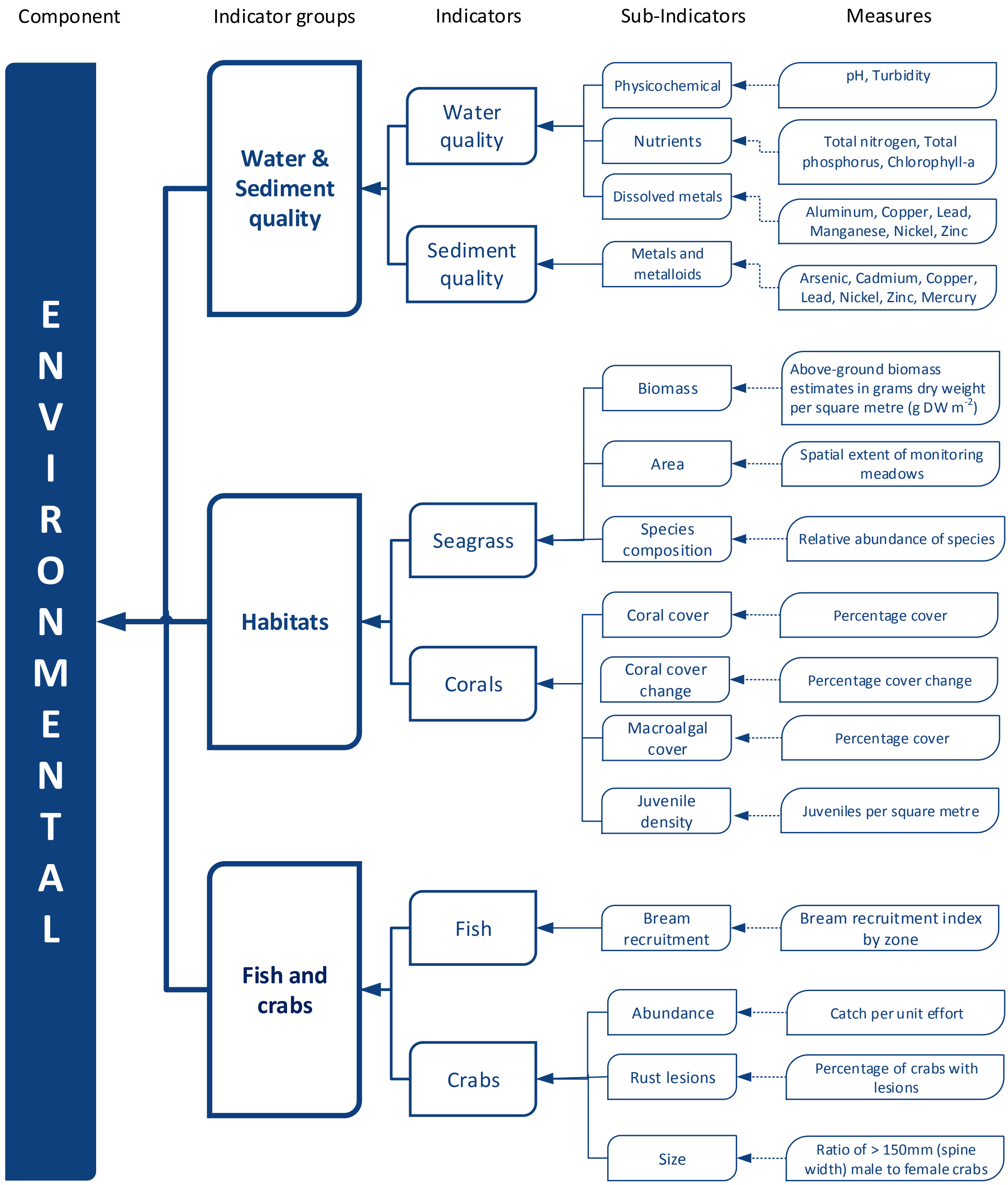


Figure 2.2a: The levels of aggregation used to determine the environmental scores and grades in the 2017 Gladstone Harbour Report Card. There are 3 environmental indicator groups, 6 Indicators, 15 sub-indicators and 29 measures.

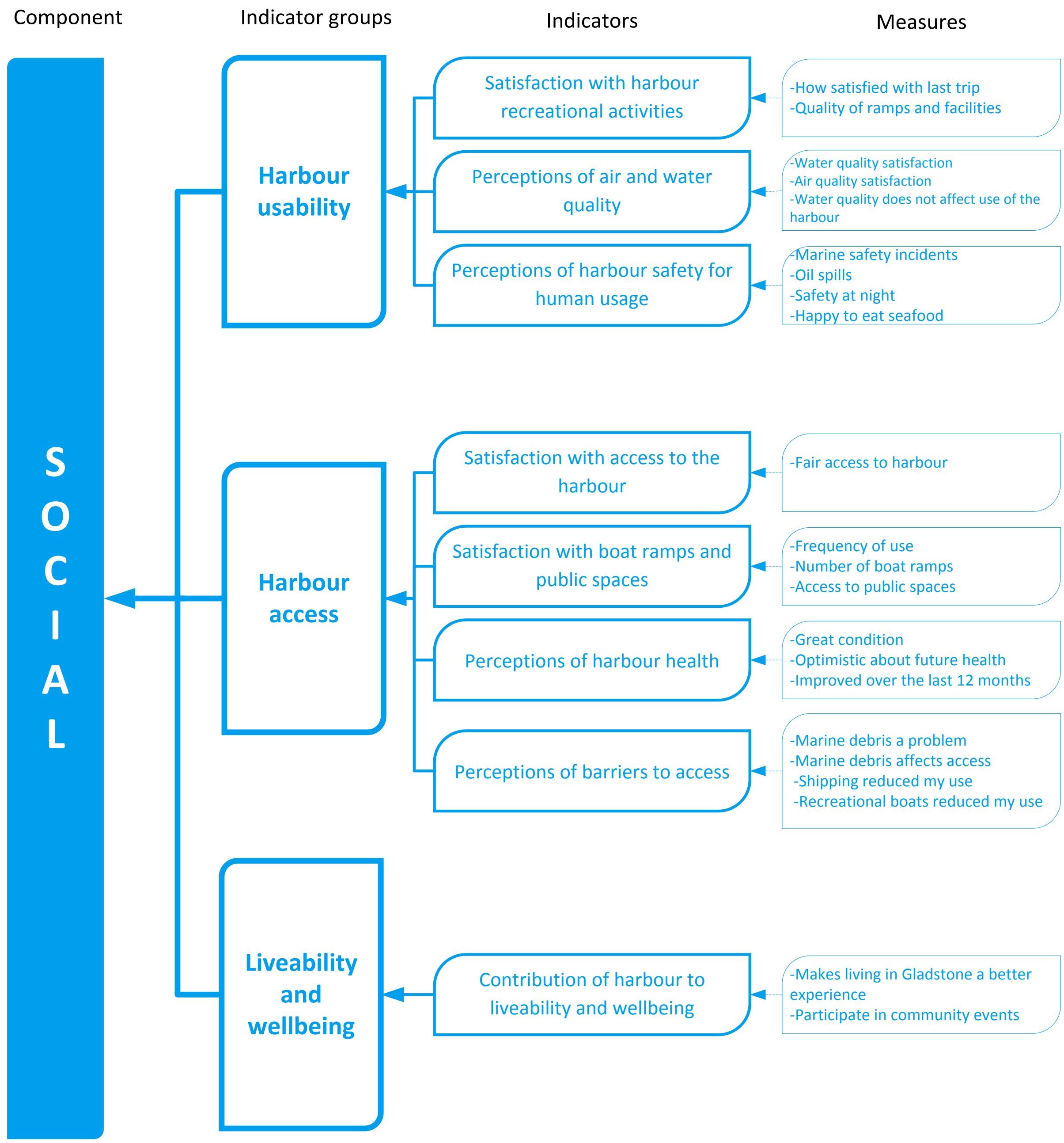


Figure 2.2b: The levels of aggregation used to determine the social scores and grades in the 2017 Gladstone Harbour Report Card. There are 3 social indicator groups, 8 indicators and 22 measures.

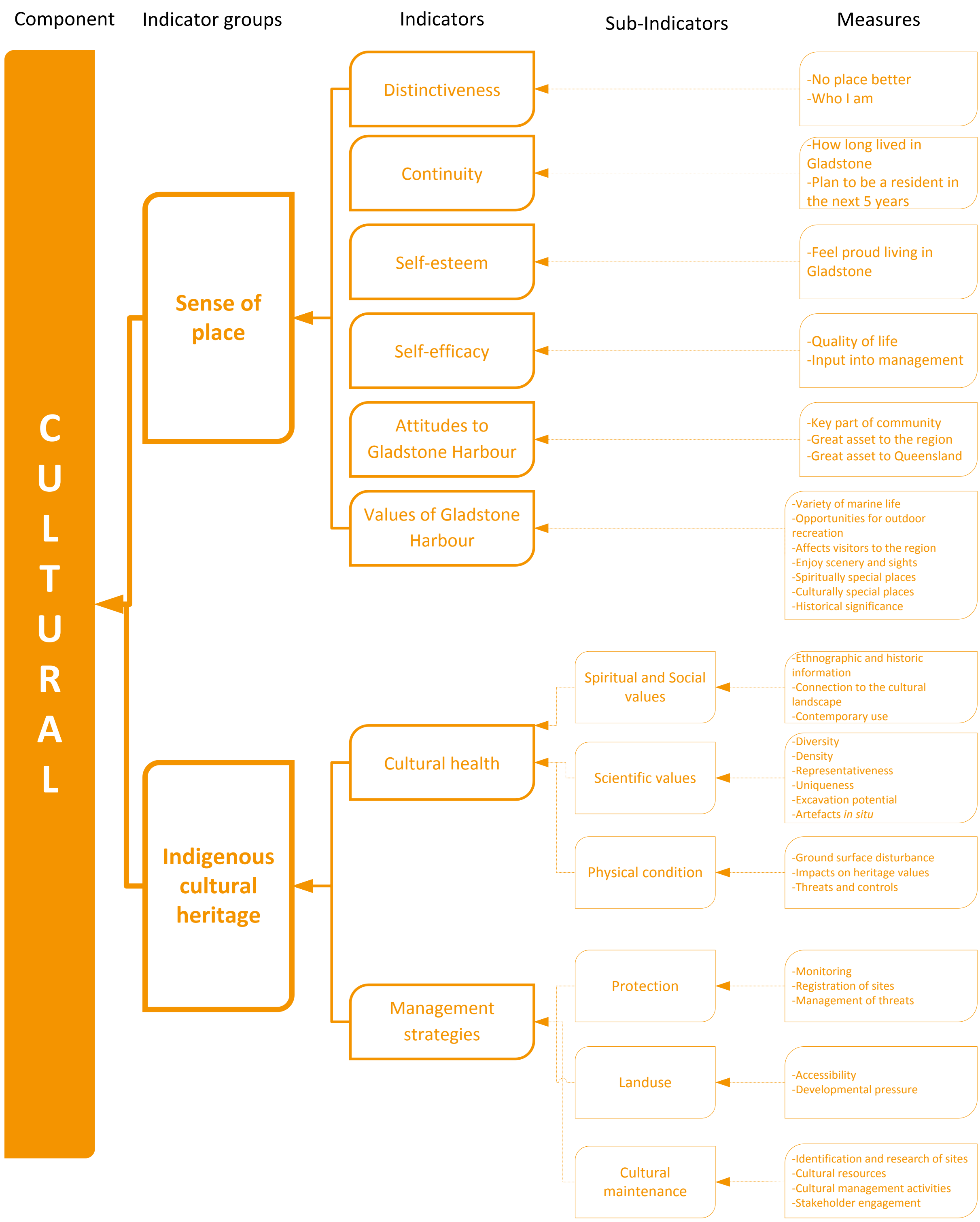


Figure 2.2c: The levels of aggregation used to determine the cultural grades and scores in the 2017 Gladstone Harbour Report Card. There are 2 cultural indicator groups, 8 indicators, 6 sub-indicators and 38 measures.

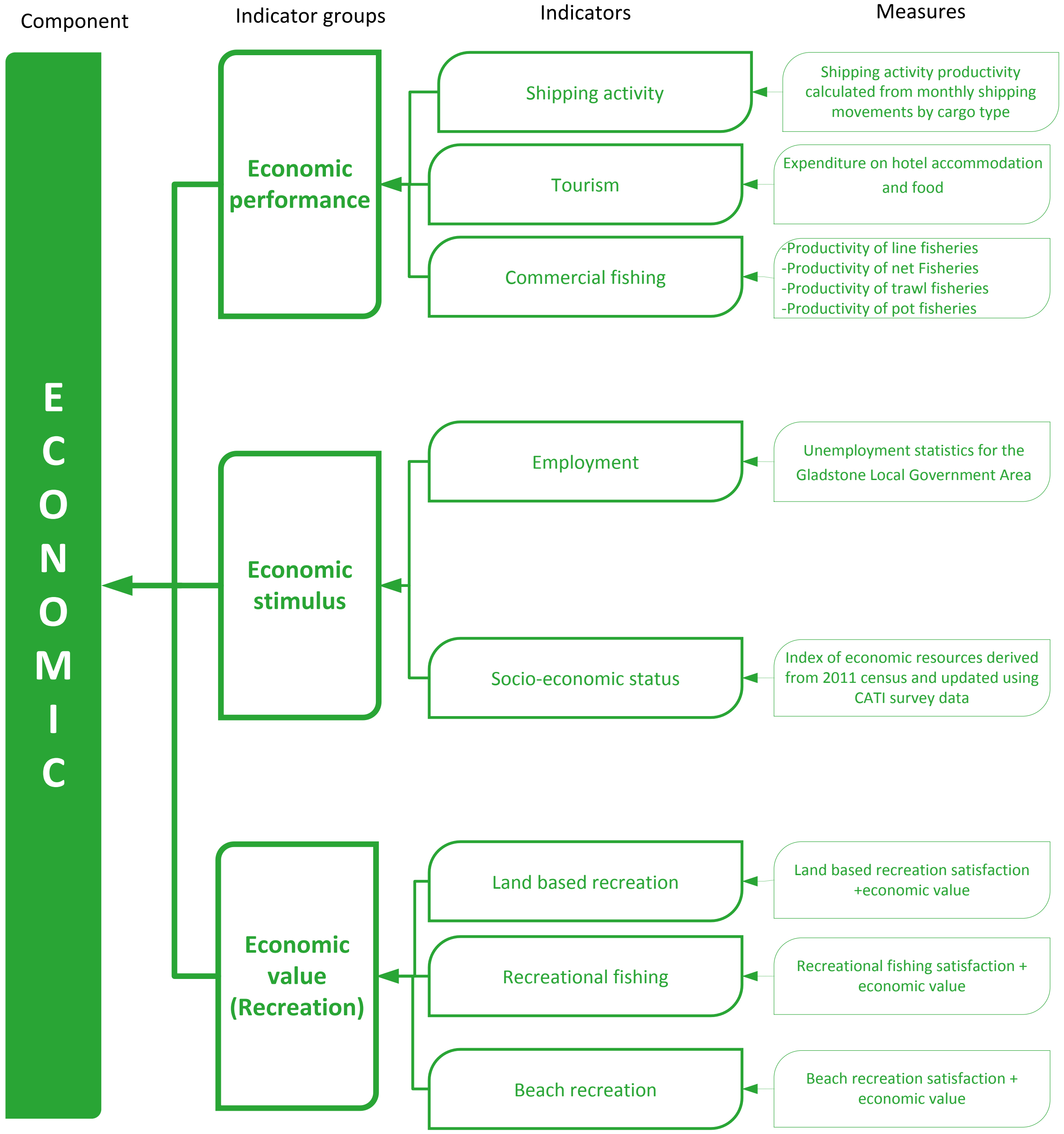


Figure 2.2d: The levels of aggregation used to determine the economic scores and grades in the 2017 Gladstone Harbour Report Card. CATI = computer-assisted telephone interviewing. There are 3 economic indicator groups, 8 indicators and 11 measures.

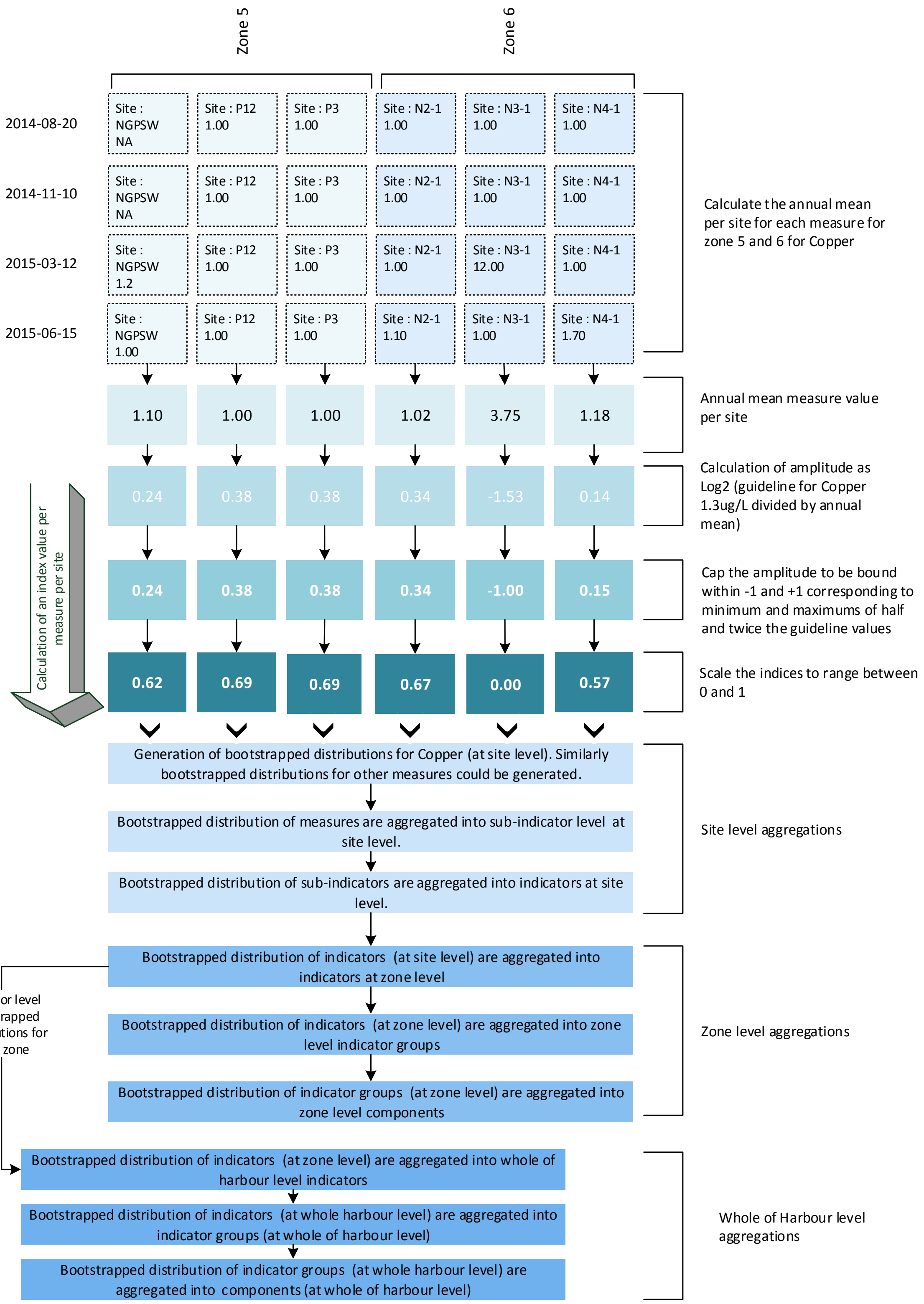


Figure 2.3: Aggregation of report card scores – a worked example using the water quality measure for copper in zones 5 and 6.

2.2. Confidence ratings

The ISP assigned the confidence rating for each of the four components within the report card on a three-point scale (low, moderate and high). These ratings were informed by assessing the appropriateness of the indicators, the number of missing indicators, the adequacy of sampling designs and the availability, completeness and quality of the monitoring data.

The Environmental component received a moderate confidence rating. Although the water and sediment quality, habitat, and fish and crab data were regarded as reliable, the full suite of indicators was not available for this year. Mangrove and fish health indicators are currently in development and when included will complete the Environmental component. Nitrous oxides (NO_x), orthophosphate and ammonia were not included in the water quality indicator, as analytical detection limits for these measures were insufficient to enable a reliable comparison to guideline values. Further limitations were that water quality sampling was only conducted on four occasions in the 2016–17 reporting year and only at 'far field' sites (sites selected to be remote from point sources of pollutants) rather than at randomly selected sites.

The Social component received a high confidence rating. This was because the computer-assisted telephone interviewing (CATI) survey that contributed most of the data used is regarded as reliable and repeatable and was improved this year by including mobile phone users. However, the 18- to 24-year-old age group is still under-represented in the survey. The Maritime Safety Queensland (MSQ) data are for recreational vessels only and the Gladstone Maritime Region includes areas well beyond Gladstone Harbour. Despite these minor issues, the overall grade for the Social component was still based on a complete set of indicators with no major issues regarding data availability, adequacy or quality.

The Cultural component, consisting of Indigenous cultural heritage and 'sense of place' derived from data collected from the CATI survey, received a moderate confidence rating. This was the same rating as 2016. While there have been improvements in the Indigenous cultural heritage indicator including weighting the scores based on inputs from Traditional Owners and Elders and including 11 new sites, several issues remain. Not all sites surveyed in 2016 were resurveyed in 2017 and not all measures in the assessment framework are suitable for all sites. Additionally, the methodology to assess Indigenous cultural heritage in a report card framework is new and untested. This indicator will be reviewed in 2018 and may be revised. The methodology to assess 'sense of place' is well established but based on a single survey only and there is no corroborating data. The development of ways to corroborate the 'sense of place' data and continued development of the Indigenous cultural heritage indicator will lead to improved confidence for this component.

The Economic component received a high confidence rating because the CATI survey design was reliable, repeatable and developed specifically for the Gladstone Harbour Report Card. Other data that contribute to the economic grade came from a variety of reputable sources. The grade for the Economic component was based on a complete set of indicators and there were no major issues with data availability, adequacy or quality.

3. Geographical scope

3.1. Environmental reporting zones

The 13 environmental reporting zones in Gladstone Harbour have developed over time from an initial 7 zones proposed by Jones et al. (2005) in a risk assessment for contaminants in Gladstone Harbour. In their 2007 Port Curtis Eco Card, the Port Curtis Integrated Monitoring Program (PCIMP) increased the number of zones to nine by including oceanic and estuarine reference sites (Storey et al., 2007). However, these two reference zones were combined in the Port Curtis Eco Card 2008–2010 (PCIMP, 2010) resulting in eight zones. The Queensland Department of Environment and Heritage Protection (DEHP) developed the current 13 zones (Figure 3.1). These zones were also used to define regionally specific water quality objectives for the Capricorn Coast (DEHP, 2014a).

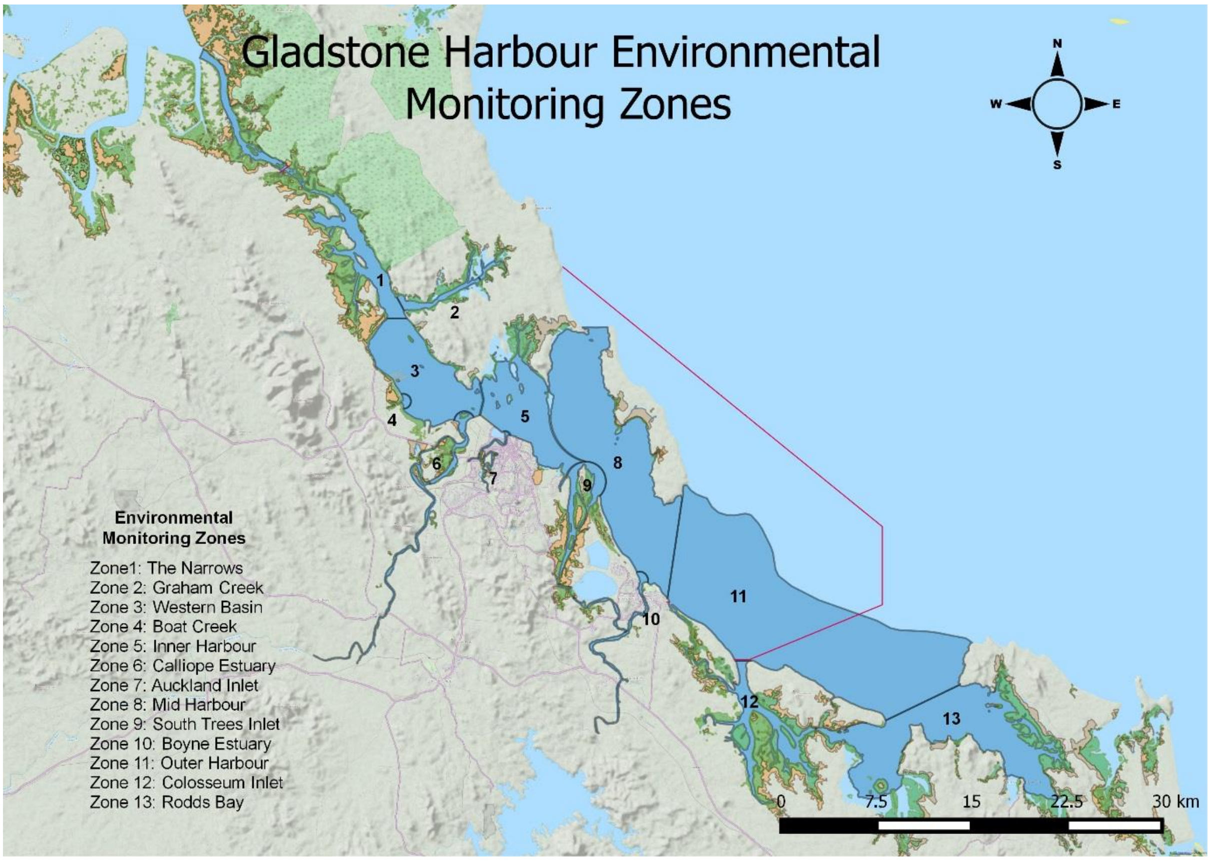


Figure 3.1: The 13 Gladstone Harbour zones for which environmental parameters were measured for the 2017 Report Card.

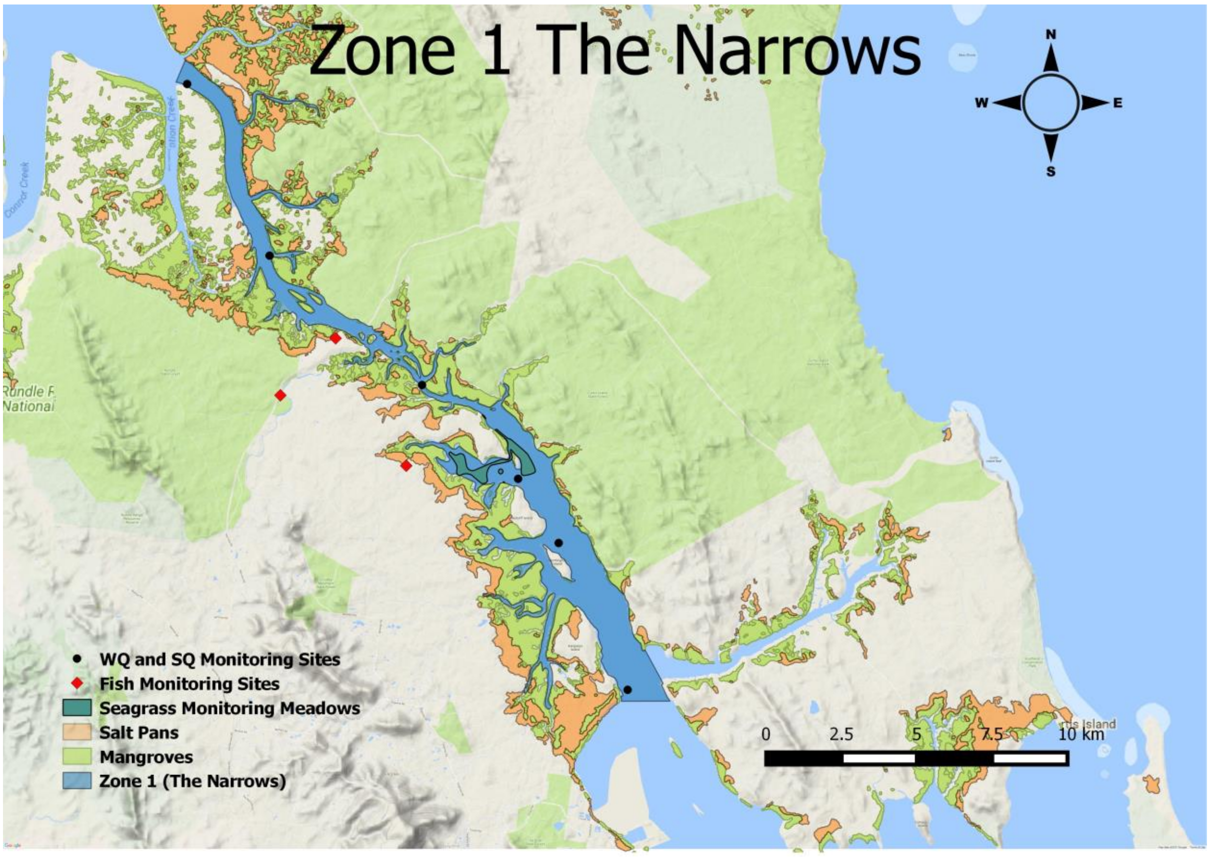


Figure 3.2: Habitat types and water and sediment quality sampling sites in The Narrows.

Six water and sediment quality monitoring sites
One seagrass monitoring meadow
Two fish monitoring sites
One crab monitoring site

Zone area: 29.25km^2

The Narrows is the northern outlet of Gladstone Harbour. It connects the harbour to Keppel Bay near the mouth of the Fitzroy River and separates Curtis Island from the mainland. Curtis Island has a number of conservation zones including national parks, regional parks and state forests and is considered to have significant environmental and cultural value (Commonwealth of Australia, 2013). The Narrows is lined by mangroves and saltmarsh; it provides sheltered water and is an important area for recreational and commercial fisheries (PCIMP, 2010). This zone has one monitored seagrass meadow—an intertidal meadow comprising aggregated patches of seagrass near Black Swan Island.

Figure 3.3: The Narrows photographed from the south with Keppel Bay in the distance.

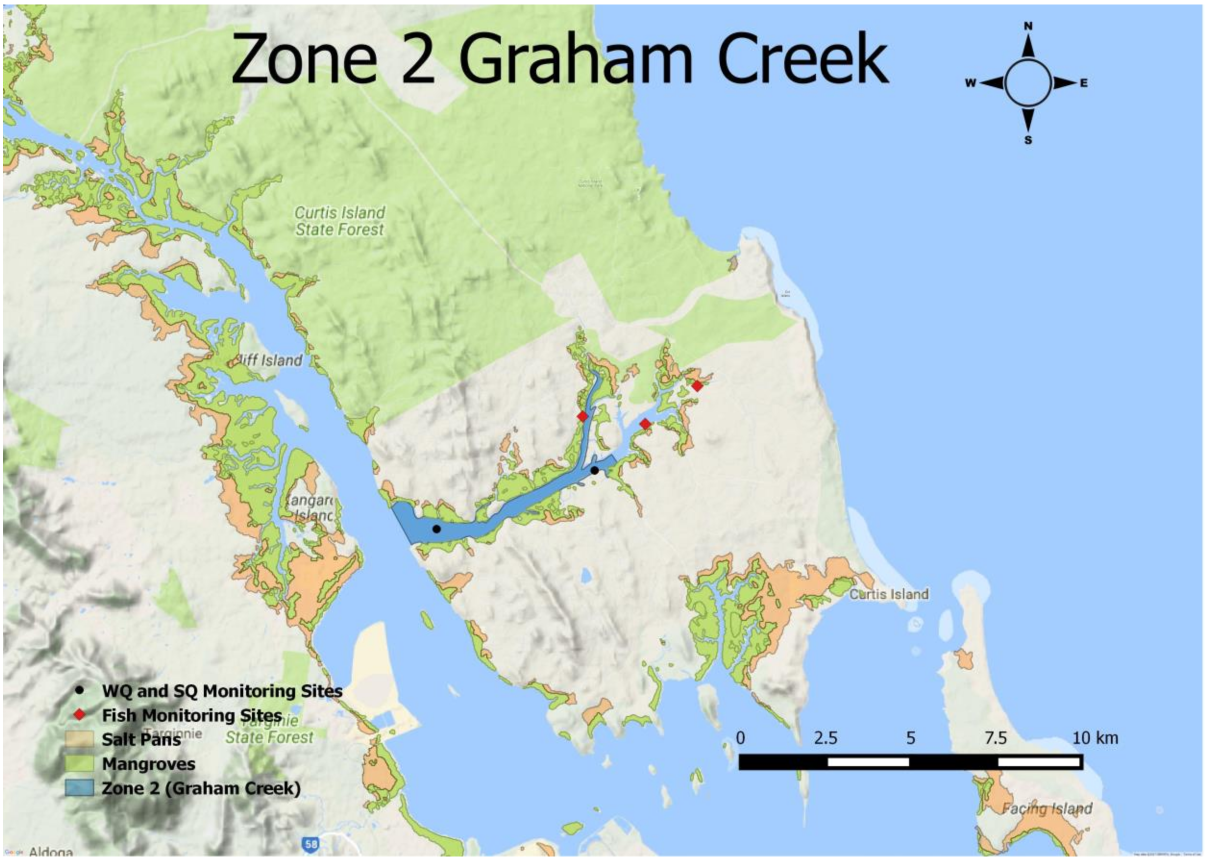


Figure 3.4: Habitat types and water and sediment quality sampling sites in Graham Creek.

Two water and sediment quality monitoring sites
Two fish monitoring sites
One mud crab monitoring site

Zone area: 5.8km^2

Graham Creek is a mangrove-lined tidal inlet located near the south-west corner of Curtis Island. It is approximately 9km long and flows into the southern end of The Narrows. It is considered one of the best fishing spots in Gladstone Harbour. Three major creeks—Rawbelle, Hobble Gully and Logbridge—flow into Graham Creek.

Figure 3.5: The south-western end of Curtis Island photographed from the north. Graham Creek is in the middle of the picture and the Western Basin is in the distance.

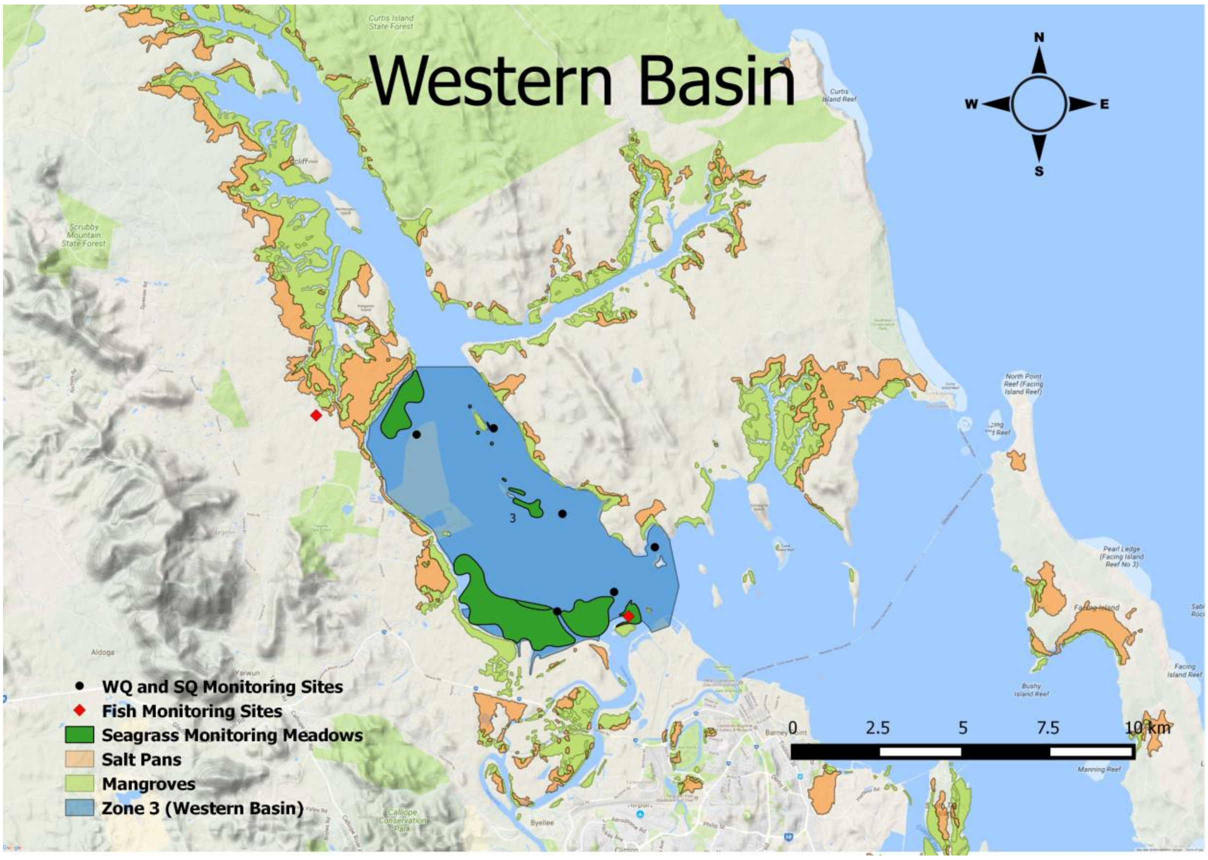


Figure 3.6: Habitat types and water and sediment quality sampling sites in the Western Basin.

Six water quality and sediment quality monitoring sites
Six monitored seagrass meadows
Two fish monitoring sites

Zone area: 39.19km^2

The Western Basin is located near the north-western end of Gladstone Harbour. Three large-scale liquid natural gas (LNG) plants have been constructed on the south-western shore of Curtis Island. The first of these started operating in late 2014. Large industrial plants located on the western shore of this zone include Queensland Energy Resources, Rio Tinto Yarwun, Orica, Transpacific Waste and Cement Australia. The zone includes six monitored seagrass meadows. Areas of mangroves and mudflats remain between Fisherman's Landing and the Wiggins Island Coal Export Terminal (WICET) and on the southern tip of Curtis Island.

Figure 3.7: The south-western corner of Curtis Island, showing two liquid natural gas plants in the foreground and the Western Basin in the distance.

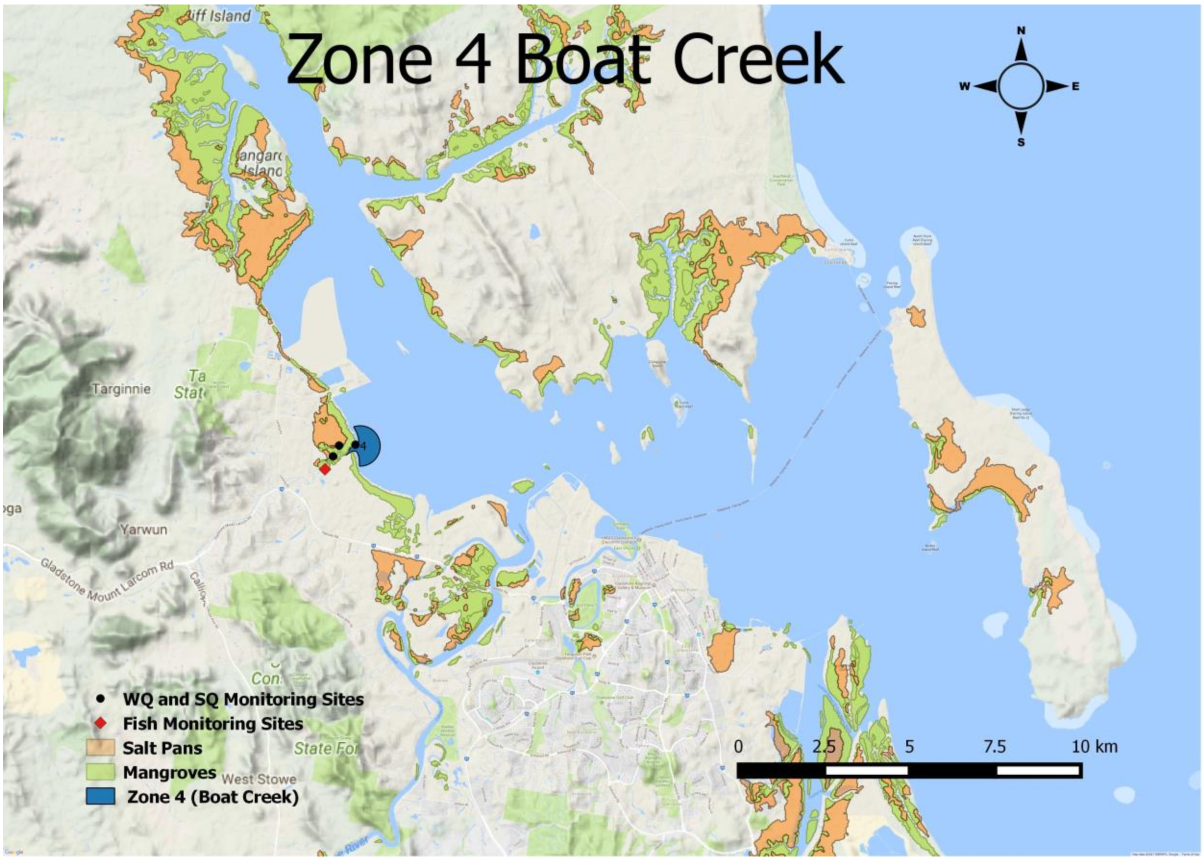


Figure 3.8: Habitat types and water and sediment quality sampling sites in Boat Creek.

Three water and sediment quality monitoring sites
Two fish monitoring sites
One mud crab monitoring site

Zone area: 0.75km^2

Boat Creek is a small mangrove-lined estuary connected to the western side of the Western Basin. This long (approximately 9km), narrow water body is not well flushed during regular tides. It is a small zone that includes approximately 2km of waterway and a small open harbour area near the mouth.

Figure 3.9: Inlet to Boat Creek photographed from the Western Basin.

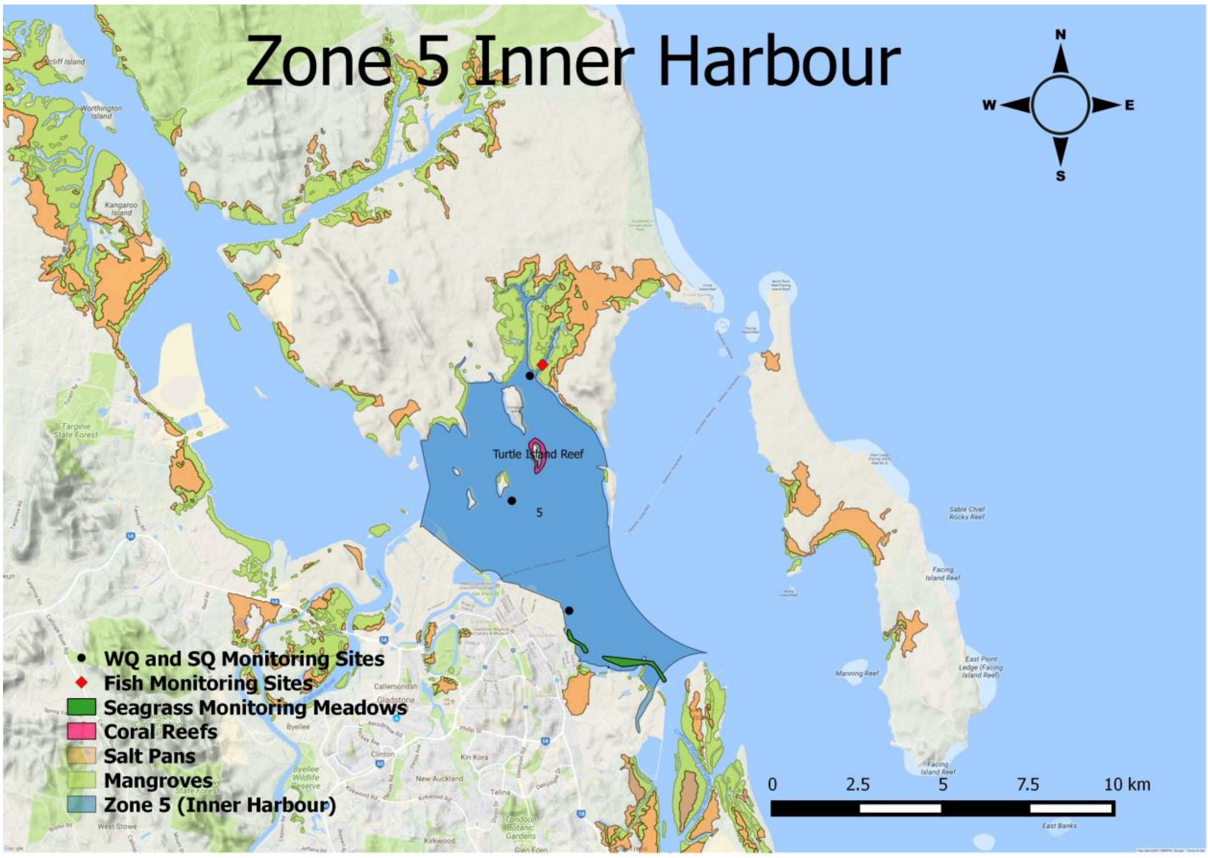


Figure 3.10: Habitat types and water and sediment quality sampling sites in the Inner Harbour.

Three water and sediment quality monitoring sites
One monitored seagrass meadow
Two fish monitoring sites
One mud crab monitoring site

Zone area: 33.68km^2

The Inner Harbour is located immediately to the east of the Western Basin and is bounded by a mangrove-dominated intertidal system on Curtis Island and the town of Gladstone on the southern edge. Coral reefs have been recorded at Turtle, Quoin and Diamantina islands although there is little evidence that these areas have recently supported viable coral communities (BMT WBM, 2013). There are several seagrass meadows, including one that is monitored in the south of this zone. The Quoin Island Turtle Rehabilitation Centre is located in the centre of this zone and the Barney Point Coal Terminal is located on the south-east banks of the zone.

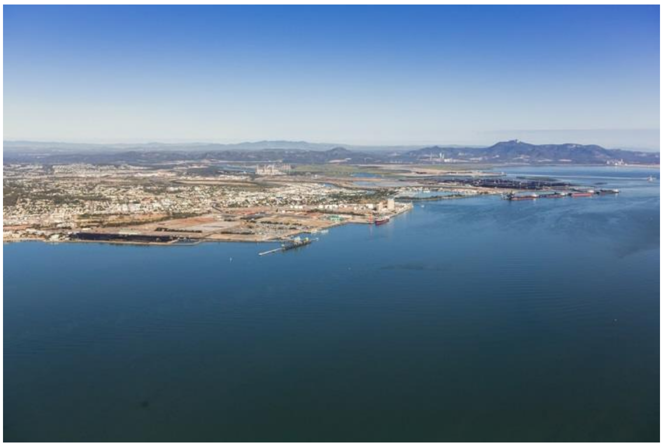


Figure 3.11: The Inner Harbour photographed from the north-east, with Auckland Point wharves and the City of Gladstone on the left and the RG Tanna coal loading facility on the right.

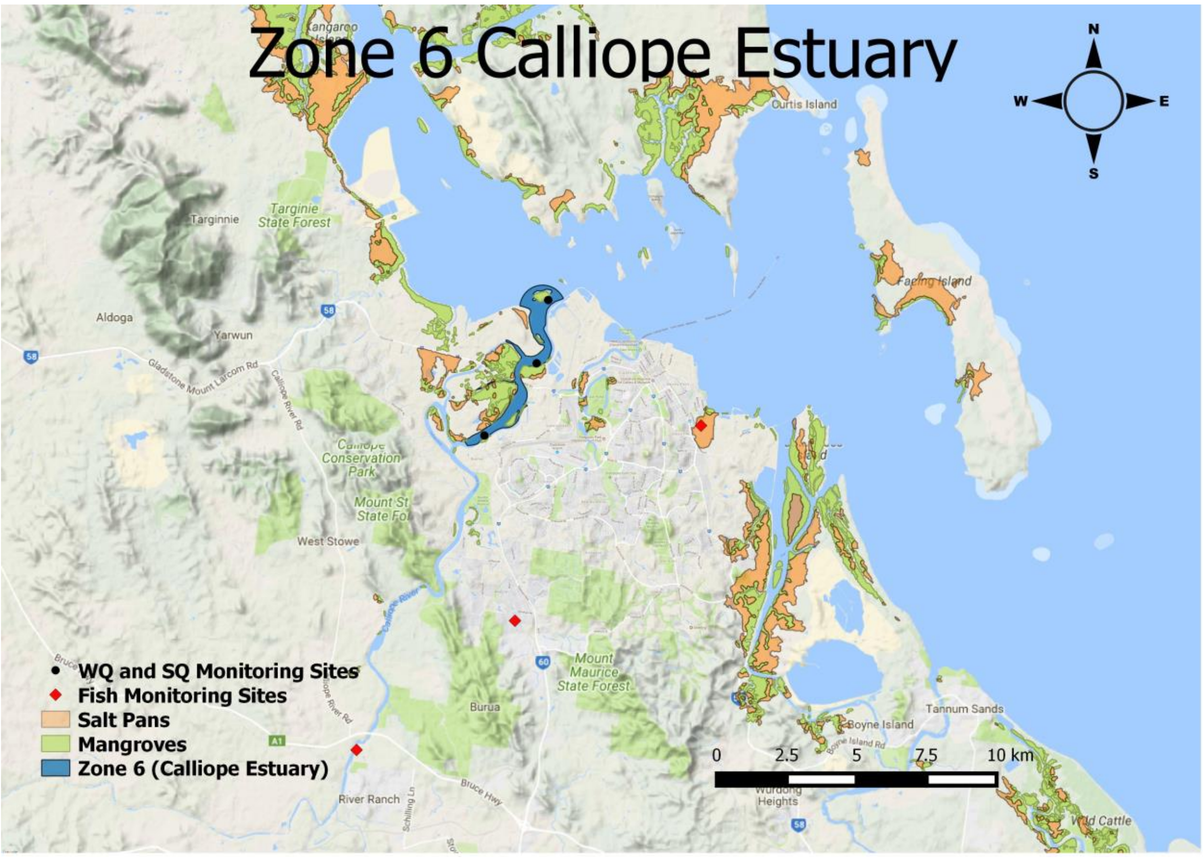


Figure 3.12: Habitat types and water and sediment quality sampling sites in Calliope Estuary.

Three water and sediment quality monitoring sites
Two fish monitoring sites
One mud crab monitoring site

Zone area: 7.71km^2

The Calliope River is fed by Gladstone Harbour's largest freshwater catchment. The river's main tributaries include Oakey, Paddock, Double and Larcom creeks. The Calliope River flows into the Western Basin and is a source of turbid freshwater during floods or other high flow events. The WICET and the RG Tanna Coal Terminal are located at the mouth of the Calliope Estuary. Queensland's largest coal-fired power station is located alongside the Calliope Estuary, approximately 4km upstream from the river mouth, and has been operating since 1976.

Figure 3.13: The Gladstone coal-fired power station, on the banks of the Calliope Estuary photographed from the north-east.

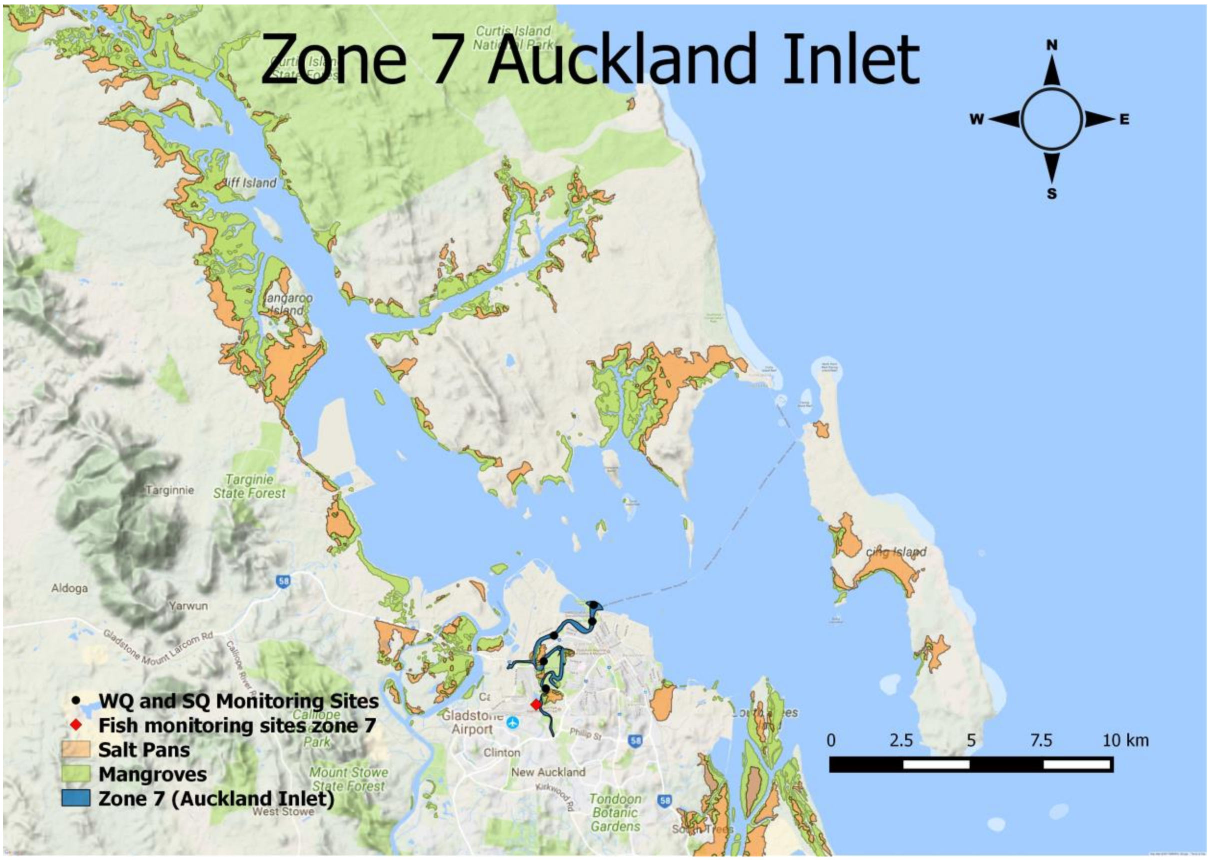


Figure 3.14: Habitat types and water and sediment quality sampling sites in Auckland Inlet.

Five water and sediment quality monitoring sites
One fish monitoring site
One mud crab monitoring site

Zone area: 1.33km^2

Auckland Inlet is a tidal inlet that connects to the Inner Harbour through a complex of small streams meandering through mangrove-lined mudflats that are often inundated at high tide. Seawater extracted from Auckland Creek is used to cool the Gladstone Power Station. Stormwater run-off outlets are located along Auckland Creek.

Figure 3.15: Auckland Inlet photographed from the south-west. Gladstone Marina is in the middle ground and the Auckland Point wharves to the left.

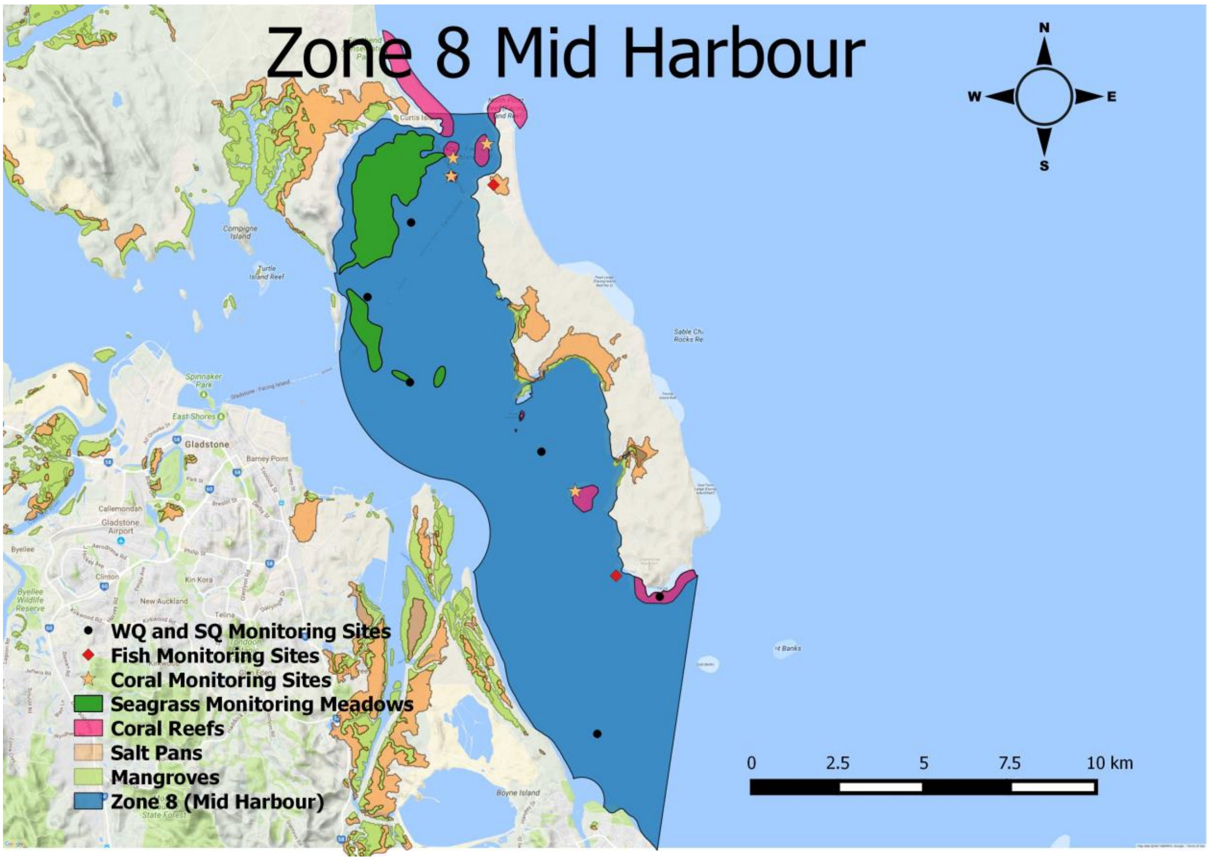


Figure 3.16: Habitat types and water and sediment quality sampling sites in the Mid Harbour.

Six water and sediment quality monitoring sites
Two monitored seagrass meadows
Four coral monitoring sites
Two fish monitoring sites

Zone area: 95.73km^2

The Mid Harbour is the second largest of the harbour zones and is bounded by Facing, Curtis and Boyne islands. Most shipping enters the harbour along the Gatcombe channels in the southern end of this zone. This zone contains two monitored seagrass meadows, including the largest seagrass meadow in the harbour at Pelican Banks. Within the zone, coral reefs occur along the western side of Facing Island and on the south-east tip of Curtis Island. There are four coral monitoring sites in this zone that is adjacent to the Great Barrier Reef Marine Park.

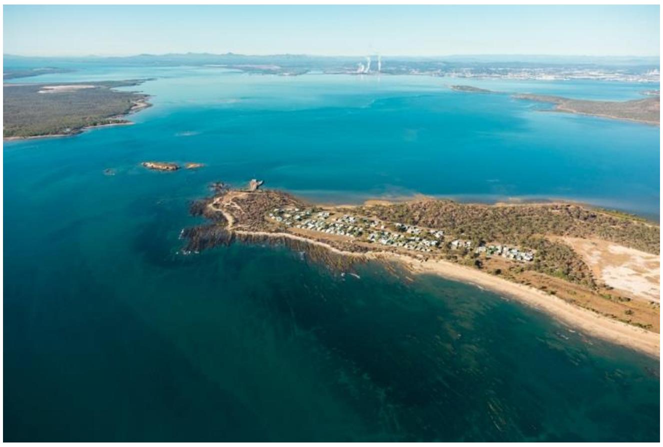


Figure 3.17: The Mid Harbour photographed from north-east. Curtis Island is in the foreground and the Inner Harbour is in the background.

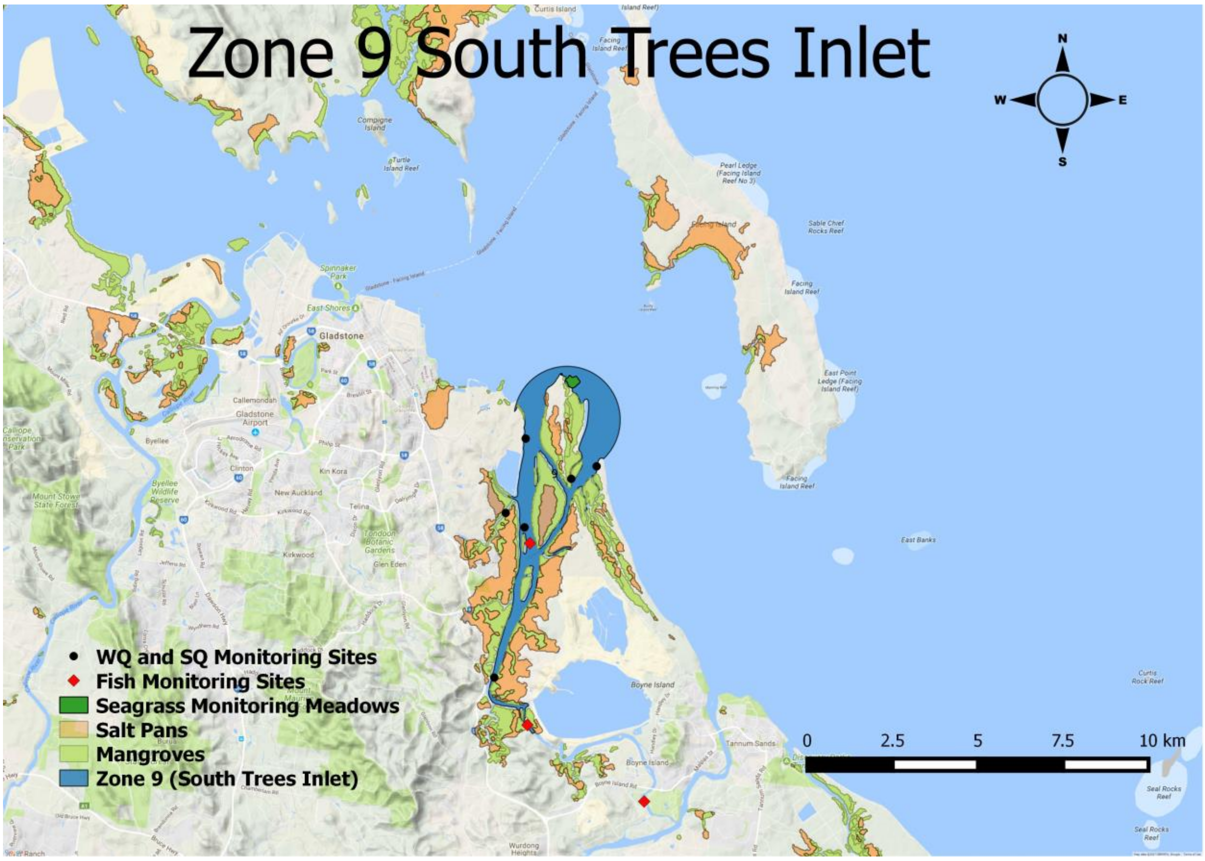


Figure 3.18: Habitat types and water and sediment quality sampling sites in South Trees Inlet.

Six water and sediment quality monitoring sites
One seagrass monitoring meadow
Two fish monitoring sites

Zone area: 9.45km^2

South Trees Inlet is a mangrove and salt pan-lined tidal inlet that flows into the Mid Harbour Zone. The zone contains one monitored seagrass meadow which sits just off the northern tip of South Trees Island. At 10.9ha it is the second smallest of the monitored meadows. The area contains a large number of industrial developments, including South Trees Wharf on South Trees Island at the inlet's mouth, Queensland Alumina Ltd to the west of the inlet, and Boyne smelters to the south-west of the inlet. The South Trees Industrial Estate is located next to Wapentake Creek which flows into the western side of the inlet just south of South Trees Island.

Figure 3.19: The mouth of South Trees Inlet photographed from the north, showing South Trees Island in the foreground and Boyne Island in the background.

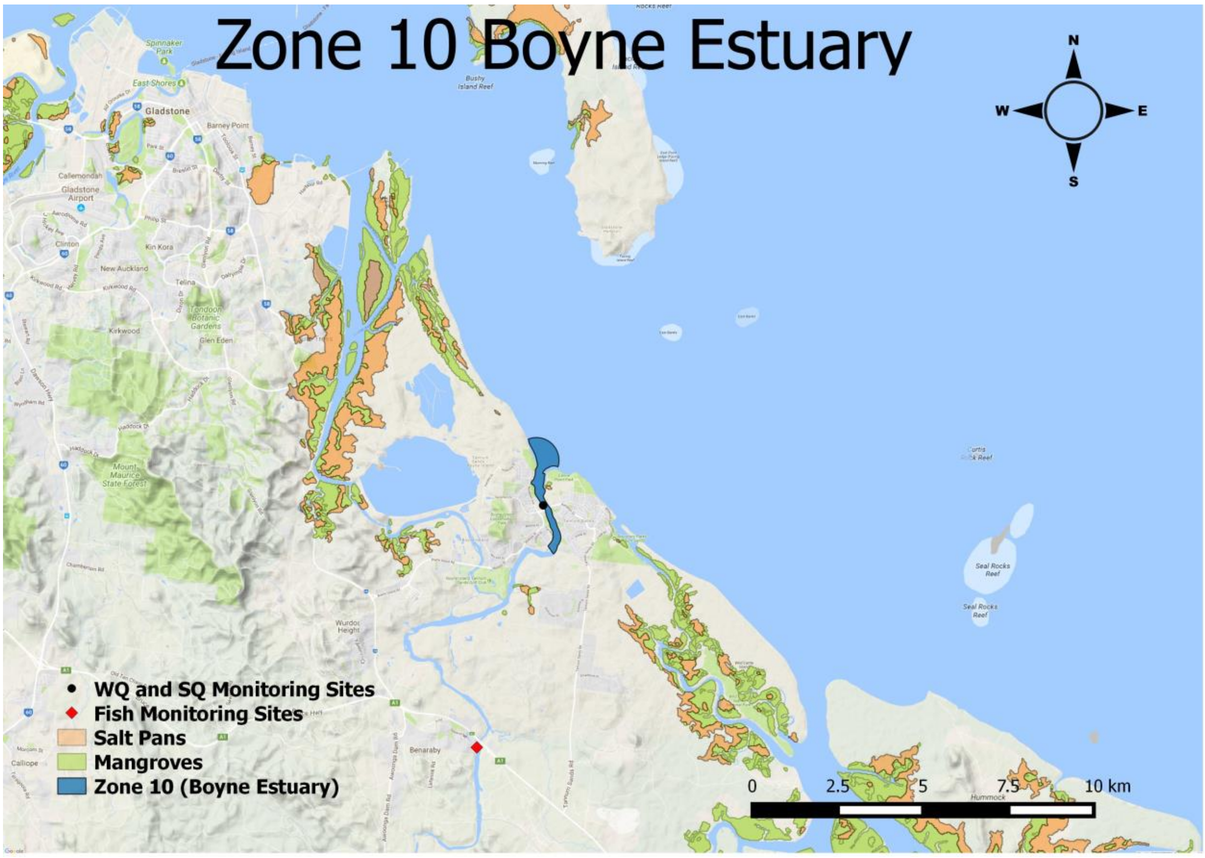


Figure 3.20: Habitat types and water and sediment quality sampling sites in Boyne Estuary.

One water and sediment quality monitoring site
Two fish monitoring sites

Zone area: 3.62km^2

The Boyne River is dammed at Lake Awoonga to provide potable water for the Gladstone area. Large numbers of barramundi are stocked in Lake Awoonga and may be introduced into the Boyne Estuary when the dam overtops. The Boyne Estuary was the site of large-scale mortality of many of these introduced barramundi and other fish in 2011. The lower reach of the Boyne River flows from the dam through predominantly agricultural land that has pockets of remnant vegetation. Before entering the south-eastern section of the Mid Harbour Zone, the Boyne River flows through the residential communities of Boyne Island and Tannum Sands.

Figure 3.21: The mouth of the Boyne River photographed from the north-east. Boyne Island is on the right and Tannum Sands on the left.

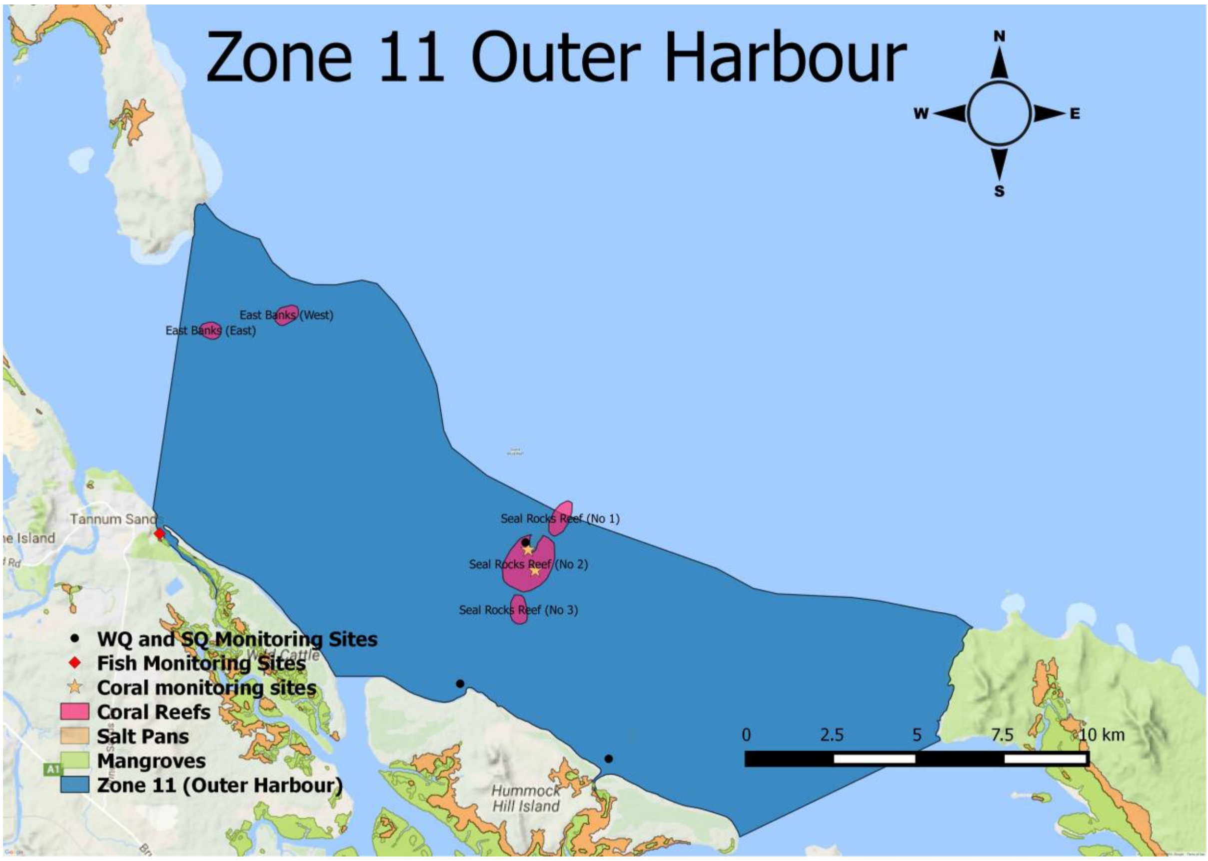


Figure 3.22: Habitat types and water and sediment quality sampling sites in the Outer Harbour.

Three water and sediment quality monitoring sites
Two coral monitoring sites

Zone area: 176.97km^2

Situated in open coastal waters between Facing Island and Rodds Bay, the Outer Harbour is the largest of the 13 monitoring zones. Just over 50% of this zone lies within the Gladstone Port Limits. The south-western boundary consists of long sandy beaches and salt pans and mangroves around the entrance to Colosseum Inlet. There are no major industries located along the coastlines of this zone. Coral reefs occur within the zone and there are two coral monitoring sites. The north-eastern boundary consists of open coastal water and a dredge spoil ground is located to the east of this boundary.

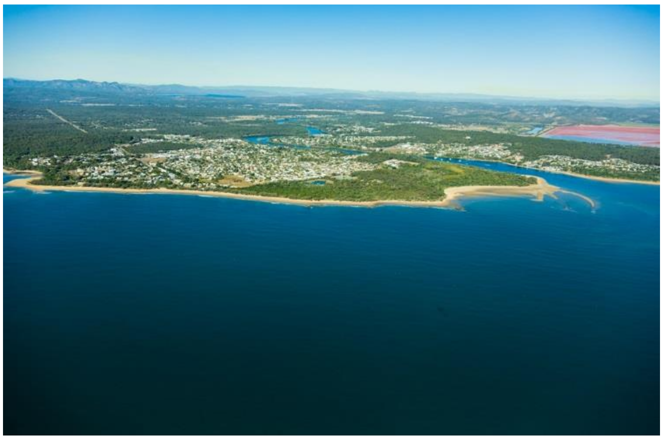


Figure 3.23: The Outer Harbour and Tannum Sands photographed from the north-east. Boyne Island and one of Gladstone's red mud (bauxite) dams are on the right.

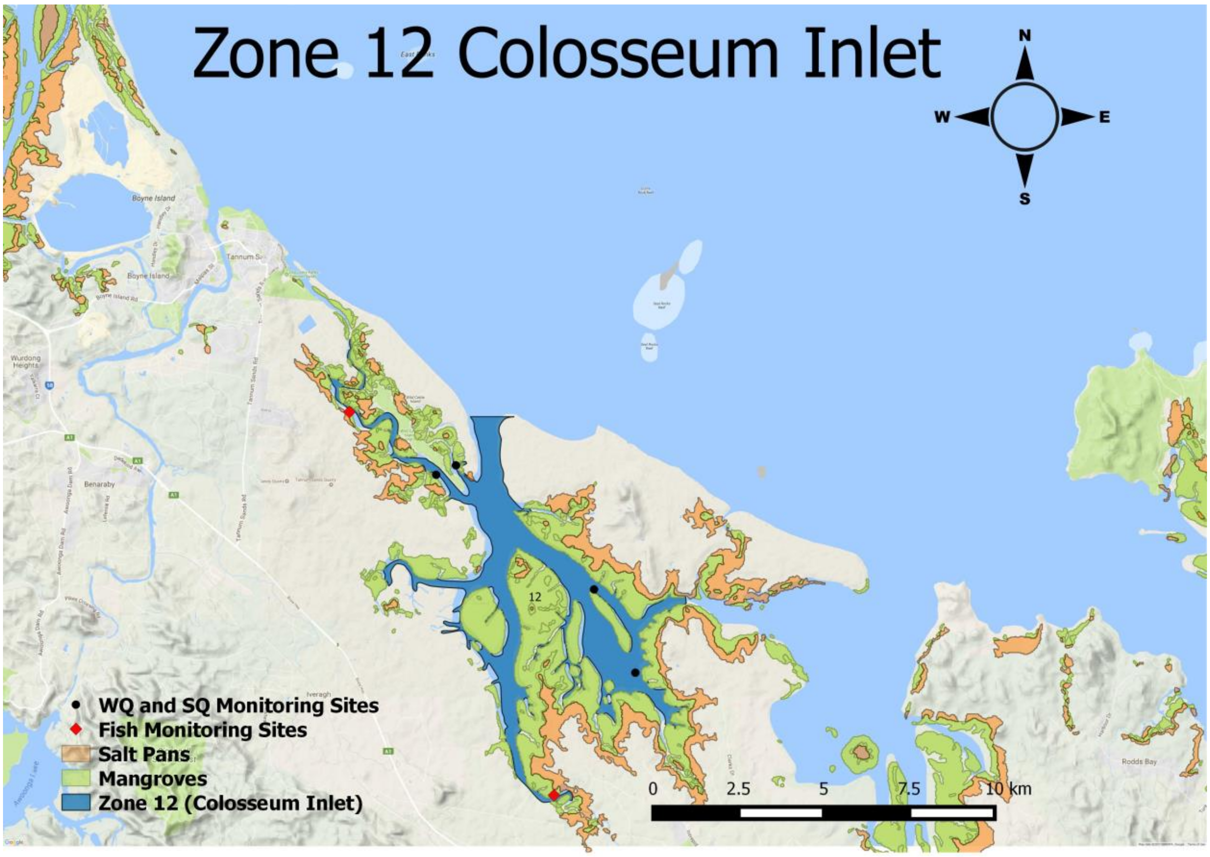


Figure 3.24: Habitat types and water and sediment quality sampling sites in Colosseum Inlet.

Four water and sediment quality monitoring sites
Two fish monitoring sites

Zone area: 18.98km^2

Colosseum Inlet is an estuarine zone that is sheltered by Hummock Hill Island. Colosseum Inlet connects to both the Outer Harbour and Rodds Bay zones. The inlet has several large tributaries branching off the main creek and all are lined with mangroves and salt pan areas. There are no urban or industrial areas along the coastline of this zone.

Figure 3.25: The northern entrance to Colosseum Inlet showing Wild Cattle Island on the right and Hummock Hill Island on the left.

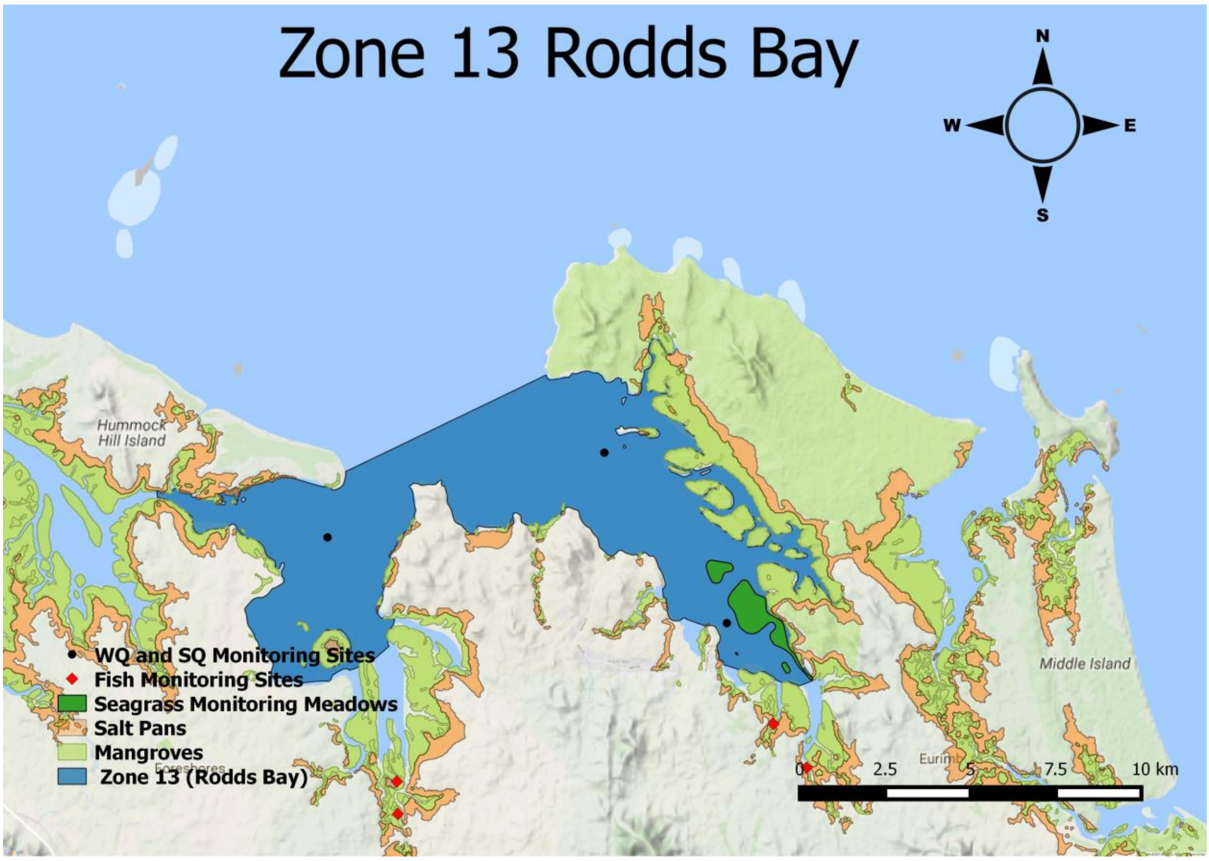


Figure 3.26: Habitat types and water and sediment quality sampling sites in Rodds Bay.

Three water and sediment quality monitoring sites
Three seagrass monitoring meadows
Four fish monitoring sites
One mud crab monitoring site

Zone area: 70.14km^2

Rodds Bay is located to the south-east of the Outer Harbour Zone. It is connected to Colosseum Inlet by a narrow channel behind Hummock Hill Island. The eastern side of Rodds Bay includes a number of mangrove islands. The creeks that flow into the bay are also mangrove-lined and contain large areas of salt pans. This zone also includes three monitored seagrass meadows and the Rodds Bay Dugong Protection area. This is a relatively pristine zone that has significant biodiversity value (Vision Environment Queensland, 2011).

Figure 3.27: The eastern arm of Rodds Bay showing Rodds Peninsula in the foreground.

3.2. Social, cultural and economic reporting areas

Data that contributed to the social, cultural ('sense of place') and economic grades were collected from the Gladstone region. Participants in the CATI survey were selected from within the Gladstone 4680 postcode area (Figure 3.28). Hotel occupancy rates were based on the Gladstone Local Government Area (LGA) (Figure 3.28). The Gladstone Ports Corporation (GPC) provided the shipping data for the Port of Gladstone.

Commercial fishing data were collected from the area within the Queensland Fisheries S30 Grid (QFish S30) and nearby open coastal waters of Mackay (Grid O25) and Rockhampton/Yeppoon (Grid R29) (Figure 3.29).

However, for the marine safety incidents and oil spills social indicator, data originated from Gladstone Maritime Region (Figure 3.30) which includes 1868km of mainland coastline from Double Island Point to St. Lawrence, 132km of island coastline and 26,190km of inland waterways. This region incorporates the Port of Gladstone, Port Alma, Port of Bundaberg and marinas in Hervey Bay, Bundaberg and Rosslyn Bay (Windle et al 2017).

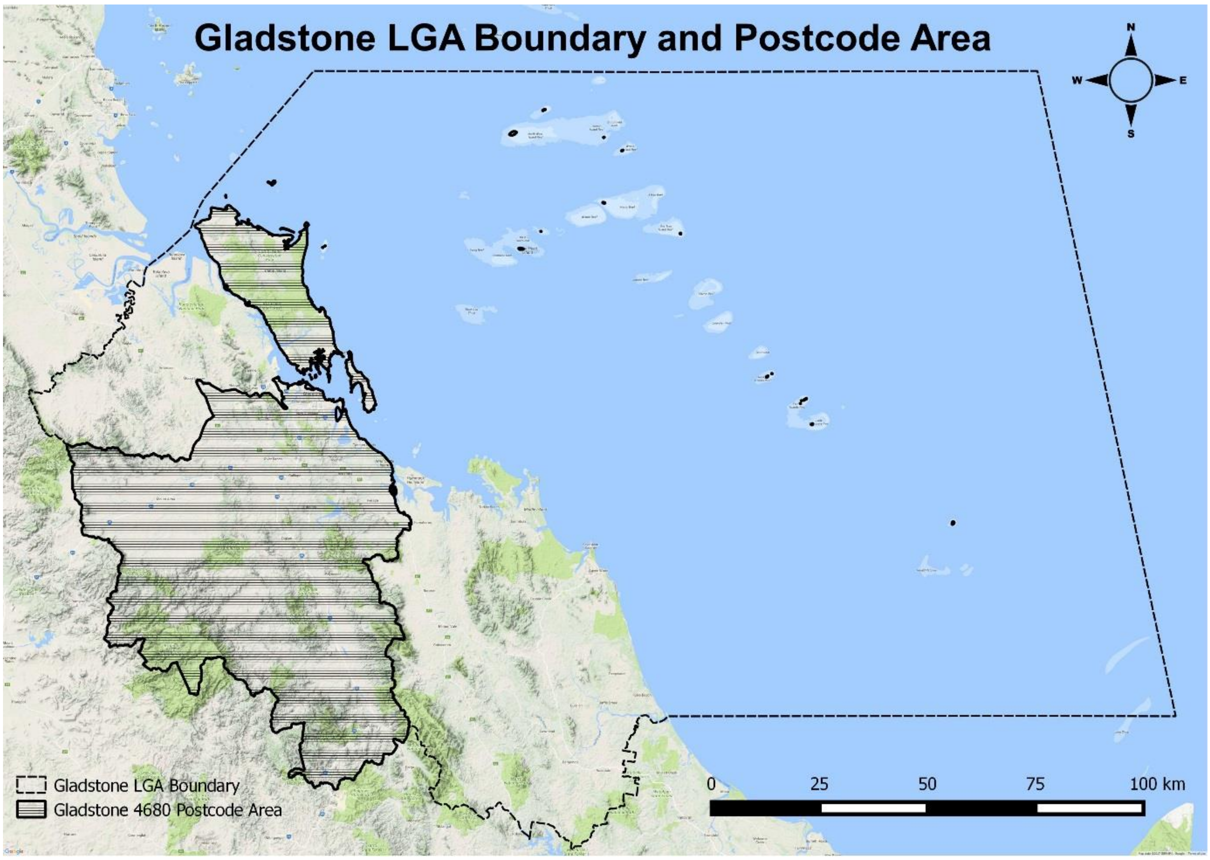


Figure 3.28: The Gladstone region showing the mainland extent of the Gladstone Local Government Area (LGA) and the Gladstone 4680 postcode area. Both were used to define areas from which some social, cultural and economic data were collected.

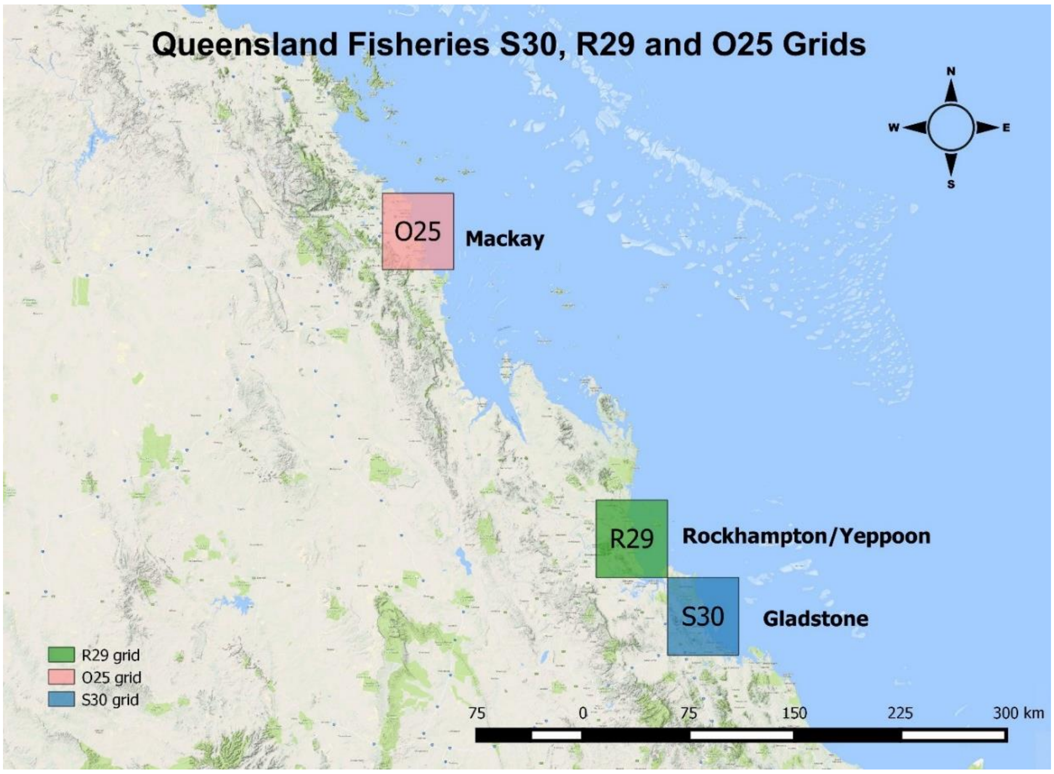


Figure 3.29: The Queensland Fisheries S30 (Gladstone), R29 (Rockhampton and Yeppoon) and O25 (Mackay) Grids. Data from these grids are used to calculate the commercial fishing indicator.

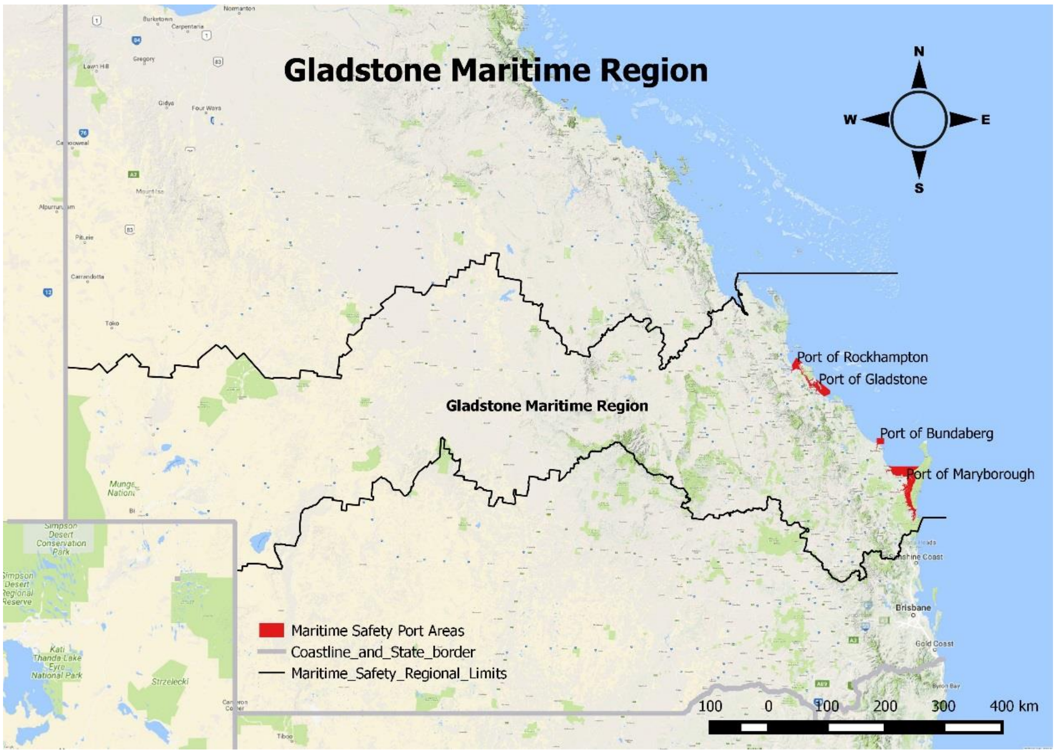


Figure 3.30: Gladstone Maritime Region from Double (Shape files courtesy State of Queensland Department of Transport and Main Roads 2017)

Data for the Indigenous cultural heritage indicator group were collected from four zones within the LGA boundary: The Narrows, Facing Island, Gladstone Central and Wild Cattle Creek (Figure 3.31).

The Narrows

The Narrows is the largest zone. It extends from Deception Creek to the Calliope River anabranch to the south and covers approximately 430km^2 of both the mainland and parts of Curtis Island. Nine sites have been identified for field surveys. The cultural locus site is a 2-km long extremely dense quarry site which was used by Traditional Owners to quarry silcrete raw material to manufacture stone tools. The Traditional Owners and Elders also identified a stone arrangement which resembles a crocodile and linked with 'Gu-ra-bi' dreaming and Mt Larcom as of similar cultural significance and weighted similar to the quarry site. A number of stone arrangements were found in the north of The Narrows and a number of semi-permanent pools were found in the south-east parts of the zone. A close examination of the material found during the surveys suggested the area was disturbed in the past by fire, water activity, cattle and trampling.

Facing Island

Facing Island is located approximately 7km east of the Gladstone Central Business District (CBD). The island covers approximately 57km^2 land area and mainly consists of long sandy beaches. Six sites have been identified for annual field surveys. The cultural locus site for the Facing Island is a large shell midden. Stone tools and shell scatters are located in the south-eastern part of the Facing Island.

Gladstone Central

The Gladstone Central zone covers approximately 173km^2 area around Gladstone CBD. This zone has been chosen for monitoring as it has a large number of sites which are of cultural significance to Traditional Owners and Elders for fishing, hunting, boating, traditional meetings and ceremonies. This zone has been further extended in 2017 and includes sites near Boyne and Calliope rivers. Barney Point was identified as the cultural locus site in 2017 as Traditional Owners and Elders see this site as being a positive place of significant cultural and social meaning and more representative of the area than the Police Creek previously chosen as a cultural locus site in 2016. There are public walking tracks and interpretive signs in this zone explaining the ecology and history of Police Creek. Six sites have been identified for annual surveys.

Wild Cattle Creek

The Wild Cattle Creek zone covers approximately 92km^2 running south along the shore from the mouth of the Boyne River, near Tannum Sands, for about 23km. This zone includes the Wild Cattle Island National Park which is important for endangered migratory birds and nesting sea turtles. The southern part of this zone consists of Hummock Hill Island. In 2017, additional sites from Hummock Hill Island were surveyed. The cultural locus site for the Wild Cattle Creek is an artefact scatter/shell midden and quarry site at Hummock Hill Island. Traditionally, access to these islands would have been through tidal mudflats and small creek crossings. Sixteen sites have been identified for annual surveys within this zone.

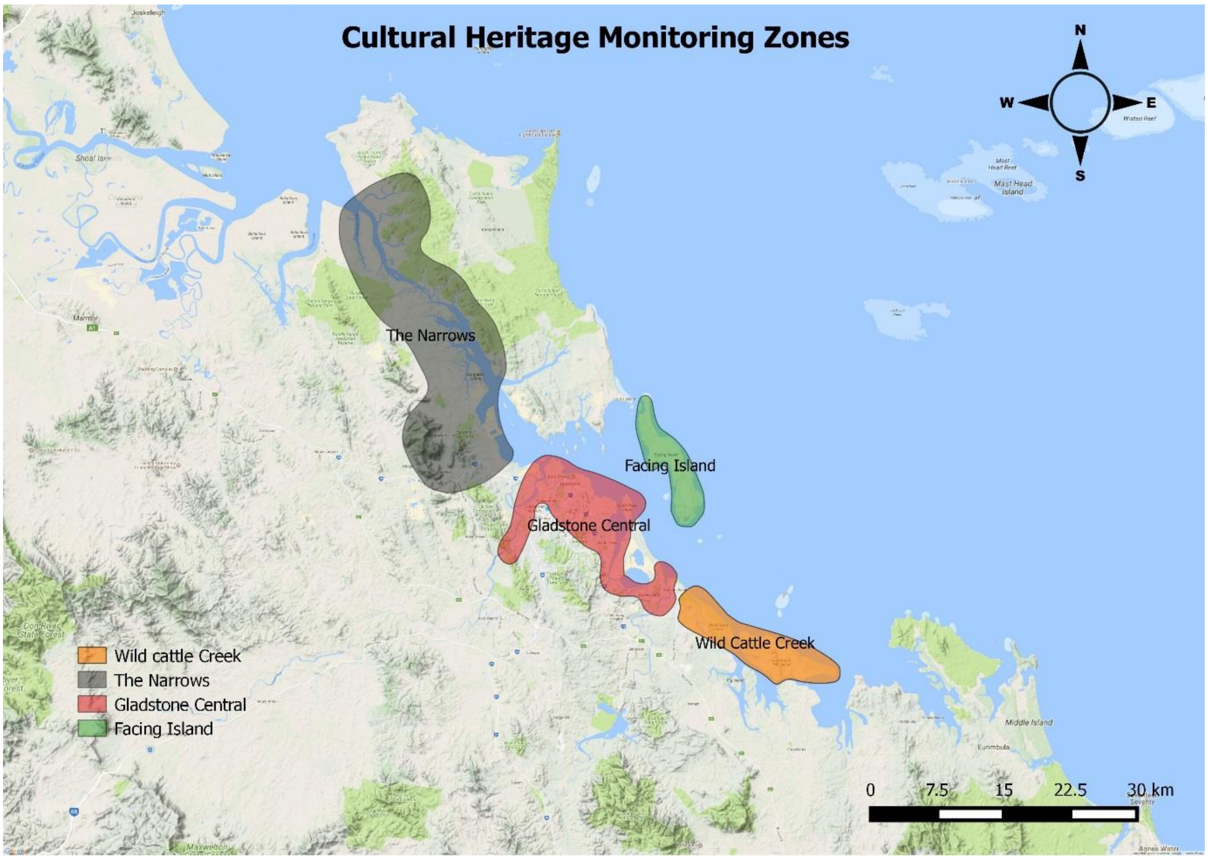


Figure 3.31: The four reporting zones from which data used to inform the Indigenous cultural heritage indicators for 2017 report card were collected.

4. The Environmental component

The Environmental component of the 2017 Report Card consists of three indicator groups: water and sediment quality, habitats, and fish and crabs. The connectivity indicator group was removed from the Environmental component in 2016 as connectivity was considered to be a system driver rather than a measure of environmental health. Gladstone Harbour connectivity will continue to be modelled and is reported in the 'drivers and pressures' section of this report (Section 9).

In 2017, the fish and crabs indicator includes fish recruitment (as in 2016) and mud crab health for the first time. Separate indicators for fish health are being developed and will be reported in future report cards. Polycyclic aromatic hydrocarbons (PAHs) will not be reported as a sediment quality indicator as this measure was not monitored in 2017 owing to the low concentrations recorded in 2015.

4.1. Water and sediment quality

Water and sediment quality are important and interconnected aspects of the harbour ecosystem. A healthy water and sediment system sustains the health of a large number of aquatic species, including fish, turtles, dugongs, seagrass, mangroves and benthic invertebrates. Catchment-related, anthropogenic and climatic factors play a major role in determining the water and sediment quality recorded in the harbour. The ISP selected the measures for water and sediment quality that are used in the Gladstone Harbour Report Card, all of which have local or national guidelines.

For the Gladstone Harbour Report Card, guideline values were provided by:

- DEHP Water Quality Objectives for the Capricorn Curtis Coast (DEHP, 2014a) for pH, turbidity and nutrients
- ANZECC/ARMCANZ (2000) for metals in water and sediments, (except aluminium and manganese)
- Golding et al. (2014) for dissolved aluminium in water
- COAG Standing Council on Environment and Water (2013) for manganese in water.

See appendices 5 and 7 for further details.

With the exception of aluminium and manganese, water quality guideline values differ among geographic zones within Gladstone Harbour (see Appendix 5 for values by zone). The aluminium guidelines developed by Golding et al. (2014) ranged from 2.1ug/L in high ecological value (HEV) zones in Gladstone Harbour (The Narrows, Colosseum Inlet, Rodds Bay) to 24ug/L in moderately disturbed (MD) zones (all other zones). This led to similar actual concentrations of aluminium being graded as very poor in HEV zones and very good in MD zones. This created the misleading impression that the aluminium concentrations were far worse in HEV zones than in MD zones. For that reason, the ISP applied the MD guideline of 24ug/L across all zones. For the same reason, the ISP also selected a consistent guideline of 140ug/L for manganese which was the appropriate guideline for MD systems with coral (COAG Standing Council on Environment and Water, 2013). Manganese guidelines varied between 20ug/L and 390ug/L depending on whether the zone was classified as HEV or MD and whether or not corals were present.

Water and sediment quality data were collected in accordance with the following standards and procedures:

- *Australian and New Zealand Standards for water quality and sediment sampling* (AS/NZS 5667.1:1998, 5667.4:1998, 5667.6:1998, 5667.9:1998 and 5667.10:1998)
- *American Public Health Association standard methods for the examination of water and wastewater* (APHA, 2005)
- *Australian and New Zealand water quality guidelines* (ANZECC, 1992, 1998; ANZECC/ARMCANZ, 2000)
- *Handbook for sediment quality assessment* (Simpson et al., 2013)
- *Department of Environmental Resource Management monitoring and sampling manual* (DERM, 2010).

4.1.1. Water and sediment quality data collection

Water quality

Under a data-sharing agreement, PCIMP provided GHHP with water quality data for calculating scores and grades for the 2017 Gladstone Harbour Report Card. Those data were based on samples collected from 50 sites across the 13 harbour zones in August and November 2016 and March and June 2017 (Figures 3.1–3.27).

Eleven water quality parameters were assessed for the 2017 Gladstone Harbour Report Card: two physicochemical measures, three nutrient measures and six dissolved metals (Table 4.1). Physicochemical parameters were measured using a multi-parameter water quality sonde (YSI6820). Measurements were taken at 0.5m depth intervals through the water column until the seabed was reached. Water samples for nutrient and dissolved metal analysis were collected from a depth of about 0.5m using a Perspex pole sampler and a 1L acid-rinsed Nalgene bottle. Field blanks, duplicate and triplicate samples and field spikes were also collected during sampling in accordance with the standard protocols described above (Anastasi, 2017). Samples for dissolved metals analysis were filtered through seawater-rinsed 0.45 µm membrane filters in the field.

Vision Environment Queensland collected the field samples and prepared them for analysis by one of four independent laboratories: primary, duplicate, field and laboratory blanks of water and sediment samples (FB and LB) – National Measurement Institute (NMI), Chlorophyll *a* – Australian Laboratory Services and dissolved nutrients – Queensland Health Laboratories (Anastasi, 2017). NMI is the Australian Government’s peak measurement body for biological, chemical, legal, physical and trade measurement. The laboratories that analyse PCIMP data have been accredited by the National Association of Testing Authorities, Australia. This is to ensure compliance with relevant international and Australian standards and competency in providing consistently reliable testing, calibration, measurement and inspection data.

Table 4.1: Water quality indicators included in the 2017 Gladstone Harbour Report Card.

Indicator	Sub-indicator	Measure	Guideline source
Water quality	Physicochemical	pH	DEHP, 2014a
		Turbidity	DEHP, 2014a
	Nutrients	Total nitrogen (TN)	DEHP, 2014a
		Total phosphorus (TP)	DEHP, 2014a
		Chlorophyll *a*	DEHP, 2014a
	Dissolved metals	Aluminium (Al)	Golding et al., 2014
		Copper (Cu)	ANZECC/ARMCANZ, 2000
		Lead (Pb)	ANZECC/ARMCANZ, 2000
		Manganese (Mn)	COAG Standing Council on Environment and Water (2013)
		Nickel (Ni)	ANZECC/ARMCANZ, 2000
		Zinc (Zn)	ANZECC/ARMCANZ, 2000

See Appendix 5 for a full list of water quality guidelines.

Sediment quality

The 2017 Gladstone Harbour Report Card assessed six sediment metals and one metalloid (arsenic) (Table 4.2). Sediment nutrients were not included as there are no relevant national or international guidelines. They may be included in future report cards should relevant guidelines become available.

PCIMP sampled sediment for the 2017 Gladstone Harbour Report Card in June 2017. They collected this data from the same sites used for water quality sampling in that month (Figures 3.1–3.27). Grab samples were collected for the sediment quality measurements using a stainless steel Ponar grab sampler. These samples were deposited into a collection tub that had been triple rinsed with seawater and then photographed. All sediment quality measurements used the top 100mm of the sample (Anastasi, 2017). For quality assurance and quality control (QA/QC), separate grabs were made for duplicate and triplicate samples. NMI analysed all samples.

Table 4.2: Sediment quality indicators included in the 2017 Gladstone Harbour Report Card.

Indicator	Sub-indicator	Measure	Guideline source
Sediment quality	Metals and metalloid	Arsenic (As)	ANZECC/ARMCANZ, 2000
		Cadmium (Cd)	ANZECC/ARMCANZ, 2000
		Copper (Cu)	ANZECC/ARMCANZ, 2000
		Lead (Pb)	ANZECC/ARMCANZ, 2000
		Nickel (Ni)	ANZECC/ARMCANZ, 2000
		Mercury (Hg)	ANZECC/ARMCANZ, 2000
		Zinc (Zn)	ANZECC/ARMCANZ, 2000

See Appendix 7 for a full list of guidelines.

What water and sediment quality measures were not included?

During early September 2017, the ISP held a meeting with the members from PCIMP discuss QA/QC issues associated with the water and sediment quality data collected for the report card. At the meeting, they discussed issues concerning the water and sediment quality raw dataset in relation to the draft scores received for 2017.

Following the meeting, the ISP made a decision not to include ammonia, NO_x, and orthophosphate measures in the report card analysis due to following:

- ammonia: When the reported values are near analytical detection limits and/or guideline values, even small analytical errors can result in an exceedance of the guideline. Some issues with field blanks in conjunction with values close to guideline values made it difficult to isolate potential errors from assessment values.
- NO_x: raw data were not available consistently over four quarters
- orthophosphate: limit of reporting was higher than the DEHP water quality guideline for two quarters.

Ten dissolved metals data cases (approximately 4% of overall water and sediment data) were also removed from the analysis. This was because, for these samples, the dissolved metal concentrations were higher than the total metal concentrations, most likely due to contamination either during collection, filtration or analysis.

4.1.2. Why were these indicators measured

4.1.2.1. Physicochemical indicators

pH

The pH of water is a measure of its alkalinity or acidity. By assessing the concentration of free hydrogen and hydroxyl ions in water, pH indicates whether the water is acidic (pH 0–6), neutral (7) or alkaline (pH 8–14). The pH is an important property of marine and estuarine water as it determines the solubility and biological availability of many nutrients and metals. As a rule of thumb, the solubility of most metals tends to increase at low pH. Plant and animal species usually tolerate a narrow pH range outside of which their ecology and behaviour are adversely impacted.

Turbidity

Turbidity is a measure of water clarity and is affected by the levels of suspended sediment (sand, silt and clay), organic matter and plankton in the water. Coloured substances, such as pigments and tannins from decaying plant matter, may also contribute to turbidity. High turbidity decreases the light levels reaching the seabed which reduces photosynthesis and the production of dissolved oxygen. This can lead to reduced growth or in more extreme cases, mortality of algae, seagrasses and corals. The suspended material in the water may also influence fish behaviour, clog fish gills and smother benthic invertebrates.

4.1.2.2. Nutrients

Nitrogen (N) and phosphorus (P) are essential nutrients for all organisms and occur in a number of forms in the natural environment. However, excess concentrations of these nutrients in the marine environment may lead to increased biomass of phytoplankton and other aquatic plants, which as they decay, may deplete the oxygen available for aquatic animals.

Total nitrogen

Total nitrogen (TN) is the sum of the four major chemical forms of nitrogen in the marine environment: nitrate, nitrite, organic nitrogen and ammonia nitrogen. Nitrogen is an essential nutrient for all organisms, but at high levels it can lead to algal blooms, deplete oxygen in the water (eutrophication) and impact the growth of corals.

Total phosphorus

In aquatic systems, phosphorus exists in different forms such as dissolved orthophosphate, organically bound phosphate and particulate phosphate. The total phosphorus (TP) measure gives an indication of all forms of phosphorus in the water body. Key sources of phosphorus in water include cleaning products, urban run-off, fertiliser run-off, rock weathering, partially treated sewage effluent and animal faeces. Phosphorus is an essential nutrient for all organisms, but at high concentrations it can lead to algal blooms, deplete oxygen in the water (eutrophication) and impact coral growth.

*Chlorophyll-*a

Chlorophyll-*a* is a plant pigment used in photosynthesis. In marine systems it is found in algae such as seaweeds and phytoplankton. High levels of chlorophyll-*a* may indicate blooms of algae which can occur when nutrients concentrations are elevated. This can lead to depleted levels of oxygen in the water and to fish kills.

4.1.2.3. Dissolved metals and metalloids

A suite of dissolved metals and one metalloid (arsenic) have been selected as indicators of harbour health.

Aluminium

The element aluminium (Al) is a silvery white metal and the most abundant metal in the Earth's crust (Zumdahl & DeCost, 2010); therefore, it is common to find traces of this element in soil, sediment and water. Aluminium in seawater can be derived from sources that are natural (e.g. weathering of mineral rocks, urban run-off) or anthropogenic (e.g. mining waste, industrial discharges). High levels of dissolved aluminium in aquatic systems are toxic to algae and marine animals.

Arsenic

Arsenic (As) is a naturally occurring element in the environment. It can be introduced into aquatic environments through natural contamination (e.g. by geothermal activity) or anthropogenically, principally through mining-related activities that may disturb arsenic deposits (Garelick et al., 2008). Arsenic may also be mobilised from bauxite residues remaining after aluminium extraction and is typically stored in red mud dams (Lockwood et al., 2014). In sediment, arsenic is available as (III), As (V) and in methylated forms. It is a highly soluble and mobile element that may be toxic to aquatic species.

Cadmium

Cadmium (Cd) is a non-essential element in plants and animals. The sources of cadmium in oceanic waters may be natural (e.g. volcanic activities, rock weathering) or anthropogenic (e.g. releases from open burning or incineration of municipal waste, mining activities, releases from landfills). In water, cadmium is mostly adsorbed onto sediment and suspended particles. Increased concentrations of cadmium in aquatic systems can lead to a range of toxic effects in fish, invertebrates, amphibians and aquatic plants (UNEP, 2010).

Copper

Copper (Cu) is an essential micro-nutrient for plants and animals. Similar to other metals, the sources of copper in oceanic waters may be natural (e.g. release from sediments) or anthropogenic (e.g. as a biocide in antifouling marine paint). Increased concentrations of copper in aquatic systems can lead to a range of toxic effects on algae, invertebrates, fish and other animals.

Lead

Lead (Pb) is a toxic heavy metal that may have anthropogenic (e.g. industrial discharge, mining discharge) or natural origins. In water, lead is mostly adsorbed onto sediment and suspended particles. Its tendency to bioaccumulate up the food chain poses a potential hazard to higher level consumers, including humans. This metal has no known benefits to aquatic plants or animals.

Manganese

Manganese (Mn) is the 11th most abundant element in the Earth's crust and an essential nutrient for the wellbeing of plants and animals. Its origin can be either anthropogenic or natural. The overall toxicity of manganese to marine biota is low. Two manganese deposits near Gladstone Harbour have previously been mined and produced over 1,000t of manganese ore. Those deposits were at Auckland Inlet (mined 1882–1900) and Boat Creek (mined 1901–1902) (Wilson & Anastasi, 2010).

Mercury

Mercury (Hg) is a toxic heavy metal that can have natural (e.g. weathering of rocks over time) or anthropogenic origins (e.g. coal-burning power stations). In sediments it can be converted to methylmercury by microorganisms. This highly toxic chemical can biomagnify in shellfish, fish and animals that eat fish. Potential effects of mercury exposure include reduced growth rate and development, abnormal behaviour and death.

Nickel

Nickel (Ni) is the 24th most abundant metal in the Earth's crust and is essential for all organisms (Cempel & Nikel, 2006). Nickel in waterways can come from sources that are industrial (e.g. industrial discharges, coal handling) or natural (e.g. through rock weathering). In water, nickel is mostly adsorbed onto sediment and suspended particles. At high concentrations, nickel becomes toxic to organisms, but it does not tend to bio-accumulate through the food web.

Zinc

Zinc (Zn) is an essential trace element for animals and plants. Anthropogenic sources include zinc from sacrificial anodes in ships, industrial discharges (e.g. mines, galvanic industries and battery production), sewage effluent, surface run-off and some fungicides and insecticides. At high concentrations zinc becomes toxic to organisms.

4.1.3. Water and sediment quality results

4.1.3.1 Water quality

The overall water quality score was derived from three sub-indicator groups, physicochemical, nutrients and dissolved metals. The physicochemical group comprised pH and turbidity, the nutrients group comprised Chlorophyll-*a*, total nitrogen and total phosphorus, and the dissolved metals group comprised aluminium, copper, lead, manganese, nickel and zinc.

The overall grade for water quality in the 2017 report card was a B (0.78). Two harbour zones, Graham Creek and Outer Harbour, received very good scores for overall water quality (0.88 and 0.90 respectively). Boat Creek received a satisfactory score. The remaining zones received good scores (Table 4.3).

Table 4.3: Overall water quality, physicochemical, nutrient and dissolved metal scores for the 13 zones in the 2017 Gladstone Harbour Report Card. Overall zone scores for 2015 and 2016 are shown for comparison.

Water quality	Physico-chemical score	Nutrients score	Dissolved metals score	Zone score 2017	*Zone score 2016*	*Zone score 2015*
1. The Narrows	0.76	0.44	0.93	0.71	*0.68*	*0.82*
2. Graham Creek	0.99	0.69	0.94	0.88	*0.75*	*0.86*
3. Western Basin	0.74	0.64	0.93	0.77	*0.70*	*0.82*
4. Boat Creek	0.58	0.32	0.89	0.59	*0.58*	*0.70*
5. Inner Harbour	0.76	0.69	0.95	0.79	*0.78*	*0.88*
6. Calliope Estuary	0.68	0.70	0.94	0.77	*0.71*	*0.86*
7. Auckland Inlet	0.83	0.60	0.94	0.79	*0.71*	*0.77*
8. Mid Harbour	0.85	0.59	0.95	0.79	*0.77*	*0.80*
9. South Trees Inlet	0.91	0.68	0.95	0.84	*0.79*	*0.85*
10. Boyne Estuary	1.00	0.53	0.95	0.83	*0.71*	*0.70*
11. Outer Harbour	1.00	0.74	0.95	0.90	*0.72*	*0.84*
12. Colosseum Inlet	1.00	0.55	0.95	0.83	*0.73*	*0.78*
13. Rodds Bay	0.80	0.50	0.95	0.75	*0.73*	*0.80*

Of the two physicochemical measures, pH received very good scores in all zones. Turbidity received very good scores in four zones (Graham Creek, Boyne Estuary, Outer Harbour and Colosseum Inlet), three zones received good scores (Auckland Inlet, Mid Harbour and South Trees Inlet) three zones received satisfactory scores (The Narrows, Western Basin and Rodds Bay), Calliope Estuary received a poor score and Boat Creek a very poor score (Table 4.4).

Scores for nutrients were typically satisfactory or above, however two harbour zone (The Narrows and Boat Creek) received poor scores (0.44 and 0.32 respectively). Total phosphorus received the lowest scores for nutrients with Boat Creek receiving a very poor score (0.15), six zones received poor scores (0.36–0.47), and the remaining six zones were satisfactory and good (0.56–0.76). This indicates that the total phosphorus concentrations were below guideline values (Appendix 5). Total nitrogen had only one poor score, 0.27 in Boat Creek. All other zones had satisfactory to good scores (0.50–0.67). Chlorophyll-a received poor scores in two zones, The Narrows (0.48) and Rodds Bay (0.47), satisfactory scores in three zones (0.54–0.64) and good to very good scores (0.65–1.00) in the remaining eight zones (Table 4.4).

Low concentrations of dissolved metals were recorded across all 13 harbour zones. Very good scores (0.85–1.00) were recorded for aluminium, lead, manganese, nickel and zinc across all zones. Copper scores were either satisfactory or good in 12 zones, with scores ranging from 0.59 to 0.69. One zone Boat Creek (0.49) had a poor score (Table 4.4).

Table 4.4: Scores for water quality measures for each of the 13 zones in the 2017 Gladstone Harbour Report Card.

Zone	Physico-chemical		Nutrients			Metals					
	pH	Turbidity	TN*	TP**	Chl-*a****	Aluminium	Copper	Lead	Manganese	Nickel	Zinc
1. The Narrows	1.00	0.53	0.50	0.36	0.48	1.00	0.59	1.00	1.00	1.00	1.00
2. Graham Creek	1.00	0.98	0.67	0.76	0.64	1.00	0.64	1.00	1.00	1.00	1.00
3. Western Basin	1.00	0.50	0.61	0.56	0.75	1.00	0.61	1.00	1.00	1.00	1.00
4. Boat Creek	1.00	0.17	0.27	0.15	0.54	1.00	0.49	1.00	0.86	1.00	1.00
5. Inner Harbour	1.00	0.52	0.64	0.60	0.83	1.00	0.69	1.00	1.00	1.00	1.00
6. Calliope Estuary	1.00	0.37	0.57	0.60	0.94	1.00	0.66	1.00	1.00	1.00	1.00
7. Auckland Inlet	1.00	0.65	0.52	0.37	0.92	1.00	0.67	1.00	1.00	1.00	1.00
8. Mid Harbour	1.00	0.71	0.57	0.38	0.85	1.00	0.69	1.00	1.00	1.00	1.00
9. South Trees Inlet	1.00	0.81	0.67	0.57	0.81	1.00	0.69	1.00	1.00	1.00	1.00
10. Boyne Estuary	1.00	1.00	0.55	0.41	0.62	1.00	0.69	1.00	1.00	1.00	1.00
11. Outer Harbour	1.00	1.00	0.59	0.63	1.00	1.00	0.69	1.00	1.00	1.00	1.00
12. Colosseum Inlet	1.00	1.00	0.52	0.47	0.65	1.00	0.69	1.00	1.00	1.00	1.00
13. Rodds Bay	1.00	0.60	0.58	0.45	0.47	1.00	0.69	1.00	1.00	1.00	1.00

*Total nitrogen
**Total phosphorus
***Chlorophyll-*a*

4.1.3.2. *Sediment quality*

The overall sediment quality score was derived from one sub-indicator: metals and metalloids. Six metals (cadmium, copper, lead, mercury, nickel and zinc) and the metalloid arsenic were assessed. Mercury was included as a measure for the first time in this report card.

The overall grade for sediment quality was an A (0.95) indicating concentrations that were below the guideline values.

Zone scores for sediment quality ranged from 0.87 in Auckland Inlet to 0.99 in Colosseum Inlet (Table 4.5) indicating low concentrations of sediment metals across the harbour. Cadmium, lead, mercury and zinc received very good scores (0.85–1.00) in all zones (Table 4.6). Arsenic received very good scores in 6 of the 13 zones, good scores in six zones and a satisfactory score in the Inner Harbour (0.62). Nickel received very good scores in nine harbour zones, good scores in Graham Creek (0.77) and Calliope Estuary (0.73) and a satisfactory score in Auckland Inlet (0. 62) and The Narrows (0.60).

Table 4.5: Sediment quality indicator scores for Gladstone Harbour zones in 2017, 2016 and 2015.

Sediment quality	Metals and metalloids score	Zone score 2017	Zone score 2016	Zone score 2015
1. The Narrows	0.92	0.92	0.92	0.94
2. Graham Creek	0.92	0.92	0.96	0.98
3. Western Basin	0.97	0.97	0.98	0.99
4. Boat Creek	0.98	0.98	0.90	0.96
5. Inner Harbour	0.93	0.93	0.94	0.98
6. Calliope Estuary	0.94	0.94	0.99	0.98
7. Auckland Inlet	0.87	0.87	0.94	0.94
8. Mid Harbour	0.95	0.95	0.97	0.99
9. South Trees Inlet	0.98	0.98	0.95	0.96
10. Boyne Estuary	0.97	0.97	0.98	1.00
11. Outer Harbour	0.97	0.97	0.96	0.96
12. Colosseum Inlet	0.99	0.99	1.00	1.00
13. Rodds Bay	0.95	0.95	0.99	0.98

Table 4.6: Scores for sediment quality measures for each of the 13 zones in the 2017 Gladstone Harbour Report Card.

Zone	Metals and Metalloids						
	Arsenic	Cadmium	Copper	Lead	Mercury	Nickel	Zinc
1. The Narrows	0.86	1.00	1.00	1.00	1.00	0.60	1.00
2. Graham Creek	0.65	1.00	1.00	1.00	1.00	0.77	1.00
3. Western Basin	0.91	1.00	1.00	1.00	1.00	0.89	1.00
4. Boat Creek	0.98	1.00	1.00	1.00	1.00	0.87	1.00
5. Inner Harbour	0.62	1.00	1.00	1.00	1.00	0.91	1.00
6. Calliope Estuary	0.92	1.00	0.95	1.00	1.00	0.73	1.00
7. Auckland Inlet	0.82	1.00	0.79	1.00	1.00	0.62	0.89
8. Mid Harbour	0.69	1.00	1.00	1.00	1.00	1.00	1.00
9. South Trees Inlet	0.90	1.00	1.00	1.00	1.00	0.94	1.00
10. Boyne Estuary	0.76	1.00	1.00	1.00	1.00	1.00	1.00
11. Outer Harbour	0.82	1.00	1.00	1.00	1.00	1.00	1.00
12. Colosseum Inlet	0.95	1.00	1.00	1.00	1.00	1.00	1.00
13. Rodds Bay	0.68	1.00	1.00	1.00	1.00	1.00	1.00

4.1.4. Water and sediment quality conclusions

Water quality

Scores for the water quality indicator have remained high since the first Gladstone Harbour Report Card in 2015 receiving a good score (B) in all years. The overall score improved from 0.72 in 2016 to 0.78 in 2017. Water quality was relatively uniform across the harbour and all zones received good or very good scores (0.71–0.90) except Boat Creek (0.59) which received a satisfactory score. The two zones with the highest scores were Graham Creek (0.88) and Outer Harbour (0.90). Improvements were observed for the turbidity score and nutrients in most zones. In 2016 five zones had poor or very poor scores for nutrients compared to only two zones in 2017. As in 2015 and 2016, scores for dissolved metals were very good in all zones.

Sediment quality

Similar to previous report cards, sediment quality scores were uniformly very good (A) across all Gladstone Harbour reporting zones. This is a result of low concentrations of all measures (arsenic, cadmium, copper, lead, nickel, mercury and zinc). Sediment mercury levels were assessed for the first time in 2017. PAHs were not monitored in 2017 owing to the very low concentrations recorded in the 2015 sediment monitoring.

4.2. Seagrass

What is seagrass?

Seagrasses are the only flowering plants that can live submerged in the marine environment; and they play an important roles in the marine ecosystem. A range of marine species including turtles, dugongs, crabs, sea-cucumbers and some fish species graze on seagrass. There are four families of seagrass in the world. The seagrass indicators in the report card are based on five seagrass species from two of these families: Hydrocharitaceae and Zosteraceae.

Species of seagrass used to inform the indicator,

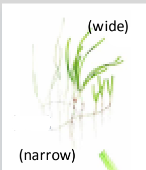
Zostera muelleri
Halophila ovalis
Halophila decipiens
Halophila spinulosa
Halodule uninervis

Zostera muelleri

Halophila ovalis

Halophila decipiens

Halophila spinulosa



Halodule uninervis

Seagrass meadows are one of the most important habitat types within Gladstone Harbour. Within the GHHP reporting area, there are 14 monitored seagrass meadows. These are located within six harbour zones: The Narrows, Western Basin, Inner Harbour, Mid Harbour, South Trees Inlet and Rodds Bay. The area and distribution of the seagrass meadows can vary annually, but at peak distribution seagrass meadows in Gladstone Harbour can cover approximately 12,000ha. This area can include intertidal, shallow subtidal and deep-water habitats. Seagrasses can inhabit various substrata from mud to rock. The most extensive seagrass meadows occur on soft substrata such as sand and mud. Seagrass meadows provide a range of important ecosystem functions, such as sediment stabilisation, nutrient cycling and carbon sequestration. They can also provide nursery areas for juvenile fish and foraging areas for dugongs, turtles and large fish such as adult barramundi.

Seagrasses are highly sensitive to reductions in available light and are susceptible to changes in a range of water quality parameters that affect light penetration. High nutrient levels from agricultural or urban run-off can cause algal blooms that shade seagrass. Increases in water turbidity from suspended sediments can reduce both seagrass growth and the size and extent of extant seagrass meadows. This is due to a decrease in available light and the effects of sediments settling on seagrass leaves. In Gladstone Harbour, increases in turbidity that may be associated with flooding or dredging can result in deposits of silt on seagrass. The large tidal movements may also result in a significant resuspension of fine sediments (Condie et al., 2015). At a local scale dredging can impact seagrasses in several ways. Dredging can increase turbidity, directly remove seagrass, bury seagrass in dredge spoil, and destabilise the seafloor allowing for resuspension of sediments (York & Smith, 2013).

Seagrass monitoring in Gladstone Harbour since 2002 has enabled changes in seagrass conditions to be assessed over that period.

Three indicators of seagrass health are measured to calculate the seagrass grades for the report card:

- biomass – changes in average above-ground biomass within a monitoring meadow
- area – changes in the total area of a monitoring meadow

- species composition – changes in the relative proportions of species.

4.2.1. Seagrass data collection

The Seagrass Ecology Group from the Centre for Tropical Water & Aquatic Ecosystem Research (TropWATER) at James Cook University collected seagrass data to determine the seagrass scores and grades. This group has been monitoring seagrass at Gladstone Harbour and Rodds Bay since 2002 when the GPC commissioned a fine-scale survey of seagrass within the Gladstone Port Limits (Rasheed et al., 2003). This baseline survey identified large areas of seagrass within the Gladstone Port Limits.

The annual seagrass monitoring program started in 2004 and currently assesses 14 representative intertidal and shallow subtidal seagrass meadows in Gladstone Harbour and Rodds Bay (Figures 3.2, 3.6, 3.10, 3.16, 3.18 and 3.26). Meadows were selected to represent the range of seagrass communities within the port considered the most likely to be impacted by port facilities and future developments. Additional out-of-port reference meadows were selected at Rodds Bay. Seagrass monitoring is conducted annually in October or November around the peak of seagrass abundance.

Biomass and species composition

Above-ground biomass was determined using visual estimates. At each site, 0.25m^2 quadrats were placed in three randomly selected locations. Each quadrat was ranked relative to a series of photographs of quadrats for which the biomass had been previously determined. The percentage of each seagrass species within each quadrat was also recorded. After the quadrats were ranked, the observer also ranked a series of calibration photographs that represented the range of seagrass biomass observed during the survey. The field biomass ranks where then converted into estimates of above-ground biomass in grams dry weight per square metre (gDWm^{-2}).

Area

The total area of the monitored seagrass meadows was determined in ArcGIS using GPS coordinates of meadow boundaries and presence of seagrass at sampling sites. Three seagrass GIS layers were created:

- site information – including percent seagrass cover, above-ground biomass, species composition, depth below mean sea level, sediment type, time and GPS coordinates
- meadow characteristics – summary information on meadow characteristics, including community type and abundance category (light, moderate or dense), based on the above-ground biomass of the dominant species
- seagrass landscape category – seagrass meadows were classified as isolated seagrass patches, aggregated seagrass patches or continuous seagrass cover.

A mapping precision estimate ranging from ±5m to ± 50m was determined for each meadow based on the mapping methodology (Table 4.7).

Table 4.7: Mapping precision and mapping methodology for seagrass meadows for seagrass surveys conducted in November 2014 (Source: Bryant et al., 2014).

Mapping precision	Mapping methodology
≥ 5m	Meadow boundaries mapped in detail by GPS from helicopter Intertidal meadows completely exposed or visible at low tide Relatively high density of mapping and survey sites Recent aerial photography aided in mapping
10m	Meadow boundaries determined from helicopter and diver/grab surveys Inshore boundaries interpreted from helicopter sites Offshore boundaries interpreted from survey sites and aerial photography Moderately high density of mapping and survey sites
20m	Meadow boundaries determined from helicopter and diver/grab surveys Inshore boundaries interpreted from helicopter sites Offshore boundaries interpreted from diver/grab survey sites Lower density of survey sites for some sections of boundary
50m	Meadow boundaries determined from helicopter and diver/grab surveys Inshore boundaries interpreted from helicopter sites Offshore boundaries interpreted from diver/grab survey sites Lower density of survey sites for some sections of boundary

4.2.2. Development of seagrass indicators and grades

Seagrass scores and grades for the Gladstone Harbour Report Card were determined by comparing the results for each seagrass meadow with a predetermined baseline condition. Bryant et al. (2014) found that the most appropriate baseline to be a fixed 10-year (2002–2012) average calculated from previous seagrass surveys.

To determine seagrass grades, threshold levels for each grade (A to E) were developed based on:

- the historical variability within each meadow
- expert knowledge of meadow types
- tests at a range of thresholds to determine which best fits the historical data.

Thresholds ranges were developed for the meadow types for the indicators biomass, area and species composition (Figure 4. 1). Grades for each indicator were determined based on these thresholds and a score between 0.00 and 1.00 was calculated to fit the GHHP range (Carter et al., 2015a).

The overall grade for each monitoring meadow was defined as the lowest grade received for each of the three indicators. The lowest score, rather than the mean of the three indicator scores, was applied because a poor grade for any one of the three scores described a seagrass meadow in poor condition.

The zone score is the average of the overall meadow scores within that zone, and the overall harbour score is the mean of the zone scores.

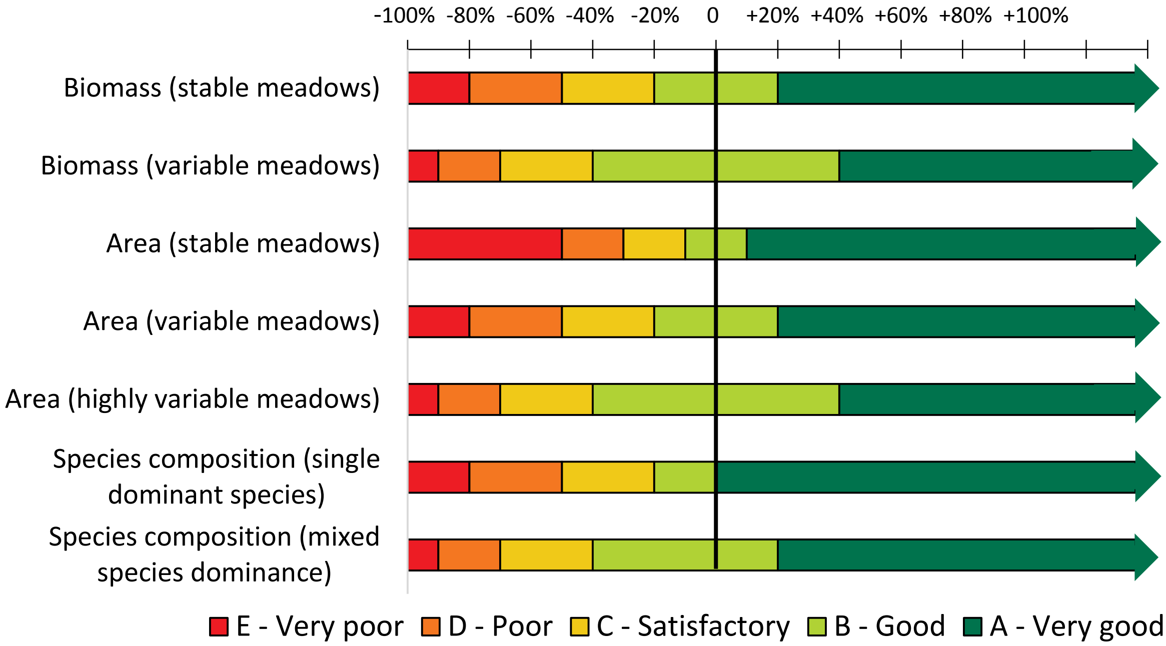


Figure 4.1: Threshold values between grades A to E varied for the seagrass meadow types for each of the three seagrass indicators (biomass, area and species composition). Each grade was determined by the percentage difference from a baseline of the 10-year mean.

4.2.3. Seagrass results

The overall score for seagrass in the 2016–17 reporting year of 0. 39 (D) means that seagrass meadows in Gladstone were in poor condition. The Inner Harbour received the lowest zone score of 0.00 (E) owing to a low score for species composition. Rodds Bay (0.19) also received a very poor score and the Mid Harbour (0.34) received a poor score (D). Two zones, The Narrows (0.59) and Western Basin (0.50) received satisfactory scores (C), and South Trees (0.75) Inlet received a good score (B). No zone was in a very good condition (A) (Table 4.8).

Table 4.8: Scores for seagrass indicators (biomass, area and species composition) and overall meadow, zone and harbour score for the 2017 and overall zone scores for 2015 and 2016.

Zone	Meadow	Biomass score	Area score	Species composition score	Overall meadow score	Zone score 2017	Zone score 2016	Zone score 2015
1. The Narrows	21	0.60	0.59	0.63	0.59	0.59	0.33	0.15
3. Western Basin	4	1.00	0.66	0.73	0.66	0.50	0.55	0.51
	5	0.70	0.69	0.52	0.52			
	6	0.78	0.76	0.54	0.54			
	7	0.68	0.36	1.00	0.36			
	8	0.87	0.29	0.18	0.18			
	52–57	0.97	0.77	0.98	0.77			
5. Inner Harbour	58	0.73	0.87	0.00	0.00	0.00	0.14	0.41
8. Mid Harbour	43	0.14	0.66	0.60	0.14	0.34	0.35	0.56
	48	0.75	0.54	0.58	0.54			
9. South Trees Inlet	60	0.75	0.96	0.98	0.75	0.75	0.48	0.52
13. Rodds Bay	94	0.17	0.06	1.00	0.06	0.19	0.25	0.45
	96	0.42	0.65	0.57	0.42			
	104	0.13	0.07	0.28	0.07			
Harbour score						**0.39**	**0.35**	**0.43**

Zone 1 – The Narrows

The Narrows has one monitored meadow at Black Swan Island. It is an intertidal meadow comprising aggregated patches of seagrass. The overall condition of this meadow has improved from very poor in 2015 to satisfactory in 2017. Compared to the previous year's survey the area score declined from 0.87 (very good) to 0.59 (satisfactory) (Figure 4.2), whereas the scores for biomass and species composition both improved. The biggest increase was in biomass which climbed from 0.33 (poor) to 0.60 (satisfactory), and species composition rose from 0.57 (satisfactory) to 0.63 (satisfactory) (Table 4.8).

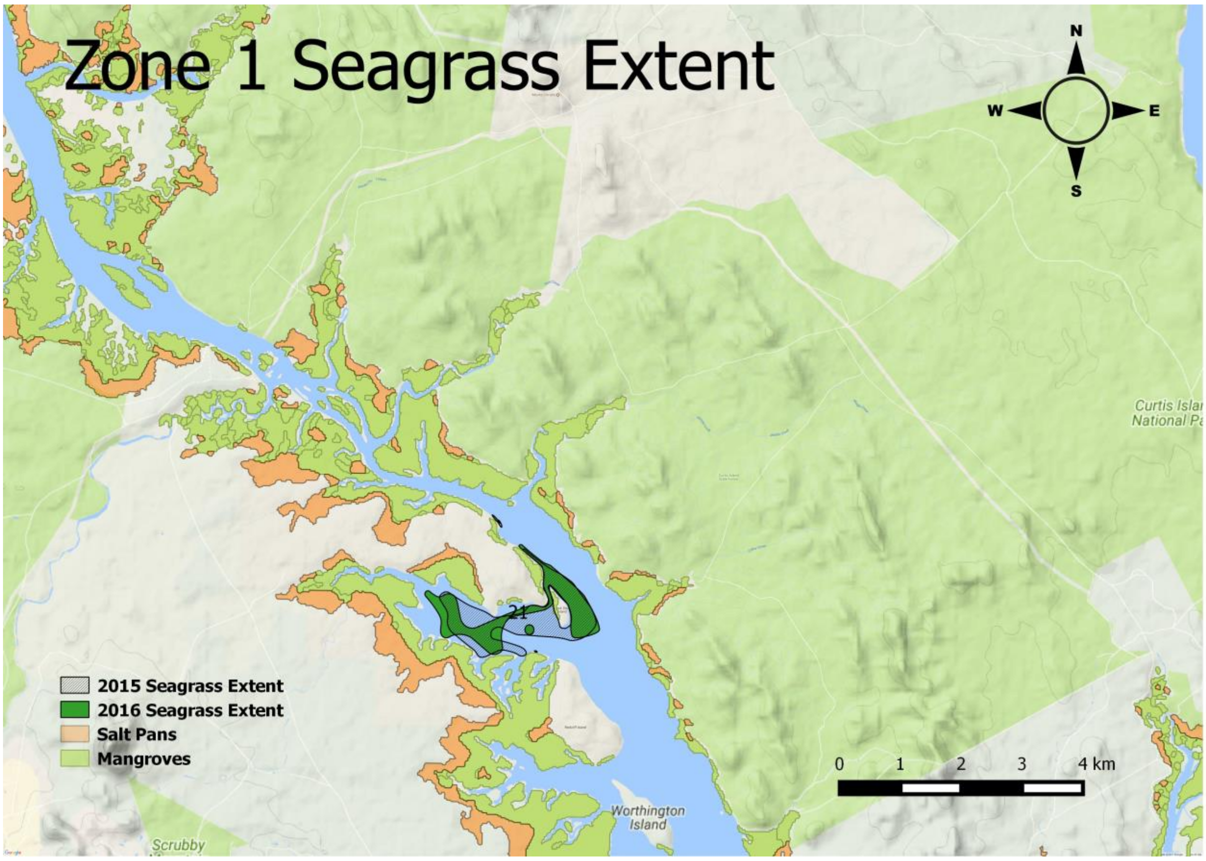


Figure 4.2: Changes to seagrass meadow area in The Narrows between November 2015 and November 2016.

Zone 3 – Western Basin

The Western Basin contains six monitored seagrass meadows; these are predominantly intertidal meadows comprised of aggregated patches of seagrass with the exception of Meadow 7 which is a sub-tidal meadow. The overall zone score remained satisfactory for the third consecutive year. The zone score decreased from 0.55 in 2016 to 0.50 in 2017.

Meadow scores were determined as the lowest of the three indicator scores. In Meadow 4 (0.66), Meadow 7 (0.36) and Meadow 52–57 (0.77) this was determined by the area score. Indicating a poor condition for Meadow 7 and a good condition for Meadow 4 and Meadow 52–57 (Figure 4.3). In Meadow 5 (0.52), Meadow 6 (0.54) and Meadow 8 (0.18) the overall meadow score was determined by the biomass score, indicating a very poor condition for Meadow 8 and a satisfactory condition for meadows 5 and 6 (Table 4.8).

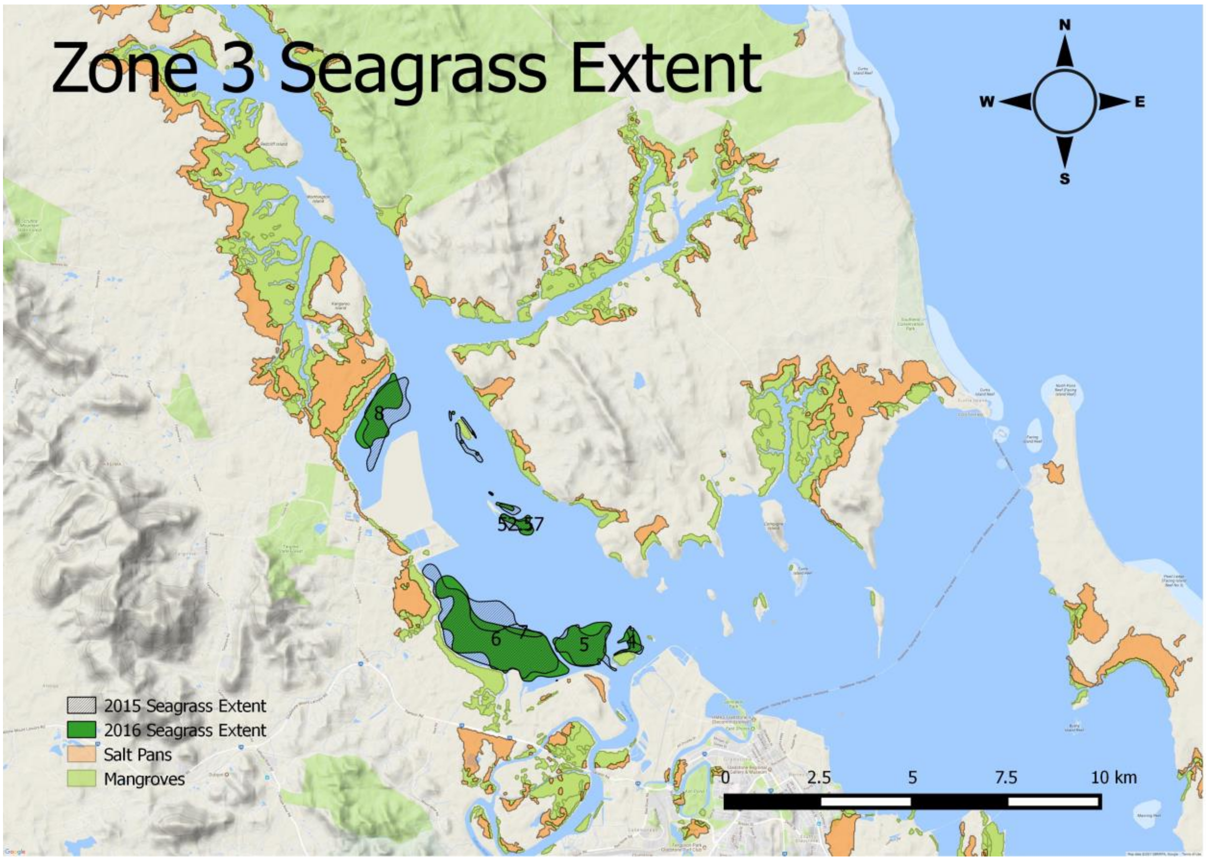


Figure 4.3: Changes to seagrass meadow area in the Western Basin between November 2015 and November 2016.

Zone 5 – The Inner Harbour

The Inner Harbour has one monitored meadow in the south-east corner of the zone near South Trees Inlet. This is an intertidal meadow comprising isolated patches of seagrass. The zone score was determined by species composition (0.00) indicating a very poor condition for Meadow 58 (Table 4.8). This meadow disappeared completely in 2010 and when re-established in 2011, most of the previously dominant *Zostera muelleri* was replaced by the colonising *Halophila ovalis*. By 2015, *Z. muelleri* accounted for just 3% of the seagrass biomass and by 2016 it had disappeared completely. Growth of colonising species in 2016 meant that meadow biomass improved from poor to good in 2017 and meadow area remained in a very good condition (Figure 4.3). The presence of *Z. muelleri* subsp. *capricorni* in previous years, and proximity to other *Z. muelleri* meadows as propagule sources, suggest this meadow should transition back to a *Z. muelleri*-dominated meadow if growing conditions remain favourable.

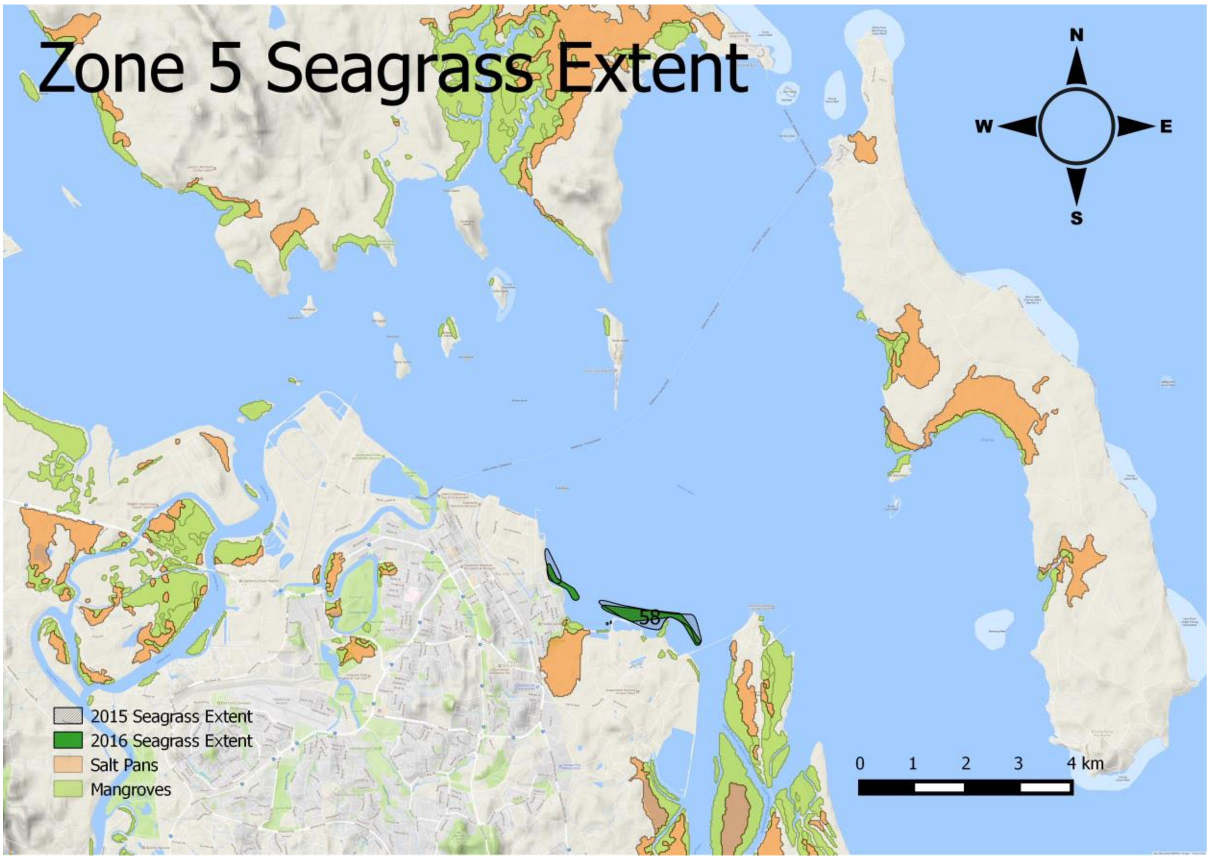


Figure 4.3: Changes to seagrass meadow area in the Inner Harbour between November 2015 and November 2016.

Zone 8 – Mid Harbour

The Mid Harbour has two monitored meadows located in the north of the zone near the south-east tip of Curtis Island. The largest meadow (43) Pelican Banks is the largest seagrass meadow in the harbour and covers an area of nearly 600ha. This meadow is considered to be the most abundant and productive seagrass in the Gladstone area and is the only meadow in which all three indicators have been classified as stable. Pelican Banks is an intertidal meadow while Meadow 48 contains both inter tidal and sub-tidal areas.

In 2017 the Mid Harbour received an overall score of 0.34 indicating a poor condition for this zone. This score is almost identical to the score of 0.35 received in the previous year.

Meadow 43 received a very poor score (0.14) for biomass compared to a poor score (0.25) in the previous year. While for Meadow 48, the biomass score improved from poor (0.46) in 2016 to good (0.75) in 2017. The area score for Meadow 43 declined from 0.78 in 2016 to 0.66 in 2017 and Meadow 48's area score (0.54) was identical to the score received in the previous year (Figure 4.4). Meadows 43 and 48 both received satisfactory scores for species composition 0.60 and 0.58 respectively (Table 4.8).

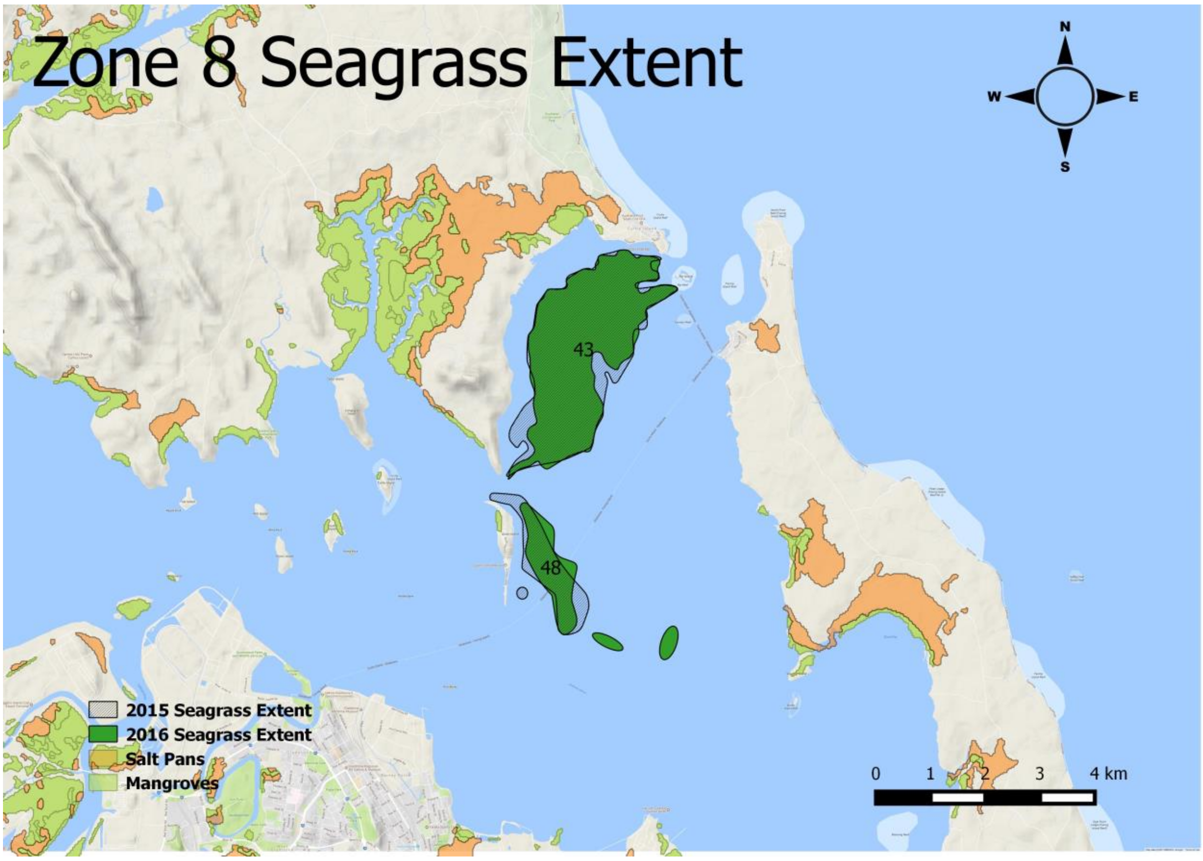


Figure 4.4: Changes to seagrass meadow area in the Mid Harbour between November 2015 and November 2016.

Zone 9 – South Trees Inlet

This zone has one monitored meadow which sits just off the northern tip of South Trees Island. It has an area of ~10.9ha making it the second smallest of the monitored meadows. Meadow 60 is an intertidal meadow of aggregated patches of seagrass. The condition of this meadow has improved from poor (0.48) in 2016 to good (0.75) in 2017 (Table 4.8). Between 2016 and 2017 the scores for all indicators improved in this meadow. The score for biomass improved from 0.48 to 0.75, the score for area climbed from 0.88 to 0.96 (Figure 4.5) and the species composition score improved from 0.59 to 0.98.

Figure 4.5: Changes to seagrass meadow area in the South Trees Inlet between November 2015 and November 2016.

Zone 13 – Rodds Bay

There are three inter-tidal seagrass meadows in Rodds Bay comprising aggregated seagrass patches dominated by *Zostera muelleri.* In 2017 the overall score was 0.19 indicating a very poor score compared to 2016 when the meadow was considered to be in poor condition (0.25). This resulted from sharp declines in area scores for Meadow 94 (0.06) and Meadow 104 (0.07) and rating them as in a very poor condition (Table 4.8). There was little change in biomass for Meadow 96 which scored 0.40 in 2016 and 0.42 in 2017 (Figure 4.6). This indicates a poor condition for this meadow, while meadows 94 and 96 were graded as very poor scoring 0.17 and 0.13 respectively. For species composition Meadow 94 improved from 0.36 to 1.00, Meadow 96 declined from 0.66 to 0.57 and the score for Meadow 104 dropped from 0.46 to 0.28. The area scores were very poor in meadows 94 and 104, 0.06 and 0.07 respectively. This was a decline from last year's score when both meadows received a poor score. Meadow 96 received a lower score for area 0.65 for 2017 compared to 0.76 in 2016 but was still considered to be in a good condition.

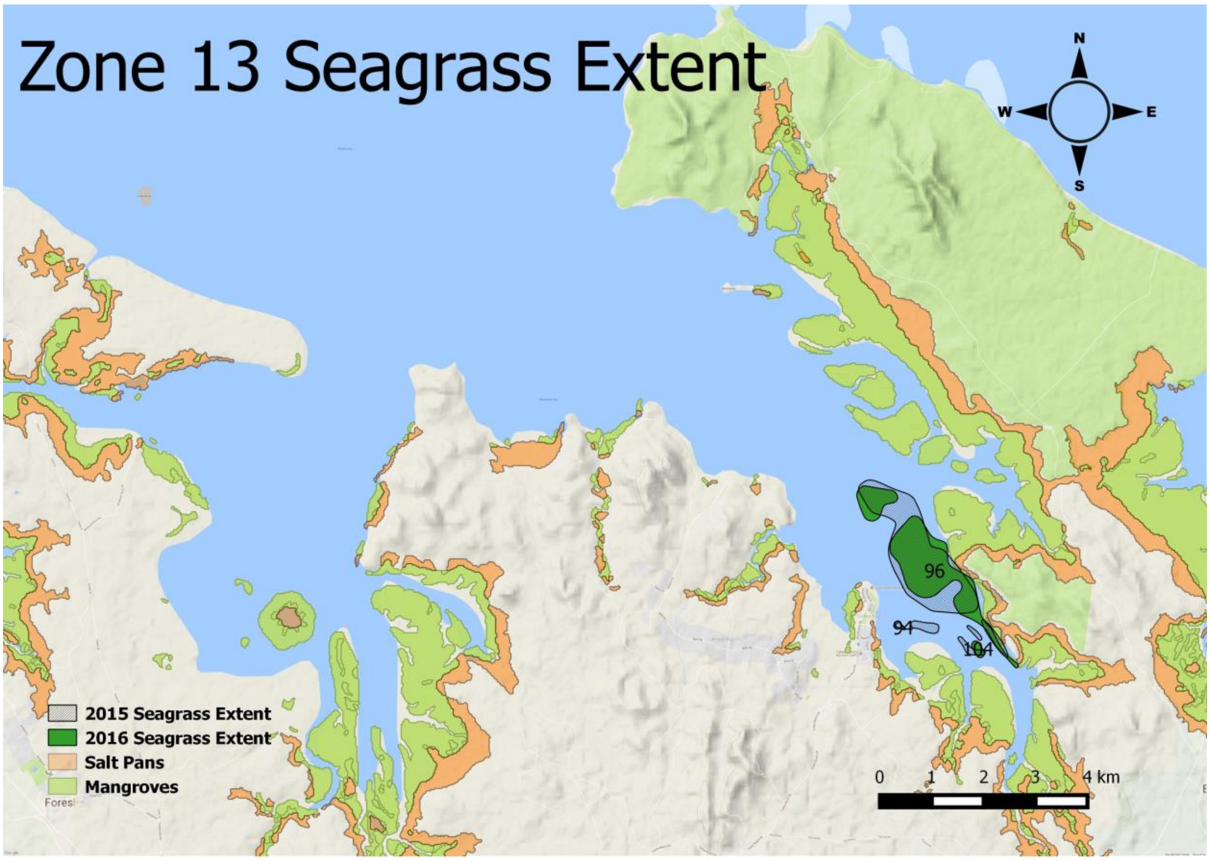


Figure 4.6: Changes to seagrass meadow area in Rodds Bay between November 2014 and November 2016.

4.2.4. Seagrass conclusions

There were limited signs of seagrass recovery across the harbour between 2016 and 2017. The overall poor condition of the seagrass meadows for four consecutive years indicates that meadows in Gladstone Harbour remain in a stable but vulnerable state. The overall seagrass condition for 2017 was poor (0.39), however this score was higher than the previous year's score of 0.35. Overall zone scores improved in two of the six monitored zones with The Narrows improving from a poor condition (0.33) to a satisfactory condition (0.59). The strongest improvement occurred at South Trees Inlet which improved from a poor condition (0.48) to a good condition (0.75). The Western Basin remained in a satisfactory condition and Rodds Bay declined from a poor condition in 2016 to a very poor condition. The Inner Harbor remained in a very poor condition.

Since monitoring commenced in 2002, seagrasses in the Gladstone region have undergone significant declines (Table 4.9) during and immediately following years of above average rainfall and flow from the Calliope River. Years with a large number of poor and very poor meadow grades corresponded with observed declines also occurring at Rodds Bay. This monitoring zone, originally established as a reference site, sits entirely outside the Gladstone Port limits just over 50km from the Western Basin. Declines in seagrass biomass were also associated with high flows in the Calliope River with the strongest associations occurring at the monitored meadows closest to the river mouth (e.g. Wiggins Island in the Western Basin). The timing of flood-related seagrass declines in 2010 and 2011 prior to the commencement of the capital dredging program makes it difficult to ascertain what additional impacts dredging may have had on seagrass condition and the subsequent rate of recovery. However, monitoring of light levels during the Western Basin Dredging and Disposal Project indicates that light levels were above locally derived guidelines at seagrass meadows outside dredging locations.

Multiple years of high rainfall, river flows and cyclone activity in the Gladstone region may have reduced the resilience and capacity for recovery of seagrass communities in Gladstone as it has in other locations in Queensland. In the 2016–17 reporting year, the seed banks necessary for recovery remained in key meadows and some seagrass was observed across most of the historical seagrass distribution. However, both were at a reduced level and may have been further impacted by the high rainfall and river flows associated with the passage of ex Tropical Cyclone (TC) Debbie in March 2017.

Table 4.9: Grades for individual seagrass monitoring meadows from annual (November) surveys, 2002–2016 (Source: Carter et al., 2017).

Zone	Meadow	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
1. The Narrows	21								A	B	C	C	E	E	D	C
3. Western Basin	4	B		C	D	B	A	B	A	E	D	C	D	D	C	B
	5	C		D	C	B	B	A	C	D	D	C	E	D	D	C
	6	B		D	C	C	B	B	A	E	E	D	D	B	B	C
	7	B		B	E	A	D	B	D	E	E	E	D	C	B	D
	8	A		E	E	B	B	C	B	C	E	D	E	D	D	E
	52–57								B	E	E	B	B	B	C	B
5. Inner Harbour	58	B		D	C	D	B	B	B	E	D	C	E	D	E	E
8. Mid Harbour	43	B		B	A	C	C	B	B	B	C	C	C	C	D	E
	48	B		C	B	A	A	B	E	D	D	D	C	C	D	C
9. South Trees Inlet	60	A		E	E	B	A	A	C	D	E	C	D	C	D	B
13. Rodds Bay	94	A		D	A	B	A	A	E	E	E	E	E	D	E	E
	96	B		D	C	B	A	A	B	D	E	D	E	D	D	D
	104	B		D	B	B	A	A	C	E	E	E	E	C	D	E

4.3. Corals

Coral communities are iconic components of marine ecosystems in Australia. In addition to their high biodiversity, coral reefs provide spawning, nursery and feeding areas for fish and a variety of other animals. These include sea turtles, crustaceans (such as prawns and crabs) and a large range of benthic organisms such as echinoderms (e.g. sea stars, sea cucumbers and sea urchins), molluscs, sponges and worms. Reefs also provide important ecosystem services such as nutrient recycling, and carbon and nitrogen fixation. In addition to their ecological value, coral reefs have considerable socio-economic importance.

Reefs within the GHHP monitoring zones include fringing, platform, headland and rubble fields with both hard and soft corals (BMT WBM, 2013). Within the Gladstone Harbour area, reefs have been recorded in the intertidal zones that have suitable substrata and sufficient light penetration around Turtle, Quoin, Rat, Facing and Curtis islands and at Seal Rocks. Coral communities have also been recorded within deeper channels (> 5m) in The Narrows and around Passage Island and the North Passage. Regions of hard and soft coral also occur along the northern edge of Hummock Island and limited coral reef development has also been identified in Rodds Bay (BMT WBM, 2013; DHI, 2013).

Threats to coral reefs include both natural and anthropogenic pressures that can operate at global (e.g. climate change, El Niño Southern Oscillation), regional or local scales. These pressures include negative effects from large-scale flooding, sedimentation, urban pollution and agricultural run-off. Coral reef communities within Gladstone Harbour can be exposed to freshwater run-off, elevated turbidity and nutrient levels and can be vulnerable to the negative impacts of sediments and increases in macroalgal cover (DHI, 2013).

Four indicators of coral health were measured to calculate the coral score for the 2017 Gladstone Harbour Report Card.

1. Coral cover (%): the combined cover of hard and soft corals relative to a baseline determined by the Australian Institute of Marine Science (AIMS) Reef Plan Marine Monitoring Program (MMP)
2. Macroalgal cover (%): the cover of macroalgae relative to a baseline consistent with the MMP
3. Juvenile coral density (no.m^{-2}): relative to the MMP baseline
4. Change in hard coral cover, averaged over three years to give the rate at which hard coral cover increases. This is the first year this indicator has been included.

4.3.1. Coral data collection

Establishment of long-term monitoring sites

Coral surveys between 6 and 8 July 2015 identified suitable sites for the long-term monitoring program. Prior to starting the surveys, existing reports on coral community locations were used to identify potential sites for long-term coral monitoring (BMT WBM, 2013; DHI, 2013) in the Inner Harbour, Mid Harbour and Outer Harbour zones. The review identified three islands within the Inner Harbour as possible sites for coral monitoring: Quoin, Turtle and Diamantina. However, surveys for areas of hard substrate and subsequent spot checks of the benthic communities were unable to locate suitable monitoring sites. The search for potential Inner Harbour survey sites was hampered by low underwater visibility on both rising and falling tides.

Four permanently marked survey sites (transects) were established in the Mid Harbour at Rat Reef, Farmers Reef, Facing Reef 2 and Manning Reef and two permanent sites were established in the Outer Harbour at Seal Rocks North and Seal Rocks South (Figures 3.16 and 3.22).

Coral monitoring

Coral monitoring for the 2017 report card was conducted on 16 May 2017 and included the following three methodologies.

Photo point intercept transects

The methodology outlined below closely follows that outlined in the AIMS Long-term Monitoring Program (Jonker et al., 2008). At each 20m transect, digital photographs were taken at 50cm intervals. Estimates of the cover of benthic components, including coral and macroalgae, were made from five fixed points overlayed on each digital image. Most hard and soft corals were identified to genus.

Juvenile corals

Juvenile coral colonies, up to 10cm in diameter were counted within a 34cm band along each permanently marked transect. Each colony was identified to genus and assigned to a size class of 0–2cm, 2–5cm or 5–10cm. The number of juvenile colonies observed along a fixed transect area will be affected by the availability of suitable substrata for settlement. To allow comparisons between reefs and over time, the numbers of recruits along each fixed transect were converted to densities per area available for settlement.

Disturbances

Incidences of coral disease, coral bleaching, coral predation by crown-of-thorns starfish, overgrowth by sponges, and smothering by sediments were counted along a 2m-wide band centred on the transect tape. These data are not used in the calculation of report card grades and scores. In the long term, however, they may be valuable for explaining changes in coral condition.

4.3.2. Development of coral indicators and grades

Each of the four coral indicators was scored against a baseline founded on expert opinion and data from the MMP for inshore reefs. The baseline for each of the three indicators represented the threshold between report card grades of C (satisfactory condition) and D (poor condition). The highest possible score of 1.00 was set to represent coral reefs in as good condition as could be expected in the local environment (Table 4.10). The lowest score of 0.00 was set to represent the worst condition that could be expected in the local environment (Table 4.10). Although it is possible for the observed results to be outside those limits, the scores were capped at 0.00 and 1.00 to allow scaling to the GHHP range of grades.

Combined cover of hard and soft coral

Healthy coral communities have sufficient recruitment and growth of colonies to replace losses resulting from disturbances and environmental limitations. High coral cover suggests that a large brood stock is available and increases the potential of other reefs in the vicinity to recover from disturbance. Additionally, high coral cover contributes to the structural complexity of a reef. This can increase its biodiversity by providing additional habitat for fish and other marine organisms. Both hard and soft coral cover were included in the assessment.

Macroalgal cover

Macroalgae can suppress coral by increased competition for space and by changing the micro-environment and inhibiting coral colonisation and growth (e.g. Foster et al., 2008; Cheal et al., 2010 cited in Thompson et al., 2015). Once established, macroalgae occupy space that might otherwise be available for coral growth and recruitment. For this indicator, macroalgae belonging to the Rhodophyta (red algae), Phaeophyta (brown algae) and Chlorophyta (green algae) were assessed.

Critical values for macroalgal cover were developed through the MMP and fitted to the Gladstone Harbour Report Card grading scheme (Figure 2.1). A baseline of 14% macroalgal cover was set at the C/D threshold for coral communities in Gladstone Harbour (Table 4.10).

Juvenile coral density

Recovery of coral reefs from disturbances such as flooding, cyclones, thermal bleaching or outbreaks of crown-of-thorns starfish is dependent on the recruitment of new coral colonies and regeneration of existing colonies. The number of juvenile colonies (< 10cm) at a reef can be negatively affected by poor water quality particularly where there is elevated concentrations of nutrients and agrichemicals and high turbidity (van Dam et al., 2011; Erftemeijer et al., 2012 cited in Thompson et al., 2015). High rates of sediment deposition will also negatively impact the number of juvenile colonies observed (Rogers, 1990). This shows that juvenile coral density can indicate a reef's potential for recovery from disturbance given the current conditions.

Thresholds for juvenile coral density are based on the MMP thresholds. These thresholds were set based on data on the densities of juvenile colonies recorded over four years of the MMP (2005–2009). That monitoring determined the mean density of juvenile corals for inshore reefs at sites 2m below lowest astronomical tide to be about 7.7 juvenile corals per m^2 of available substrate. For this study, the limits were set at the 10th and 90th percentiles of the distribution, or 1 and 16 juvenile colonies per m^2 respectively (Table 4.10).

Change in hard coral cover

While low coral cover may occur following acute disturbance such as large floods it does not necessarily give a good indication of the coral community's ability to recover. This is assessed by measuring the rate at which hard coral cover increases and provides a direct measure of recovery potential. This indicator captures the coral growth performance per reef by comparing observed rate of change (where there is no acute disturbance) to the rate of change observed in the time series of coral cover from 47 near-shore reefs monitored by the Long Term Monitoring Program and the Marine Monitoring Program from 1987 to 2007.

The model projections of future coral cover on Great Barrier Reef inshore reefs over the period 1987–2002 indicated a long-term decline in coral cover (Thompson & Dolman, 2010). For this reason, the positive score of 1 was reserved for those reefs at which the observed rate of change in cover exceeded the upper 95% confidence interval of the change predicted. Observations falling within the upper and lower confidence intervals of the change in predicted cover were scored as neutral (indicator score 0.5) and those not meeting the lower confidence interval of the predicted change received an indicator score of 0. The rate of change is averaged over three years of observations including the most recent. Therefore, it was not possible to have this metric in the Gladstone Harbour Report Card until the third year of surveys in 2017. Years in which disturbance events occurred at particular reefs were not included as there is no logical expectation for an increase in cover in such situations.

Table 4.10: Coral indicator thresholds for the Gladstone Harbour Report Card.

Indicator	Baseline (aligned with the report card C/D threshold of 0.50)	Upper bound (score = 1.00)	Lower bound (score = 0.00)
Combined cover of hard and soft corals	40%	90% (This has been reduced from 100% as coral cover rarely attains 100% coverage due to areas of colonisable substrate and variable population dynamics.)	0%
Macroalgal cover	14%	5%	20% of hard substrate area
Juvenile coral density	$5.8m^{-2}$	$16m^{-2}$	$1m^{-2}$
Change in hard coral cover	Lower 95% confidence interval	Twice the 95% confidence interval	Twice the lower 95% confidence interval

Aggregation of indicator scores

Bootstrapping was used to aggregate individual scores for each indicator within a zone to produce the zone score. This involved constructing a bootstrap distribution of 10,000 samples for each indicator in each zone. The mean of those distributions represented the zone score for each indicator. Aggregating the indicator distribution from each zone (indicator score) generated the harbour level scores, and the whole-of-harbour score was calculated as the mean of the whole-of-harbour indicator scores.

4.3.3. Coral results

The overall coral grade for the 2017 report card was a D (0.28). This resulted from a low cover of living coral, low abundance of juvenile corals and high macroalgal cover at most of the surveyed reefs and a poor overall score for change in hard coral cover. Although coral cover received the same score (0.07) as 2016, there were slight improvements in the scores for juvenile density and macroalgal cover (Table 4.11). The Mid Harbour received a poor zone score (0.33), while the Outer Harbour received a very poor zone score (0.21) primarily as a result of a very low score for macroalgal cover (Table 4.11).

Table 4.11: Coral indicator scores for the Mid Harbour and Outer Harbour and overall zone and harbour scores (Costello et al., 2017).

Zone	Coral cover	Change in hard coral cover	Macroalgal cover	Juvenile density	Overall score
8. Mid Harbour	0.08	0.44	0.50	0.33	0.33
11. Outer Harbour	0.06	0.37	0.00	0.44	0.21
Harbour score	**0.07**	**0.40**	**0.24**	**0.38**	**0.28**

Coral cover (%) was very low at all reefs and substantially lower than the 40% threshold required to receive a C grade (Table 4.12). The present cover remains considerably lower than that recorded in previous surveys. In 2009, a mean cover of 39% was recorded for hard corals in the Mid Harbour zone (BMT WBM, 2013). Similarly, a visual estimate of coral cover at Seal Rocks North (Outer Harbour) in December 2012 was around 50% (R.C. Babcock, personal communication in Thompson et al., 2015).

At both Seal Rocks sites and Facing Island 2, the high cover of macroalgae was dominated by the large brown algae genera *Sargassum* and *Lobophora.* The dominant form at Manning Reef was the red algae *Asparagopsis*. The overall score for macroalgae cover was 0.24 indicating a very poor condition for this indicator. Facing Island, Manning Reef, and north and south Seal Rocks received the same very poor scores (0.00) they received in 2016, whereas Farmers Reef and Rat Island received very good scores (0.95 and 1.00 respectively).

Scores for juvenile coral density ranged from very poor at Manning Reef (0.22) to satisfactory at Farmers Reef (0.53). Table 4.13 presents the number of juvenile coral colonies in each size class recorded in the coral surveys. The results of the 2015 and 2016 surveys are also presented for comparison.

The size of juvenile coral communities can indicate their age as corals spawn annually. Juvenile coral colonies in the 0–2cm range can broadly be considered a result of the previous spawning event. Juvenile coral colonies in the 2–5cm range are estimated to be between one and two years old. Juvenile coral colonies in the 5–10cm range are estimated to be greater than two years old. Over the three years of monitoring (2015–2017), there has been a steady increase in the number of juvenile colonies recorded particularly in the 5–10cm category which has increased across all reefs. This indicates that since monitoring began in 2015, conditions have remained favourable for these juvenile colonies.

Table 4.14 presents causes of coral mortality recorded in the Gladstone Harbour coral surveys from 2015 to 2017. These results suggest that in addition to the localised pressure of high macroalgal cover that bio-eroding sponges factor in the slow recovery of the monitored reefs.

Table 4.12: Individual coral indicator scores site level (Costello et al., 2017).

Zone/Reef	Coral cover		Hard coral cover change		Macroalgal cover		Juvenile density	
	Value (%)	Score	Value	Score	Value (%)	Score	Value (m^{-2})	Score
8. Mid Harbour								
Facing Island 2	9.5	0.12		0.50	26.5	0.00	3.37	0.25
Farmers Reef	7.1	0.09		0.50	5.9	0.95	6.49	0.53
Manning Reef	0.5	0.01		0.51	37.0	0.00	3.12	0.22
Rat Island	6.6	0.08		0.24	2.6	1.00	3.96	0.31
11. Outer Harbour								
Seal Rocks North	0.6	0.01		0.25	61.2	0.00	4.47	0.36
Seal Rocks South	9.3	0.12		0.50	49.3	0.00	6.03	0.51

Table 4.13: Number of juvenile hard coral colonies in three size classes (Costello et al., 2017).

Zone	Reef	Year	Size-class categories		
			< 2cm	2–5cm	5–10cm
			Estimated age		
			~1 year	1–2 years	>2 years
8. Mid Harbour	Facing Island 2	2015	107	28	0
		2016	67	58	7
		2017	32	58	8
	Farmers Reef	2015	32	17	5
		2016	37	26	9
		2017	64	39	16
	Manning Reef	2015	52	6	2
		2016	55	40	0
		2017	49	29	7
	Rat Island	2015	19	23	8
		2016	48	43	10
		2017	44	28	16
11. Outer Harbour	Seal Rocks North	2015	111	31	1
		2016	80	48	8
		2017	55	64	9
	Seal Rocks South	2015	52	30	3
		2016	27	55	9
		2017	58	58	21

Table 4.14: Causes of coral mortality at the time of the 2015, 2016 and 2017 Gladstone Harbour coral surveys. No data are presented for Manning Reef and Seal Rocks North owing to the very low coral cover at these sites (Thompson et al., 2016a, Costello et al., 2017).

Zone	Reef	Year	Cause	Coral genus	Colonies affected
8. Mid Harbour	Facing Island 2	2015	Bio-eroding sponge (*Cliona orientalis*)	*Porites*	13
		2016	Bio-eroding sponge	*Turbinaria*	1
				Porites	8
		2017	Bio-eroding sponge	*Porites*	12
	Farmers Reef	2015	Bio-eroding sponge	*Cyphastrea*	4
				Favia	1
		2016	Bio-eroding sponge	*Cyphastrea*	9
		2017	Bio-eroding sponge	*Cyphastrea*	9
				Favia	1
	Rat Island	2015	Bleaching	*Favites*	1
			Bio-eroding sponge	*Cyphastrea*	6
				Turbinaria	5
		2016	Bio-eroding sponge	*Cyphastrea*	7
				Turbinaria	4
		2017	Bio-eroding sponge	*Cyphastrea*	
11. Outer Harbour	Seal Rocks South	2015	Bio-eroding sponge	*Turbinaria*	3
		2016	AN*	*Turbinaria*	1
			Bleaching	*Pocillopora*	2
			Bio-eroding sponge	*Turbinaria*	4
			Unknown	*Turbinaria*	1
		2017	Bio-eroding sponge	*Turbinaria*	6
			White syndrome	*Turbinaria*	6
				Psammocora	1
			Bleaching	*Montipora*	1
	Seal Rocks North	2017	Bleaching	*Montipora*	1

*AN = *Atramentos necrosis* (coral disease)

4.3.4. Coral conclusions

The overall grade for corals improved from an E (0.12) in 2016 to a D (0.28) in 2017. This is largely attributable to the addition of the coral cover change indicator as scores for coral cover, juvenile density and macroalgal cover have remained broadly similar to those recorded in previous years, although there has been a slight decline in juvenile density and a slight increase in coral cover (Table 4.15).

The information strongly suggests that the low coral cover observed at these survey sites from 2015 to 2017 resulted from flooding in 2013. Reduced salinity levels from freshwater run-off in flood plumes is a recognised cause of coral mortality. Major flooding of the Boyne and Calliope rivers, a result of heavy rainfalls associated with TC Oswald in January 2013, temporarily lowered salinity levels within Gladstone Harbour. Converting temperature and conductivity data to practical salinity units (psu) for the Mid Harbour (Vision Environment Queensland 2013a,b) revealed a period of approximately three days from 27–29 January during which salinity levels remained below 20psu at a depth of 0m. A minimum level of 5psu was reached on 28 January. These sustained low levels are likely to have caused high coral mortality within the harbour. Berkelmans et al. (2012) demonstrated a salinity threshold for *Acropora* (e.g. staghorn and elkhorn corals) of 22psu for three days; beyond this level mortality can be expected.

The loss of coral cover caused by freshwater plumes is not limited to Gladstone Harbour. Flooding from the Fitzroy River caused severe coral mortality in Keppel Bay in 1991 and 2011. The Great Barrier Reef Report Card 2016 indicated that coral reefs in the Fitzroy region remained in a poor condition.

The bio-eroding sponge *Cliona orientalis* found at all reefs except Seal Rocks North may also be playing a role in limiting the recovery of corals in Gladstone Harbour (Costello et al., 2017).

Table 4.15: A comparison of coral indicator scores for the Mid Harbour and Outer Harbour for surveys conducted in 2015, 2016 and 2017 (Costello et al., 2017).

Zone	Reef	Year	Score				Reef score
			Coral cover	Coral Cover change	Juvenile density	Macroalgal cover	
8. Mid Harbour	Facing Island 2	2015	0.16	–	0.41	0.00	0.19
		2016	0.08	–	0.37	0.00	0.15
		2017	0.12	0.50	0.25	0.00	0.22
	Farmers Reef	2015	0.06	–	0.26	1.00	0.44
		2016	0.09	–	0.28	0.00	0.12
		2017	0.09	0.50	0.53	0.95	0.52
	Manning Reef	2015	0.00	–	0.12	0.00	0.04
		2016	0.00	–	0.25	0.00	0.08
		2017	0.01	0.51	0.22	0.00	0.19
	Rat Island	2015	0.08	–	0.11	0.50	0.23
		2016	0.07	–	0.39	0.29	0.25
		2017	0.08	0.24	0.31	1.00	0.42
11. Outer Harbour	Seal Rocks North	2015	0.00	–	0.42	0.00	0.14
		2016	0.00	–	0.38	0.00	0.13
		2017	0.01	0.25	0.36	0.00	0.19
	Seal Rocks South	2015	0.10	–	0.25	0.00	0.12
		2016	0.17	–	0.28	0.00	0.15
		2017	0.12	0.50	0.51	0.00	0.28

4.4. Fish and crabs

In 2017, the fish and crabs indicator group comprises two indicators—fish recruitment and mud crabs.

4.4.1. Fish recruitment

Fish recruitment is one of the three key dynamic functions that affects a fish population, the other two are growth rate and mortality. The fish recruitment index is based on the total catch of juveniles of two bream species and is defined as the annual production of juvenile fish entering the mature fish population in Gladstone Harbour (Sawynok & Venables, 2016). The fish recruitment index captures the reproductive vigour and the spatial extent of the two bream species and will be refined in subsequent years to improve its robustness and representativeness as more data become available.

What fish were used as indicators of harbour health ?

Yellowfin bream

Yellowfin bream is a slow growing (5 years to reach 23cm), silvery bronze body fish endemic to Australia with maximum length of about 60-65 cm. Its home range extends from Townsville (Queensland) to Gippsland Lakes in Victoria. Yellowfin bream inhabit mostly inshore areas and estuaries and forage for small fish, crustaceans, gastropods, bivalve molluscs, polychaete worms and ascidians.

Their spawning mostly occurs near estuary mouths during winter months. Larval stages are then moved to estuaries, develop into small juveniles and live in shallow waters sheltered by seagrass beds and mangrove channels. Yellowfin bream is a protandrous hermaphrodite meaning they undergo sex change during the life cycle.

Pikey bream

Pikey bream is a bottom living dark silvery grey body fish with a maximum length of about 50cm. In Australia its home range extends from Darwin (Northern Territory) to Port Clinton in Victoria. This species is not endemic to Australia and also reported in Southern Japan, Southern China, Vietnam, Philippines, Thailand, Malaysia, Indonesia and Papua New Guinea.

Pikey bream inhabit mostly shallow inshore areas and estuaries up to a depth of 50m. Being benthic feeders, their diet includes crustaceans, amphipods and tanaids. Their spawning mostly occurs in estuarine environment in the months of May-August. Pikey bream is a protandrous hermaphrodite meaning they undergo sex change during the life cycle.

(Source: Department of Agriculture and Fisheries, Fishes of Australia.Net, Garratt 1993, Harrison 1991 and James et al 2003)

A detailed fish recruitment survey in 2014 helped identify potential species to monitor. Barramundi was considered an unsuitable recruitment indicator for Gladstone Harbour (Venables, 2015), whereas yellow-finned bream *Acanthopagrus australis* and pikey bream *A. berda* looked promising. Bream surveys were conducted in the 2016–17 reporting year and data from this survey are reported here.

4.4.2. Fish recruitment data collection

Data for the two bream species were collected monthly from 26 sites across 12 harbour zones between December 2016 and March 2017. The Outer Harbour zone was excluded from the surveys as there were no suitable bream habitats (Table 4.16). Where possible within each zone, a minimum of two sites were selected to cover the upper tidal limit and another within the daily tidal influence. Each survey was completed within two weeks following the largest spring tides as recruitment of fish into nursery habitats is influenced by these large tides. A species fork length up to 100mm defined juvenile or year 0 recruits. A small number of large pikey bream were caught in December 2016 (max. fork length 258mm) and these were most likely to be year 1 recruits. Including these data did not affect the results. The fork length profiles of both species for key periods across the reporting year are shown in Figure 4.7.

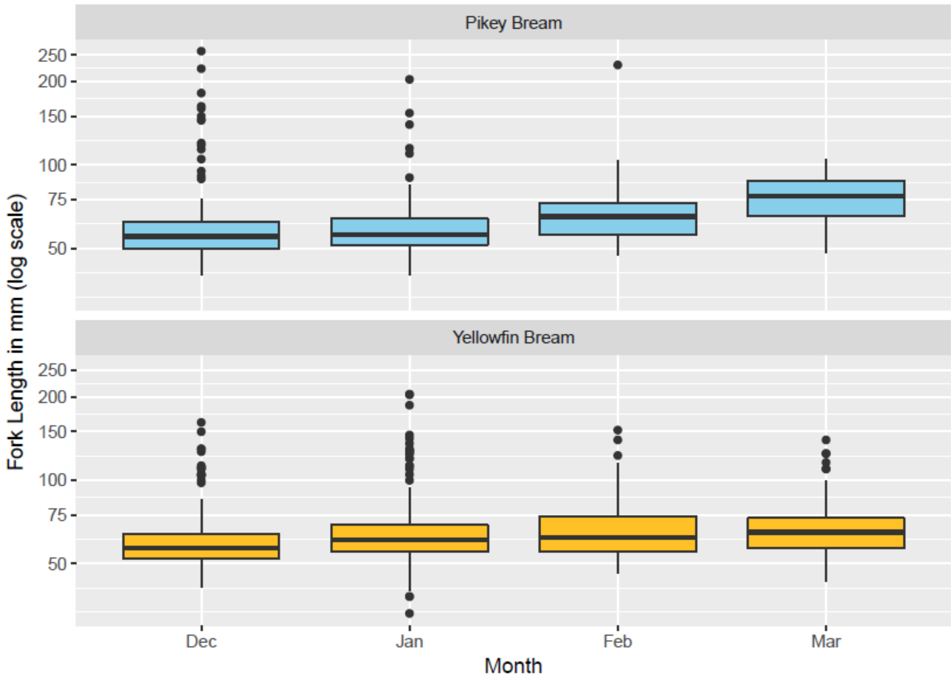


Figure 4.7: Fork length profiles of two bream species used in the study for all available data (Sawynok & Venables, 2017).

Each site was sampled 10 to 20 times using a standard cast net (monofilament net with a drop of 2.4m, mesh size 20mm and spread of 3.6m). Species were identified in the field and the length of each species, site ID, GPS coordinates, type of sub-strata, vegetation and site photographs were recorded at each site. Surveys were not done if the water temperature exceeded 32°C. Three experienced cast netters were involved in the surveys with some assistance from Gidargil rangers under the supervision from the principal investigator (Sawynok & Venables, 2017 (Figure 4.8).

4.4.3. Development of fish recruitment indicators and grades

A negative binomial statistical model (with a log link) was developed for the catch per trip to a site using data collected for this report card and other historical data collected since 2011. This model assesses the proportional changes in catch rate between years relative to a notional baseline. A number of potential environmental predictors related to fish habitats were also tested to determine if they helped to explain variation in the juvenile catch data. The estimates were aggregated (using bootstrapping technique) to obtain report card results, similar to other environmental scores.

The final statistical model comprises:

- a response variable – total yellow-finned and pikey bream juvenile catch count per visit, together with an offset term of log (number of casts), gives an effective response of catch per cast

- random effect terms – sampling site (allowing for productivity differences between sites not explained by the fixed effects), year (as the main effect), year by site interaction (previously year x zone) to better account for the variability in spatio-temporal scale

- log link – allows all difference or changes to be assessed on a proportional or relative scale rather than an absolute one

- fixed temporal effects – month term allowing for systematically different catch rates within the survey year

- fixed environmental effects – presence and absence of rocks, water depth at a site.

There are no external criteria available to set baseline levels for fish recruitment, therefore the scores were constructed with respect to internal criteria derived objectively from the data (Sawynok & Venables, 2016). A score of 0.50 indicates a season at the median reference level, indicating no increase or decrease in the catch rate from the long-term average.

4.4.4. Fish recruitment results

A considerably high number of bream recruits was reported during the 2016–17 monitoring year (910). There were 104 surveys conducted over four months catching 574 (325 previous monitoring year) yellow-finned bream and 336 (179 previous monitoring year) pikey bream (Table 4.16). The number of casts in the current year (2080) was also slightly higher than the 2020 casts in the previous monitoring year.

No fish with health issues were recorded during the survey period between December 2016 and March 2017.

Table 4.16: Number of sites surveyed in each zone to collect bream recruitment data (please refer to the site maps in section 3.1).

Harbour zone	Sites	Yellow-finned bream	Pikey bream
Zone 1. The Narrows	Ramsay Crossing	22	48
	Munduran Creek	29	0
	Black Swan Creek	17	77
	Targinnie Creek	21	2
Zone 2. Graham Creek	Graham Creek	0	8
	Hobble Gully	0	24
Zone 3. Western Basin	Mud Island	3	3
Zone 4. Boat Creek	Boat Creek	0	1
Zone 5. Inner Harbour	Little Enfield Creek	4	24
	Barney Point Pond	0	0
Zone 6. Calliope Estuary	Beecher Creek	20	2
	Old Bruce Highway Bridge	8	37
Zone 7. Auckland Inlet	Callemondah	35	43
Zone 8. Mid Harbour	Farmers Point	26	0
	Gatcombe Anchorage	0	1
Zone 9. South Trees Inlet	Wappentake Creek	3	1
	South Trees	15	16
	Crematorium Pool	123	0
Zone 10. Boyne Estuary	Old Boyne	42	0
	Boyne Highway	49	0
Zone 11. Outer Harbour	Not surveyed	Not surveyed	Not surveyed
Zone 12. Colosseum Inlet	Broadacres	11	12
	Iveragh	20	3
Zone 13. Rodds Bay	Oaky Creek	25	12
	7 Mile Creek	19	16
	Worthington Creek	14	4
	Sandy Bridge	68	2
Total	**26 sites**	**574**	**336**

As the report card results were generated through a modelling approach, the estimates and the confidence of the model is dependent on the quantity of the input data (Logan, 2016). By adding 2016 data, the model has become more stable and should be able to compare results in future report cards.

Overall the fish recruitment score in the 2017 report card was 0.71 (B), indicating a good result. Out of the 12 zones monitored, 1 zone (Boat Creek) indicated a poor score and only 2 zones (Graham Creek and Inner Harbour) had satisfactory scores (Table 4.17). The improvement in the scores compared to the previous years is generally indicative of better recruitment.

Table 4.17: Fish recruitment scores for all harbour zones and overall harbour score for fish recruitment.

Zone	2017	2016	2015*
1. The Narrows	0.75	0.30	0.86
2. Graham Creek	0.58	0.44	0.72
3. Western Basin	0.78	0.36	Not surveyed
4. Boat Creek	0.47	0.36	0.80
5. Inner Harbour	0.64	0.33	0.80
6. Calliope Estuary	0.79	0.43	0.70
7. Auckland Inlet	0.91	0.53	0.80
8. Mid Harbour	0.71	0.29	Not surveyed
9. South Trees Inlet	0.71	0.43	0.72
10. Boyne Estuary	0.74	0.54	0.69
11. Outer Harbour	Not surveyed	Not surveyed	Not surveyed
12. Colosseum Inlet	0.71	0.45	Not surveyed
13. Rodds Bay	0.74	0.58	Not surveyed
Harbour average	**0.71**	**0.40**	**0.80**

*The 2015 results are shown for comparison only and were not included in the 2015 report card.

4.4.5. Fish recruitment conclusions

Recruitment plays a key role in a fishery population. The 2017 score of 0.71 (B) for fish recruitment means a season with increased catch rate relative to the median reference level. In other words, the model identified that the 2016–17 year had a higher recruitment rate than the previous years after correcting for a number of environmental and temporal variables.

Figure 4.8: A pikey bream caught at Black Swan Creek in The Narrows zone.

4.4.6. Mud crabs

Mud crabs are one of Gladstone Harbour's iconic species. They were identified as a major community concern at workshops conducted by GHHP in 2013. This is due to their value to commercial and recreational fishers and the reported high rates of rust spot disease in the harbour's population. Mud crabs spend most of their post-larval lives in burrows in estuarine mangrove habitats and their abundance, size distribution and health are related to environmental conditions within these habitats. Based on conceptual models, Dambacher et al., (2013) indicated that the abundance of adult mud crabs was a highly interpretable variable and would be a meaningful indicator for the Gladstone Harbour Report Card.

Figure 4.9: Gladstone Harbour Mud Crab Monitoring 2017.

GHHP aims to establish a long-term mud crab monitoring program that will be sufficiently sensitive to show change over time in response to either natural or anthropogenic pressures, or in response to management actions aimed at improving the health of Gladstone Harbour. A pilot study in 2017 evaluated mud crab monitoring sites, and developed both suitable indicators of mud crab health and a methodology for determining report card grades and scores. The accuracy and reliability of the mud crab grades may improve as more data are collected and all indicators are included as this work moves beyond its first year.

4.4.7. Mud crab data collection

Monitoring site selection

Potential monitoring sites were selected based on historical sampling locations such as Queensland Fisheries Long Term Monitoring Program (Jebreen et al., 2008), local knowledge of mud crab populations, accessibility and a reconnaissance trip on 5–6 June 2017. A survey of Gladstone Harbour conducted between 19 and 23 June 2017 assessed the suitability of sites for permanent mud crab monitoring in eight of GHHP's environmental monitoring zones during (Figure 4.9). A second round of mud crab surveys between 3 and 5 July 2017 identified an additional site for Rodds Bay and tested the potential for including a mark recapture component of the abundance measure.

From the nine sites assessed, seven were included in the 2017 report card and recommended for future monitoring (Table 4.18). Two sites were excluded from future monitoring. Rodds Bay site A was excluded owing to insufficient mud crab habitat to accommodate the number of pots required and South Trees Inlet owing to a very low catch rate in the initial survey.

Table 4.18: GHHP zones assessed as permanent report card mud crab monitoring sites in 2017. From the nine sites assessed seven were selected for inclusion in the report card and recommended for on-going mud crab monitoring.

Zone	Permanent monitoring site	1st Survey date	2nd Survey date
1. The Narrows	✓	20/6/2017	3/7/2017
2. Graham Creek	✓	20/6/2017	3/7/2017
4. Boat Creek	✓	21/6/2017	4/7/2017
5. Inner Harbour	✓	19/6/2017	5/7/2017
6. Calliope Estuary	✓	21/6/2017	4/7/2017
7. Auckland Inlet	✓	23/6/2017	Not surveyed
9. South Trees Inlet	✗	19/6/2017	Not surveyed
13. Rodds Bay, site A	✗	22/6/2017	Not surveyed
13. Rodds Bay, site B	✓	Not surveyed	6/7/2017

Mud crab monitoring

Twenty heavy duty, four-entry collapsible crab pots were set at a minimum of 100m apart at each site. The exception was Boat Creek where only 15 pots could be placed within the confines of this small zone. All surveys were conducted on days when low tide fell between 10.30am and 3.00pm. The baited crab pots were set at least two hours before the low tide, and collected at least two hours after the low tide, resulting in soak times of approximately five hours per pot. All pots were placed so that they would be submerged for the duration of deployment to prevent mortality of any fish or other bycatch.

Upon retrieval of the pots, the following data were collected at each site for the first 40 mud crabs:

- species
- sex
- carapace width (notch to notch) (mm)
- mass (g)
- abnormalities: type, body location, dimensions of rust spot lesions, grade of rust spot lesion (Andersen et al., 2000).

During the initial survey, the first 40 mud crabs were also marked with a unique code using nail varnish (to assess the potential for mark–recapture surveys).

At sites where more than 40 crabs were caught only species and sex were recorded. For all bycatch (crabs and fish), the species was recorded and blue swimmer crabs were weighed, measured and checked for abnormalities. All mud crabs and bycatch were released alive at the site of capture.

A further round of site assessment based on accessibility, habitat type, capture rates, and proximity to other GHHP monitoring sites and historical mud crab monitoring sites was used to derive the final recommendation for ongoing monitoring (Table 4.19). Data from the June sampling round were used to calculate the 2017 report card grades and scores for all zones except Rodds Bay where the July data were used.

Mud crab feeding at a BRUV during the 2017 mud crab monitoring (Photo courtesy of Central Queensland University).

Baited Retrievable Underwater Videos (BRUV)

18 BRUVs were deployed over the course of the monitoring to evaluate their potential for future monitoring in Gladstone Harbour. Mud crabs were recorded on 9 of the 18 BRUVs. Other species recorded included yellow-finned bream, crescent grunter, sand gobies, crustaceans and worms. Potential future use of the BRUVs includes installation on selected crab pots to collect information on crab behaviour.

4.4.8. Development of mud crab indicators and grades

A literature search for potential mud crab indicators identified nine classes of potential mud crab indicators (Table 4.19). This included the three indicators identified by the ISP for consideration: abundance, size distribution and visual health (McIntosh et al., 2014). Other potential indicators were identified in the literature or were those used in other mud crab surveys in the Gladstone area.

Table 4.19: Potential mud crab indicators were identified and ranked based on their suitability for calculating report card grades and scores.

Potential mud crab indicators	Total score (30 = highest possible score)
Size sex ratio based on legal size limit	26.5
Biomass ratio of carapace width to body weight	25.3
Abundance catch per unit effort (CPUE)	25
Prevalence of rust lesions visual assessment	24
Bioaccumulation of toxicants bioaccumulation of metals in tissues structural deformities of organs (associated with metals) bioaccumulation of persistent organic pollutants bioaccumulation of pesticides	21.3
Nursery value juvenile crabs (CPUE)	18
Morphometrics e.g. claw size ratio	18
Prevalence of other diseases and parasites • visual assessment	17.5
Biomarkers Glutathione S-transferases induction and ChE inhibition RNA/DNA ratios glutathione peroxidase activity and lipid peroxides antioxidant enzymes and oxidative stress parameters	14

The potential indicators were scored against 10 criteria by the project team (see Flint et al., 2017a) and four indicators were selected for the report card:

1. Size: sex ratio based on legal size limit

$$\frac{\textit{male mud crabs} > 15.0\textit{cm} \,/\, \textit{female mud crabs} > 15.0\textit{cm}}{\textit{male mud crabs} < 15.0\textit{cm} \,/\, \textit{female mud crabs} < 15.0\textit{cm}}$$

2. Abundance: catch per unit effort (CPUE)

$$\frac{\textit{total number of mud crabs}}{\textit{number of pots set}}$$

3. Visual health: prevalence of rust lesions

$$\frac{\textit{number of crabs with lesions}}{\textit{number of crabs assessed for lesions}}$$

4. Biomass: body condition index

$$\frac{\textit{carapace width}}{\textit{body weight}}$$

The report card scores were calculated using a methodology similar to that used in the South East Queensland Report Card (Fox, 2013) and the Fitzroy Basin Report Card (Flint et al., 2017b). The indices for size, abundance and visual health were calculated and compared to a benchmark and a worst-case scenario (Table 4.20). Calculated index values lower than the worst-case scenario scored 0; values higher than the benchmark value scored 1. This resulted in a range of scores between 0 and 1. Owing to a lack of baseline data, biomass was not included in the 2017 report card. This indicator will likely be included within the next three years as sufficient data are collected through the mud crab monitoring program to inform a reliable benchmark and worst-case scenario.

Benchmarks and worse-case scenarios were selected based on existing data and data collected during the 2017 report card monitoring. The benchmark for abundance (measured as CPUE) was set as the 75th percentile of the 2017 report card monitoring data as representative of a minimally disturbed condition. CPUE data from the Long Term Monitoring Program were collected in summer using different soak times and smaller pots and therefore not included. The worst-case value was set at 0.25, equivalent to one crab from four pots. The maximum number of pots that a recreational crabber is allowed is four and a catch of < 1 mud crab from four pots is undesirable.

Table 4.20: Calculation of mud crab scores for the 2017 report card.

Measure	Benchmark	Worst case scenario	Method
Size–sex ratio	Male:female sex ratio of 3:1 from an unfished mud crab population reported in Alberts-Hubatsch et al., 2016 (3)	25th percentile of Long Term Monitoring Program data (0.25)	1-((B-x)/(B-WCS)) Where: x = recorded CPUE B = benchmark (3) WCS = worst-case scenario (0.25)
Abundance (CPUE)	75th percentile of the 2017 data (3.5)	Catch rate of < 1 crab per allowable 4 pots (0.25)	1-((B-x)/(B-WCS)) Where: x = recorded CPUE B = benchmark (3.5) WCS = worst-case scenario (0.25)
Prevalence of rust lesions	25th percentile of the 2017 data (4%) 0.04	Dennis et al. 2016 mean prevalence in Gladstone Harbour (37%) 0.35	1-((x-B)/(WCS-B)) Where: x = recorded prevalence B = benchmark (0.04) WCS = worst-case scenario (0.35)
Biomass	Not collected	Not collected	Will be included as an indicator when three years of data are available (2020)

The benchmark and worst-case scenario for the prevalence of rust lesions can also be set using the 2017 report card monitoring data or historical data (e.g. Andersen et al., 2000; Dennis et al., 2016). A background level of 5% of crabs with rust spot lesions has previously been reported. However, the 25th percentile of the 2017 monitoring was approximately 4% (0.04) and this lower figure was adopted as the benchmark as a precautionary approach. The worst-case scenario (0.35) was based on a study by Dennis et al. (2016) which was conducted at a time of unusually high fish and crab disease and is representative of a population in poor condition.

While data to set a size–sex ratio benchmark are available from the Long Term Monitoring Program and the 2017 monitoring, both datasets are from fished populations. This indicator assesses fishing pressure as only male crabs can be retained. A minimally disturbed benchmark requires data from an unfished population, where an undisturbed male female ratio can be determined. Hence a ratio of 3:1 reported for unfished populations in Micronesia (Alberts-Hubatsch et al. 2016) was used. This benchmark will be re-assessed in data from an unfished population in Queensland becomes available. As the Long Term Monitoring Program data are the longest time series available, the worst-case scenario was set at the 25th percentile (0.25).

4.4.9. Mud crab results

The overall mud crab grade for the 2017 report card was a C (0.55). This was a result of very poor to poor scores for sex ratio (0.00–0.39) in six of the seven zones and very poor scores for abundance in three of the seven zones. Grades for prevalence of rust spot lesions were very good in five zones and in the remaining two zones one had a good score and the other had a satisfactory score (Table 4.21).

Table 4.21: Mud crab indicator scores for the 2017 Gladstone Harbour Report Card.

Zone	Size (sex ratio)	Abundance (CPUE)	Prevalence of rust lesions	Biomass	Zone score 2017
1. The Narrows	0.00	1.00	1.00	NC	0.66
2. Graham Creek	0.36	0.52	0.95	NC	0.61
4. Boat Creek	0.11	1.00	1.00	NC	0.70
5. Inner Harbour	0.71	1.00	0.89	NC	0.87
6. Calliope Estuary	0.36	0.14	0.90	NC	0.47
7. Auckland Inlet	0.00	0.12	0.63	NC	0.25
13. Rodds Bay	0.39	0.03	0.67	NC	0.36
Harbour scores	**0.28**	**0.54**	**0.86**	**NC**	**0.55**

NC: not collected

Size–sex ratio

In some zones no female crabs of < 143mm were caught. Therefore, it was not possible to calculate a size–sex ratio comparing the ratio of male crabs of ≥ 143mm to female crabs of ≥ 143mm with the ratio of male crabs of < 143mm to female crabs of < 143mm (Table 4.22). An alternative male/female ratio was used which calculates the ratio of male crabs over 143mm to female crabs over 143mm (Table 4.22). The highest value for the sex ratio, 2.2 males for every female, was recorded in the Inner Harbour and the lowest value of 0.24 males for every female was recorded in The Narrows. Report card scores were calculated from these indices using the formula in Table 4.20.

Abundance: catch per unit effort (CPUE)

Abundance was the total number of crabs caught per pot during the 2017 mud crab monitoring for seven harbour zones. Highest catch rates were recorded in The Narrows, Boat Creek and Inner Harbour. The lowest catch rate was recorded in Rodds Bay (Table 4.23). Report card scores were calculated from the CPUE using the formula in Table 4.20.

Table 4.22: Size and sex of mud crabs caught and released during the 2017 mud crab monitoring.

Zone	Males ≥ 143mm	Females ≥ 143mm	Male female ratio ≥ 143mm	Males < 143mm	Females < 143mm	Ratio < 143mm	Size–sex ratio
1. The Narrows	6	25	0.24	7	2	3.5	0.0686
2. Graham Creek	16	13	1.23	8	0	∞	0.0000
4. Boat Creek	5	9	0.56	24	3	8.0	0.0694
5. Inner Harbour	22	10	2.20	8	0	∞	0.0000
6. Calliope Estuary	5	4	1.25	5	0	∞	0.0000
7. Auckland Inlet	1	9	0.11	2	1	2.0	0.0556
13. Rodds Bay (site B)	2	2	1.00	7	0	∞	0.0000

Table 4.23: Catch per unit effort for pots set in seven harbour zones during the 2017 mud crab monitoring.

Zone	Number of pots	Total crabs caught	Crabs per pot (CPUE)
1. The Narrows	21	97	4.62
2. Graham Creek	19	37	1.95
4. Boat Creek	15	54	3.60
5. Inner Harbour	20	70	3.50
6. Calliope Estuary	20	14	0.70
7. Auckland Inlet	20	13	0.65
13. Rodds Bay (site B)	20	7	0.35

Visual health: prevalence of rust lesions

The prevalence of rust lesions was assessed for the first 40 crabs caught in each zone (Table 4.24). The lowest incidence of lesions was recorded in Boat Creek and The Narrows where less than 3% of the mud crabs had visual lesions. The highest incidence was recorded in Auckland Inlet (15.4%) and Rodds Bay (9.1%). Report card scores were calculated from the percentage of mud crabs with lesions using the formula in Table 4.20.

Table 4.24: Percentage of mud crabs with external lesions (rust spot) recorded for the first 40 crabs caught within each zone, except for Boat Creek where 41 crabs were assessed.

Zone	Mud crabs with lesions	Mud crabs without lesions	% with lesions
1. The Narrows	1	39	2.5
2. Graham Creek	2	35	5.4
4. Boat Creek	1	40	2.4
5. Inner Harbour	3	37	7.5
6. Calliope Estuary	1	13	7.1
7. Auckland Inlet	2	11	15.4
13. Rodds Bay	1	10	9.1

4.4.10. Mud crab conclusions

The mud crab indicators have been selected to represent range of pressures on mud crabs in Gladstone Harbour. These pressures include commercial and recreational fishing and environmental condition. They are capable of revealing change over time and elucidating trends in mud crab health. Confidence in the indicator will improve as the dataset grows annually.

In 2017 the zone with the highest overall grade was the Inner Harbour (0.87). This was a result of very good grades for abundance and prevalence of rust lesions and a good grade (0.71) for sex ratio. Boat Creek and The Narrows also received very good scores for abundance and prevalence of rust lesions (Table 4.21); but only received a good overall zone score owing to very poor scores for size (sex ratio). Graham Creek received a satisfactory overall score (0.61) as despite receiving a very good score for prevalence of rust lesions (0.95) it received a poor score for size (sex ratio) (0.36) and a satisfactory score for abundance (0.52). The remaining three zones Calliope Estuary (0.47), Auckland Inlet (0.25) and Rodds Bay (0.36) all received poor overall scores. This was a result of very poor scores for abundance and poor and very poor scores for size (sex ratio).

In Queensland mud crab fisheries it is illegal to take female crabs, hence changes in the ratio of male to female crabs can indicate changes in fishing pressures (recreational and commercial). In addition to potential changes to population dynamics there is also potential for changes in ecosystem process owing to differences in behaviour between male and female crabs. For example, only male crabs dig burrows, a behaviour which may aid the process of bioturbation (disturbance of sedimentary deposits by living organisms) in mangrove ecosystems.

A simple sex ratio was substituted for the size–sex ratio in 2017 (see Table 4.20) owing to no captures of small female mud crabs in four zones. The size–sex ratio method will be revaluated in future years in case 2017 had an unusually low capture rate for small female crabs. Additionally, as the benchmark is considered to be of low reliability (derived from an international study), the possibility of sampling an unfished Queensland population to improve this benchmark will be investigated. In 2017 all zones except the Inner Harbour had poor or very poor scores for this indicator (Table 4.21).

Abundance scores ranged from very good in The Narrows (1.00), Boat Creek (1.00) and the Inner Harbour (1.00) to very poor in Calliope Estuary (0.14), Auckland Inlet (0.12) and Rodds Bay (0.03). Results for Graham Creek (0.52) were satisfactory (Table 4.21). However, caution is required in interpreting the abundance scores as CPUE data can be highly variable. Variability will arise as a result of capture technique, sampling area and time, or owing to differences in crab distribution, growth or survival related to habitat and environmental conditions (Alberts-Hubatsch et al., 2016). When these factors are controlled for, a measure of abundance can provide a simple indicator of changes to external pressures (e.g. fishing or changes to habitats) or changes in recruitment levels. The reliability of this indicator is expected to improve over time as more data are collected using consistent sampling methods.

The prevalence of rust lesions was scored with moderately high confidence in the benchmark and worst-case scenario as they are based on research data from Gladstone Harbour (Andersen & Norton, 2001, Dennis et al., 2016) and data collected during the 2017 GHHP monitoring. Five of the seven zones received very good scores (0.89–1.00), Rodds Bay (0.67) received a good score and Auckland Inlet (0.63) received a satisfactory score (Table 4.21). These scores indicate a generally low prevalence of rust spot lesions across the harbour. The average incidence of rust spot lesions across the seven monitored zones was 6%, substantially lower than the 37% incidence recorded in 2012 (Dennis et al., 2016) or the 22% recorded in the late 1990s by Andersen et al. (2000).

4.5. Environmental component and indicator groups results

The overall Environmental component score for the 2017 report card was 0.60 (C). This score was derived by aggregating the three environmental indicator groups (water and sediment quality, habitats, and fish and mud crab) using the bootstrapping methodology (Logan, 2016).

Direct comparisons to the 2016 results for the environmental component are not possible owing to changes in the indicators and sub-indicators assessed. In 2017 one new indicator, crabs, was added to the fish and mud crab indicator group and the sub-indicator coral cover change was added to the coral indicator.

The indicator group score for water and sediment quality was derived from the aggregation of the water and sediment quality indicator scores, whereas for habitats this was derived from the aggregation of the seagrass and coral indicator scores. The overall harbour scores for these three indicator groups were: water and sediment quality 0.87 (A), habitats 0.33 (D), and fish and crabs 0.63 (C) (Table 4.25).

The zone scores for the habitats indicator group only include the habitat indicators present in each zone. Hence five of the habitat scores were based on seagrass scores only which may not reflect the overall habitat value of the zone as other habitat types may be present (e,g. mangroves in a majority of zones and benthic habitats in all zones. A project to include mangrove habitats in future report cards is currently in development.

Unlike other environmental indicators in the report card, the scores for seagrass meadows were based on the lowest score for the sub-indicators, rather than the aggregation all sub-indicator scores. The zone score of 0.00 for the single Inner Harbour seagrass meadow has been determined by the sea grass score for species composition. However this meadow received a good score for biomass (0.73) and a very good score for area (0.87) and can be regarded as having some value as a seagrass habitat.

A project to include mangrove habitats in future report cards is currently in development

Table 4.25: Environmental indicator group scores and overall environmental scores for the 13 harbour zones and the overall harbour scores.

Zone	Indicator groups		
	Water and sediment quality	Habitats (seagrass and corals)	Fish and crabs (bream recruitment)
1. The Narrows	0.81	0.59	0.70
2. Graham Creek	0.90	NA	0.59
3. Western Basin	0.87	0.50	0.78
4. Boat Creek	0.78	NA	0.57
5. Inner Harbour	0.86	0.00	0.75
6. Calliope Estuary	0.85	NA	0.62
7. Auckland Inlet	0.83	NA	0.57
8. Mid Harbour	0.87	0.34	0.71
9. South Trees Inlet	0.91	0.75	0.71
10. Boyne Estuary	0.90	NA	0.74
11. Outer Harbour	0.93	0.21	
12. Colosseum Inlet	0.92	NA	0.71
13. Rodds Bay	0.85	0.19	0.55
Harbour score	**0.87**	**0.33**	**0.63**

5. The Social component

Report cards have become an increasingly popular way to document environmental condition. The 2017 Gladstone Harbour Report Card also reports on the social, cultural and economic condition of the harbour. Eight indicators aggregated into three indicator groups (harbour usability, harbour access, and liveability and wellbeing) were used to assess the social health of the harbour (Table 5.1). These indicators were developed from the GHHP vision and piloted in 2014 (Pascoe et al., 2014).

Table 5.1: Indicator groups, indicators and measures used to determine social grades and scores for the 2017 report card (Source: Windle et al., 2017).

Indicator groups	Indicators	Measures	Data source	Baseline
Harbour usability	Satisfaction with harbour recreational activities	How satisfied with last trip	CATI survey (average of Q11b, 15b and 25)	10-point scale
		Quality of ramps and facilities	CATI survey (average of Q28 and 28a)	10-point scale
	Perceptions of air and water quality	Water quality satisfaction	CATI survey (Q40)	10-point scale
		Air quality satisfaction	CATI survey (Q41)	10-point scale
		Water quality does not affect use of the harbour	CATI survey (Q42)	10-point scale
	Perceptions of harbour safety for human use	Marine safety incidents	Marine incidents in Queensland Annual Report 2016 by Department of Transport and Main Roads, Maritime safety Queensland	10-year moving average (Data from 2007–16 calendar year—rate of incidents in Gladstone Maritime Region as compared to other ports in Queensland)
		Oil spills	Marine pollution data 2002–17 Queensland Department of Transport and Main Roads	10 year moving average (Data from 2007–16 calendar year—rate of oil spills in Gladstone Maritime Region as compared to other ports in Queensland)
		Safe at night	CATI survey (Q44)	10-point scale
		Happy to eat seafood	CATI survey (Q43)	10-point scale

Table 5.1 (cont.): Indicator groups, indicators and measures used to determine social grades and scores for the 2017 report card (Source: Windle et al., 2017).

Indicator groups	Indicators	Measures	Data source	Baseline
Harbour access	Satisfaction with access to the harbour	Fair access to harbour	CATI survey (Q29)	10-point scale
	Satisfaction with ramps and public spaces	Frequency of use	CATI survey (Q8)	10-point scale
		Number of ramps	CATI survey (Q27)	10-point scale
		Access to public spaces	CATI survey (Q26)	10-point scale
	Perceptions of air and water quality	Great condition	CATI survey (Q33)	10-point scale
		Optimistic about future health	CATI survey (Q34)	10-point scale
		Improved over the last 12 months	CATI survey (Q35)	10-point scale
	Perception of barriers to access	Marine debris a problem	CATI survey (Q36)	10-point scale
		Marine debris affects access	CATI survey (Q37)	10-point scale
		Shipping reduced use	CATI survey (Q31)	10-point scale
		Recreational boats reduced use	CATI survey (Q32)	10-point scale
Liveability and wellbeing	Contribution of harbour to liveability and wellbeing	Makes living in Gladstone a better experience	CATI survey (Q45)	10-point scale
		Participate in community events	CATI survey (Q46)	10-point scale

5.1. Data collection

The GHHP ISP suggested a series of candidate indicators to assess the social aspect of harbour health in 2014 (McIntosh et al., 2014). The ISP and a workshop of experts in social science and economics identified 'appropriate' measures for evaluating these candidate indicators (Pascoe et al., 2014). 'Appropriateness' was based on a measure's relationship with the indicator, indicator group and its measurability.

A CATI survey interviewed 401 residents from the Gladstone 4680 postcode area during the last two weeks of May 2017 (Figure 3.28). Participants in the Gladstone 4680 postcode area were contacted using a random dialling technique. Both landline and mobile phone users were contacted for the surveys (in 2016 the CATI survey was only restricted to landlines). Trained research interviewers administered the survey which was thoroughly monitored for data QA/QC. The survey questions were largely qualitative and related to the GHHP social, cultural and economic objectives. All questions were designed to be answered on a 10-point agree–disagree scale. One question in the CATI survey asked participants to suggest the first three words that come to their mind when thinking about Gladstone

Harbour. The responses were cleaned and used to develop a word cloud (see more details in Pascoe et al., 2014 and section 5.3 of this report including Figure 5.5).

The marine safety incidents and oil spills measures in the Social component were not assessed through the CATI survey and instead a secondary dataset was used with a 10-year moving average as the baseline for comparison. The questions and 10-point scale were designed so that the results would be comparable to other studies, such as the Social and Economic Long Term Monitoring Program for the Great Barrier Reef, to elicit trends over time and to facilitate translation into the A–E report card grades (Pascoe et al., 2014).

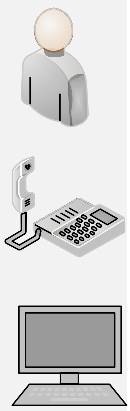
5.2. Development of indicators and grades

Although the social indicator questions used in the CATI survey were qualitative, they were recorded on a 10-point agree–disagree scale and the average satisfaction rating has been used in the analysis. Scores of 9 or 10 indicated very strong agreement; scores of 1 or 2 indicated very strong disagreement. A response of 9 or 10 provided a grade of A, a response of 7 or 8 provided a grade of B, 5 or 6 provided a C, 3 or 4 provided a D, and 1 or 2 provided an E.

Each measure was also weighted to reflect its relative importance as a management objective using information collected through an online survey of 83 community participants, 31 management experts (those with a management or industry role) and 19 technical experts (marine or coastal-social scientist). As such the combination of the measures for each indicator is reflective of the final grade and not the simple average of the measure scores. Three weighting techniques—simple ranking methods, scoring-based methods and analytic hierarchy processes were trialled in 2014 and scoring-based method was used for weighting as it had the lowest variance (Pascoe et al., 2014).

What is a CATI survey ?

CATI is the abbreviation used for Computer Assisted Telephone Interview, a popular qualitative and quantitative data collection technique in social science and economics. Before the interview begins, all survey questions are entered into a special computer software. The data collection begins when the interviewer randomly dials a person's landline or mobile in the chosen geographic area for the study. If the participant agrees, the interviewer then starts reading out each question prompted by the software and records responses using a computer keyboard. The software used for the data collection is also programmed to show questions in a planned order and skipped questions, and allow randomisation of questions, schedule re-dialing, automate record keeping and most importantly send data directly to statistical software for data analysis. Australian Bureau of Statistics and Queensland Government Statisticians Office often use CATI as their primary method of data collection in various annual surveys.



The other two variants of CATI is CAPI (Computer Assisted Personal Interview) where the interviewer talks to the interviewee in person and CASI (Computed Assisted Self Interviewing) where there will be no interviewer and interviewee directly enters responses into a specially designed software package.

A Bayesian Belief Network (BBN) was used to aggregate measures into indicator scores, indicator groups and component. This BBN model provided the probabilities of each outcome rather than a deterministic outcome. From the conditional probability distributions, an expected mean outcome and confidence interval were determined. The final grade for each indicator was the most probable grade after the relevant weights have been applied (Pascoe et al., 2014).

Harbour usability

Community satisfaction with harbour usability was primarily assessed through the CATI survey. The harbour usability indicator group comprised three indicators: satisfaction with harbour recreational activities, perceptions of air quality and water quality (in the harbour area), and harbour safety for human use. The harbour usability survey questions related to participants' satisfaction with their last trip to the harbour, quality of ramps and facilities, satisfaction with air and water quality, safety at night, and whether people were happy to eat seafood from the harbour. Secondary data on marine pollution and marine safety incidents were also incorporated into the harbour safety indicator as measures into the final score. A 10-year moving average was used as the baseline for both marine safety incidents and oil spills measures.

There were minor changes in the marine incidents and oil spills data since 2014. The marine safety incidents measures in 2014 and 2015 were estimated using the ratios of incidents with both recreational and commercial vessels registered within each maritime region. In 2016, however, new regulations lead to jurisdictional changes such that Queensland reporting included details of only Queensland-regulated ships (99.8% recreational vessels) and not commercial vessels. Rates of oil spills and incident rates were therefore only available for recreational vessels and commercial vessel counts were not included in the assessment. This method was repeated in 2017 to make grades and scores of both years comparable. The rate has been calculated as per 10,000 Queensland-regulated ships (99.8% are recreational vessels).

Harbour access

The harbour access indicator group comprised four indicators: satisfaction with access to the harbour, satisfaction with boat ramps and public spaces, perception of harbour health, and perception of barriers to access. There were 11 harbour access-related CATI survey questions such as perceptions on frequency of harbour use, number of boat ramps, access to public spaces, shipping and recreational boating, participants' perceptions on the state of the harbour health, and satisfaction with fair access to the harbour.

Liveability and wellbeing

Two questions in the CATI survey assessed the indicator for the harbour's contribution to liveability and wellbeing in Gladstone. The liveability and wellbeing survey questions related to whether Gladstone Harbour makes living in Gladstone a better experience and the level of participation in community events.

5.3. Results

The 2017 CATI survey comprised 401 respondents, 232 via mobile phone and 169 via landline. The genders were equally represented (Table 5.2). There is a steady increase in the proportion of respondents in the 25–34 and 35–44 age groups since the first report card in 2014. Representation in the younger age group (18–24) remains low in 2017 but similar to previous years. This is well below the percentage provided by the Australian Bureau of Statistics (ABS) for this age group for Gladstone (11%).

The Traditional Owner representation in the 2017 CATI survey was 13% (2016 – 11%, 2015 – 13%) and higher than the 4% of Indigenous residents in Gladstone according to 2016 ABS census data. For annual household income, results were similar to 2014, 2015 and 2016 reporting years with the highest representation in the over $156,000 bracket (Table 5.2).

There were no known major events in Gladstone that influenced the opinion of respondents during the CATI survey period (Windle et al., 2017).

Table 5.2: Demographics of 2017 CATI survey participants (Source: Windle et al. 2017).

Percentage of respondents	CATI survey 2014	CATI survey 2015	CATI survey 2016	CATI survey 2017	ABS census data (2016)
Gender					
Percentage of male	51.0%	49.5%	50.4%	50.0%	51.0%
Age category					
18–24 yrs	3.0%	3.0%	6.0%	4.0%	11.0%
25–34 yrs	7.0%	9.0%	10.0%	15.2%	19.1%
35–44 yrs	20.0%	16.0%	17.0%	23.9%	19.8%
45–54 yrs	25.0%	26.0%	27.0%	21.4%	20.6%
55–64 yrs	21.0%	25.0%	18.0%	19.5%	16.3%
65+ yrs	24.0%	22.0%	21.0%	16.0%	13.1%
Annual household income					
Less than $20,799	12.0%	13.0%	11.0%	11.4%	4.4%
$20,800–$41,599	13.0%	12.0%	13.0%	11.4%	15.3%
$41,600–$64,999	10.0%	11.0%	11.0%	9.2%	12.9%
$65,000–$77,999	5.0%	7.0%	7.0%	6.2%	7.3%
$78,000–$103,999	18.0%	14.0%	15.0%	15.7%	12.2%
$104,000–$129,999	12.0%	14.0%	13.0%	NA	NA
$130,000–$155,999	11.0%	8.0%	11.0%	NA	NA
$104,000–155,999[a]				20.3%	25.7%
Greater than $156,000	20.0%	21.0%	19.0%	25.7%	22.3%
Education					
Post school qualification		NA	NA	52.6%	51.0% [b]
Tertiary travel		NA	NA	24.9%	13.0% [b]

[a] The two household income categories $104,000–$129,999 and $130,000–$155,999 were merged in 2016 hence a combined value in 2017.

[b] 2011 values provided as 2016 census data not available until October 2017.

The overall grade for the Social component of the 2017 Gladstone Harbour Report Card was 0.66 (B) and remained unchanged from the previous year. The overall social health of Gladstone Harbour has gradually increased from 0.58 (C) in the 2014 Pilot Report Card to 0.64 (C) and 0.66(B) in the 2015 and 2016 report cards respectively (Table 5.3).

For the three indicator groups the scores in 2017 were: harbour usability 0.62 (C), down from 0.66 in 2016; harbour access 0.66 (B), up from 0.65 in 2016; and liveability and wellbeing 0.66 (B), the same as 2016 (Figure 5.1, Table 5.3).

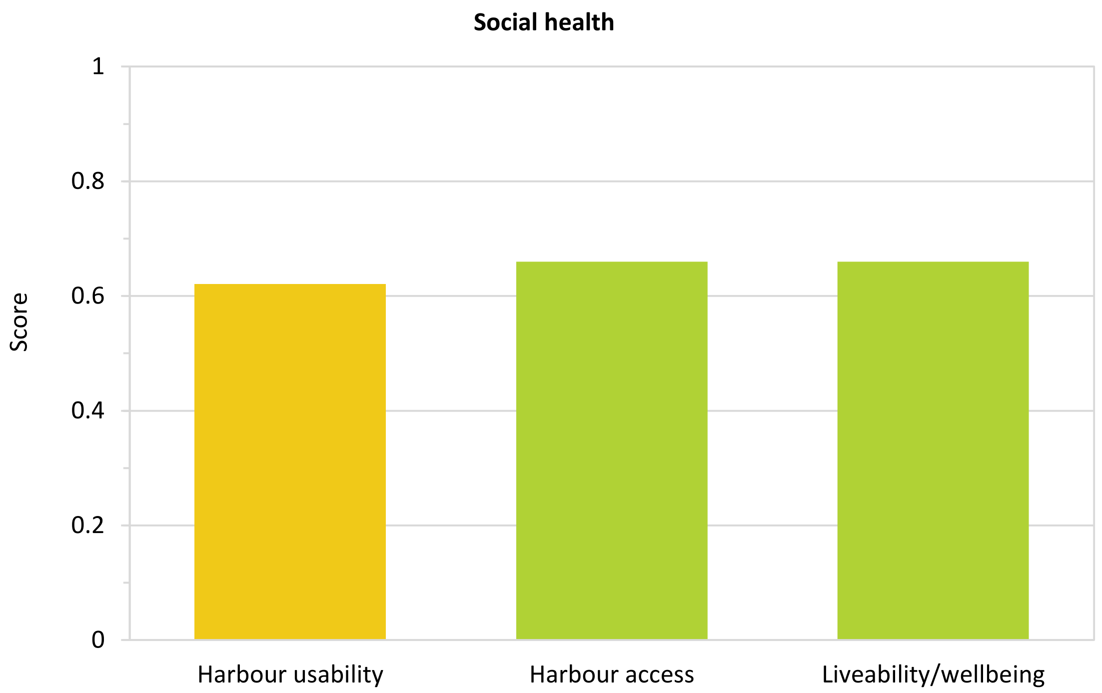


Figure 5.1: Indicator group scores within the Social component of harbour health in the 2017 Gladstone Harbour Report Card.

Harbour usability

Between 2016 and 2017, the overall harbour usability score decreased, resulting a change in the grade from B to a C. The most notable decline was with the score for harbour safety (declined from 0.76 in 2016 to 0.60 in 2017). The scores for the three indicators of harbour usability ranged from 0.56 (C) for *perceptions of air and water quality*, up to 0.60 (C) and 0.69 (B) for *perceptions of harbour safety* and *satisfaction with harbour recreational activities* respectively (Figure 5.2).

Scores from two measures, *how satisfied with the last recreational trip (beach, land and fishing) and quality of boat ramps and facilities* determined the final scores for *satisfaction with harbour recreational activities* indicator. The scores were averaged from the satisfaction ratings received for three CATI questions for the former and two CATI questions for the latter. Overall the indicator score increased from 0.67 to 0.69 in 2017.

The score for the *perceptions of air and water quality* has steadily increased over the last three years and remained at 0.56 in 2017 (0.46 in 2014, 0.52 in 2015, and 0.55 in 2016) (Table 5.3). Both the *water quality* (0.56 in 2016 to 0.58 in 2017) and *air quality* (0.45 in 2016 to 0.47 in 2017) satisfaction scores increased in 2017.

The score for *perceptions of harbour safety for human use* indicator declined in 2017 (0.60) compared to 2016 (0.76) (Table 5.3). This decline changed the grade from a B to a C in 2017. This indicator has two measures based purely on the secondary data and two based on satisfaction ratings from the annual CATI survey. The *marine safety incidents* (0.76) scored highly although the *oil spill* (0.38) measure scored low in 2017. Both scores were considerably lower than the respective 2017 scores of 0.90 and 0.88.

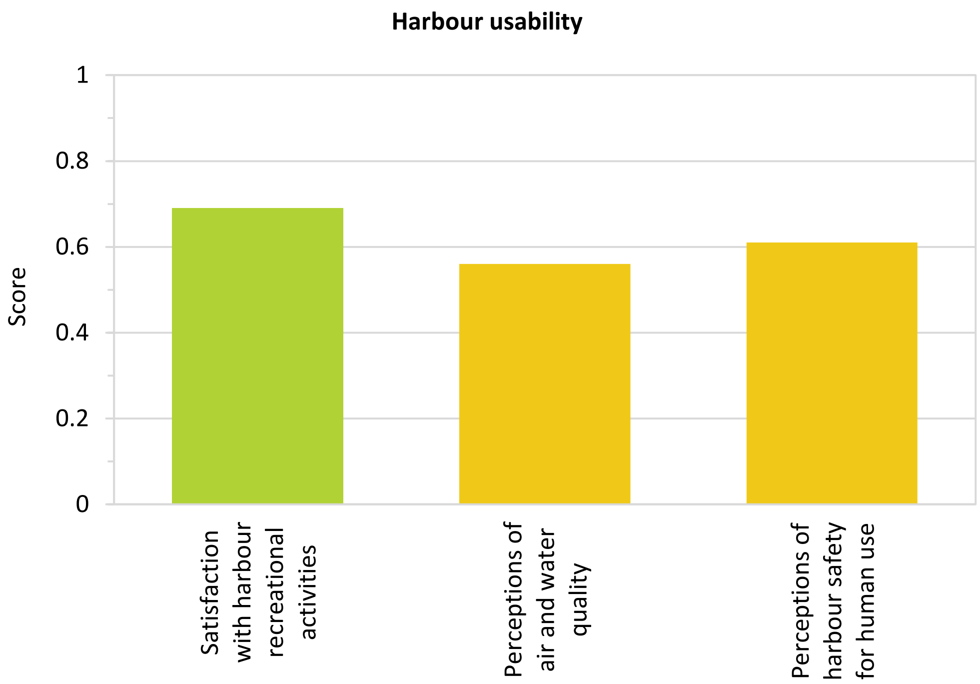


Figure 5.2: Scores for the three indicators of harbour usability in the 2017 Gladstone Harbour Report Card.

Harbour access

The scores for the four indicators of harbour access ranged from 0.63 for *perceptions of harbour health* to 0.72 for *satisfaction with harbour access* (Figure 5.3). All indicator scores except the score for *perceptions of barriers to access to har*bour increased in 2017 (Table 5.3).

Out of 401 survey participants, 364 (91%) visited the Gladstone Harbour for recreation and this is a minor increase from 2016 (347, 86.5%). Similar results were reported in 2015 (86%) and 2014 (87%). About 36% of the respondents owned a boat (35% in 2016) for the last 12 months and there had been little change in their use of boat ramps since the pilot report card (39%, 40%, 41% and 42% of respondents used a boat ramp in 2014, 2015, 2016 in 2017 respectively).

All four harbour access indicator scores have been increasing since the pilot report card in 2014. The score for community *perceptions of barriers to access* indicator remains the same as last year (0.65). Similar to 2016, three out of four measures used to assess this indicator scored well, however, the overall score was impacted by the low score of 0.50 received for the measure *marine debris as a problem*.

Figure 5.3: Scores for the four indicators of harbour access in the 2017 Gladstone Harbour Report Card.

Liveability and wellbeing

The contribution of Gladstone Harbour to the liveability of Gladstone and wellbeing was scored at 0.66 (B) (Figure 5.4). Liveability refers to the elements in a region that affect how individuals feel about living there. These elements include physical environment (natural and human) and social elements such as feelings of community spirit, personal health and wellbeing, culture and opportunities for work and recreation (Greer et al., 2012).

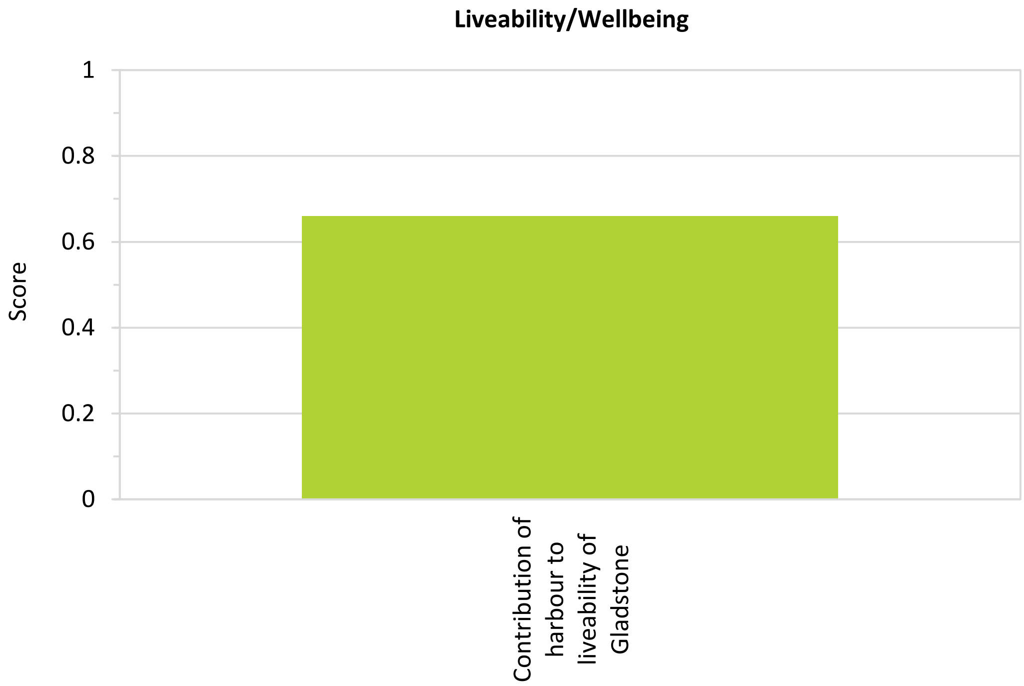


Figure 5.4: Score for the contribution of Gladstone Harbour to the liveability and wellbeing of Gladstone in the 2017 Gladstone Harbour Report Card.

Two survey questions assessed the liveability and wellbeing indicator group – *Gladstone harbour makes living in Gladstone a better experience* and *I regularly participate in community events in the Gladstone Harbour area*. About 86% (87% in 2016, 70% in 2015) of people surveyed implied they were satisfied with a score of '6 and above' indicating that Gladstone Harbour makes living in Gladstone a better experience. About 61% (60% in 2016, 53% in 2015) of the respondents implied they agreed with a score of 6 and above indicating they regularly participated in community events in the harbour area. Compared with last year, similar proportions of respondents were in agreement that the harbour makes living in Gladstone a better experience and will continue to increase their participation in community events in the harbour area.

Word cloud analysis

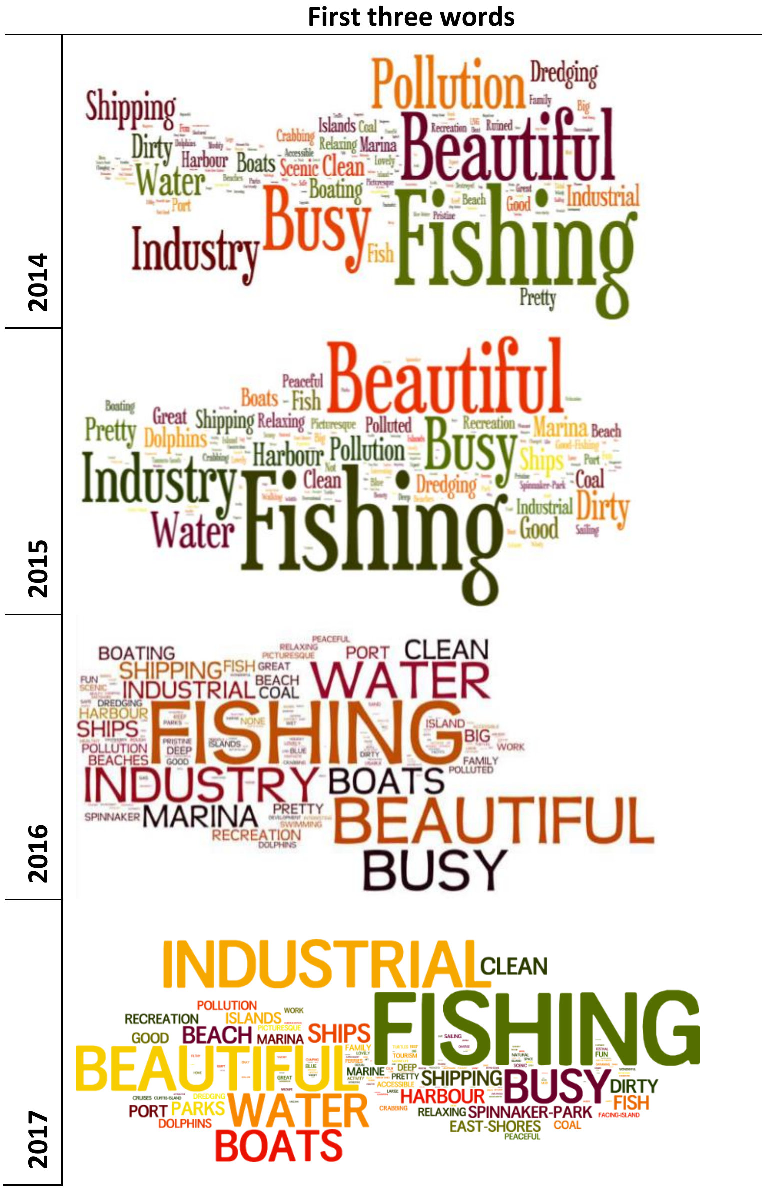


Figure 5.5: Word cloud analysis of all three words provided by CATI respondents to the question – *When you think of the Gladstone Harbour area, what are the first three words that come to mind*?

The most frequent three words used to describe the Gladstone harbour area in 2017 remained similar to previous reporting years. The word size relates to the word's frequency when participants responded to the CATI survey. Overall the responses indicate that most continue to perceive the harbour area positively as the words 'beautiful', 'busy', 'fishing' and 'industrial' appeared in all three years. In 2017, word cloud references to geographical locations adjacent to the harbour, such as East-shore and Spinnaker Park, became prominent which was less evident prior to 2016.

5.4. Social indicator conclusions

The overall social health of the harbour has been gradually increasing since the pilot year indicating that the Gladstone community continue to enjoy the harbour as in previous years (Table 5.3), although the 2016 harbour usability grade declined from 'good' to a 'satisfactory' in 2017. Harbour access and liveability/wellbeing grades both remained 'good'.

Responses received towards measures under harbour usability, harbour access, and liveability and wellbeing indicator groups were very similar to the 2016 reporting year. The strongest decline was in *perception of harbour safety for human use* which declined from 0.76 to 0.60 in 2017.

Harbour usability

The overall decline in harbour usability score was strongly influenced by low grades reported for two indicators, *perceptions of air and water quality* and *perceptions of harbour safety for human use*. Since 2014 there has been a gradual increase in community perceptions of air and water quality (0.46 in 2014, 0.52 in 2015, 0.55 in 2016, 0.56 in 2017). The low score for *perceptions of air and water quality* was strongly influenced by two satisfactory scores (*water quality satisfaction* and *water quality does not affect harbour use*) and one poor score (*air quality satisfaction*). However, the satisfaction of respondents on water quality and air quality has been gradually increasing since 2014.

The satisfactory grade received for *perceptions of harbour safety for human use* was strongly influenced by low scores received for *oil spills* followed by *safety at night* and *happy to eat seafood* measures. In particular, the *oil spills* measure also declined considerably 2017 (0.38) compared to 2016 (0.88). The number of *oil spills* in 2016 (18) was considerably higher than the total number of *oil spills* reported for 2015 (5) for the Gladstone maritime region. The *marine safety* incidents also increased in 2016 (64) compared to 57 in 2015. This resulted from a decline in the score from 0.90 (2016) to 0.76 (2017). The most commonly reported incidents included collision between ships, collision with objects, swamping and grounding (Department Transport and Main Roads, 2016). Although the *safety at night* and *happy to eat seafood* measures received satisfactory grades in 2017, both scores have been increasing since 2015.

Similar to 2016, the majority of the community viewed the harbour area as a place that provides recreational facilities and an environment for leisure activities. The residents continue to see the harbour as a producer of healthy seafood for consumption and a safe place to enjoy by day and night. Concerns continue about air and water pollutants but these do not appear to impede the community's usability of the harbour area and its resources. Air and water quality concerns may be an artefact of past issues and the proximity of industry in and around the Gladstone Harbour area.

Harbour access

The 2017, harbour access results indicate that residents were more satisfied with access to the harbour, public spaces and boat ramps and perceptions of harbour health. Residents further agreed that they have fair access to the harbour compared to other users of the harbour, although the frequency of harbour use remains similar to last year (8 times per year). Residents' perceptions around barriers to access also did not change and remain the same as last year. However, respondents continue to perceive marine debris and litter as a problem in Gladstone Harbour but did not see the amount of marine debris, commercial shipping and recreational boating activity as a hindrance to access to the harbour. The harbour environment is viewed positively by many residents and they hold strong beliefs of this continuing into the future.

Liveability and wellbeing

There has been very little change in this indicator over the past four years and it remains relatively stable. Generally, people living in the Gladstone region feel that Gladstone Harbour provides them with a positive living experience and quality of life. Many residents continue to participate in community events, such as The Gladstone Harbour Festival, Eco-fest, Boyne-Tannum Hook Up, that are held in and around the harbour area and their involvement supports the physical and mental health of the community.

Table 5.3: Social indicator group scores of reporting years.

		2017	2016	2015	2014
Indicator group	**Harbour usability**	0.62	0.66	0.65 [a]	0.6
Indicators	Satisfaction with harbour recreational activities	0.69	0.67	0.69 [b]	0.7
	Perceptions of air and water quality	0.56	0.55	0.52	0.46
	Perceptions of harbour safety for human use	0.6	0.76	0.72	0.38
Indicator group	**Harbour access**	0.66	0.65	0.62	0.61
Indicators	Satisfaction with access to the harbour	0.72	0.69	0.68	0.67
	Satisfaction with boat ramps and public spaces	0.65	0.64	0.62	0.6
	Perceptions of harbour health	0.63	0.62	0.58	0.53
	Perceptions of barriers to access	0.65	0.65	0.61	0.64
Indicator group	**Liveability and wellbeing**	0.66	0.66	0.64	0.64
Overall harbour score		**0.66**	**0.66**	**0.64**	**0.58**

[a] An error in the 2015 scores means they were reported at 0.75 instead of 0.65, hence there has been little real change from 2015 to 2016.

[b] The indicator 'satisfaction with harbour recreational activities' scored 0.67, compared with 0.69 in 2015 and 0.70 in 2014, but anomalies in data analysis negate any meaningful comparison. An error in the 2016 calculation meant that only one of the two measures was assessed ('quality of boat ramps and facilities') with a score of 0.68 in 2016 and 0.66 in 2015.

6. The Cultural component

To assess the cultural health of the harbour, the 2017 report card uses six 'sense of place' indicators and two Indigenous cultural heritage indicators. The latter was piloted in 2016. These indicators were developed from the GHHP vision.

6.1. Data collection

'Sense of place'

A CATI survey of 401 people in the last two weeks of May 2017 assessed the 'sense of place' indicator. That survey included 17 questions dedicated to gathering community views on six cultural indicators (Table 6.1). 'Sense of place' was employed as a broad construct and it is assumed to incorporate elements of both place identity and place attachment (Twigger-Ross & Uzzell, 1996). 'Sense of place' may also be useful for exploring community stewardship.

Indigenous cultural heritage

Field data for the Indigenous cultural heritage indicator group were collected through a series of field surveys at The Narrows, Facing Island, Wild Cattle Creek and Gladstone Central (Figure 3.31). The cultural health indicators were assessed at site level, whereas the indicators related to the management strategy were assessed at zone level. The Wild Cattle Creek zone has been extended by including sites around Hummock Hill Island. The Narrows and Gladstone Central zones also included new sites.

Overall 11 new sites have been assessed during the 2017 reporting period. The sites assessed in the previous year were not reassessed during 2017 surveys. However, a few new sites within each zone were identified and surveyed as indicated in Table 6.2 with the exception of Facing Island. Traditional Owners and Elders from Goreng Goreng and Byellee groups assisted the field studies and development of weightings for sites. Various heritage aspects relevant to assessing the cultural health (e.g. knapping floor, chopper tools, signage, gravestones, and monuments) were recorded in detail at each site. The 2017 results are based on both 2016 and 2017 site surveys.

Similar to the previous year, a series of 360° panoramic images was also captured during the site visits to build a photographic timeline for the ongoing assessment of the physical health of each site. All field data were then transferred to an Indigenous Cultural Heritage Database (ICHD). The ICHD will be used to store detailed monitoring information on individual cultural heritage sites visited during annual surveys and will help track the scoring against the indicators of cultural health of the four zones over time (Terra Rosa Consulting, 2017).

Similar to last year the spiritual and social values sub-indicator was assessed through ethnographic interviews with key indigenous community members similar to previous year.

Definition of indicators 'sense of place'

The 'sense of place' indicator had 17 measures grouped into the following six indicators.

- 'Distinctiveness' is the degree to which the harbour provides an identity that is unique or distinct from other identities. This includes the distinctiveness of a place (e.g. coastal views, industry landmarks), the qualities which distinguish it from any other place (e.g. iconic marine species such as dolphins and dugongs), structure (the mental representation of a place) and meaning (subjective feelings linked to physically separate places).

- 'Continuity' adds a temporal aspect to 'sense of place'. It is the extent to which there has been continuity of 'self' (including ancestors) and activities in a place. It also includes both continuity in the way harbour resources have been used by past and present generations of a family as well as the ancestral links to places held by Indigenous Australians.

- 'Self-esteem' concerns people's values and standards and assesses pride in one's identity in relation to place. It reflects the pride that an individual has in identifying with the place (Gladstone) and assesses the value and importance they assign to this association.

- 'Self-efficacy' relates to the extent to which a place facilitates or enables one's chosen lifestyle, or conversely, the extent to which a place does not hinder one's social and economic opportunities. This indicator assesses the sense of 'feeling at home' and the extent to which this provides spiritual fulfillment or is restorative.

- 'Attitudes to Gladstone Harbour' the attitudes of people in Gladstone with emphasis on its importance as a great asset to the local community and central Queensland.

- 'Values of Gladstone Harbour' community values on marine life, recreational and tourism activities, cultural, spiritual and historical significance of the harbour.

Indigenous cultural heritage

Cultural health and management strategies of zones consists of 21 measures grouped into 6 sub-indicators, namely spiritual and social values, scientific values, physical condition, protection, land use, and cultural maintenance.

The spiritual and social values sub-indicator for cultural health uses three measures:

- *ethnographic and historical information* – the availability of such information (e.g. detailed written archaeological recording of site features and elements) significant to sites and Traditional Owners' awareness of it.

- *connection to the cultural landscape* – the level of spiritual and social values attached to a site as they relate to the traditional patterns of cultural activities within a zone.

- *contemporary use* –visits to the site by those for whom it is most significant.

The scientific values sub-indicator for cultural health uses six measures:

- *diversity of heritage features* –the complexity of the heritage features and elements that have been recorded within a monitoring station.

- *density of heritage features* – number of elements in each monitoring station.

- *representativeness* –how representative a certain heritage feature or element in one site is compared to other sites in a reporting zone.

- *uniqueness* –monitoring stations and sites containing heritage features that have not been identified anywhere else in the reporting zone.

- *excavation potential* –the stratification through visual inspection and sub-surface probing where appropriate to understand whether the deposit exhibits clear and deep stratification.

- *artefacts in-situ* –the percentage of local heritage features and elements that have been retained over time in their original positions.

The physical condition sub-indicator for cultural health uses three measures:

- *ground surface disturbance* –the proportion of a site surface that has not been disturbed versus that which has been impacted by environmental, animal or human causes. By comparing annual scores over time, the speed of site deterioration can be calculated.

- *impacts on heritage values* –the impact of ground surface disturbance on the heritage values of a particular site. By comparing scores over time, the speed at which the heritage features within a site deteriorate over time could be calculated.

- *threats and controls* – the number of threats and ongoing controls to remove the effects of these threats on the cultural heritage values of a site. Threats could be environmental (e.g. storm surges, inundation and erosion), animal (e.g. burrowing, animal waste) or human related (e.g. tracks, vehicles, paths, trampling).

The protection sub-indicator for management strategies uses three measures:

- *monitoring* – assesses a team's ability to establish new monitoring stations and visit existing monitoring stations annually.

  site registration – relates to the immediate response to site discovery and registration with GHHP ICHD.

- *threat management* – relates to the percentage of implemented control measures to remove the effect of identified threats on cultural heritage values.

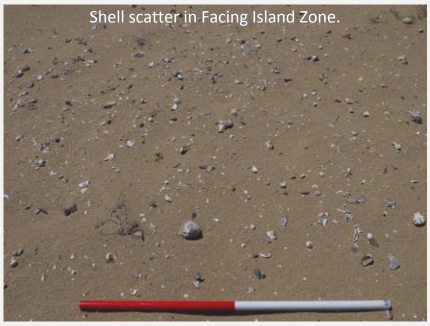
What are heritage elements and heritage features?

A heritage element refers to a single stone tool such as flake or chopper tool often become a part of a larger feature within a site. A heritage element can also be an isolated artefact.

A heritage feature refers to a group of interrelated heritage elements such as knapping floor or reduction sequence, a single element worthy of consideration as a feature such as a backed blade or stone arrangement, and cultural archaeological and ethnographic features such as signage monuments and gravestones.


A stone arrangement in the Narrows Zone.


Pebble tools in Facing Island Zone.


Shell scatter in Facing Island Zone.

(Images courtesy Terra Rosa Consulting)

The land use sub-indicator for management strategies uses two measures:

- *accessibility* – relates to the percentage of sites within a zone that can be easily accessed for heritage management.

- *developmental pressure* – relates to the pressures impacting on sites due to tourism, housing recreational and industrial development activities.

The cultural maintenance sub-indicator for management strategies uses four measures:

- *site identity and research* – relates to the heritage sites identified or researched within the zone to be included in the ICHD annually.

- *cultural resources* – relates to availability of digital and physical resources (e.g. ICHD, panoramic tours and signage) that store knowledge and information about cultural heritage within each zone.

- *cultural management activities* – relates to proactive heritage management within a zone such as installing fencing, signage, interpretive information and environmental restoration.

- *stakeholder engagement* – ranks the ability of the project to interface with associated stakeholders, such as Traditional Owners, Gidarjil rangers, GHHP representatives, landholders, government agencies and other local agencies, to facilitate further monitoring and research that achieve joint cultural heritage and land management aims.

Table 6.2: Indicator groups, indicators and measures used to determine cultural grades and scores for the 2017 Gladstone Harbour Report Card.

Indicator group	Indicators	Sub-indicator	Measures	Data source	How grades determined
'Sense of place'	Distinctiveness		No place better	CATI survey	10-point scale
			Who am I	CATI survey	10-point scale
	Continuity		How long lived in the area	CATI survey	Proportion of life lived in the area (0–100%)[a]
			Plan to be a resident in the next five years	CATI survey	10-point scale
	Self-esteem		Feel proud living in Gladstone	CATI survey	10-point scale
	Self-efficacy		Quality of life	CATI survey	10-point scale
			Input into management	CATI survey	10-point scale
	Attitudes to Gladstone Harbour		Key part of the community	CATI survey	10-point scale
			Great asset to the region	CATI survey	10-point scale
			Great asset to Queensland	CATI survey	10-point scale
	Values of Gladstone Harbour		Variety of marine life	CATI survey	10-point scale
			Opportunities for outdoor recreation	CATI survey	10-point scale
			Attracts visitors to the region	CATI survey	10-point scale
			Enjoy scenery and sights	CATI survey	10-point scale
			Spiritually special places	CATI survey	10-point scale
			Culturally special places	CATI survey	10-point scale
			Historical significance	CATI survey	10-point scale
Indigenous cultural heritage	Cultural health	Spiritual and social values	Ethnographic and historical information, connection to the cultural landscape, contemporary use	Desktop study and field data collection	10-point scale
		Scientific values	Diversity, density, representativeness, uniqueness, excavation potential, artefacts in-situ	Field data collection	10-point scale
		Physical condition	Ground surface disturbance, impacts on heritage values, threats and controls	Field data collection	10-point scale
	Management strategies	Protection	Monitoring, site registration, threat management	Field data collection	10-point scale
		Land use	Accessibility, developmental pressure	Field data collection	10-point scale
		Cultural maintenance	Identification and research of sites, cultural resources, cultural management activities, stakeholder engagement	Field data collection	10-point scale

[a] The total time spent in the Gladstone region was categorised into 10-year bands (0–9 years, 10–19 years, 20–29 years, 30–39 years, 40–49 years and 50 years +)

Table 6.2: Sites within each zone surveyed during 2016 and 2017 surveys.

Zone	Number of sites surveyed in 2016	Number of sites surveyed in 2017
The Narrows	6	3
Facing Island	6	0
Wild Cattle Creek	11	5
Gladstone Central	3	3
Total	**26**	**11**

6.2. Development of indicators and grades

'Sense of place'

Responses to cultural indicator questions in the CATI survey were converted to grades in the same manner as for the Social component. Thus, a response of 9 or 10 on a 10-point agree–disagree scale provided a grade of A, a response of 7 or 8 provided a grade of B, 5 or 6 provided a C, 3 or 4 provided a D, and 1 or 2 provided an E. As for the social indicators, each 'sense of place' indicator was given a weighting that was developed during the pilot phase in 2014 via online surveys (Pascoe et al., 2014). A BBN aggregated measure scores into indicators and then to the 'sense of place' indicator group.

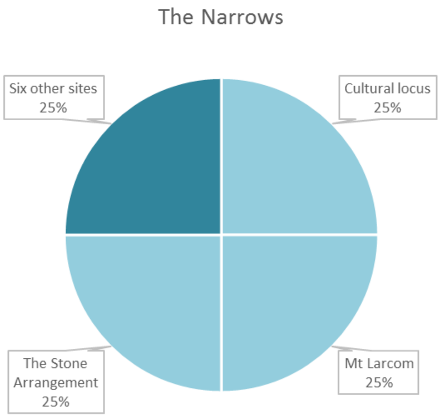
Indigenous cultural heritage

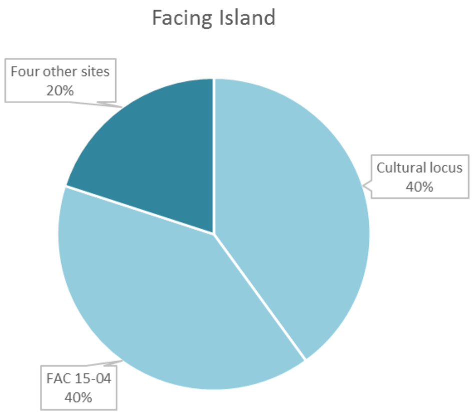
The initial list of sites and zones was selected following an in-depth literature review and extensive consultation with the Gidarjil Development Corporation in 2016 (Terra Rosa Consulting, 2016) (Figure 6.1). Information related to the cultural heritage sites documented in Aboriginal and Torres Strait Islander Cultural Heritage Register Database, Queensland Heritage Register, Cultural Heritage Information Management System, National Heritage List, Commonwealth Heritage List, register of the National Estate, UNESCO World Heritage List and works by Burke (1993) were also used in the review. This list was revised and new sites were surveyed in 2017 with the help of Goreng Goreng and Byellee Traditional Owners and Elders over 16 days.

The indicators of Indigenous cultural heritage were assessed based on a range of qualitative (e.g. ethnographic and historical information) and quantitative measures (e.g. number of heritage features at each monitoring station). Each measure was assessed based on ten criteria and given a score between 1 and 10. All site scores from the previous year were converted to 10-point scale by doubling the score and as in 2016 the sites were scored on a 1–5 scale (Terra Rosa Consulting, 2017). GHHP grading thresholds were only applied to the aggregated scores.

The indicators under cultural health were weighted on a spatial scale. In 2016, the project team identified a cultural locus site in consultation with the Traditional Owners and Elders as a reference site for each zone. A cultural locus site is considered to be the most important for ongoing monitoring and management of that zone (Terra Rosa Consulting, 2017). For Wild Cattle Creek (site HH17-04) and Gladstone Central (Barney point), new cultural locus sites were identified in 2017. The health of the cultural locus sites was assessed independently to benchmark other sites within each zone. The arbitrary weightings used in 2016 for the cultural locus site and other sites in the absence of detailed ethnographic consultation were revised in 2017 (Figure 6.2). To accomplish this, the knowledge of Traditional Owners and Elders was consulted and weights were allocated based on the significance of each site within the cultural landscape and priorities of sites for Traditional Owners (Terra Rosa Consulting, 2017). The management strategy indicators were given fixed weightings at the sub-indicator level.

Figure 6.1: **A** - Access to a site on the bank of Calliope River was restricted in Gladstone Central zone, **B** - Stone arrangement in The Narrows, **C** - Cultural locus site at Barney Point and D-Recording site features at The Narrows zone (Source: Terra Rosa Consulting, 2017)





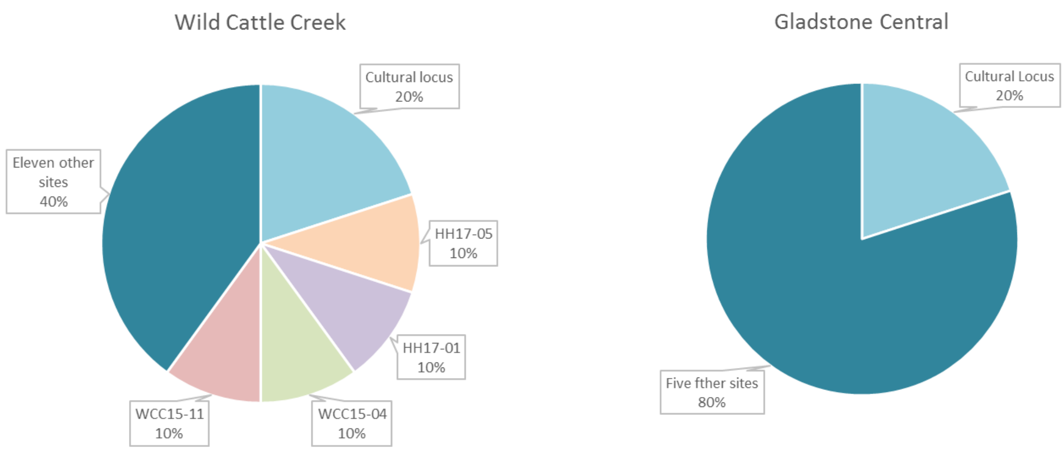


Figure 6.2: Weightings derived from ethnographic consultation for cultural locus and other sites within each zone for cultural health indicators.

6.3. Results

The overall score for the Cultural component of the Gladstone Harbour Report Card for 2017 was 0.62 (C). This comprised two indicator groups, 'sense of place' and Indigenous cultural health (Figure 6.3). 'Sense of place' received a score of 0.65 (B) and Indigenous cultural heritage received a score of 0.55 (C). This grade was based on six 'sense of place'-related indicators and two Indigenous cultural heritage indicators.

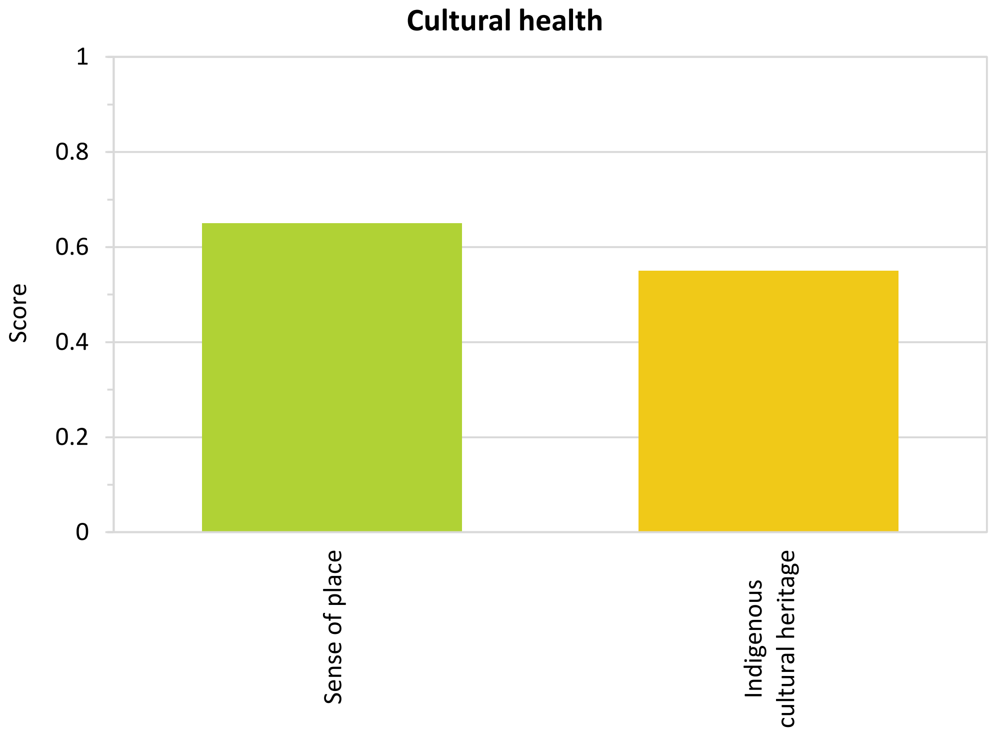


Figure 6.3: Indicator group scores within the Cultural component of the 2017 Gladstone Harbour report Card.

'Sense of place'

The 'sense of place' indicator scores ranged from 0.54 (C) for continuity to 0.81 (B) for attitudes to the harbour (Figure 6.4). *Distinctiveness* (0.57) and *self-efficacy* (0.58) received similar scores; the other scores were *self-esteem* (0.72), *attitudes to harbour* (0.81) and *values of Gladstone harbour* (0.66). The 2017 scores for *self-esteem*, *self-efficacy*, *attitudes to Gladstone Harbour* and *values of the harbour* scores were similar to 2016.

The highest score of 0.81 received for attitudes to harbour was driven by three measures which received equally high scores (key part of community – 0.81, great asset to region – 0.80 and great asset to Queensland – 0.79). The lowest score of 0.54 for continuity was influenced by a low score (how long lived in the area – 0.43) and a high score (plan to stay the next 5 years – 0.64).

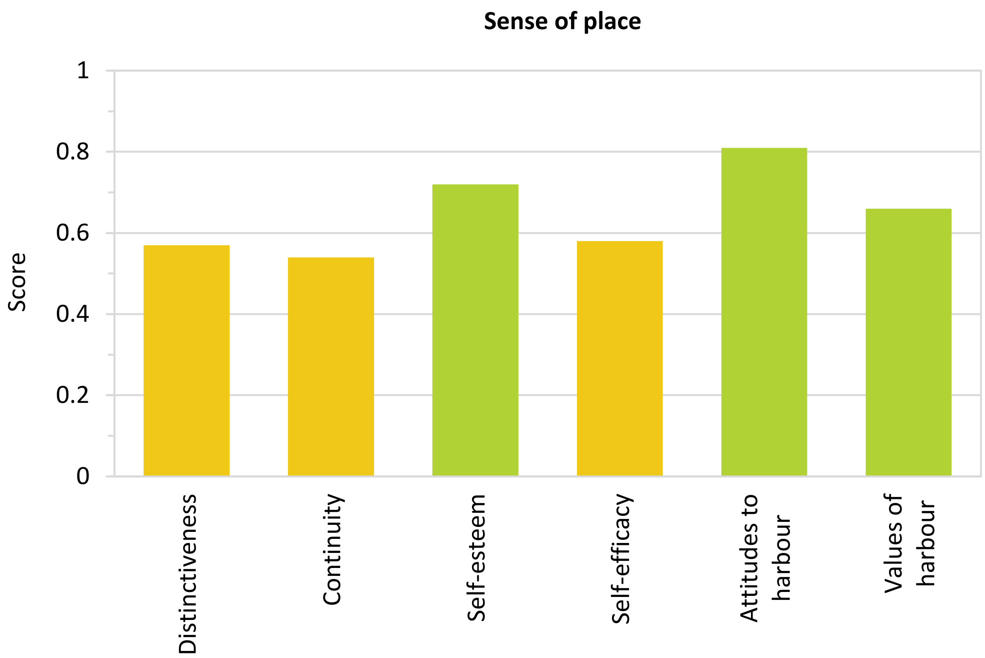


Figure 6.4: Indicator scores for 'sense of place' indicator group used for cultural health in the 2017 Gladstone Harbour Report Card.

Indigenous cultural heritage

The overall harbour score for Indigenous cultural heritage was 0.55 (C) and improved from 2016 score of 0.53 (C).

The score for the Wild Cattle Creek improved considerably from 0.44 (D) in 2016 to 0.50 (C) in 2017. This was largely due to the new sites around Hummock Hill Island. Similarly, the score for The Narrows and Gladstone Central improved from the previous year but the grade remained unchanged. This increase was due to the three new sites being in relatively good condition (Figure 6.5).

The management strategies-related indicator received a satisfactory score (0.50) in 2017 and this was an increase from a poor score of 0.48 in 2016. The satisfactory management strategies score was strongly driven by the poor scores received for cultural maintenance-related measures in all zones and good scores received for cultural protection-related measures.

Four measures were used to assess the cultural maintenance sub-indicator, *identification and research of sites*, *availability of cultural resources* such as physical and digital interpretive elements, *cultural management activities* such as availability of heritage management plan and its progress and *stakeholder engagement*. The low overall score reflects the lack of cultural management in each zone. Three measures were used to assess the protection sub-indicator: *monitoring* (percentage of existing monitoring stations visited/establishment of new sites each year), *registration of sites in the database* and *management of threats* (percentage of control measures implemented in a zone).

Further, the overall management strategies were impacted by the poor land use scores recorded for The Narrows. The land use sub-indicator has two measures, *accessibility* (proportion of sites within a zone which can accessible for heritage management activities) and *development pressures* (nature of the developmental pressure). The cultural protection score for The Narrows and Facing Island remains in good condition.

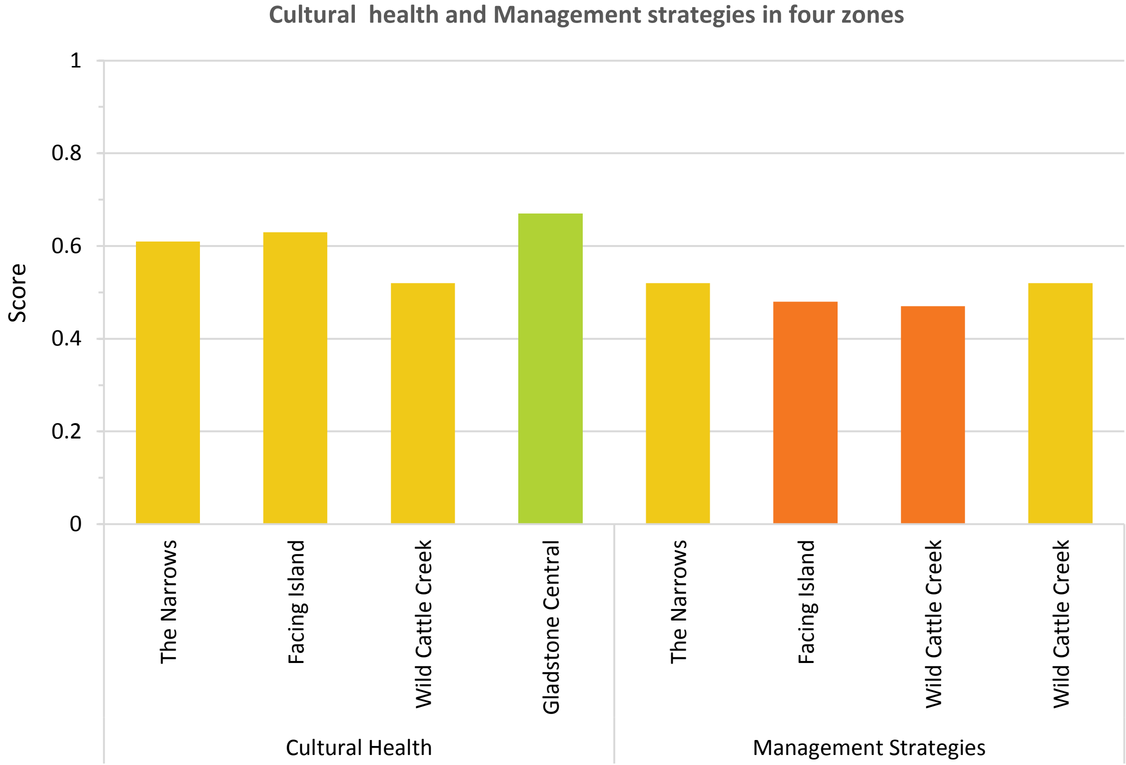


Figure 6.5: Indicator scores Cultural health and Management strategies across four reporting zones in the 2017 Gladstone Harbour Report Card.

6.4. Cultural indicator conclusions

'Sense of place'

Overall, the score for 'sense of place' is similar to previous years (0.65 in 2015, 0.66 in 2016 and 0.65 in 2017) and remains classified in good condition (Table 6.3).

The 'sense of place' indicators showed relatively little temporal variation compared with the previous report card scores. The continuity indicator showed the highest decline compared to 2016 and relates to the fact that many of the respondents had moved to Gladstone and not lived there all their lives. The scores for all six indicators of 'sense of place' suggest that the community's expectations of the Gladstone Harbour area are mostly being met.

The unchanged scores to 2016 (0.81) the *attitudes to Gladstone harbour* show that residents continue to have a positive outlook for the harbour area and what it provides to the community.

The harbour is a place viewed with pride and this is reflected in the relatively high *self-esteem* score which increased from 0.72 in 2015 to 0.74 in 2016 but declined to 0.72 in 2017. This indicates that residents continue to feel proud living in the Gladstone community.

The score for the *values of Gladstone harbour* indicator remains unchanged from 2016 (0.66). This suggests that overall community perceptions around harbour values are stable. The majority of residents value the harbour area because it supports a variety of marine life, provides opportunities for outdoor recreation, attracts visitors to the region and is aesthetically appealing. Fewer residents valued Gladstone harbour highly based on its spiritual, cultural and historical significance.

The *self-efficacy* indicator also remained stable indicating residents continue to feel their quality of life has improved. However, the *community input into management* measure continues to receive a lower score similar to the previous year (0.49 in 2016 and 0.50 in 2017).

Overall, the lower *distinctiveness* measure suggests people possess only a moderate identity with the harbour. The scores received for the distinctiveness declined compared to 2016 indicating reduced engagement with, and appreciation of, the harbour-related activities.

Continuity received the lowest score of all 'sense of place' indicators. This score also decreased in 2017 compared to 2016. This indicator was assessed using two CATI questions: the length of time people have lived in the area and whether they planned to stay for the next five years. The low score (0.43) for the former indicates that many respondents had moved to Gladstone but not lived there all their lives, however the high score of the latter (0.64) indicates that the community is becoming less transient and more stable (this may reflect the downturn in construction work similar to 2016). The average time respondents had lived in the Gladstone region declined from 26.5 years in 2016 to 23.9 years in 2017 due to changes in the sample age profile (Windle et al., 2017).

Table 6.3: Comparison of 'sense of place' indicator grade and score between 2015 and 2017 report cards.

		2015	2016	2017
Indicator group	'Sense of place'	0.65	0.66	0.65
Indicators	Distinctiveness	0.55	0.59	0.57
	Continuity	0.57	0.59	0.54
	Self-esteem	0.72	0.74	0.72
	Self-efficacy	0.56	0.58	0.58
	Attitudes to Gladstone harbour	0.80	0.81	0.81
	Values of Gladstone harbour	0.64	0.66	0.66
Overall harbour score		**0.65**	**0.66**	**0.65**

Indigenous cultural heritage

The overall grade for Indigenous cultural heritage is a result of 21 measures used to assess the various aspects of Indigenous cultural heritage under six sub-indicators in four zones. The scoring structure not only looked at impacts of ongoing development on a number of Indigenous heritage resources, but also acknowledged the constantly changing cultural landscape. In 2017, Traditional Owners and Elders:

- contributed to assessing sites, identifying cultural locus sites and developing weightings
- drew attention to the need to have broader engagement with stakeholders in the Gladstone region in order to gain access to many cultural sites as possible which are currently inaccessible due to land restrictions by various companies
- identified The Narrows Quarry (NAR 15-01) and Gatcombe Heads midden (FAC 15-06) sites as worthy of further archaeological research.

Adding new sites in relatively good condition to The Narrows and Wild Cattle Creek zones improved the overall score but did not change the grade in 2017 (Table 6.4a–c). The management strategies-related indicators scored poorly and this reflects the lack of management activities at sites for minimising current impacts and future threats. The scores were further influenced by the following factors:

- land use pressures and changes such as industrial and residential developments
- natural impacts such as erosion of coastal foreshore and dune systems and storm surges
- human impacts from activities such as recreational vehicles access
- access restrictions sites on privately owned lands and other developments in the area.

The low scores could be greatly improved by focusing heritage management activities at sites that have greater significance (higher weighting) to the Traditional Owners and Elders around the Gladstone Harbour. Fencing, weed control, dune rehabilitation, imposing restrictions on 4WD access, installing cultural signage, and conducting further research suitable for each zone preferably through a heritage management plan are some of the management activities considered appropriate. Further, by minimising access restrictions to heritage sites for Traditional Owners and Elders, the visits can be improved and thereby improving the intergenerational transfer of cultural knowledge (Terra Rosa Consulting, 2017).

Table 6.4a: Scores for cultural health

Zone	Spiritual & social values		Scientific values		Physical Condition	
	2017	2016	2017	2016	2017	2016
The Narrows	0.73	0.54	0.57	0.62	0.53	0.53
Facing Island	0.57	0.57	0.65	0.75	0.66	0.64
Wild Cattle Creek	0.39	0.40	0.54	0.51	0.64	0.45
Gladstone Central	0.84	0.85	0.67	0.50	0.50	0.60

Table 6.4b: Scores for management strategies

Zone	Protection		Land use		Cultural maintenance	
	2017	2016	2017	2016	2017	2016
The Narrows	0.70	0.70	0.45	0.40	0.38	0.35
Facing Island	0.70	0.70	0.50	0.50	0.25	0.25
Wild Cattle Creek	0.65	0.60	0.55	0.40	0.25	0.25
Gladstone Central	0.50	0.40	0.80	1.00	0.40	0.40

Table 6.4c: Overall harbour scores for Cultural component

Zone	Overall	
	2017	2016
The Narrows	0.56	0.53
Facing Island	0.55	0.57
Wild Cattle Creek	0.50	0.44
Gladstone Central	0.60	0.59
Overall harbour score	**0.55**	**0.53**

7. The Economic component

To assess the economic health of the harbour, this report card uses eight indicators aggregated into three indicator groups: economic performance, economic stimulus and economic value (recreation). These indicator groups were developed from the GHHP vision and piloted in 2014.

7.1. Data collection

The Gladstone LGA was used as the broader geographic area for collecting economic data (Figure 3.28). However, slightly different geographic boundaries within the broader Gladstone LGA were used for some primary and secondary data as described below.

- Shipping data: collected for the Port of Gladstone
- CATI survey: administered to residents within the Gladstone 4680 postcode area (Figure 3.28)
- Commercial fishing data: collected from the area within QFish S30 which includes Gladstone Harbour and the open coastal waters immediately adjacent to the harbour. Data collected from Grid O25 and R29 were also used in the analysis to control for spatial differences in catch across years (Figure 3.29).

Compared with the measures developed for the Social component of the report card, most economic measures were more quantitative and different approaches were required to calculate indicator scores (Table 7.1). These include the following measures:

- capacity utilisation – capacity used as a proportion of the total capacity available
- revenue-based information – based on total revenue over a particular time period
- index of economic resources (IER) – a weighted index based on income, housing expenditure and ownership, cost of living and household assets
- travel cost method (TCM) – assesses the value of a recreational activity from the expenditure made to participate in that activity, including travel costs, travel time and site costs.

Revenue-based information was used when the capacity utilisation method was too difficult or complex (e.g. for tourism and to some extent fisheries). Other economic data required to supplement the economic value of recreation and economic stimulus were collected through the CATI survey. A section of this survey was devoted to household economics, including questions related to income and home ownership. A section on the non-market economic values of recreation in the Gladstone Harbour area was also included. Scores for these values were determined using the TCM. Other data types were sourced from a range of organisations to derive other economic measures (Table 7.1).

Overall, the data collection and analytical techniques remained the same for all economic indicators as for the 2016 reporting year. The following minor modifications improved the quality of the dataset:

- a standard 10-year baseline (moving average) is applied for shipping data and commercial fishing indicator

- tourism indicator is supplemented with expenditure data from passengers and crew members who disembarked at Gladstone Port since 2016.

Table 7.1: Data sources and baselines employed to derive the economic scores and grades for the 2017 Gladstone Harbour Report Card.

Indicator group	Indicator	Measure	Data source	Baseline
Economic performance	Shipping activity	Shipping activity productivity calculated from monthly shipping movements by cargo type (2016–17 financial year)	Gladstone Ports Corporation	10-year average from 2007–2017
	Tourism expenditure	Gladstone Region's total tourism expenditure output (2015–16 financial year) and estimated spending from cruise ship passengers and crew	Expenditure on hotel accommodation (for 2006–07 to 2012–13 financial years) Expenditure on hotel accommodation and food (2013–14 financial year to present) from Gladstone Regional Council – REMPLAN Economic Profile (2016) AEC (2016). Economic Impact. Assessment of the Cruise industry in Australia, 2015–16. Report for the Australian Cruise Association.	10-year average from 2006–2016
	Commercial fishing	Productivity of line (fish) fisheries	**Prices (average $/kg for fish prawns and crabs)** ABARES – Australian fisheries and aquaculture statistics 2015 (published in December 2016) **Production (fishing effort)** Queensland Fishing (QFish), Queensland Department of Agriculture and Fisheries	10-year average 2007-2017
		Productivity of net (fish) fisheries		
		Productivity of trawl (otter) fisheries		
		Productivity of pot (mud crabs) fisheries		

Table 7.1 (Cont.): Data sources and baselines employed to derive the economic scores and grades for the 2016 Gladstone Harbour Report Card.

Indicator group	Indicator	Measure	Data source	Baseline
Economic stimulus	Employment	Unemployment statistics for the Gladstone Local Government Area (2017 March quarter)	Queensland Government Statistician's Office, sourced from the Australian Department of Employment, Small Area Labour Market	Queensland 2017 distribution for March quarter
	Socio-economic status	Index of economic resources derived from 2011 ABS census and updated using the community CATI survey	CATI survey; Australian Bureau of Statistics, 2011 census	Australian 2011 distribution
Economic value (Recreation)	Land-based recreation	Land-based recreation satisfaction and economic value	Satisfaction from CATI survey and economic value from Pascoe et al., 2014	10-point scale
	Recreational fishing	Recreational fishing satisfaction and economic value	Satisfaction from CATI survey and economic value from Cannard et al., 2015	10-point scale
	Beach recreation	Beach recreation satisfaction and economic value	Satisfaction from CATI survey and economic value from Pascoe et al., 2014	10-point scale

7.2. Development of indicators and grades

Economic performance

The economic performance indicator group consisted of three indicators: the level of shipping activity, tourism (expenditure), and commercial fishing. These were selected to reflect the key industries using the harbour and weighted according to relative contributions to revenue share across shipping, tourism and commercial fishing.

Shipping

The GPC provided data on monthly shipping movements by cargo type, destination and origin. The report card score for shipping activity was based on capacity utilisation (current level of activity relative to potential level of activity) and estimated through data envelopment analysis.

The analysis used a 10-year baseline data from 2007–17. A 20-year array was used in 2016; however, a standard 10-year moving average baseline will be used for shipping from 2017.

Shipping activity is weighted higher than the other two sectors due to its greater economic contribution to the Gladstone economy in Gladstone.

Tourism

The tourism grade is based on the expenditure on hotel accommodation, food and other local services relative to a 10-year average from 2006 to 2016 in the Gladstone region. This information is sourced from an annual input–output analysis by the REMPLAN consultancy group and the latest estimates were for 2015–16 financial year (REMPLAN Economy Profile, 2016). The group estimated the output of tourism for Gladstone. An input–output analysis is based on interdependencies between economic sectors and examines how the output from one industry may become the input of another industry. For the

CAPACITY UTILISATION

Capacity utilisation measures the productive efficiency (performance) of an industry for a given time period. It is often expressed as a percentage. Reasons for increased capacity utilisation include increased market demand and availability of new technology to increase production. Reasons for decreased capacity utilisation include seasonal variations, reduced market demand, lower production or (perversely) increased capacity.

For example: A factory produces cement. It has a maximum output of 10,000kg per month. During January, the actual output was 5,000kg. So, what was the capacity utilisation in January? It can be calculated as a percentage using the following formula:

$$\textbf{Capacity utilisation} = \frac{\textbf{actual level of output (5,000)}}{\textbf{maximum possible output (10,000)}} \times \textbf{100}$$

$$= 50\%$$

DATA ENVELOPMENT ANALYSIS (DEA)

The DEA or frontier analysis is a tool developed in 1978 by Charnes, Cooper and Rhodes to measure the performance or relative efficiency of organisations such as banks, hospitals and schools. During the analysis a reference is set using the best performing organisations. This 'efficiency frontier' acts as the threshold for assessing the performance of other organisations. The organisations in the frontier are considered 100% efficient and the others outside the efficiency frontier are considered less than 100% efficient. This analysis is very important when we compare organisations with multiple inputs and outputs. Specialised software is required to calculate the efficiency scores. For two of the report cards there is a DEA analysis of the capacity utilisation measures for the indicators shipping and commercial fishing.

INDEX OF ECONOMIC RESOURCES (IER)

The IER is a composite measure of the economic wellbeing of a community. For the 2016 Gladstone Harbour Report Card this was calculated using census data collected by the ABS. The index focuses on census variables such as the income, housing expenditure and ownership, cost of living and assets of households. The variables used in the index are also weighted by the ABS. This index does not consider educational and occupation variables as these are not direct measures of economic resources.

first time, the tourism indicator was supplemented with expenditure made by passengers and crew members of four cruise ships docked at Gladstone port.

Commercial fishing

The indicator score for commercial fishing was based on production (fishing effort based on number of licences and number of days fished) and the value of the landed catch (in kg) in four sectors: the net (fish), line (fish), pot (mud crab) and otter trawl (prawns) fisheries in Gladstone Harbour relative to a 10-year average starting from 2007–08. Production figures come from the three grids, but prices are Queensland state-wide estimates.

Commercial fishers operating in Queensland's state-managed fisheries are required to complete daily catch-and-effort logbooks. These logbooks enable fishers to record approximately where, when and how fishing took place, and what was caught. Catch-and-effort data are available from the QFish database maintained by Fisheries Queensland (Queensland Department of Agriculture and Fisheries). Those data are recorded from 30 x 30 nautical mile grids and therefore provide only a very general indication of the location of fishing activity. Fishing production data collected from Grid S30 were used as the primary data source for the commercial fishing indicator. This covers most of the Gladstone Harbour and open coastal waters immediately adjacent to the harbour (Figure 3.29).

The total value of commercial fishing was estimated based on catch data by fishing method from the QFish database and average prices for each species group (fish, prawns and crabs) were derived from the most recent Australian fisheries and aquaculture statistics published by ABARES statistics (Windle et al., 2017).

The total value of fisheries production in Mackay (Grid O25) and Yeppoon (Grid R29) was also included in the analysis for two reasons—to control for spatial differences in catch across years as they provided more balanced information on fishing productivity in the region and to control for fish mobility (Windle et al., 2016, 2017).

A capacity utilisation approach is applied and the measures of relative productivity were estimated using the DEA. The four fishery sector scores were weighted by their relative contribution to gross value of production (GVP).

Economic stimulus

The economic stimulus indicator group consists of two indicators: employment and socio-economic status.

The score for employment was based on the unemployment rate for the Gladstone LGA compared with the benchmark of unemployment rates across all Queensland LGAs. This comparison used the most recent ABS data available which were for the 2017 March quarter.

The score for socio-economic status was derived using the IER which is a composite measure of the economic wellbeing of a community. It takes into account income extremes (both high and low) in a population, as well as household ownership, costs of living and other indicators relevant to economic wellbeing in the community. The IER was calculated using 2011 Australian census data and a system of weightings (Pink, 2013) for the different variables and estimates for the Gladstone region were further refined using data collected through the CATI survey. The IER for Gladstone is compared with the IER for other LGAs in Australia to generate a report card score. The IER does not include information on savings or equities as these were not collected through the 2011 census.

Economic value (Recreation)

The economic value (recreation) indicator group was assessed through three indicators: land-based recreation, recreational fishing and beach-based recreation.

Two components of the recreational values can be assessed:

I. the commercial value of the recreation and tourism (estimated based on financial records of commercial tourist operators)
II. non-market value (value associated with residents who use the harbour for recreation but their activity is not reflected in financial records of commercial providers)

The former component is already captured in the economic performance indicator; the latter is included in the economic value (recreation) indicator group.

The scores for the three indicators in the economic value (recreation) indicator group are based on the satisfaction ratings for each recreation activity type and the non-market economic value of the recreation activity type.

TRAVEL COST METHOD (TCM)

Travel cost method is an important economic non-market evaluation technique developed by Clawson (1959). It assesses the monetary value of natural resources used extensively for recreation (e.g. fishing, the beach) that cannot be evaluated through market prices. The key principle behind the TCM is that the cost of travel and time a person invests to visit a place can be used to assign a dollar value to the place and hence would be extremely useful in resource management.

Information on the non-market economic value (recreation) of harbour area activities was collected through a community survey of 401 people within the Gladstone region via CATI survey. Data on travel costs, travel time, and other access and site costs were used in the TCM to calculate the economic value using a recreational site based on the investment that people have made. In 2014, the economic value of land-based ($61 per trip) and beach-based recreational trips ($40 per trip) was estimated (Pascoe et al., 2014). Additional information was collected in 2015 to estimate the value of a recreational fishing trip ($141) (Cannard et al., 2015). The value of recreational trips will be updated every five years.

The economic value assessment has been established in 2014 and 2015 and updated annually through the data (participation frequency rates) collected from the CATI survey. The user satisfaction information on the three types of recreational activities has also been collected from the CATI survey.

The indicator scores for land-based recreation, recreation fishing and beach recreation were determined by the satisfaction rating (from CATI survey) for each activity. These were then weighted by their relative contribution to the economic value of recreation (value of a recreation trip multiplied by the participation frequency rate).

7.3. Results

The scores for each of the three economic indicator groups were high (Figure 7.1) and this contributed to an overall score for the Economic component of the 2017 Gladstone Harbour Report Card of 0.74 (B). Of those indicator groups, economic performance received the highest score of 0.90 (A), economic value of recreation received a score of 0.73 (B) and economic stimulus received a score of 0.67 (B).

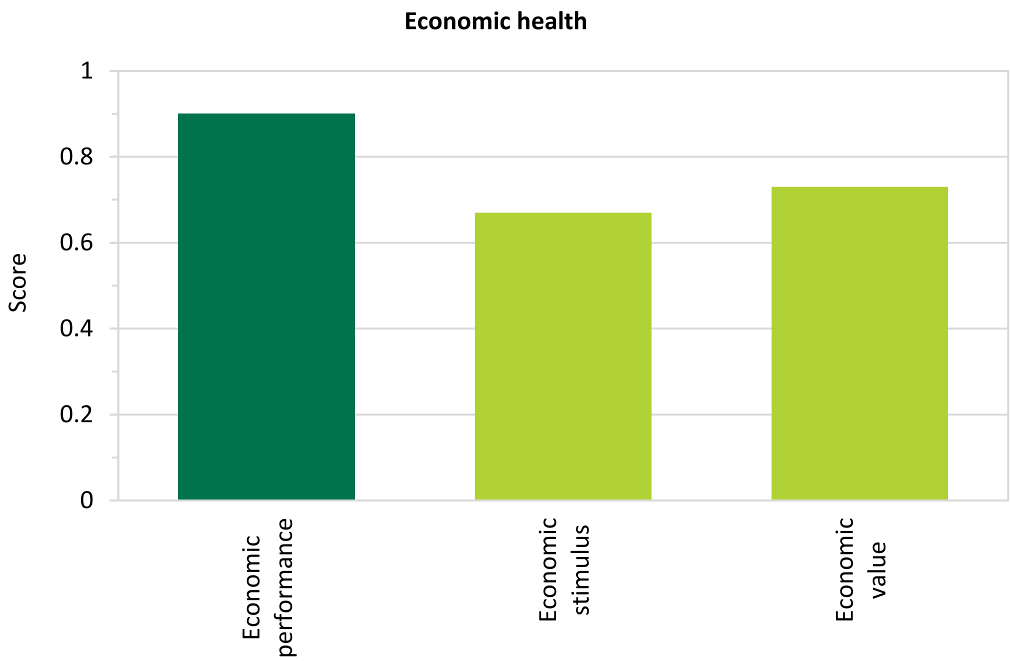


Figure 7.1: The scores for each of the three economic indicator groups in the 2017 Gladstone Harbour Report Card.

Economic health

Economic performance

Compared to 2016, the economic performance of Gladstone Harbour increased from 0.87 to a 0.90 and remain in very good state in 2017.

The highest score was received by shipping activity 0.90 (0.87 in 2016), followed by tourism 0.90 (0.72 in 2016). The commercial fishing received the lowest score of 0.35 (0.43 in 2016) and continues to be in poor state (Figure 7.2). Similar to previous years, the overall economic performance score was strongly influenced by the high scores for shipping activity and tourism.

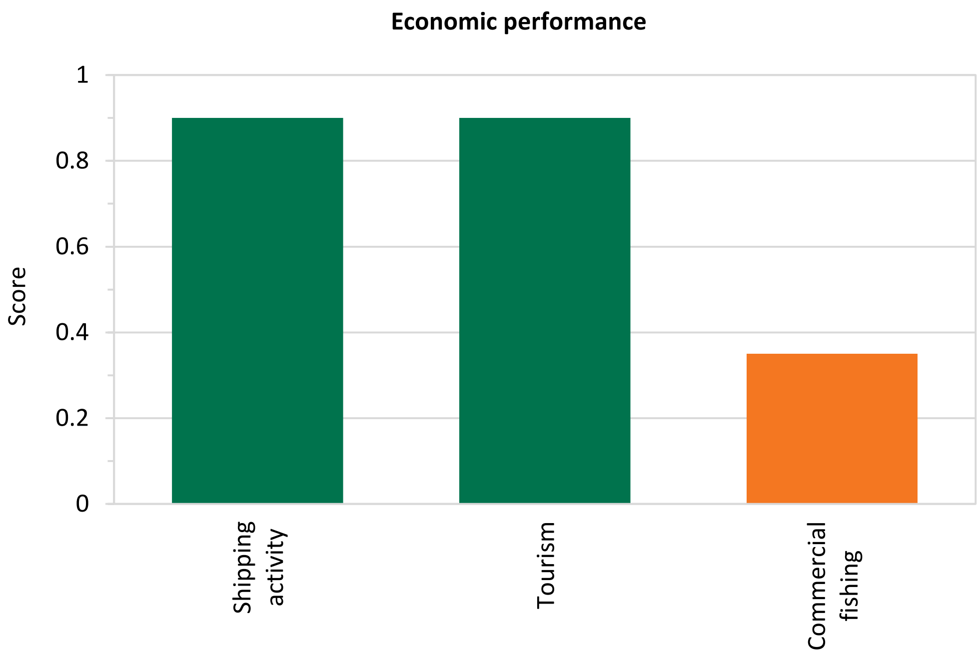


Figure 7.2: Scores for the three indicators of economic performance in the 2017 Gladstone Harbour Report Card.

Shipping activity

The shipping activity indicator, based on the movement of shipping by cargo type in Gladstone Harbour, increased from 0.87 (A) to 0.90 (A) in 2017. The total income generated by the Gladstone Ports Corporation in 2015–16 was $479 million (this figure was used to calculate the report card scores for 2016–17) and this is an increase from the $453 million in 2014–15.

The coal exports (dominated shipping activity type) in Gladstone fluctuated over the reporting months while LNG exports continued to increase during the 2016–17 reporting year. The alumina exports which historically have been the second largest export from Gladstone Harbour remain low over the reporting period (Figure 7.3). The total ship movements in and out of the harbour was slightly greater in 2016 and total monthly vessel count exceeded 150 (Figure 7.4). Capacity added to the port from the expansion of Fisherman's Landing and increased shipping activity resulted in a higher score for the shipping indicator than in 2016.

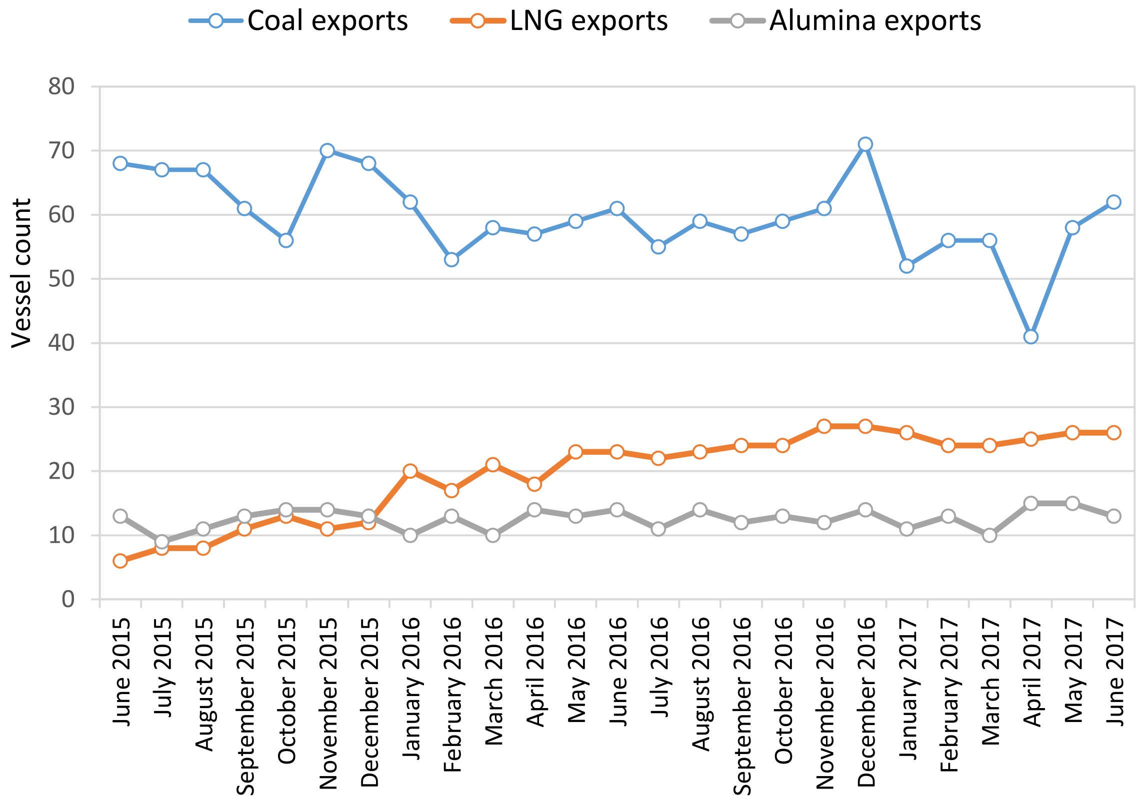


Figure 7.3: Trends in the three main commodity exports from Gladstone Harbour (Source: Gladstone Ports Corporation trade statistics prepared by Windle et al., 2017).

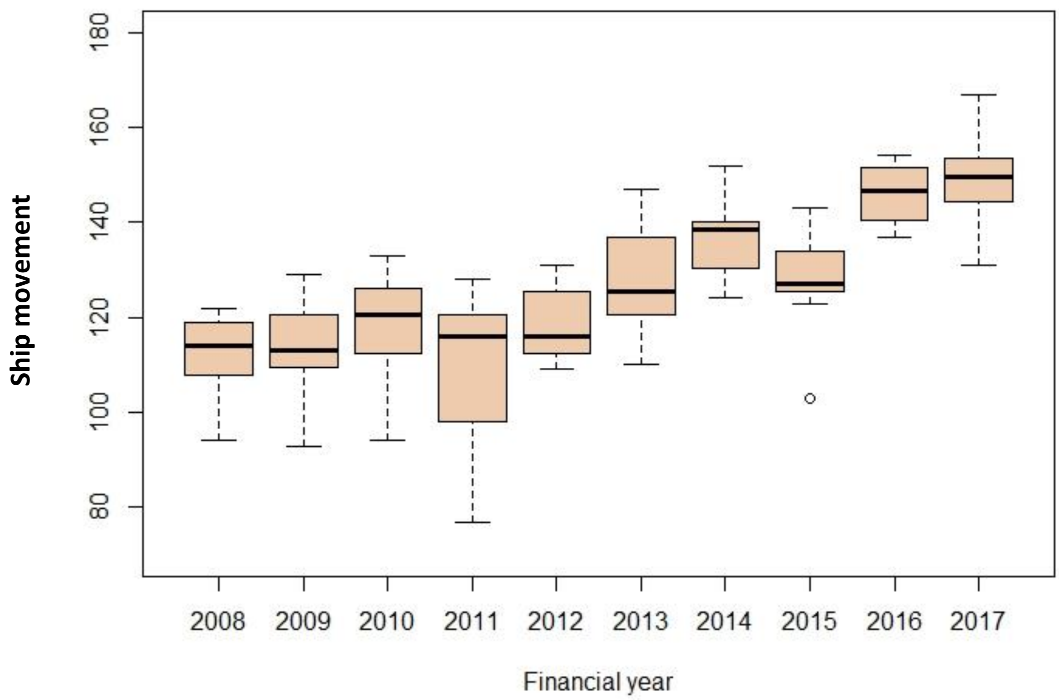


Figure 7.4: Trends in annual shipping movements in and out of the since 2008 (Source: Gladstone Ports Corporation trade statistics prepared by Windle et al., 2017).

Tourism

The tourism indicator increased from 0.72 (B) in 2016 to 0.90 (A) in 2017.

Expenditure on tourism (accommodation, food and other local services) in the Gladstone region was $317 million in 2015–16 and increased from previous years ($274.8 million in 2014–15, $266.7 million in 2013–14). Although there were some analytical differences since the 2014 pilot year, generally the score increased over time.

For the 2015–16 financial year (the most recent data available), four cruise ships docked at Gladstone Port with a carrying capacity of approximately 7850 people who spent an estimated $0.32 million in Gladstone (Windle et al., 2017). This contribution is approximately 0.1% of the total tourism expenditure in the region. Tourism expenditure due to cruise ships has been added to the overall Gladstone region estimate of $316.67 (Windle et al., 2017).

Overall, the increase in tourism expenditure may be associated with the general increase in the expenditure and additional value due to cruise ship operations in Gladstone Harbour. Overall the increase in tourism expenditure may be affiliated with increases in tourism, including additional cruise ships.

Commercial fishing

The commercial fishing indicator declined from 0.43 (D) in 2016 to 0.35 (D) in 2017. Three factors likely contributed to this: the decline in GVP compared to previous year, three months of missing fishing production data (fishing effort based on number of licences and number of days fished) at the time of the score calculation, and a reduction in net (fish) and trawl (prawn) fishery productivity compared to the previous year.

The calculated GVP for Gladstone Harbour fisheries for 2016–17 was $1.93 million and was well below the 2015–16 estimate of $2.83 million and 2013–14 estimate of $4.68 (Figure 7.5b). The GVP in Gladstone has been declining since 2014. Note at the time of completing the analysis, the GVP data for April to June 2017 were not available in the QFish database (Windle et al., 2017). There was also a relatively high proportion of missing values principally related to the line fisheries which were converted to ‘0’, so all production years in the dataset can be included in the analysis similar to previous years. However, the contribution from line fisheries to the overall GVP is minimal (~1%).

Similar to the previous year, commercial fishing productivity in Gladstone remained relatively strong compared with neighbouring regions of Mackay and Yeppoon with similar fisheries (Figure 7.5a). The fisheries prices (Queensland state-wide estimation) for fish, prawns and mud crabs also remained relatively steady since 2012 (Figure 7.6).

The low score for the commercial fishing was influenced by low scores for net fisheries productivity (0.30), and trawl fisheries productivity (0.25). The line fisheries production improved considerably compared to the previous year resulting in a high score (0.90).

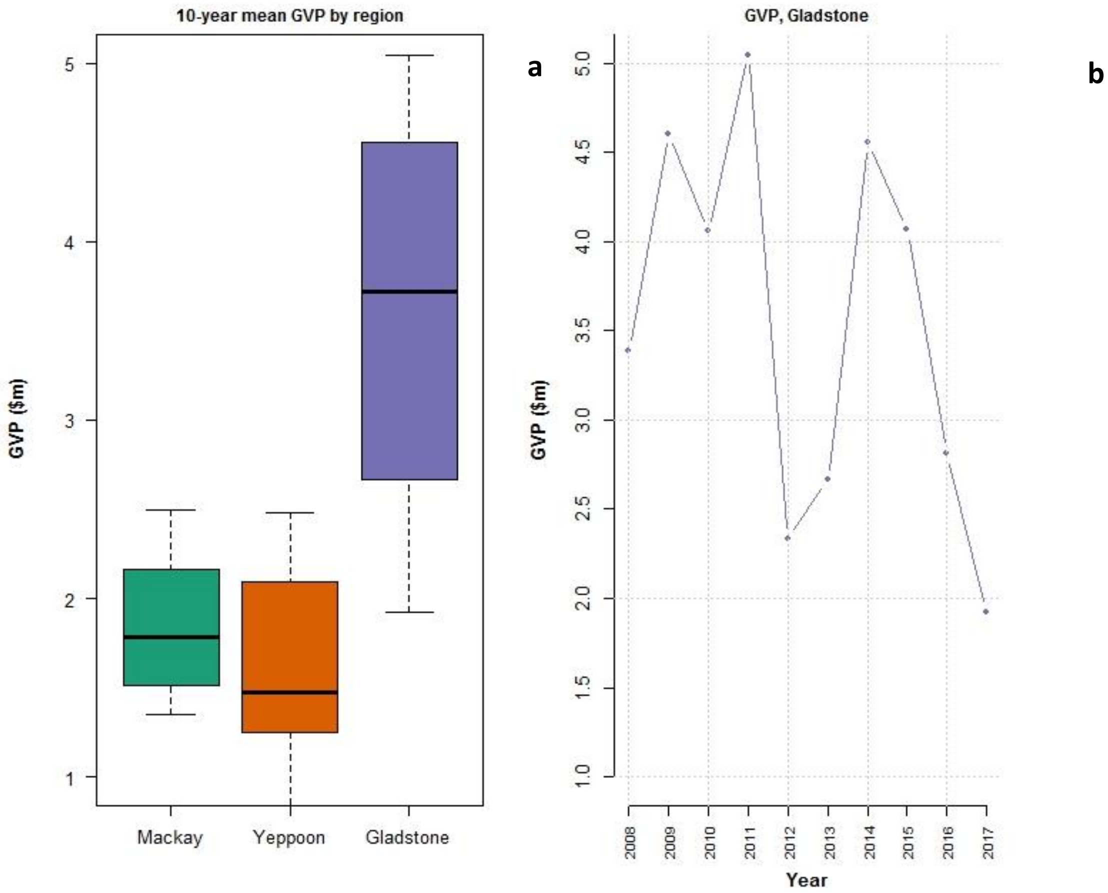


Figure 7.5: Gross value production of a) regions Mackay and Yeppoon and b) Gladstone between 2008 and 2016 (Source: Windle et al., 2017).

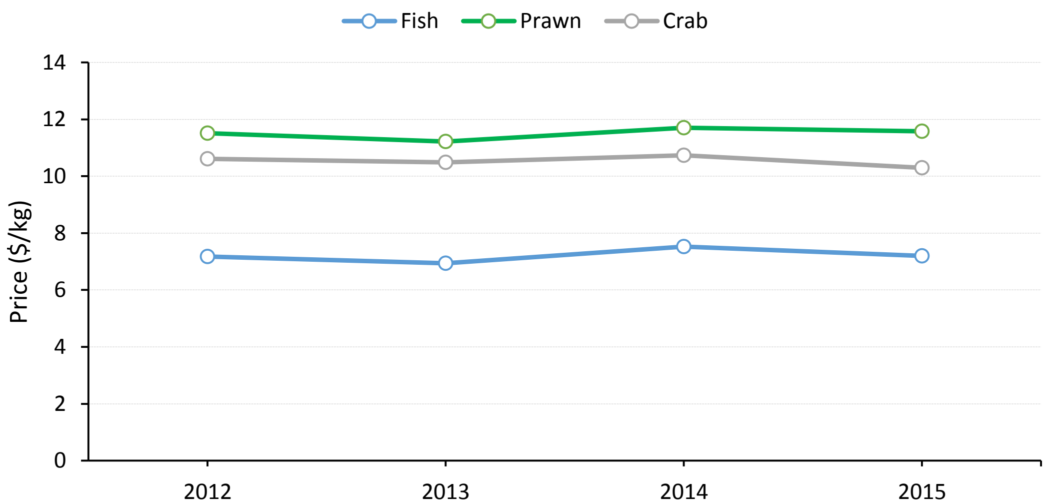


Figure 7.6: Price changes over time for fish (line and net), prawns (otter) and mud crabs (pot) between 2012 and 2015 (Source: Windle et al., 2017).

Economic stimulus

The score for economic stimulus of 0.67 (B) was aggregated from the scores of two indicators: employment 0.53 (C) and socio-economic status 0.70 (B) (Figure 7.7).

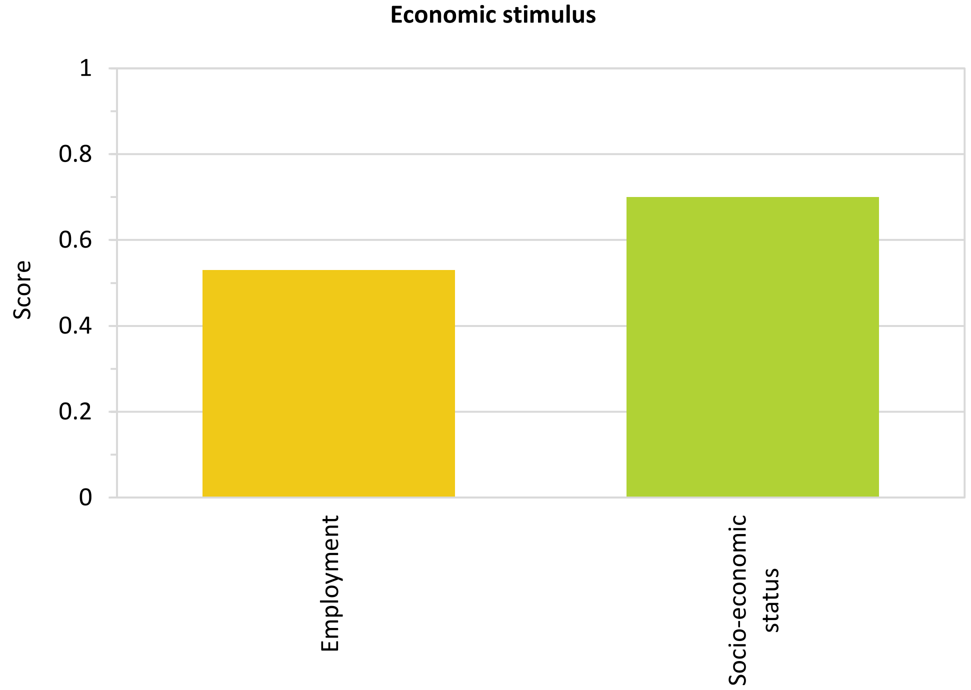


Figure 7.7: Scores for the two indicators of economic stimulus in the 2017 Gladstone Harbour Report Card.

The unemployment rate of 7.0% for the 2017 March quarter was higher than the previous year rate of 6.2% for the same period and also higher than the state average of 6.4% (note last year, Gladstone average was lower than the state average). Although unemployment increased from the previous year's rate, the relative position of Gladstone deteriorated slightly compared to other LGAs in Queensland in the past 12 months. The score for employment declined steadily from 0.62 in 2016 to 0.53 in 2017.

The socio-economic status score for 2017 (0.70, B) has declined slightly for the Gladstone region from a score of 0.80 (B) in 2016. Overall the low scores reported for socio-economic status reflect the impact of job losses and increased unemployment in Gladstone region. There has been statistically significance decrease in mean household income ($t=4.077$, $p=0.00$), number of adults over 18 years in the household ($t=2.85$, $p=0.004$) and average number of bedrooms in the home ($t=2.078$, $p=0.038$). The decline in household income may be associated with the increased unemployment rate in Gladstone and other declines may be related to the younger age profile in the sample.

Economic value (Recreation)

The overall economic value received a score of 0.73 (B) and has not changed considerably compared to previous reporting years (0.73 in 2016, 0.72 in 2015). Similarly, good scores were received for land-based recreation (0.76), recreational fishing (0.65) and beach recreation (0.74) (Figure 7.8).

Both the beach recreation indicator (0.75 in 2016 and 0.74 in 2017) and the recreational fishing score (0.66 in 2016 and 0.65 in 2017) decreased slightly from the previous year but the grade B remained the same as 2016.

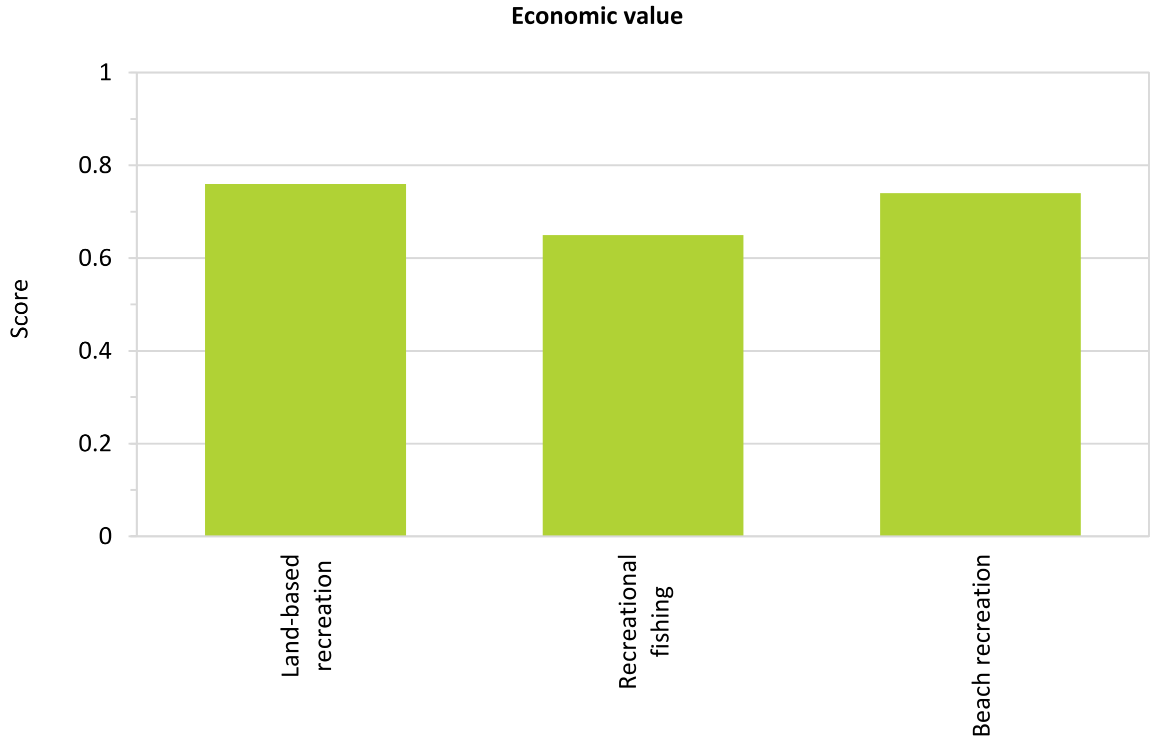


Figure 7.8: Scores for the three indicators of economic value (recreation) in the 2017 Gladstone Harbour Report Card.

According to the CATI survey, the most popular land-based activities along the shores of Gladstone Harbour were walking (similar to 2015 and 2016), picnicking or barbecuing, and relaxing by the water. The most popular beach visited by the survey participants, similar to last year, was Tannum Sands followed by Spinnaker Park artificial beach and Boyne Island. Land-based and beach recreation were much more prevalent than recreational fishing. The average satisfaction ratings for the three types of recreation by CATI respondents were similar in 2016 and 2017 (Windle et al., 2017).

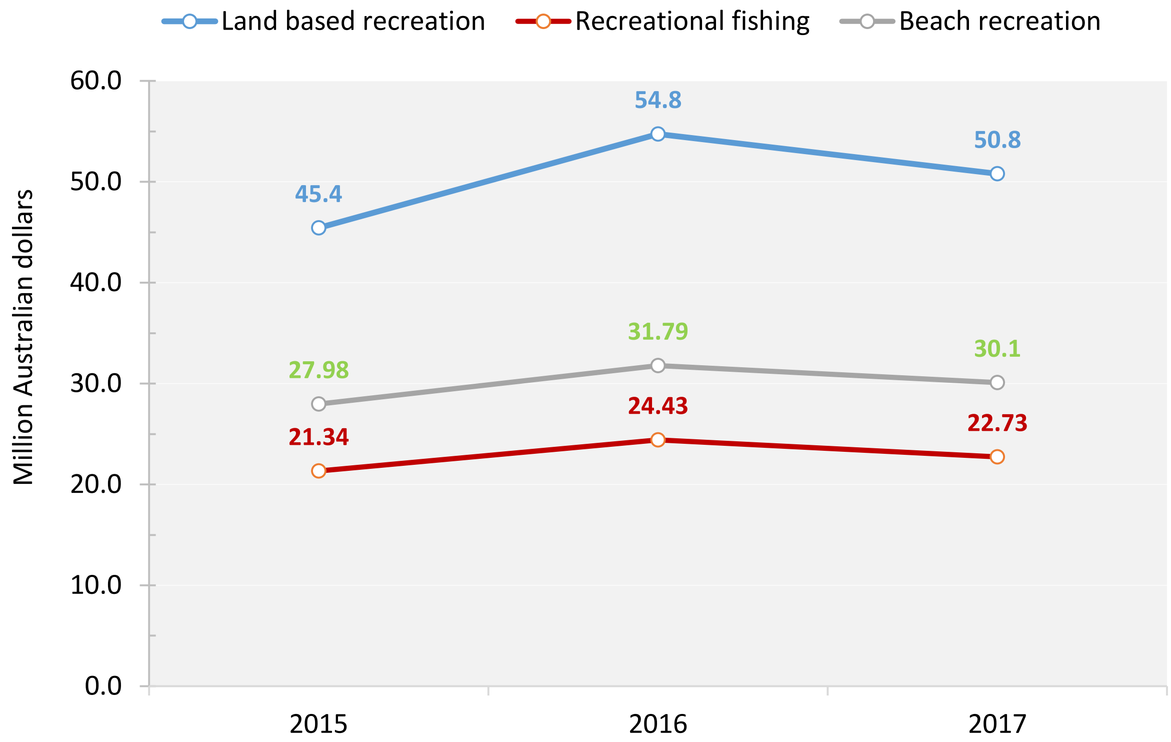


Figure 7.9: The estimated average annual value of recreational trips for 2015, 2016 and 2017 years.

The highest average annual economic value of $50.8 million ($54.8 million in 2016) was reported for land-based recreation followed by $30.1 million for beach recreation ($31.79 million in 2016) and $22.73 million for recreational fishing ($24.43 million in 2015) (Figure 7.9). Overall, the economic value estimates for 2017 were lower than the 2016 values.

The land-based recreation trip value declined by $4 million this year compared to 2016 (Figure 7.9). However, the average satisfaction rating increased from 8.22 (2016) to 8.31 in 2017. As a result, the score remained unchanged compared to the previous year.

The recreational fishing trip value decreased from 2016 ($24.43 million) to 2017 ($22.73 million) (Figure 7.9), and also the average satisfaction rating on recreational fishing trips declined from 7.15 in 2016 to 6.99 in 2017. The beach recreation trip value also decreased by $1.69 million in 2017 and the average satisfaction of respondents who had visited the Gladstone Harbour area for recreation with the last beach trip decreased (8.12 in 2016 and 8.11 in 2017). Accordingly, the scores for the recreational fishing and beach recreation values declined in 2017.

Recreational fishing had a higher per trip value ($143) than beach ($40) and land-based ($61) recreation. The annual total value of the recreational trip was $104 million and higher than the previous years ($24.43 million in 2016, $21.34 million in 2015).

7.4. Economic indicator conclusions

The overall economic health of Gladstone Harbour remains good. However, the overall score has gradually declined since the pilot year (Table 7.2).

The overall economic health for 2017 was strongly influenced by:

- growth in shipping activity due to increased LNG exports
- more tourism activities in the region
- reduced employment opportunities
- decline in socio-economic status with significant decrease in mean household income and number of adults over 18 years in the household
- decline in net (fish) and trawl (prawn) production.

Economic performance

Economic performance assesses the performance of three key industries based on Gladstone Harbour. The performance of these three industries is critical to the regional economy.

Shipping activity provides a proxy for economic activity in key exports such as coal and gas, as well as the imports and exports associated with harbour-based industries such as mineral processing. The high score for shipping activity confirms that these export-focused industries are generating a major economic stimulus to the local economy. Tourism and fishing remain important sectors for the harbour-based city of Gladstone.

The commercial fishing indicator score declined sharply from 2016 to 2017. This result must be interpreted cautiously as there have been some missing data and revisions in the QFish database that have affected data for both the current and previous years. It is possible that the downgrade is a combination of lower activity in net and trawl as well as data changes.

Economic stimulus

Economic stimulus captures the potential stimulus from economic activities that may flow through to the community. The high unemployment rate indicates that the economic stimulus from harbour-based industries on the local economy and job creation is lower than it has been in the past.

The good score for socio-economic status indicates that the economic stimulus from harbour-based industries was flowing through the local economy to create greater income and wealth and provide better access to economic resources such as housing. However, the flow-on effects from increased unemployment, decline in mean household income and the number of adults over the age of 18 in the household also resulted a decrease in the socio-economic status score in 2017 compared with 2016.

Economic value

Economic value (recreation) assesses how the community generates economic value from the harbour through recreation. Economic activity in Gladstone generates income and wealth to the local community. The contribution of harbour-based recreation can then be assessed by how much of that wealth is spent on recreational activities in the harbour.

Land-based recreation was the most important recreational activity followed by beach recreation and recreational fishing based on average annual values of recreational trips for 2017. Overall, respondents have spent more on their recreational trips in 2017 compared to previous years ($104 million in 2017, $24.43 million in 2016, $21.34 million in 2015).

Table 7.2: Comparison of economic indicator scores between 2014 and 2016 report cards.

		2017	2016	2015	2014
Indicator group	**Economic performance**	0.90	0.87	0.79	0.83
Indicators	Shipping activity	0.90	0.87	0.82	0.83
	Tourism	0.90	0.72	0.64	0.6
	Commercial fishing	0.35	0.43	0.63	0.66
Indicator group	**Economic stimulus**	0.67	0.74	0.82 [a]	0.87
Indicators	Employment	0.53	0.62	0.64	0.72
	Socio-economic status	0.70	0.8	0.95 [b]	0.90
Indicator group	**Economic value (Recreation)**	0.73	0.73	0.72	0.75
	Land-based recreation	0.76	0.76	0.73	0.76
	Recreational fishing	0.65	0.66	0.71	0.67
	Beach recreation	0.74	0.75	0.7	0.71
Overall harbour score		**0.74**	**0.75**	**0.77**	**0.82**

[a] A value of 0.715 was estimated when the same 2015 datasets were recalculated using the automated process from the R script as applied for the 2016 data. It is possible there was an error in the original 2015 analysis.

[b] A value of 0.74 was estimated when the 2015 datasets were recalculated using the automated process from the R script as applied for the 2016 data. It is possible there was an error in the original 2015 analysis.

8. Iconic species of Gladstone Harbour

Gladstone Harbour and its associated water bodies and islands provide important habitat, breeding sites and roosting locations for a number of iconic marine species such as dolphins, dugongs, marine turtles and migratory shorebirds. However, these species are not necessarily the best indicators of annual harbour health. In some instances, there can be a considerable lag between an environmental impact and a response in these species. For example, a decline in seagrass cover will provide a signal of change long before malnourishment or fewer sightings are detected in marine turtles or dugongs within the harbour. Additionally, the ranges for most of the marine megafauna usually extend well beyond the confines of Gladstone Harbour. This makes it difficult to associate change in their condition or population with impacts in the harbour. Making such associations may be even harder in the case of migratory shorebirds as changes in numbers observed may be significantly influenced by impacts in the northern hemisphere or other parts of their flyways.

Although these species may not be suitable as report card indicators, research on the distribution, population and trends and the use of the harbour by these species is vital for understanding and managing/mitigating potential impacts within Gladstone Harbour—both natural and anthropogenic. As these species are listed under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act), there are also legislative requirements to protect and mitigate anthropogenic impacts on these species.

Dolphins

The Indo-Pacific humpback dolphin *Sousa chinensis*, the bottlenose dolphin *Tursiops truncates*, and the Indo-Pacific (inshore) bottlenose dolphin *Tursiops aduncus* have been observed in Gladstone Harbour (DEHP, 2014b). The Indo-Pacific humpback dolphin is an EPBC-listed migratory species and is listed as near threatened in Queensland under the *Nature Conservation Act 1992*. Humpback dolphins in the Capricorn–Curtis coast region form two geographically distinct sub-populations, referred to as the Fitzroy River and the Port Curtis Indo-Pacific humpback dolphin sub-populations (Cagnazzi, 2013). In surveys between 2006 and 2008, the Fitzroy River and Port Curtis populations were estimated to be 115 and 84 individuals respectively. In 2011, abundance estimates for both sub-populations declined to about 104 and 45 dolphins respectively (Cagnazzi, 2013).

Between May and August 2014, dolphin surveys in the Port Alma and Port Curtis area (including Rodds Bay) identified 140 Indo-Pacific humpback dolphins from unique markings on their dorsal fins (Cagnazzi, 2015). With the exception of the smaller estuaries, groups of Indo-Pacific humpback dolphins were recorded in all harbour zones including The Narrows and the mouth of Graham Creek (Cagnazzi, 2015). In 2016, humpback dolphins were again found within the harbour and a single snubfin dolphin *Orcaella heinsohni* was sighted in Rodds Bay (Cagnazzi, 2016). Although not directly comparable to the results of previous surveys, these results indicate that Indo-Pacific humpback dolphins continue to use extensive areas of Gladstone Harbour. Small numbers of bottlenose dolphins were also seen during those surveys.

Dugongs

The dugong, *Dugong dugon*, is an EPBC Act-listed marine and migratory species that is also listed as vulnerable in Queensland under the Nature Conservation Act. Dugongs are found throughout the western Indo-Pacific region (eastern Africa to eastern Australia) in tropical and subtropical waters. Within the Gladstone Harbour area, including Rodds Bay, dugongs are predominantly associated with the *Halophila ovalis* seagrass meadows which are the major component of their diet. Sobtzick et al. (2013) reviewed the status of the dugong population in the Gladstone area as part of the Ecosystem Research and Monitoring Program (ERMP) funded by GPC. This review found that the Port Curtis–Rodds Bay area provides important habitat for a relatively small population of dugongs. The authors indicated that as these areas overlap with areas of human use, the risk to dugongs from human activity may be substantial. The review also found that seagrass meadows within the Gladstone area have regional significance as they provide valuable connecting habitat between dugong populations in southern Queensland (Sobtzick et al., 2013).

Small numbers of dugongs were sighted during recent dolphin surveys of the Port Alma and Port Curtis region (Cagnazzi, 2015, 2016) and dugong feeding trails were mapped at five seagrass meadows within Port Curtis, Pelican Banks, South Tree Inlet, Wiggins Island and Rodds Bay.

These incidental sightings demonstrate the continued presence of dugongs in Gladstone Harbour, but are insufficient for identifying trends in the harbour's dugong population.

Marine turtles

Six species of marine turtle have been observed in the Port Curtis region. However, nesting has only been recorded for three of them: the loggerhead, green and flatback turtles. Sightings of the other three species are rare. The status of turtles within Gladstone Harbour has also been reviewed as a component of the ERMP (Limpus et al*.,* 2013) as follows.

- green turtle *Chelonia mydas* – EPBC status: vulnerable, marine and migratory. Isolated green turtle nesting has been recorded within the port limits of Port Curtis, but not annually.
- flatback turtle *Natator depressus* – EPBC status: endangered, marine and migratory. The flatback turtle is the dominant species of turtle recorded as nesting on the beaches of Port Curtis. Most nesting occurs on the southern end of Curtis Island, with low density nesting on seaward beaches within the port limits.
- loggerhead turtle *Caretta caretta* – EPBC status: endangered, marine, and migratory. Isolated loggerhead turtle nesting has been recorded within the port limits of Port Curtis, but not annually.
- hawksbill turtle *Eretmochelys imbricata* – EPBC status: vulnerable, marine and migratory. There are no records of this species nesting within a 500km radius of Port Curtis.
- olive ridley turtle *Lepidochelys olivacea* – EPBC status: endangered, marine and migratory. There are no records of this species nesting in eastern Australia.
- leatherback turtle *Dermochelys coriacea* – EPBC status: endangered, marine and migratory. Leatherback turtles are rarely recorded in the waters of Port Curtis.

An acoustic and satellite tagging study between 2013 and 2014 documented the movement of green turtles within the harbour (Babcock et al., 2015). The study revealed that during high tide, green turtles would move into shallower areas that generally contained more food than the deeper areas of the harbour and would shift into slightly deeper water at the edge of channels at low tide. Babcock et al. (2015) also found that green turtles in the vicinity of Wiggins Island feed predominantly on red algae growing on mangroves, whereas turtles at Pelican Banks feed primarily on seagrasses.

Migratory shorebirds

Migratory shorebirds are EPBC Act-listed species. While there are a number of threats to these birds, the main three in order of severity are considered to be: coastal development outside Australia, climate change and coastal development within Australia (DoE, 2015). Surveys of migratory shorebirds have been conducted in the Gladstone region since 2011 as a component of the ERMP.

In February 2017, a total of 154 roosts were surveyed over five days at Port Curtis, Fitzroy Estuary, North Curtis Island, Mundoolin-Colosseum and Rodds Peninsula. Mainland shoreline and the Western Basin Reclamation Area. These surveys recorded 14,003 migratory shorebirds from 21 species. This was 2,429 more than in the 2016 surveys and 14% more than the overall average for the summer counts (2011–2017). The ten most abundant species accounted for 97% of the birds observed and this was similar to previous years. These species in order of abundance were: bar-tailed godwit *Limosa lapponica*, red-necked stint *Calidris ruficollis*, terek sandpiper *Xenus cinereus*, whimbrel *Numenius phaeopus*, grey-tailed tattler *Tringa brevipes,* lesser sand plover *Charadrius mongolus,* greater sand plover *Charadrius leschenaultia,* eastern curlew *Numenius madagascariensis,* great knot *Calidris tenuirostri* and grey plover *Pluvialis squatarola*.

9. Gladstone Harbour drivers and pressures

9.1. Background

Drivers and pressures are defined as external forces that play key roles in the health of Gladstone Harbour. As a busy industrialised harbour in a subtropical climate with distinct wet and dry seasons, Gladstone Harbour is influenced by a number of environmental, social, cultural and economic drivers. Changes in the demographics of the human population or major climatic events are examples of drivers; both may have strong influences over the environmental, social, cultural and economic condition of the harbour (McIntosh et al., 2014) (Figure 9.1). Pressures are the human forces that may change the environmental condition of the harbour. Examples of pressures are the release of toxic material, physical disturbance of habitats such as mangroves or seagrass, and alterations to the coastline (McIntosh et al., 2014) (Figure 9.2).

The environmental, social, cultural and economic health of Gladstone Harbour could be influenced by major events that operate on scales that extend spatially or temporally beyond the reporting boundaries specified for the four components. For instance, connectivity may be driven by changes in oceanic circulation and wind and rainfall patterns; water chemistry may be influenced by pressures originating from human activities in river catchments. This section summarises some key drivers and pressures that may have influenced the 2016–17 report card scores and grades.

In the reporting year from June 2016 to July 2017, acute climatic events, such as flooding and cyclones, and changes to economic circumstances did not influence the report card grades.

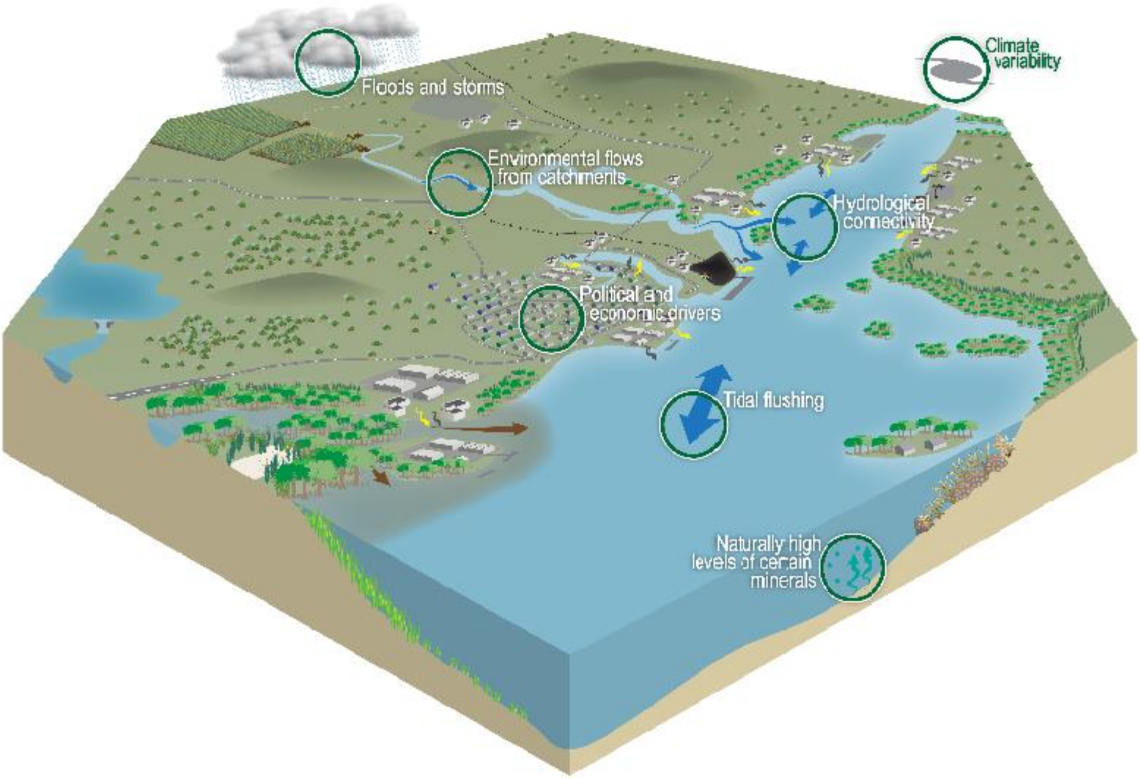


Figure 9.1: Major drivers of environmental change within Gladstone Harbour (Source: McIntosh et al., 2014).

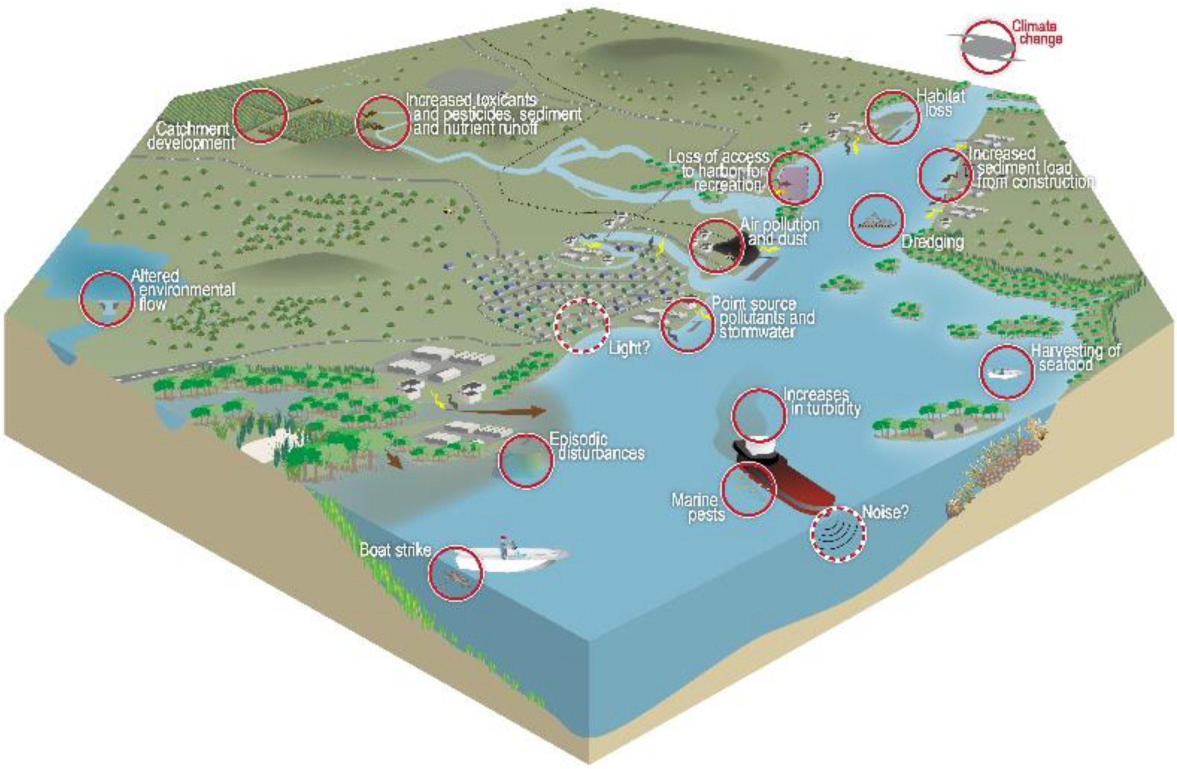


Figure 9.2: Pressures which can drive environmental change within Gladstone Harbour (Source: McIntosh et al., 2014).

9.2. Climate

Gladstone has a subtropical climate with an average maximum of 27.3°C (Figure 9.3) and an average minimum of 18.1°C. Rainfall is highly variable; the average annual rainfall recorded at Gladstone (Airport) for the period 1995–2017 was 866mm. The maximum and minimum annual rainfall totals recorded at this site were 1,542mm in 2010 and 308mm in 2001 respectively. Consistent with a subtropical climate, the summer months are wetter than winter months.

2016–17 rainfall

In the 2016–17 reporting year, total monthly rainfall for all months except July, September, January, March and May were below the monthly average over the past 17 years. The March 2017 rainfall of 615mm is nearly five times that month's average of 137mm, largely due to the passage of ex TC Debbie. Rainfall for July 2016 was 141mm, more than four times the July average of 32mm (Figure 9.4). The 2016–17 reporting years annual rainfall of 1190mm was above the annual average of 904mm (Figure 9.5).

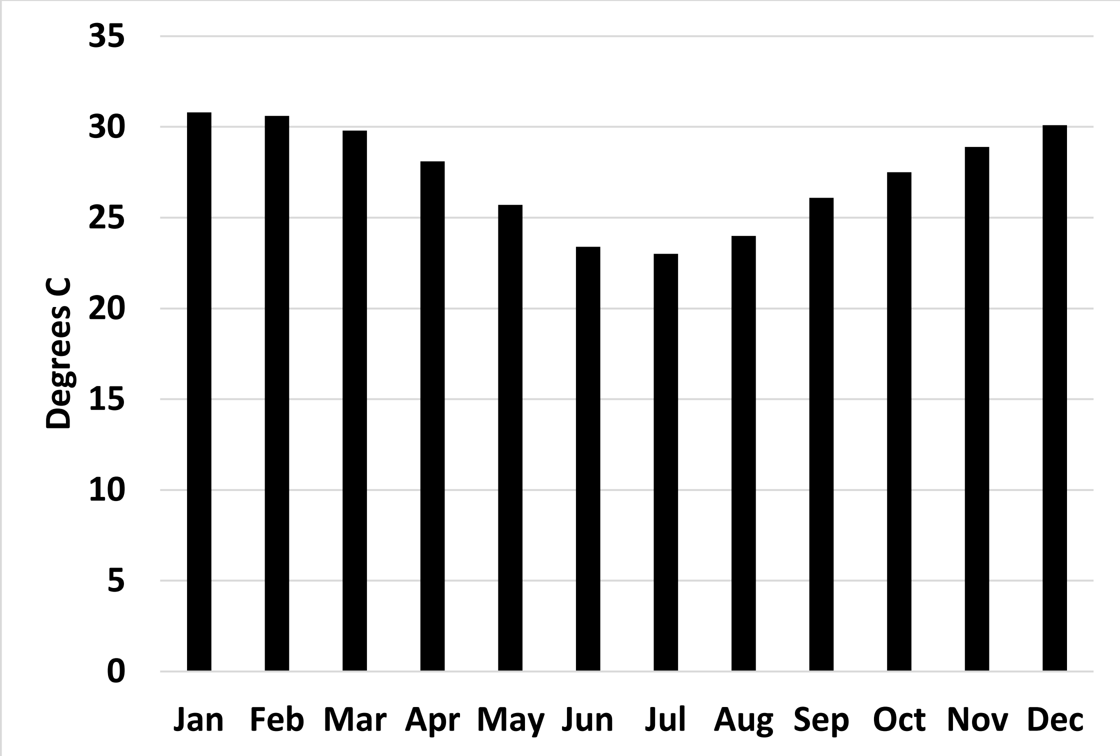


Figure 9.3: Average maximum monthly temperatures at the Gladstone Airport weather station from 1994–2017. Annual average = 27.3° C (Australian Bureau of Meteorology data).

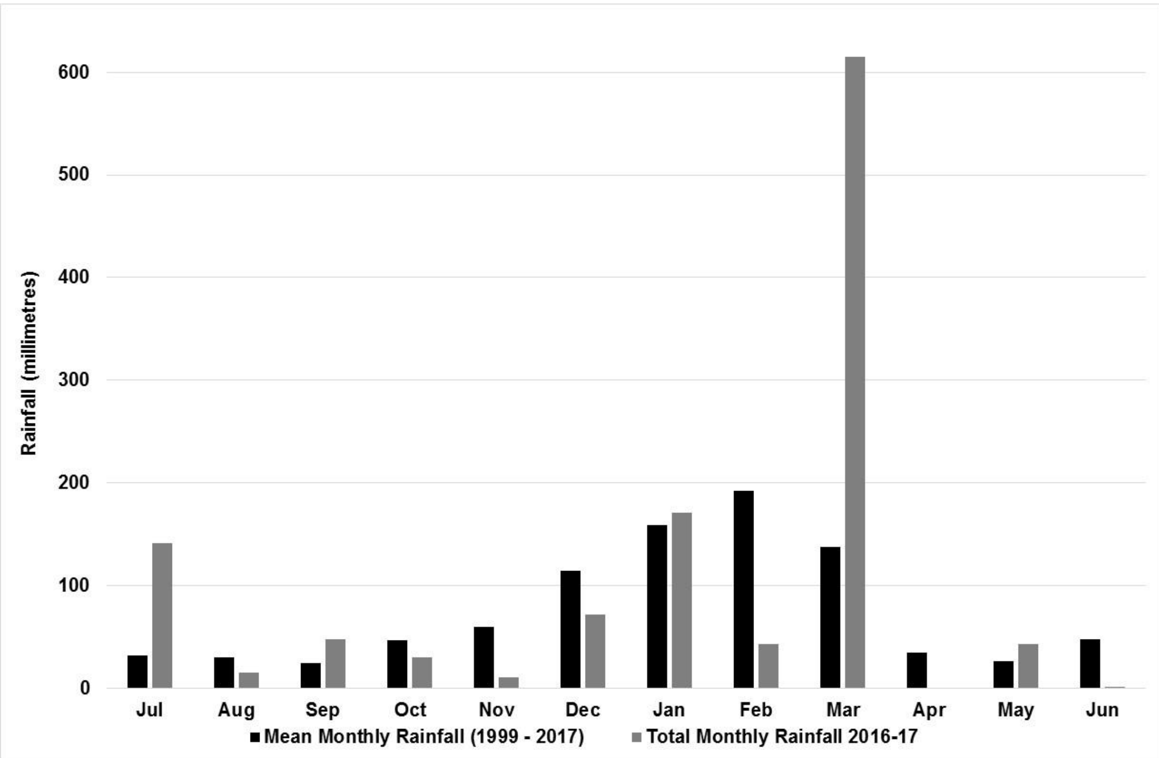


Figure 9.4: Mean monthly rainfall (mm) at the Gladstone Airport weather station (1999–2017) compared to total monthly rainfall for the 2016–17 reporting year (Australian Bureau of Meteorology data).

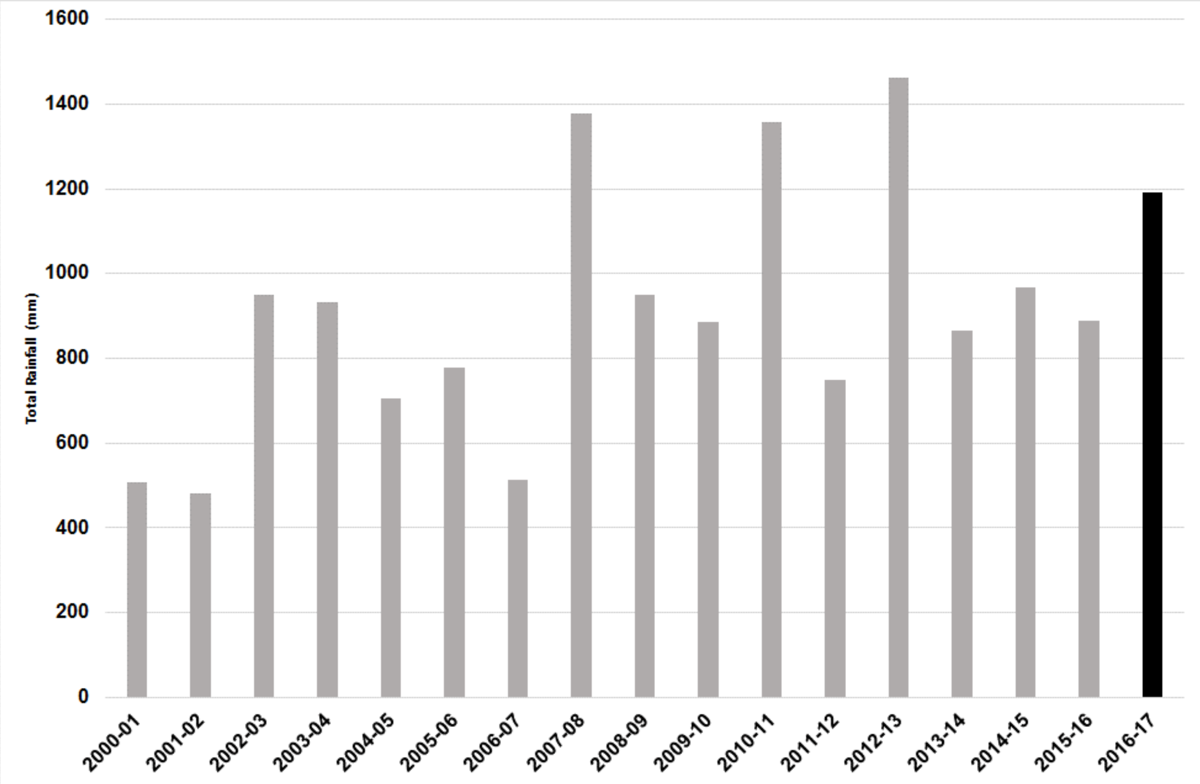


Figure 9.5: Annual rainfall (reporting year) at the Gladstone Airport weather station from 1999–2000 to 2016–2017 (Australian Bureau of Meteorology data).

Freshwater inflow

The two major sources of freshwater flow into Gladstone Harbour are the Boyne River that discharges into the Mid Harbour and the Calliope River that discharges into the Western Basin. Freshwater flows may also enter the harbour via The Narrows when the Fitzroy River floods. Since European settlement, significant changes in land use in both catchments have resulted in increased sediment and nutrient loads in the Port of Gladstone (DSEWPaC, 2013).

Streamflow in the Boyne River is highly modified owing to the presence of Awoonga Dam, whereas flow in the Calliope River is relatively unmodified. Annual average streamflows for the Boyne and Calliope rivers are presented in Table 9.1.

Flows measured at the Calliope River between January 2014 and June 2017 show two brief but significant high flow events occurring with the passage of TC Marcia and ex TC Debbie (Figure 9.6). Rainfall associated with TC Marcia caused a peak flow of 91,666ML/day on 21 February 2015 and rainfall associated with ex TC Debbie produced a peak flow of 105,980ML/day on 30 March 2017. This compares a median daily flow of 34ML/day for the January 2014 to June 2017 period (DNRM Water Monitoring Information Portal).

Although the 2017 high flow event lies within the 2016–17 reporting year, it does not fall between the dates for the 2016–17 seagrass monitoring which occurred in November 2016. Therefore, disturbance associated with the 2017 high flow event, such as increased harbour turbidity, will not have affected seagrass scores and grades for the 2016–17 reporting year.

Table 9.1: Streamflow summary for the Boyne River (1984–85 to 2011–12) and the Calliope River (1938–39 to 2014–15) (DNRM Water Monitoring Information Portal downloaded 08/09/16).

Boyne River at Awoonga Dam Headwaters (1984–85 to 2011–12)			
Annual streamflows (ML)		December streamflows (ML)	
Mean	97,728	Mean	24,279
Median	0	Median	0
Maximum flow (2010–11)	1,194,335	Maximum flow (Total flow December)	634,999
Calliope River at Castlehope (1938–39 to 2014–15)			
Annual streamflows (ML)		December streamflows	
Mean	167,431	Mean	21,949
Median	102,113	Median	3,061
Maximum flow (Total flow 2012–13)	916,693	Maximum flow (Total flow December)	401,837

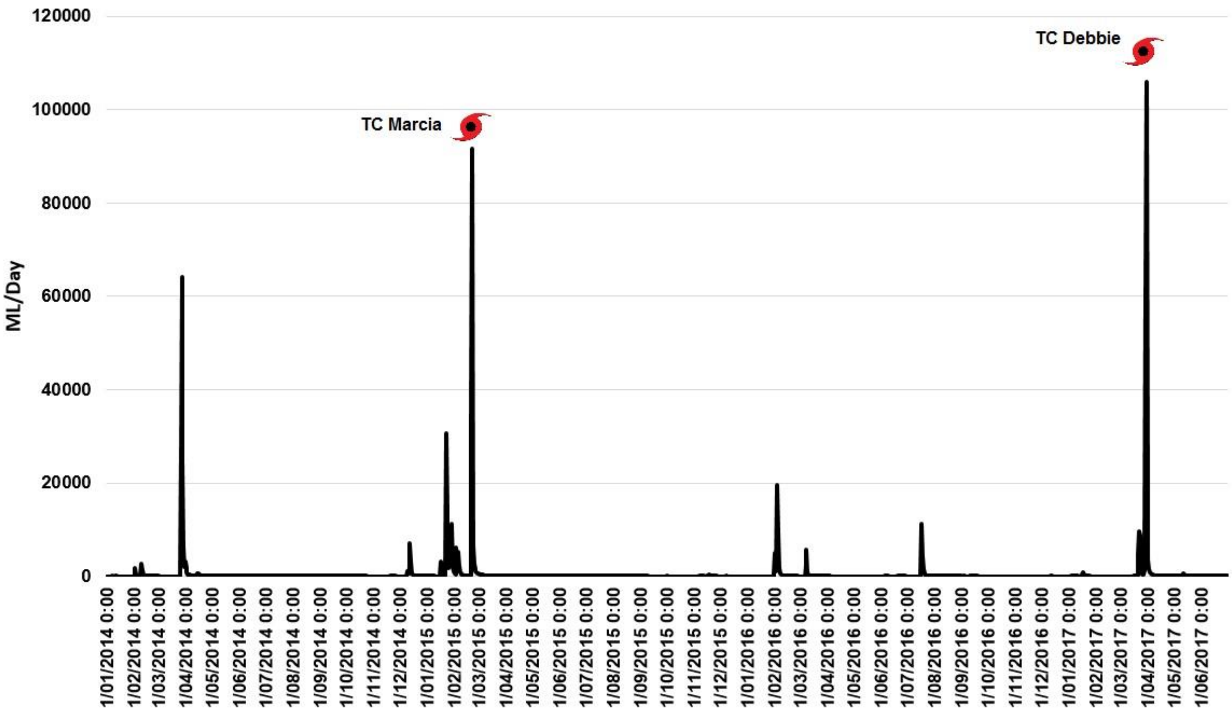


Figure 9.6: Calliope River flows recorded at Castlehope between January 2014 and June 2017. A flow of 91,666ML/day was recorded on 21 February 2015 in association with the passage of Tropical Cyclone (TC) Marcia and a flow of 105,980ML/day was recorded on 30 March in association with the passage of TC Debbie. These peak flows compare with a daily median flow of 34ML/day for the same time period (DNRM Water Monitoring Information Portal downloaded 18/07/17).

The main water storage for Gladstone is the Awoonga Dam located on the Boyne River approximately 25km south-west of Gladstone. The dam has a storage capacity of 250,000ML and is overtopped when the storage level exceeds 40m Australian height datum (AHD). Since the height of the dam wall was raised in 2002, it has overtopped five times—in 2002, 2010, 2013, 2015 and in the 2016–17 reporting year in March 2017 (Table 9.2 and Figure 9.7). The 2017 overtopping was caused by heavy rainfall associated with ex TC Debbie. As can be seen in Table 9.2 this was a minor event compared to the flooding that occurred in January 2013.

Table 9.2: Awoonga Dam levels and 2017 overtopping levels compared to the largest overflow recorded in 2013 (Source: Gladstone Water Board).

Storage level	Date	Level (m AHD)	Volume (ML)	Capacity (%)	Surface area (ha)
Current storage	30-June-17	39.79	762,706	98.18	6,696
Level one month ago	31-May-17	39.92	771,461	99.31	6,748
Level one year ago	30-June-16	38.85	701,505	90.3	6,329
Last overflow of 40m spillway	30-Mar-17	41.94	915,936	117.92	7,562
Highest level	27-Jan-13	48.3	1,498,586	192.9	10,810

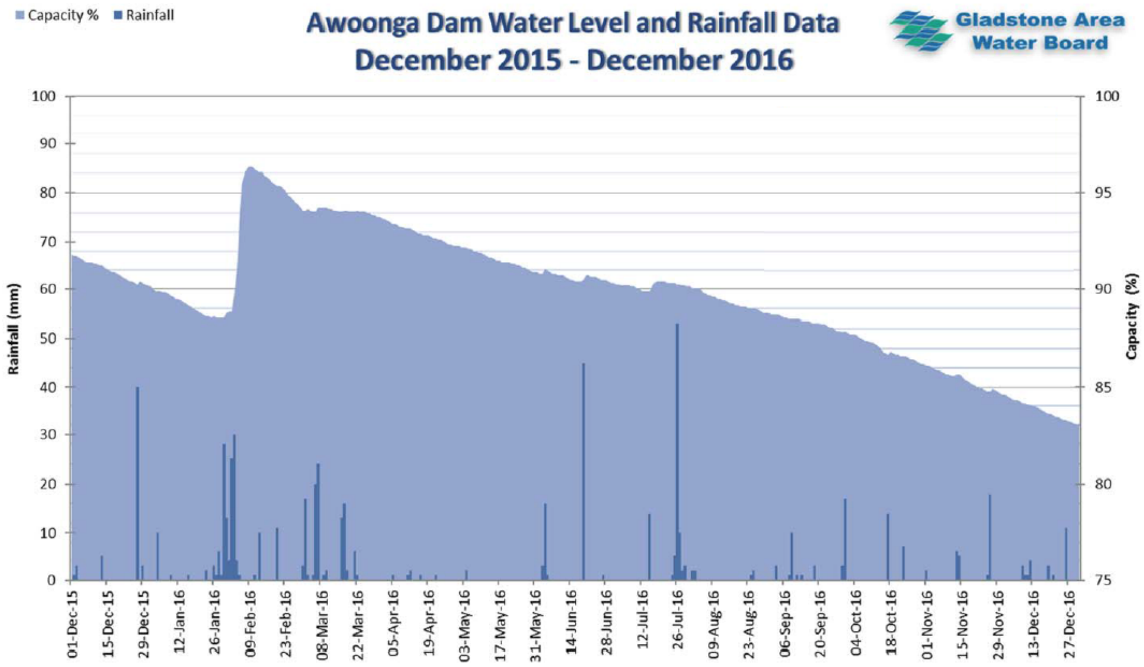


Figure 9.7: Awoonga Dam levels December 2015 to December 2016 (Source: Gladstone Area Water Board).

9.3. Catchment run-off

Gladstone Harbour is bordered by five drainage basins, the Fitzroy (142,545km^2), the Calliope (2,241km^2), the Boyne (2,496km^2), Curtis Island (577km^2) and Baffle Creek (4,085km^2) (Queensland Government Wetland*Info* downloaded 01/06/2016) (Figure 9.8).

The primary sources of riverine discharge into Port Curtis come from the Calliope and Boyne rivers, with some flow through The Narrows when the Fitzroy River is in flood. Compared to the Fitzroy River catchment area (142,665km^2), the Calliope and Boyne are relatively small. Their catchment areas are 2,236km^2 and 2,590km^2 respectively. The predominant land use within these two catchments is grazing (Figures 9.9 and 9.10). Much of the flow from the Boyne River into Port Curtis is restricted by Awoonga Dam, constructed in phases beginning in the 1960s. The current spillway height of 40m AHD was achieved in 2002. In periods of normal flow it would be expected that coarser sediment particles would settle behind the structure.

Catchment run-off can strongly influence water quality within estuarine systems. It is a major source of sediments, nutrients and pesticides delivered to marine waters (Bartley et al., 2017). Land use within a catchment will influence the type and volume of material exported from that catchment. Suspended sediments are dominated by grazing inputs, while pesticides are sourced from dryland and irrigated cropping and grazing lands (Dougall et al., 2014). Catchment pollutant load exports are modelled for the 35 major basins that discharge into the Great Barrier Reef Lagoon including the Boyne, Calliope and Fitzroy rivers (McCloskey et al., 2017). The modelled data show increases in a range of parameters from the pre-development period compared to the loads modelled for 2014-15 (Table 9.3). For example, the average annual loads of fine sediments from the Calliope River has increased to 57,000 tonnes per year compared to 7,000 tonnes per year in the pre-development period.

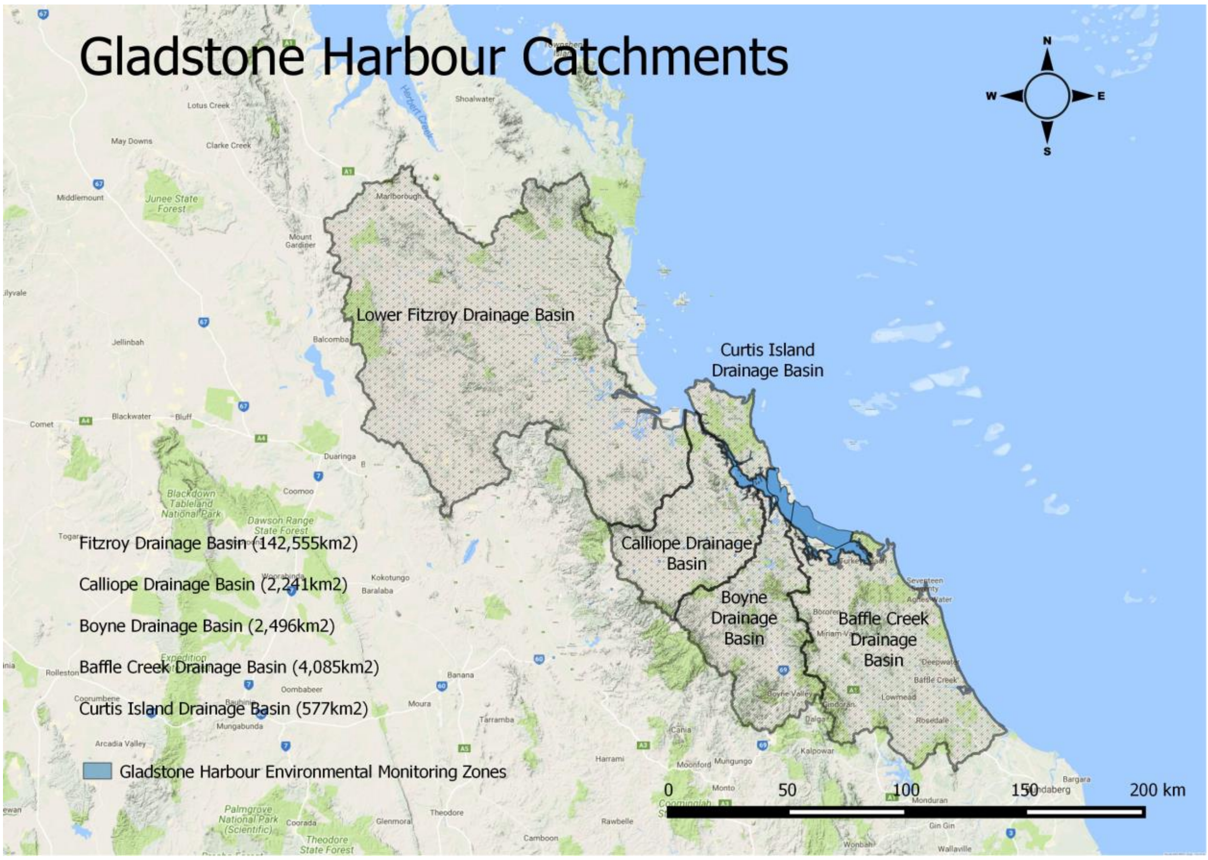


Figure 9.8: Drainage basins surrounding the Gladstone Harbour Environmental monitoring zones.

Table 9.3: Modelled pre-development and 2014–15 catchment load exports from the Boyne, Calliope and Fitzroy catchments (McCloskey et al., 2017).

Catchment	Pre-development load	Total load (2014–15)	Increase from pre-development load % of total load
GHHP Report Card Parameters			
Total nitrogen loads (TN) (tonnes per year)			
Boyne River	195	266	27%
Calliope River	208	639	67%
Fitzroy River	2,875	6,280	54%
Total phosphorous loads (TP) (tonnes per year)			
Boyne River	76	105	28%
Calliope River	74	281	74%
Fitzroy River	1,054	2,745	62%
Other Parameters			
Total fine sediments (kilo-tonnes per year)			
Boyne River	8	24	67%
Calliope River	7	57	88%
Fitzroy River	181	1,493	88%
PSII herbicides toxic equivalent loads (kilograms per year)			
Boyne River	0	1	100%
Calliope River	0	2	100%
Fitzroy River	0	38	100%
Particulate nitrogen (tonnes per year)			
Boyne River	90	113	20%
Calliope River	81	439	82%
Fitzroy River	918	3,056	70%
Dissolved inorganic nitrogen (tonnes per year)			
Boyne River	35	37	< 1%
Calliope River	42	47	11%
Fitzroy River	641	799	20%
Particulate phosphorus (tonnes per year)			
Boyne River	48	60	20%
Calliope River	41	221	81%
Fitzroy River	558	1,817	69%

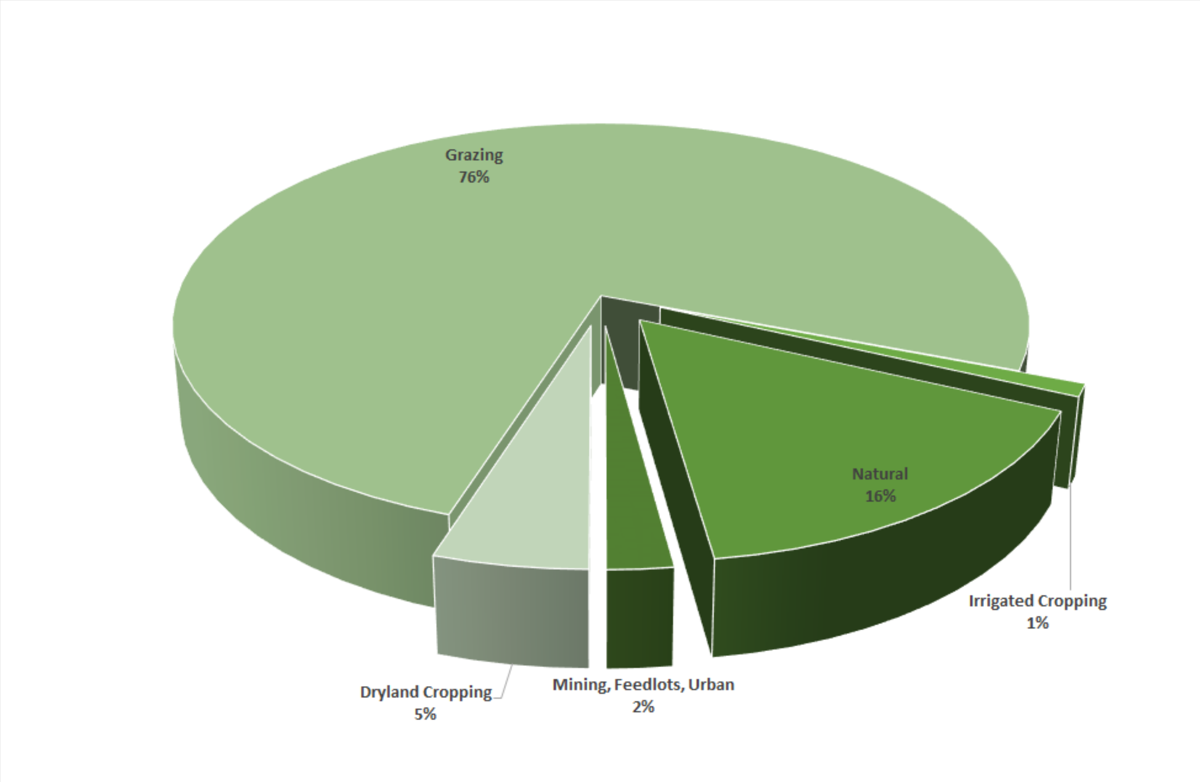


Figure 9.9: Land use in the Boyne catchment (Data source QSpatial, Land use mapping – Fitzroy NRM region 2009, Catchment boundaries, Queensland Wetland*Info*).

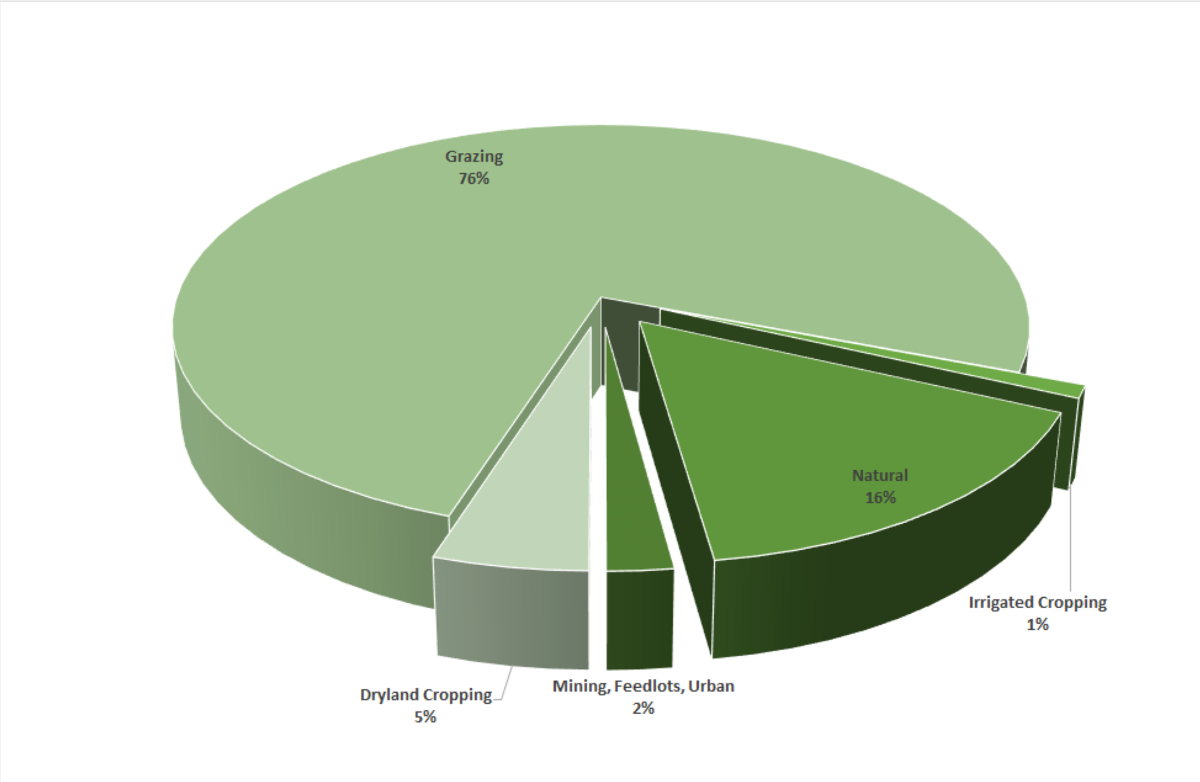


Figure 9.10: Land use in the Calliope catchment (Data source QSpatial, Land use mapping - Fitzroy NRM region 2009, Catchment boundaries, Queensland Wetland*Info*).

Tidal movement and turbidity

Turbidity in Gladstone Harbour is strongly influenced by the large tidal movement. This results in significant resuspension of fine sediments which is directly related to the tidal cycle; larger tides result in increased turbidity (Figure 9.11). Turbidity levels in Gladstone Harbour tend to be much higher on falling tides than on rising tides (Baird & Margvelasvili, 2015). Collecting water quality samples throughout the day provides samples at various times in the tidal cycle. Thus, the measured variation in turbidity among sites is largely determined by the timing of sampling.

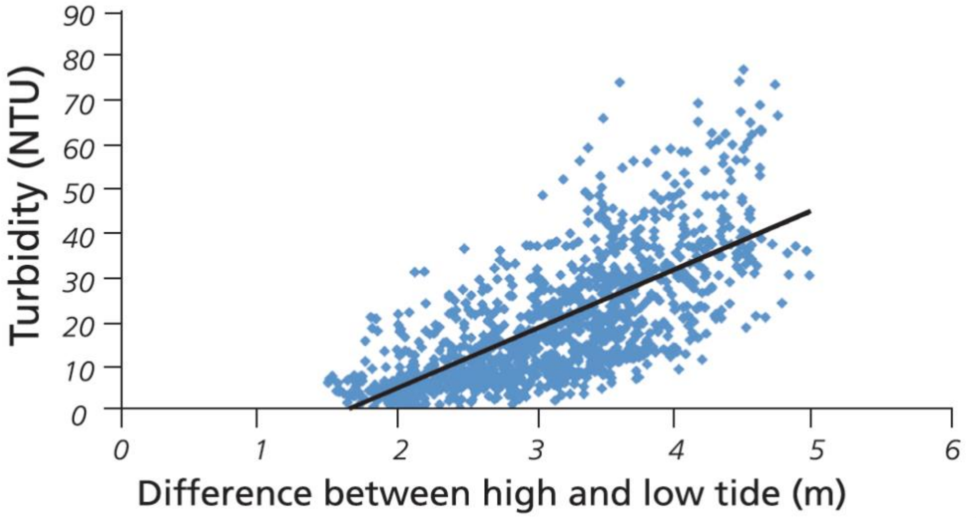


Figure 9.11: The relationship between tidal movement and turbidity in Gladstone Harbour (DEHP 2014 personal communication). NTU: nephelometric turbidity unit.

9.4. Social and economic pressures

Gladstone is an industrial hub of international significance owing to its large-scale production and export facilities. The Gladstone region's social and economic growth and development patterns have been strongly influenced by the rapid development of the manufacturing, construction and retail trade sectors. This has resulted in a steady increase in Gladstone's population from 2011 (57,890 people) to 67,426 in 2016 Gladstone (Gladstone Regional Council 2017a).

The value of both residential and non-residential building approvals continues to decline in the 2016–17 year following a sharp peak in 2012–13 when residential and non-residential approvals reached $450 million and $402 million respectively. For the 2016–17 (until May) monitoring period, the value of residential buildings in Gladstone remained $60 million and for non-residential buildings $38.7 million (Figure 9.12). The number of dwellings approved for construction also followed a similar pattern and continues to decline from 2012 (ABS, 2017). These data are based on the approval permits issued by the local government authorities, work authorised by the commonwealth, state, semi-government and local government authorities and major building approvals in areas not subject to normal administrative approval (ABS, 2017).

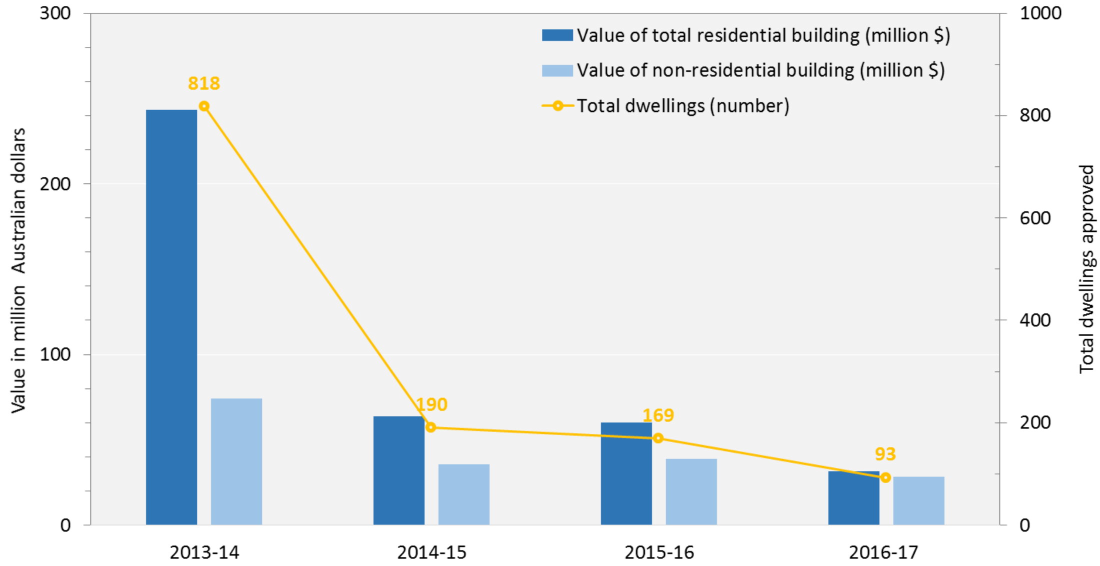


Figure 9.12: Total value of residential and non-residential building approvals and approved total new dwellings in Gladstone LGA from 2012 to May 2017 (based on data collected monthly and averaged to obtain an annual value).

The number of businesses actively trading in Gladstone also steadily declined from June 2014 (4,081) to June 2015 (3,915) and then to 3842 June 2016. From 2015 to 2016, there was a slight decrease in businesses with turnovers of greater than $2 million, $50k to less than $100k, and zero to less than $50k (Figure 9.13). However, compared to June 2015, businesses with $100k to less than $200k turnover, $200k to less than $500k, and $500k to less than $2million increased in June 2016 (Gladstone Regional Council, 2017b). Business counts provide a snapshot of the businesses which actively traded in goods and services for the financial year recorded in Australian Bureau of Statistics Business Register.

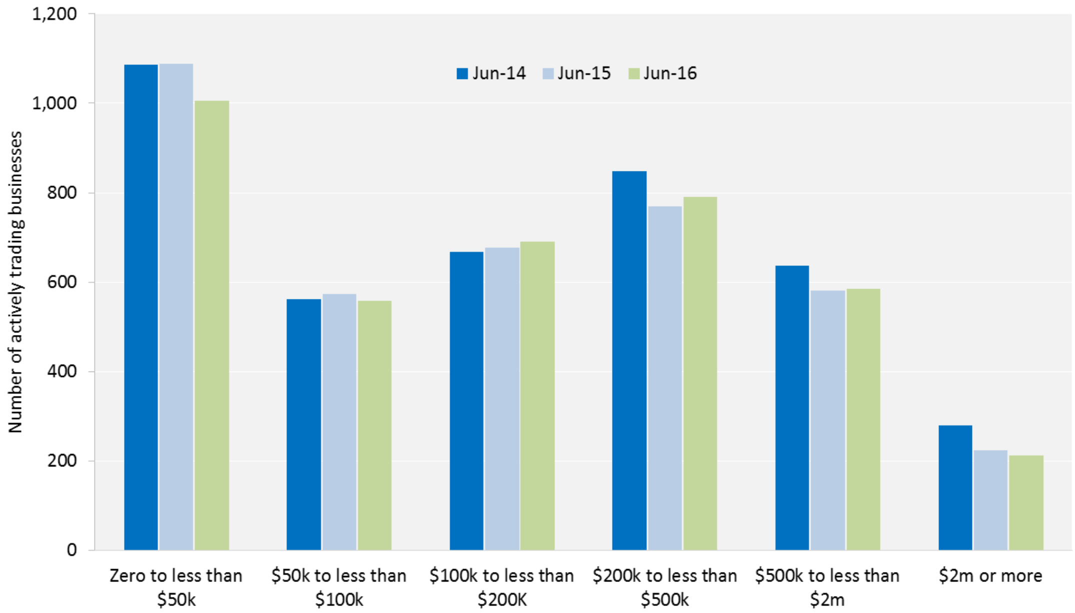


Figure 9.13: The number of actively trading businesses in Gladstone in 2014, 2015 and 2016 financial years. Categories related to the annual turnover value of the business in Australian dollars reported to the Australian Taxation Office.

The three LNG processing and export facilities projects on Curtis Island, QCLNG, APLNG and GLNG, moved from the construction to operational phase during the 2015–16 financial year. This involved downsizing, offloading equipment and machinery, and releasing leased rental properties back to the rental market in Gladstone (Australian Mining, 2015). As the LNG plants on the islands are reaching full capacity, in September 2016, a $17 million investment was made by the GLNG and QCLNG to build a new marine operations terminal catering for the daily ferries and vessels to Curtis Island (Queensland Government, 2016).

A new form of tourism emerged in Gladstone with the arrival of the first cruise ship, Pacific Dawn, at Gladstone's Auckland Point Terminal with 2,000 passengers in March 2016 (ABC Capricornia, 2016). According to P&O Cruise Dates Gladstone (2017), four large cruise ships were expected to bring more Australian and international visitors to Gladstone between January and June 2017.

9.5. Connectivity

From 2016, 'connectivity' will not contribute to the report card score for the Environmental component as it is considered to be a driver of ecological systems and not a measure of environmental health. Additionally, the connectivity indicators—ecological connectivity, containment connectivity and flushing rate—are generally not affected by human intervention. However, connectivity is an important explanatory variable that contributes to our understanding of the environmental grades and scores and the environmental health of Gladstone Harbour. It will therefore continue to be reported as a system driver.

The connectivity of water bodies is an important driver of productivity in marine ecosystems and helps to maintain ecosystem function. Hydrological connectivity contributes to the health of habitats found within Gladstone Harbour (such as seagrass meadows, mangroves and coral reefs) by cycling nutrients, facilitating biological and genetic connectivity, and by diluting and flushing contaminants. However, connectivity between contaminant inputs (e.g. from industrial discharges) and vulnerable habitats (e.g. seagrass meadows) can also have negative effects on harbour health. The development of shipping channels, land reclamation and coastline armouring has the potential to alter connectivity within the harbour and is also being assessed by this project.

CSIRO has developed a state-of-the art-hydrodynamic model to address the Gladstone Harbour Report Card objective relevant to connectivity: 'maintain/improve connectivity of water within and between Gladstone Harbour, related rivers, estuaries and adjacent waters'. This model calculates connectivity indices and scores for the report card. It also constitutes a key component of a separate Gladstone Harbour Model that CSIRO is developing on behalf of GHHP (see Appendix 1 for details).

Three indicators have been developed to inform the overall connectivity for the Gladstone Harbour Report Card (Figure 9.14):

1. flushing time – a measure of water exchange through the system. This indicator is commonly used as an indirect indicator of water quality.
2. ecological connectivity – a measure of water exchange between known spawning grounds and nursery areas
3. contaminant connectivity – a measure of the potential of contaminants to move to other parts of the harbour from the input source.

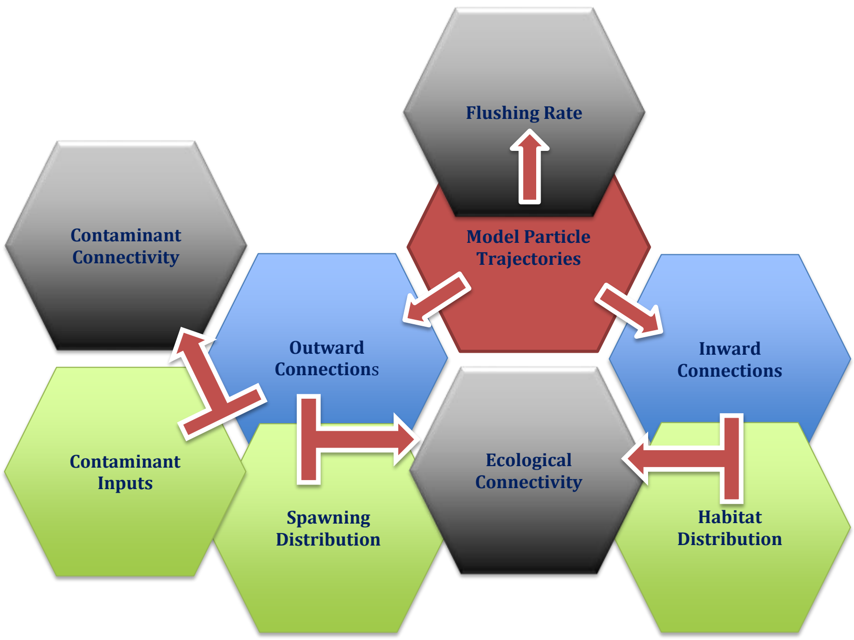


Figure 9.14: The three connectivity indicators calculated from the trajectories of virtual particles within the hydrodynamic model.

Data collection

CSIRO developed a three-dimensional hydrodynamic computer model of Gladstone Harbour for the GHHP which generated the data for calculating connectivity scores for the report card. This model uses a three-dimensional curvilinear grid bounded by the harbour and includes the Boyne and Calliope rivers. There are two open boundaries. One is the curvilinear grid extending offshore in an arc from Curtis Island to Rodds Peninsula and the other is formed by The Narrows (Figure 9.15). The resolution is variable over the grid and ranges from 100–250m within Gladstone Harbour to approximately 1,000m at the offshore boundary. The model has 21 vertical layers with depth ranges of between 0.4m at the surface to 5.0m in the deepest offshore waters. Two layers above mean sea level are included to take tidal movement into account.

CSIRO's eReefs model (eReefs Marine Modelling Overview) provided initial and open boundary conditions, atmospheric forcing was included using data supplied by the ACCESS-A meteorological model run by the Bureau of Meteorology (ACCESS NWP Data Information), and freshwater flow information was based on flow data at Castlehope for the Calliope River and at Awoonga Dam headwaters for the Boyne River (Water Monitoring and Data Portal). Real-time data for the Boyne River are no longer available.

A detailed technical description of the hydrodynamic model and its implementation is provided in Condie et al. (2015).

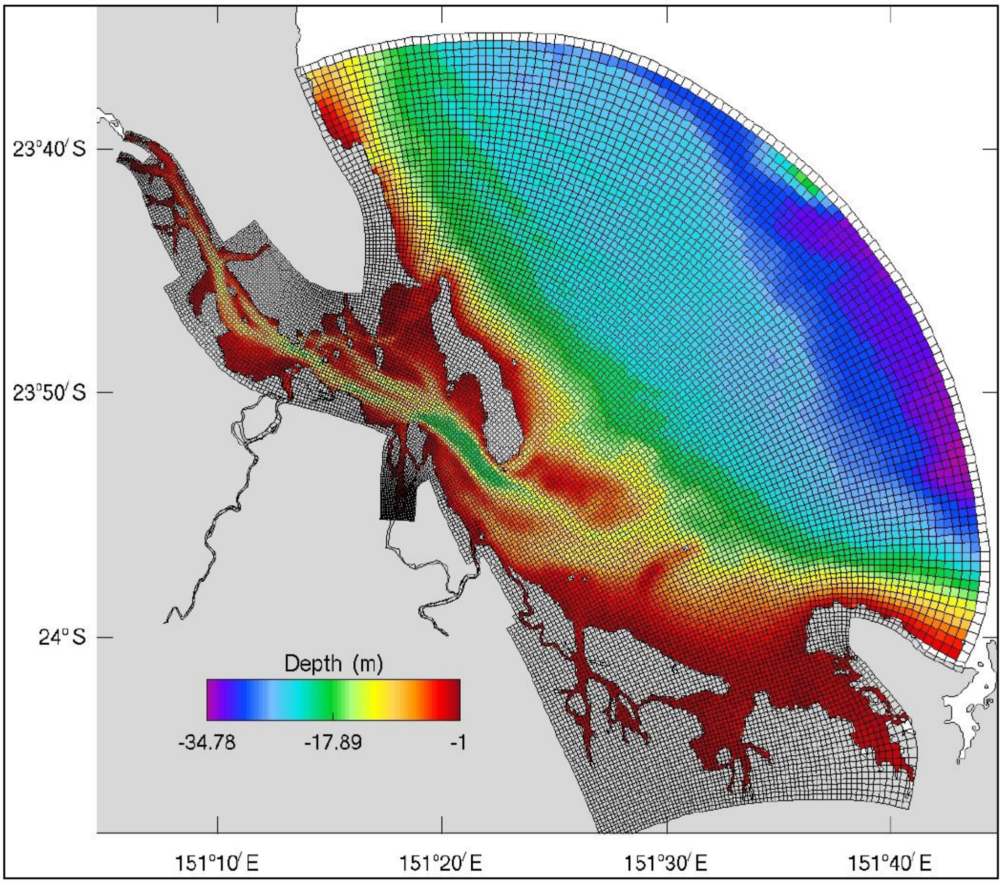


Figure 9.15: The Gladstone Harbour hydrodynamic model's curvilinear grid overlayed on harbour bathymetry (Source: Condie et al., 2015).

Two model runs covering the period September 2010 to August 2014 generated the data for determining baseline conditions. A model run from July 2016 to June 2017 generated the scores for the 2017 report card. The 2010 to 2014 period was required to generate a sufficient baseline for calculating report card grades and scores. The Western Basin Dredging and Disposal Project resulted in changes to the harbour bathymetry and coastline. This required separate model runs for the periods before and after capital dredging to incorporate these changes (Table 9.4).

Table 9.4: Hydrodynamic model runs used to determine a connectivity baseline and scores for 2016.

Model run	Outputs
Pre-capital dredging: September 2010–August 2012	Pre-capital dredging baseline values Estimation of pilot indicator values
Post-capital dredging: September 2012–August 2014	Post-capital dredging baseline values Estimation of pilot indicator values
Near real time: June 2015–June 2016	2016 connectivity assessments and scores

Each of the three connectivity indicators was assessed by particle tracking from all three model runs. In each model run, 2,000 neutrally buoyant 'particles' were randomly seeded throughout the virtual water column within the computer model. This model included 11 of the 13 water quality reporting zones in Gladstone Harbour. Auckland Inlet and Boat Creek Estuary were not included in this analysis as these small estuaries are not sufficiently resolved by the hydrodynamic model to support particle tracking. In the remaining zones, reseeding of particles occurred every 20 days to account for particles lost through the outer edges of the zones. This timing ensured that particles were released at different points of the tidal cycle, thus minimising tidal bias in the long-term statistics.

Particles were moved in 10-minute time steps by currents generated by the hydrodynamic model. A small 'random walk' element was added to the particle trajectory to represent the dispersive influence of small-scale turbulent motion that is not included in the circulation model. All particles were individually tracked and their virtual locations were recorded once every hour.

Flushing rate

The flushing rate indicator was calculated for each 20-day reseeding by plotting the number of particles remaining in a zone over time and calculating the time until only 36.8% of particles remained.

Ecological connectivity

Significant areas of potential nursery habitat (wetlands, seagrass meadows or coral reefs) and spawning grounds of key species (e.g. barramundi, yellow-finned bream and mud crabs) were identified in the 11 harbour zones for which connectivity scores are reported (Table 9.5). A habitat score for each zone (1 to 3) was calculated by adding the number of habitats recorded in each zone (1 point for each habitat type) plus one additional point to account for less well documented habitat types (e.g. soft sediments). A similar approach was used to derive a spawning score for each zone (Table 9.5). Each zone was allocated one point for each key spawning ground it contained plus one point to account for undocumented spawning grounds and/or other species. Although this is a simple scoring system, it effectively differentiated between zones with and without key habitats. In the future, refinements to this scoring system could be made if suitable data become available (e.g. if additional habitats are located).

The ecological connectivity score is based on the modelled movement of virtual particles between zones for each of the 20-day reseedings. Movement of particles into a zone weighted by the habitat score provides a relative measure of how favourable the system connectivity was for recruitment to habitats within that zone. The movement of particles out of a zone into other zones weighted by the spawning scores provides a relative measure of how favourable the system connectivity was to the dispersal of eggs and larvae from that zone.

Contaminant connectivity

The contaminant connectivity indicator was based on annual loads of toxic substances discharged into the waterways as reported to the National Pollutant Inventory (www.npi.gov.au). These figures are reported annually in January, seven months after the end of each financial year. Thus, the 2013–14 data are the most recent available and so were used as the best available estimate for the 2014–15 loads. This approach was tested back to 2007–08 and found to result in smaller errors than averaging over the previous two or three years.

Within each of the 11 zones for which a connectivity score is reported, annual loads that occurred within the zones were multiplied by a relative measure of their aquatic ecotoxicology and then summed to obtain a relative annual toxicity load for each zone. These calculations were made for the three harbour zones with reported contaminant release: Western Basin, Inner Harbour and South Trees Inlet (Table 9.6). Although there are no data available for directly estimating background pollutant release into the harbour, the model was set to give a ratio of recorded loads to the harbour to diffuse background loads that were within the range typical of impacted estuarine systems. This background load was applied equally to all zones.

The contaminant score is based on the movement of particles (for each 20-day reseeding) out of a zone weighted with the zone score (annual load multiplied by aquatic toxicity) into other harbour zones.

Table 9.5: Key sites with the potential to support ecological connectivity. Particle trajectories were not available for Boat Creek and Auckland Inlet (Source: Condie et al., 2015).

Zone	Key nursery habitats				Key spawning grounds			
	Wetlands	Seagrass	Reefs	Habitat score	Barra-mundi	Bream	Mud crab	Spawning Score
1. Graham Creek	1			2				1
2. The Narrows	1	1		3				1
3. Boat Creek	1			2				1
4. Calliope Estuary	1			2				1
5. Western Basin		1		2	1			2
6. Auckland Inlet				1				1
7. Inner Harbour				1	1			2
8. South Trees Inlet	1			2				1
9. Boyne Estuary				1				1
10. Mid Harbour		1	1	3	1	1		3
11. Colosseum Inlet	1			2				1
12. Rodds Bay	1	1		3				1
13. Outer Harbour		1	1	3		1	1	3

Table 9.6: Relative aquatic ecotoxicology (Wright et al., 1998) and four years of annual loads from some industrial facilities as reported to the National Pollutant Inventory (www.npi.gov.au) (Source: Gorton et al., 2017).

	Substance (including compounds)	Relative aquatic eco-toxicology	Annual Loads (kg)																	
			Western Basin Yarwun Site Stuart Project Rio Tinto Alcan Yarwun						Inner Harbour Gladstone Terminal Port Central						South Trees Inlet Boyne Smelters Queensland Alumina					
			2010-2011	2011-2012	2012-2013	2013-2014	2014-2015	2015-2016	2010-2011	2011-2012	2012-2013	2013-2014	2014-2015	2015-2016	2010-2011	2011-2012	2012-2013	2013-2014	2014-2015	2015-2016
Metals	Arsenic	0.20	91.5	93.5	208	257	12.0								560	568	543	270		440
	Beryllium	1.0		17.6	40.3															
	Cadmium	2.0	8.61			11.9	0.12								18.6	6.8	5.8	22.6		
	Chromium	0.33	14.1		21.8			4.0	0.58		0.03	0.01	0.01	0.01						
	Copper	1.0				18.1			0.15	0.03	0.03	0.05			18		84.3	363		
	Iron	0.005																		
	Lead	0.20							0.04	0.01	0.01	0.01		0.01	1.3		23.1	0.41		
	Manganese	0.10														58.0				
	Mercury	16.7		0.01			0.05													
	Nickel	0.17		11.7					0.16	0.01	0.02		0.01	0.01		54.5	192			
	Vanadium	0.05																		
	Zinc	0.125	363	485	695	708			2.0	0.08	0.30	0.01			380	288	3780	257		
Other substances	Ammonia	0.24	5906	6833	6279	6321														
	Benzene	0.10									0.11									
	Carbon tetrachloride	0.42																		
	Chlorine	0.50	132	128	117															
	Chlorobenzene	1.0																		
	Chloroform	0.42																		
	Cyanide	0.10																		
	Dichloroethane	0.50																		
	Fluoride	0.01	16412	13504	29928	49940	570000	56000							134000	129240	239500	111000	102000	100000
	Formaldehyde	1.0																		
	Hexochlorobenzene	167																		
	Hexochlorobutadiene	50																		
	Methylenechloride	0.50																		
	Nitrobenzene	0.25																		
	Nitrophenol	0.50																		
	Tetrachloroethylene	0.50																		
	Toluene	0.13							0.01	0.01	0.52	0.02	0.01							
	Trichloroethylene	0.50																		
	Xylene	0.17							0.01	0.01	0.28	0.01	0.01	0.01						

Connectivity grades and scores for 2017 were calculated relative to zone-specific baseline values for flushing rate, ecological connectivity and contaminant connectivity indicators. These baselines were calculated using the four-year model run (September 2010–August 2014). This period gives equal weighting to pre-capital and post-capital dredging conditions to the baseline. Connectivity can be influenced by factors with high seasonal and inter-annual variability, such as rainfall, which may influence flushing rates in zones containing estuaries. Although the baseline period largely captures the variability of rainfall over the last 10 years (Australian Bureau of Meteorology rainfall data for Gladstone Airport), drier conditions such as those experienced in the preceding decade would have resulted in lower flushing rates.

Flushing rates for all 20-day reseedings over the four baseline years were used to calculate a mean flushing rate and standard deviation for each zone. These values form the baseline (Figure 9.16) to which the 2014–15 flushing time statistics were compared to derive the flushing rate scores.

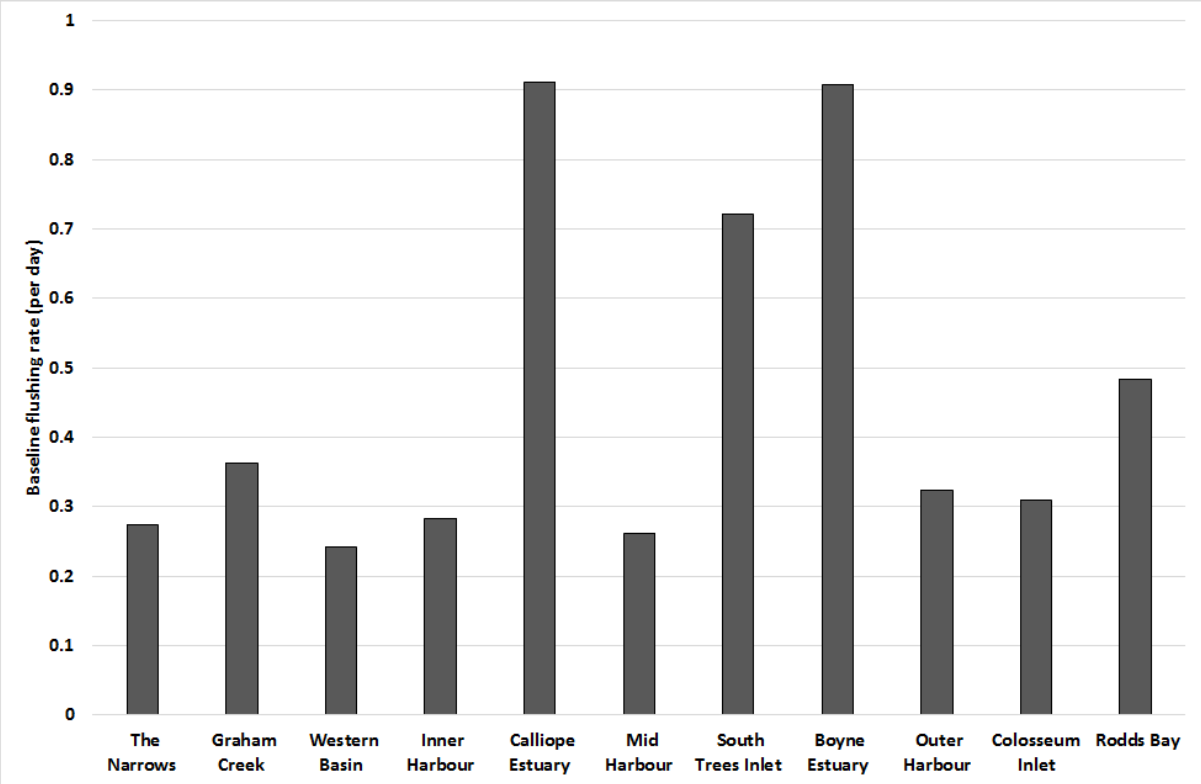


Figure 9.16: Baseline four-year average flushing rates in each of the modelled harbour zones.

The baseline for ecological connectivity was calculated from the 20-day reseeding scores of the weighted in-degree (movement of particles from other zones into a zone weighted by the habitat score) and the weighted out-degree (movement of particles out of a zone into other zones weighted by the spawning scores). The average of these two scores produced the ecological connectivity score. Means and standard deviations were calculated from these scores over the four years of model runs to give baseline values for ecological connectivity (Figure 9.17).

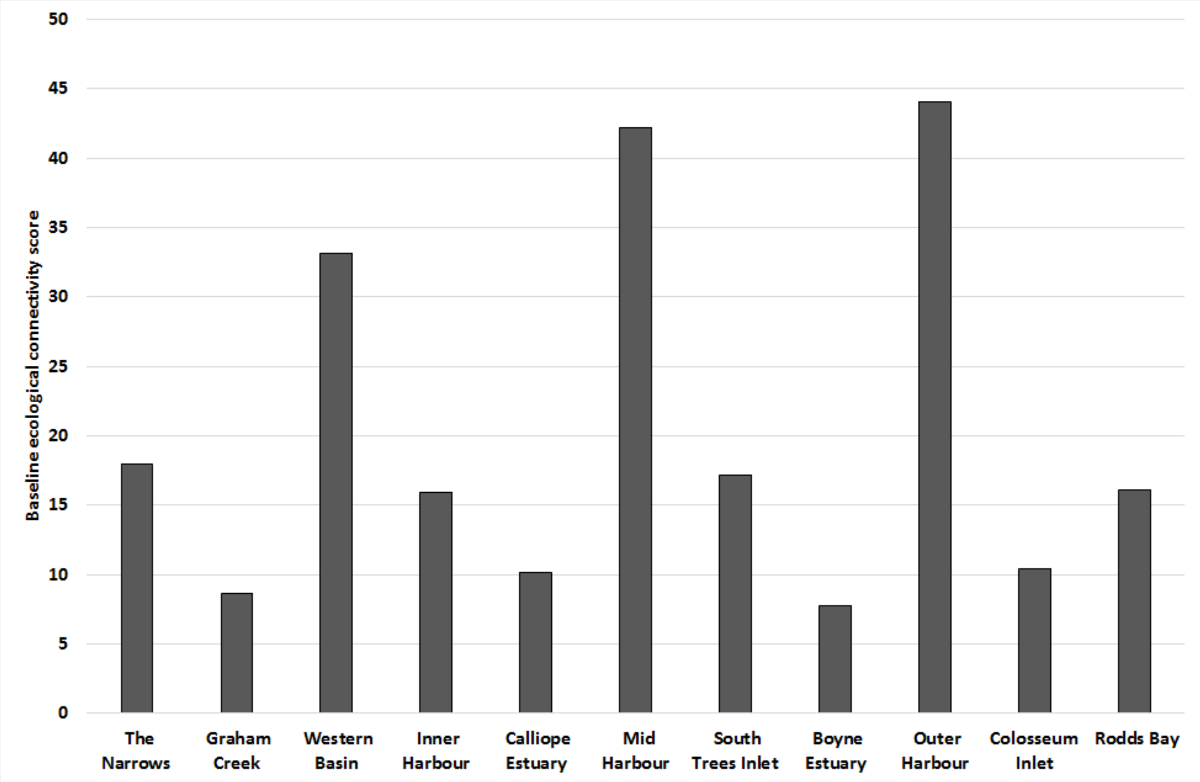


Figure 9.17: Baseline four-year average ecological connectivity in each of the modelled harbour zones.

Baseline values for contaminant connectivity were calculated from the weighted out-degree scores (the movement and number of particles from each zone into other zones) in each of the 20-day reseedings over the model run 2010–2014. Means and standard deviations of the weighted out-degree scores were then computed over the four years to give the baseline values to which the 2014–15 data were compared to derive the 2016 report card score for this indicator (Figure 9.18).

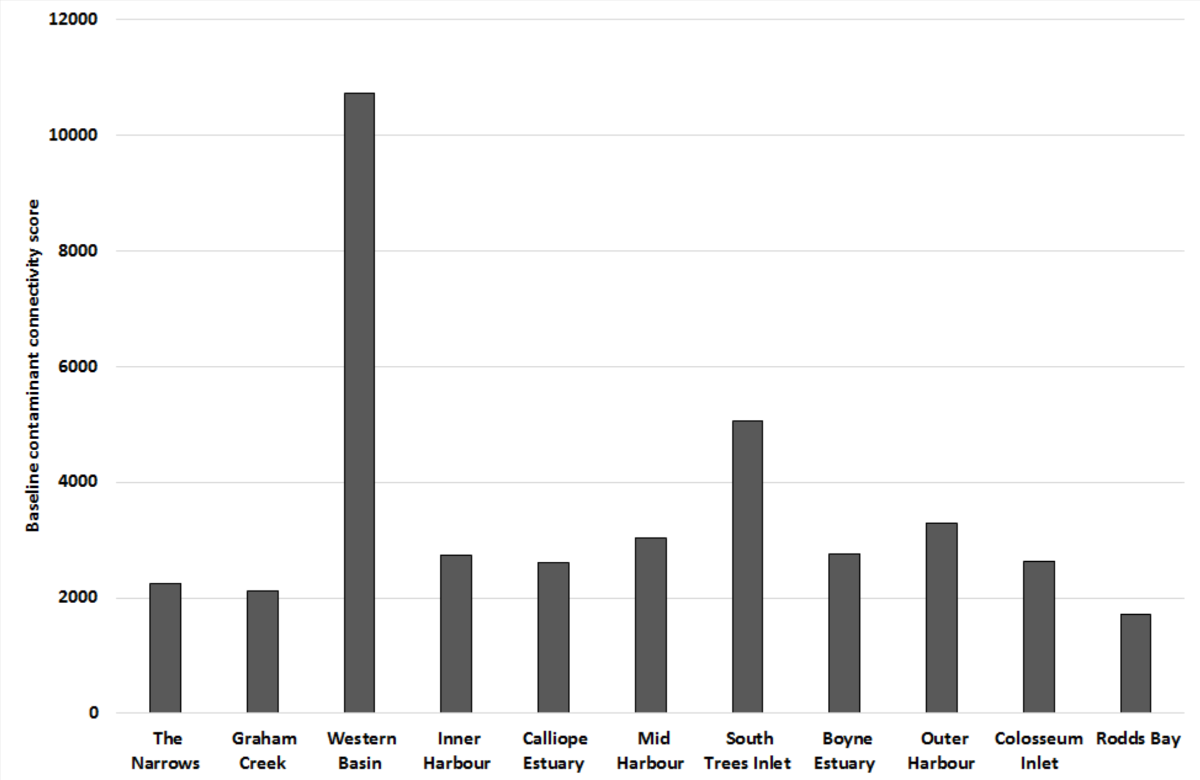


Figure 9.18: Baseline four-year average contaminant connectivity in each of the modelled harbour zones.

Scores for each indicator were calculated by comparing the means and variability in the 2015–16 indicators relative to the mean and variability of the baseline using the t-statistic. A numerical score consistent with the GHHP ranges of scores and grade descriptions was derived by applying a linear transformation to the t-statistics.

Average connectivity for each zone is the average of the three indicators.

Results

The overall score for connectivity in 2017 was 0.59 indicating a satisfactory condition. Nine of the eleven zones in which connectivity was measured received satisfactory or good scores; and only two zones (Calliope Estuary and South Trees Inlet) received poor scores (Table 9.7).

The overall score for flushing rate of 0.79 indicates a good flushing rate across the harbour zones. Nine of the eleven zones received scores that were higher than the four-year flushing rate average. However, Mid Harbour received a poor score and Calliope Estuary received a very poor score indicating that the flushing rates in these zones was below the four-year flushing rate average.

Ecological connectivity (0.23) was low compared to the baseline although The Narrows and Mid Harbour both received satisfactory scores. The low scores in the other zones were associated with lower water exchange rather than habitat changes.

The overall score for containment connectivity of 0.76 indicates a low export of contaminants to other zones relative to the four-year baseline. Eight zones received good or very good scores one zone (Outer Harbour) received a satisfactory score and two zones (The Narrows and South Trees Inlet) received very poor scores.

Table 9.7: Connectivity scores for each zone and harbour-wide averages for 2017.

Zone	Flushing rate	Ecological connectivity	Contaminant connectivity	Average connectivity
1. The Narrows	1.00	0.50	0.00	0.50
2. Graham Creek	1.00	0.00	1.00	0.67
3. Western Basin	1.00	0.29	1.00	0.76
4. Boat Creek	Not modelled owing to insufficient model resolution			
5. Inner Harbour	1.00	0.40	0.80	0.73
6. Calliope Estuary	0.22	0.12	1.00	0.45
7. Auckland Inlet	Not modelled owing to insufficient model resolution			
8. Mid Harbour	0.41	0.50	1.00	0.64
9. South Trees Inlet	1.00	0.01	0.00	0.34
10. Boyne Estuary	0.50	0.13	1.00	0.54
11. Outer Harbour	0.66	0.42	0.58	0.55
12. Colosseum Inlet	1.00	0.00	1.00	0.67
13. Rodds Bay	0.91	0.13	1.00	0.68
Harbour score	**0.79**	**0.23**	**0.76**	**0.59**

Above average rainfall in the 2016–17 reporting year resulted in high flushing rates across the harbour. Contaminant connectivity generally had high scores across the harbour suggesting that overall the potential for zones to export contaminants to other zones was low. Ecological connectivity scored poorly in most harbour zones.

This combination indicates that particle retention was relatively high in some zones, but a high proportion of particles that were distributed from their starting zone were subsequently transported entirely out of the harbour. These conditions limit the potential for larvae to recruit to nursery habitats in other harbour zones and thereby tend to reduce ecological connectivity scores. They also reduce the potential for contamination of neighbouring zones. For historically impacted zones, such as Western Basin and Calliope Estuary, contaminant connectivity scores improved as a result of a general downward trend in contaminant loads.

Compared to 2015–16 all grades improved or remained the same for flushing rate (at least in part a result of higher rainfall). The largest improvement for this indicator was in the Inner Harbour which improved from 0.61 to 1.00. Scores for containment connectivity were generally lower than the previous year. All zones performed well compared to their baselines with the exception of two zones, The Narrows and South Tree Inlet.

10. Guide to the infrastructure supporting the GHHP website

10.1. Data Information Management System

The GHHP Data Information Management System (DIMS) is an essential infrastructure developed by AIMS which allows a range of users to store, calculate and visualise report card raw data and results (Figure 10.1). Given the large social, cultural, economic and environment monitoring datasets used to inform a report card, this system will help to systematically and consistently manage the data with a reliable backup system. The DIMS will also be an information source for the website that can collate and analyse different data types and produce graphical outputs and tables.

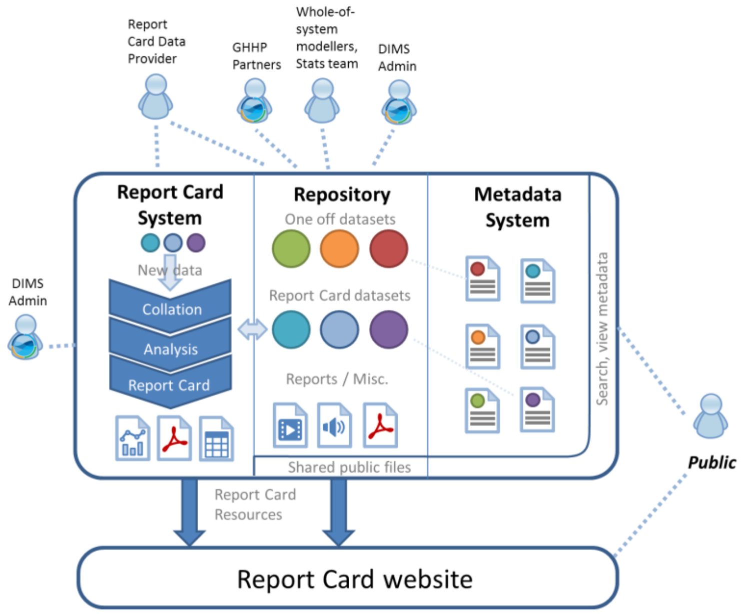


Figure 10.1: Schematic diagram of the links between the report card website and the Data Information Management System (DIMS) to illustrate major components and primary inputs and outputs (Diagram courtesy Australian Institute of Marine Science).

The DIMS server consists of the following four key components.

1. Metadata system – This is a metadata catalogue and provides public access to all metadata records related to report card raw data. The metadata system ensures that all raw data in the DIMS are documented appropriately using ISO19115 Marine Community Profile metadata standard. This system consists of a metadata entry system based on open source metadata catalogue software Geo Network and a public front-end based on the e-Portal Metadata Viewer.

2. DIMS repository – This is a web-based file-sharing and storage application that provides storage for all report card-related files. DIMS repository is based on Pydio open source file-sharing platform.

3. Report card system – This is the core of the DIMS that is responsible for data ingest, script execution and report card score/grades generation for review by the ISP. The report card system

is based on Java servlet, Ember.js and R programming language (Figure 10.2).

4. GHHP and report card website – The GHHP website is the primary interface for the public to access all levels of report card information, GHHP activities and GHHP publications. The Gladstone Harbour Report Card web pages will source information from the DIMS.

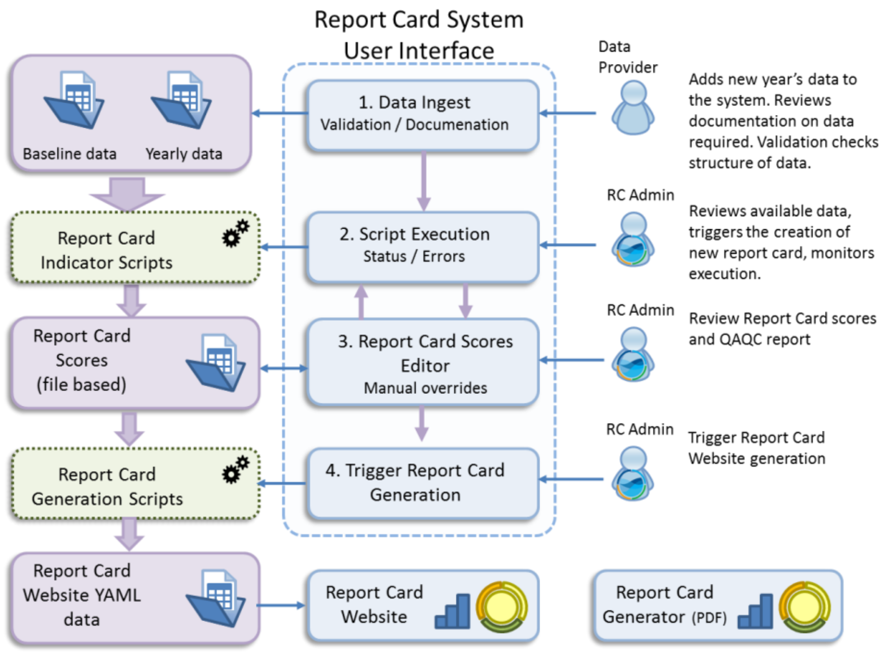


Figure 10.2: Schematic diagram of the report card system showing all data ingestion, script execution and report cards results generation modules (Diagram courtesy Australian Institute of Marine Science).

To enable DIMS to perform the above tasks, a range of off-the-shelf and custom-built software packages has been deployed on Amazon server Amazon EC2 (Elastic Cloud Virtual Servicers) with S3 (reliable storage services) backup (Figure 10.3). This approach makes the system highly portable and not dependent on AIMS systems. A core advantage of using the Amazon system for backup is its ability to scale up the server capacity as the needs of the DIMS services expand over time.

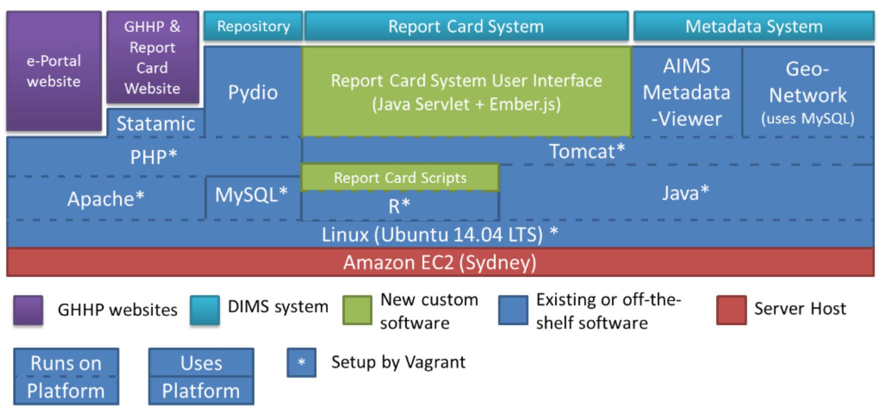


Figure 10.3: Software infrastructure underlying the Data Information Management System (DIMS) operations (Diagram courtesy Australian Institute of Marine Science).

10.2. The Gladstone Harbour Model

Like all busy ports, Gladstone is a complex place, with numerous links between the harbour, industry and the community. These connections have an effect on the marine food webs and habitats in and around the harbour. The Gladstone Harbour Model has used a wide range of information to draw a 'scientific cartoon' of what is in the system including natural processes, such as the strong tidal flows and river inputs. The model also contains a human component (socio-economic model) with facilities to consider the response of Gladstone's demographic make-up, port industries and business to a range of potential future scenarios.

The Gladstone Harbour Model considers all parts of marine ecosystems—biophysical, economic and social. This Full System Model will be used to discover what the future of Gladstone Harbour may look like in response to a range of potential futures that could include a rise or fall in industrial development, unusual climatic events (e.g. very wet or very dry years) or changes in the legislative environment.

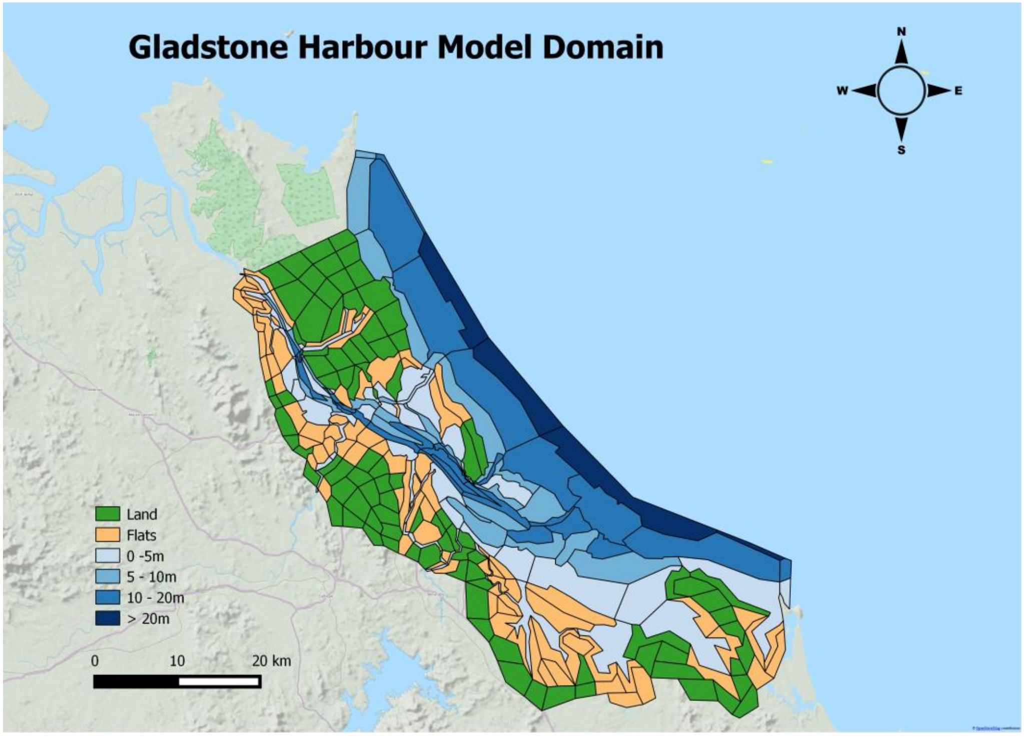


Figure 10.4: The map used in the GHHP Atlantis model consist of 305 boxes including 190 land boxes and 115 wet boxes. The properties represented in each box are based on the available geomorphology of sediments and soils, water column properties, temperature, salinity, dissolved oxygen, major current patterns, and distribution of habitats.

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12. Glossary

Terms and acronyms	Definition
ABS	Australian Bureau of Statistics
AHD	Australian height datum
AIMS	Australian Institute of Marine Science
asset	a particular feature of value to the GHHP for monitoring and reporting, e.g. seagrass meadows or swimmable beaches
baseline	a point of reference from which to measure change
BBN	Bayesian belief network
CATI	computer-assisted telephone interviewing
component	The Gladstone Harbour Report Card will report on four components of harbour health: environmental, cultural, social and economic.
CPUE	catch per unit effort
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DAFF	Department of Agriculture, Fisheries and Forestry
DEHP	Department of Environment and Heritage Protection
DIMS	Data Information Management System
ecosystem health	an ecosystem that is stable and sustainable, maintaining its organisation and autonomy over time and its resilience to stress. Ecosystem health can be assessed using measures of resilience, vigour and organisation. Source: http://www.biodiversity.govt.nz/picture/doing/nzbs/glossary.html
environmental indicators	metrics derived from observation used to identify indirect drivers of environmental problems (e.g. population growth), direct pressures on the environment (e.g. overfishing), environmental condition (e.g. contaminant concentrations), broader impacts of environmental condition (e.g. health outcomes) or effectiveness of policy responses (de Sherbinin et al., 2013)
ERMP	Ecosystem Research and Monitoring Program
FHRP	Fish Health Research Program
GHHP	Gladstone Healthy Harbour Partnership
GHM	Gladstone Harbour Model
GPC	Gladstone Ports Corporation
guidelines and criteria	science-based numerical concentration limits or descriptive statements recommended to support a designated water use. Guidelines are not legally enforceable.

GVP	gross value of production
HEV	high ecological value
ICHD	Indigenous Cultural Heritage Database
indicator	numerical values that provide insight into the state of the environment, or human health etc. The environment is highly complex and indicators provide a simple, practical way to track changes in the state of the environment over time.
IER	index of economic resources
ISP	Independent Science Panel
LAT	lowest astronomical tide
LGA	local government area
liveability	In this report, liveability is used to refer to a sense of place, quality of housing, provision of health services, recreation facilities, attraction of the urban environment and availability of services.
LNG	liquid natural gas
MC	Management Committee
MD	moderately disturbed
metadata	'data about data', the series of descriptors used to identify a particular dataset (e.g. author, date of creation, format of the data, location of the data points)
MMP	Marine Monitoring Program
model/modelling	the creation of conceptual, graphical or mathematical models to describe, visualise or test abstract concepts and processes. Models help explain complex real-world interactions and add to our ability to understand how human actions impact on ecosystems. Models can be used to analyse scenarios to support decision making.
MSQ	Maritime Safety Queensland
NMI	National Measurement Institute
NTU	nephelometric turbidity units
PAH	polycyclic aromatic hydrocarbons
PCIMP	Port Curtis Integrated Monitoring Program
physicochemical	physical and chemical forces that influence the environment and the biodiversity and people within e.g. temperature, salinity
point source	a single, identifiable localised source of a release e.g. a stormwater outlet
psu	practical salinity units
QA/QC	quality assurance/quality control – the processes used to ensure the quality of a product (QA), and then to assess whether the product or services meet quality standards then correct where necessary to meet those standards (QC). Raw data may contain errors or be in formats

	unsuitable for further analysis, so appropriate QC needs to be applied to assess and correct data.
QFish	Queensland Fishing
raw data (also 'primary data')	data that have not been processed or otherwise manipulated apart from QA/QC to ensure accuracy
RC	report card
reference condition	recorded indicator values are compared against values from sites not impacted by human disturbance or alteration, or, which represent a control site considered to be 'healthy' (Connolly et al., 2013)
standards	legal limits permitted for a specific water body
TC	Tropical Cyclone
TCM	travel cost method
TropWATER	Centre for Tropical Water & Aquatic Ecosystem Research (James Cook University)
WICET	Wiggins Island Coal Export Terminal

Appendix 1: The Gladstone Healthy Harbour Partnership (GHHP) science program

ISP001 Mapping and synthesis of data and monitoring in Gladstone Harbour (Completed)

Australian Institute of Marine Science, Townsville

This study identified the state of knowledge of Gladstone Harbour and identified knowledge gaps that if addressed could assist in the development of the Gladstone Harbour Report Card and the Gladstone Harbour Model. Environmental, social, cultural and economic data were considered and three primary outputs were produced:

- a report including a synthesis of available information relating to environmental, social, cultural and economic aspects of Gladstone Harbour
- identification of potential baseline and landmark studies
- a centralised online metadata repository (GHHP ePortal).

The report assessed potential information sources that were within the Gladstone Harbour Port Limits, neighbouring locations that may influence the harbour, and areas that the harbour itself may influence. Where possible, the data were associated with subregions of Gladstone Harbour. A total of 100 data sources from universities, publicly funded research organisations, government databases and reports, and readily available data holdings from stakeholder groups were identified.

There was a large volume of data related to water and sediment quality and iconic species (including dolphins, turtles and dugongs and macroscopic flora, particularly seagrass and to a lesser extent mangroves). A large portion of this data was considered to be of high quality although some gaps remain. By contrast, large gaps remain in social, cultural and economic information, including gaps that could link to the environmental condition of the harbour. In many cases, data in these categories could only be associated with broader regions such as the Fitzroy catchment or the Gladstone Local Government Area.

The report identified 45 potential landmark or baseline studies across 19 topic areas, although it was acknowledged that the potential baseline studies may not reflect the final choice of indicators for the report card selected by the Independent Science Panel. The GHHP ePortal contains nearly 340 metadata records and is updated regularly. Many records relate to multiple reports or datasets resulting in 600 files being included. Scientific reports and other published work owned by commercial entities were not included owing to copyright restrictions, however a separate bibliography with links to their abstracts is included.

Reports and publications

Llewellyn, L., Wakeford, M., & McIntosh, E. (2013). *Mapping and synthesis of data and monitoring in Gladstone Harbour*. A report to the Independent Science Panel of the Gladstone Healthy Harbour Partnership, August 2013. Australian Institute of Marine Science, Townsville.

Download the final report for this project.

View the GHHP ePortal

ISP002 Review of the use of report cards for monitoring ecosystem and waterway health (Completed)

Central Queensland University, Griffith University, The University of Queensland

Effectively communicating monitoring results and the free flow of relevant information is critical in supporting management decisions about ecosystem health and ensuring that environmental management is achieving its stated goals. This project conducted a critical review of the regional, national and international use of report cards with an emphasis on coastal marine areas including estuarine and tropical systems. The project assessed the effectiveness of report cards at communicating monitoring results to a wide range of audiences, including the general public, industry groups, Indigenous groups and various levels of government. It also considered the ability of a report card program to support management decisions concerning ecosystem health as well as to synthesise and communicate monitoring results and other scientific information. Fourteen report card programs were reviewed in this study.

The review found that:

- report cards were an effective tool for communicating complex results in an easily understood format
- few programs report social, cultural and economic indicators
- challenges and opportunities are presented by new and emerging technologies, particularly around online interactive report cards, data portals and visualisations and new tools for data collection, storage and analysis.

This review identifies five key elements critical to the successful implementation and ongoing effectiveness of a report card program. These are:

1) clear goals
2) strong links to all stakeholders
3) flexible implementation
4) effective communication
5) rigorous science.

The findings of this study continue to guide the development of The Gladstone Healthy Harbour Partnership program.

Reports and publications

Connolly, R.M., Bunn, S., Campbell, M., Escher, B., Hunter, J., Maxwell, P., Page, T., Richmond, S., Rissik, D., Roiko, A., Smart, J., & Teasdale, P. (2013). *Review of the use of report cards for monitoring ecosystem and waterway health*. Report to: Gladstone Healthy Harbour Partnership, November 2013. Queensland, Australia.

Download the final report for this project.

ISP003 Models and indicators of key ecological assets in Gladstone Harbour (Completed)

CSIRO Wealth from Oceans Flagship, Hobart

To determine potential indicators for the Gladstone Harbour Report Card and monitoring program this project developed models of key ecological assets within the Gladstone Harbour system. These models were developed to capture a conceptual understanding of cause-and-effect relationships between social, cultural and economic pressures on environmental and ecological components of the system. In essence these models provide a rigorous analytical framework to predict how a system will respond to disturbance and to identify key indicators for tracking the health of Gladstone Harbour. Developing the model was strongly driven by stakeholder engagement building on the experience of Gladstone Healthy Harbour Partnership (GHHP) stakeholders (including community members, industry, scientists and regional managers) through a series of workshops held in Gladstone over three days.

The final set of assets selected for qualitative modelling by the Independent Science Panel were based on the GHHP vision statement and included non-migratory species resident in the harbour or ecosystems that provided critical habitats or ecological services. These assets were: barramundi, yellowfin bream, mud crab, tidal wetlands, mangroves, mangrove ecosystems, coral reefs and seagrass ecosystems.

The results of this work have provided the information and conceptual understanding to determine key indicators that are relevant to community-based values and consistent with the GHHP vision statement. The qualitative models developed during this project will be incorporated into the Gladstone Harbour Model being developed (see ISP 006). The long-term predictions from the qualitative models will be tested against data from the monitoring program to provide a sound platform for improve our understanding of the key ecological assets in Gladstone Harbour.

Reports and publications

Dambacher, J.M., Hodge, K.B., Babcock, R.C., Fulton, E.A., Apte, S.C., Plagányi, É.E., Warne, M., & Marshall, N.A. (2013). *Models and indicators of key ecological assets in Gladstone Harbour*. A report prepared for the Gladstone Healthy Harbour Partnership. CSIRO Wealth from Oceans Flagship, Hobart.

Dambacher, J.M., Hodge, K.B., Babcock, R.C., Fulton, E.A., Apte, S.C., Plagányi, É.E., Warne, M., & Marshall, N.A. (2013). *Précis for models and indicators of key ecological assets in Gladstone Harbour*. A report prepared for the Gladstone Healthy Harbour Partnership. CSIRO Wealth from Oceans Flagship, Hobart.

Download the final report for this project.

ISP004 Guidance for the selection of social, cultural and economic indicators for the development of the Gladstone Healthy Harbour Report Card (Completed)

Central Queensland University, Rockhampton

The Gladstone Harbour Report Card will extend beyond environmental health to include Social, Cultural and Economic components. In the long term, it will consider the links between these four components. This project considered and made recommendations for the selection of social, cultural and economic indicators that measure progress towards the Gladstone Healthy Harbour Partnership (GHHP) vision for Gladstone Harbour developed in conjunction with the community of Gladstone. These recommendations were based on reviews of the use of social, cultural and economic indicators in report cards and more specifically the use of these indicators in rural Queensland. The final report also considered appropriate frameworks to provide a structure for the selection, measurement and combinations of indicators. The key recommendations from this study are presented below:

- Provide a clear hierarchal structure in the report card.
- Base the report card on a balanced reporting of the Environmental, Social, Cultural and Economic components of the health of Gladstone Harbour.
- Subject the selection of social, cultural and economic indicators to a pilot process.
- Select the final indicators following consultation with the Gladstone community.
- Include both objective and subjective measures to broaden the opportunity for those affected by harbour health (positive or negative) to contribute to the overall grade.
- Present environmental health separately from the Social, Cultural and Economic components.
- Report on the performance of the report card and the direct outcomes of its application to the Gladstone community.

Reports and publications

Greer, L., & Kabir, Z. (2013). *Guidance for the selection of social, cultural and economic indicators for the development of the GHHP Report Card*. Report to the Gladstone Healthy Harbour Partnership, School of Human Health and Social Science. Central Queensland University Australia, Rockhampton.

Download the final report for this project.

ISP005 Piloting of social, cultural and economic data for the Gladstone Healthy Harbour Report Card (Completed)

CSIRO Marine and Atmospheric Research

Report cards have become an increasingly popular method to document progress towards environmental goals. In general, these report cards focus on the biophysical components of the system. These include water quality and the condition of key ecosystems such as seagrass meadows and coral reefs. The Gladstone Harbour report card is unique in that, in addition to reporting on progress towards environmental goals, it will also report on progress towards social, cultural and economic goals for the Gladstone Harbour region. These goals developed by the Gladstone Healthy Harbour Partnership (GHHP) in conjunction with stakeholders have been outlined in the vision statement for Gladstone Harbour. The specific objectives for cultural, social and economic indicators are listed below:

Cultural objectives

- Registered cultural heritage sites associated with the harbour and waterways are protected.
- The Gladstone community's sense of identity and satisfaction with the condition of the harbour is increased.

Social objectives

- Maintain/improve easy access to the harbour waters and foreshore for recreation and community users.
- Maintain/improve a safe harbour for all users (e.g. swimming, boating and foreshore activities.
- Enhance liveability and wellbeing in the region.

Economic objectives

- The Gladstone Harbour is managed to support shipping, transport and a diversity of industries.
- Economic activity in the Gladstone Harbour continues to generate social and economic benefits to the regional community.

The key aim of this project was to develop and pilot a system for collecting and analysing data relating to appropriate cultural, social and economic indicators guided by these objectives and to report on these for the 2014 Pilot Report Card. A summary of the findings of this study is presented in the body of this document and the full report can be downloaded via the link included below.

Reports and publications

Pascoe, S., Cannard, T., Marshall, N., Windle, J., Flint, N., Kabir, Z., & Tobin, R. (2014). *Piloting of social, cultural and economic indicators for the Gladstone Healthy Harbour Partnership Report Card*. Draft report prepared for the GHHP by CSIRO, Oceans and Atmosphere Flagship.

Cannard, T., Pascoe, S., Tobin, R., Windle, J., & Rolfe J. (2015). *Social, cultural and economic indicators for the Gladstone Healthy Harbour Partnership Report Card*. Draft report for the Gladstone Healthy Harbour Partnership. CSIRO Oceans and Atmosphere Flagship. Australia.

Download the final report for this project.

ISP006 Development of a Gladstone Harbour Model to support the Gladstone Healthy Harbour Report Card (In progress)

CSIRO Wealth from Oceans Flagship, Hobart

When completed, this full system model will comprise a suite of models that will be collectively referred to as the Gladstone Harbour Model. The primary purpose of the model is to enable the GHHP Management Committee (MC) to undertake annual scenario analysis to effectively road test management strategies before implementing them. These analyses will assist the MC to advise how the Gladstone Healthy Harbour Partnership (GHHP) should respond to annual report card results and provide stakeholders with a tool to explore various future management options.

As outlined below, the Gladstone Harbour Model will include existing models and new models being developed by CSIRO and it will be delivered in three stages.

1) Receiving water quality model

In addition to providing direct inputs into the report card, the receiving water quality model will provide a direct link between the hydrodynamic models and system models. This component of the model will enable management scenarios to be developed and run that involve water-column processes. This component of the project will use the CSIRO's Environmental Modelling Suite which integrates hydrodynamic, sediment transport and biogeochemical modules. These will effectively capture the water quality dynamics of Gladstone Harbour and allow realistic distributional modelling of the key habitats within the harbour.

2) Qualitative (conceptual) model of the Social and Economic components of Gladstone Harbour

This component of the project will develop qualitative models that synthesise a conceptual understanding of the cause-and-effect relationships between human pressures and the Environmental and Ecological components of the Gladstone Harbour region. These models will be based on workshops with key social, economic and cultural experts and consultation with the Gladstone community. The community will include people with expertise/interest in areas such as agriculture, commercial fishing, recreational fishing, retail, real estate, tourism, media and communication, shipping and ports, mining, heavy industry, the environment and education.

The aim of the workshop and subsequent consultation will be to identify:

- the human behavioral drivers that explain anthropogenic pressures on the harbour
- how these pressures may increase or reduce other pressures on the harbour
- the key connections within the social and economic aspects of the Gladstone Harbour region that define its overall behavior
- where the social, economic and stewardship indicators sit in the broader social and economic context of Gladstone Harbour.

The models developed from this process will help define the human components and interactions modelled within the Gladstone Harbour Model.

3) Full systems model (using the Atlantis framework) for the Gladstone Harbour and immediate surrounds. The full systems model will be fully operational in 2017.

The final stage of this project is the development of the Gladstone Harbour Model. This model will improve our understanding of the potential outcomes of an expanding list of possible interactions between factors that may directly or indirectly affect the health of Gladstone Harbour.

Conceptualising a system-wide understanding of the interacting components and developing a structural basis for quantitative modelling has several steps. The first will be linking the qualitative modelling work already completed (ISP 003) with the conceptual models developed during Stage 2 of this project. Building on this, the construction of the full system model will involve collating and adding large volumes of data on all aspects of the system including biological, physical, social, cultural and economic data. This information will come from a range of sources. These include environmental and ecological research and monitoring, economic input and output statistics for all major industries in the area and Australian census data for the region. A review of system-relevant information will enable an inventory of the key drivers of change in and around Gladstone Harbour to be compiled. Close collaboration with stakeholders during model development will ensure that the Gladstone Harbour Model is fit-for-purpose and that it is flexible enough to handle modifications as new information becomes available.

A workshop with the GHHP MC in early 2016 formulated scenarios to be run on the full system model. These scenarios will be developed in conjunction with the MC in response to the first full report card delivered in 2015. The final technical reports for this project will be delivered early in 2017.

Reports and publications

Fulton, E.A. & van Putten, I. (2014) Project ISP006: Milestone Report December 2014. CSIRO, Australia.

Baird M., Margvelashvili N. (2015) *Receiving Water Quality & Sediment Scenarios:* Final Report. CSIRO, Australia.

ISP007 Development of connectivity indicators for the Gladstone Healthy Harbour Report Card (Completed)

CSIRO Wealth from Oceans Flagship, Hobart, University of Queensland

Connectivity of water bodies is an important driver of productivity in marine ecosystems that helps to maintain ecosystem function. It contributes to the health of habitats found within Gladstone Harbour (such as seagrass meadows, mangroves and coral reefs) by cycling nutrients, facilitating biological and genetic connectivity and diluting and flushing contaminants. However, connectivity between contaminant inputs and vulnerable habitats, such as between dredging activities and seagrass meadows, can also have negative effects on harbour health. Developing shipping channels, land reclamation and coastline armouring has the potential to alter connectivity within the harbour due to altered bathymetry and is also being assessed as a component of this project.

To address the Gladstone Harbour Report Card objective for connectivity, 'maintain/improve connectivity of water within and between Gladstone Harbour, related rivers, estuaries and adjacent waters', CSIRO is developing a state-of-the art hydrodynamic model to calculate connectivity indices for the Gladstone Harbour Report Card and to provide sufficient information for calculating report card scores. This model will also constitute a key component of the Gladstone Harbour Model.

Three classes of indicator have been developed to inform the connectivity score for the Gladstone Harbour Report Card:

1) flushing time – This indicator will provide a measure of water exchange through the system and is commonly used as an indirect indicator of water quality.
2) ecological connectivity – This indicator will provide a measure of water exchange between spawning grounds and nursery areas for iconic species such as barramundi.
3) contaminant connectivity – This indicator will provide a measure of the potential of contaminants to move to other parts of the system from the input source.

The results of this project are detailed in the project report (below) and a summary of the project appears in the body of this document.

Reports and publications

Condie, S., Herzfeld, M., Andrewartha, J., Gorton, B., & Hock, K. (2015). *Project ISP007: Development of connectivity indicators for the 2014 Gladstone Harbour Report Card*. CSIRO Wealth from Oceans Flagship, Hobart, University of Queensland.

Download the final report for this project.

Condie, S., Herzfeld, M., Andrewartha, J., Gorton, B., & Hock, K. (2015). *2014-15 Connectivity Indicators for the 2015 GHHP Gladstone Harbour Report Card*. CSIRO Wealth from Oceans Flagship, Hobart, University of Queensland.

ISP008 Provision of statistical support during the development of the Gladstone Harbour Report Card (Completed)

Queensland University of Technology

Providing statistical support covers two critical elements for developing the pilot report card—assessing the indicators and reference conditions and developing the report card scoring methodologies. This involves assisting in determining reference conditions for each report card indicator, statistical support to develop new monitoring programs and to validate existing ones, developing methods to calculate indicator scores, developing methods to aggregate overall report card scores, and assessing report card indicators. In the pilot report card year, particular attention was paid to developing indicators for water and sediment quality and developing the methods to be used to aggregate report card grades and scores.

Specific objectives for this project include working with project teams, developing indicators and scores for the pilot report card and full report card to:

- assist with refining report card indicators and indices
- provide advice on aggregating indices and report card scoring methodology
- perform investigative and validation studies required to inform the monitoring program design
- develop methods to address statistical quality assurance and quality control issues.

ISP008-2015 Provision of statistical support during the development of the Gladstone Harbour Report Card (Completed in December 2015)

Australian Institute of Marine Science

This project played a key role in developing grades and scores for the 2015 Gladstone Harbour Report Card. Working closely with the Data Information Management System, this project provided statistical support for a number of tasks specifically aimed at:

- reviewing the statistical methods used for the pilot report card
- updating the statistical methods suitable for 2015 report card in collaboration with the ISP
- documenting QA/QC assurance protocols for water and sediment quality data
- providing environmental scores and grades for the 2015 report card.

The final report for this project will be made available through the Gladstone Healthy Harbour Partnership (GHHP) website after the review process has been completed.

Reports and publications

Johnson, S., Logan, M., Fox, D. & Mengersen, K. (2015). ISP008 Final Report (revised) Provision of statistical support during the development of the Gladstone Harbour Report Card. Queensland University of Technology, Brisbane.

Download the final report for this project.

Logan, M. (2015) *Provision of final environmental grades and scores for the 2015 Gladstone Harbour Report Card.* Report prepared by the Australian Institute of Marine Science for Gladstone Healthy Harbour Partnership. December 3, 2015.

Download the final report for this project.

ISP009 Development of a Data Information Management System for the Gladstone Harbour Report Card monitoring data (Completed)

Australian Institute of Marine Science, AIMS, Townsville

To facilitate knowledge transfer across the monitoring and project areas and to the broader community, a Data Information Management System (DIMS) is being developed in parallel with the pilot report card. When completed this system will:

- allow report card data providers, GHHP partners, and modellers to upload datasets and other information to an online repository
- contain an automated report card system which analyses and collates data to generate a report card score that includes graphs and figures
- allow the public, through the report card website and metadata system, to view the current and past report cards and to search and view DIMS for reports and other information related to the health of Gladstone Harbour.

The DIMS will be linked to the Gladstone Harbour Report Card website and consist of three major components: the report card system, the repository and the metadata system. These components and the linkages between system administrator's data providers and user groups are illustrated in Figure 10.1 in the main body of this report.

A limited but operational version of DIMS was delivered in October 2014 and was used to generate the pilot report card.

Reports and publications

AIMS. (2014). *Design and architecture of the Data Information Management System (DIMS) for the GHHP Report Card monitoring data*. Project ISP009. Australian Institute of Marine Science, Townsville.

ISP010 Statistical assessment of the fish indicators and score for the pilot report card (Completed in February 2015)

Dr Bill Venables, CSIRO Research Fellow

The Gladstone Healthy Harbour Partnership (GHHP) vision statement 'Supports a sustainable population of marine species (including megafauna—dolphins, dugongs and turtles)' will be addressed by measuring indicator species such as barramundi *Lates calcarifer*, yellowfin bream *Acanthropagus australis* and pikey bream *A. berda* and mud crabs *Scylla serrate.* These species have been chosen as indicators as they will respond rapidly to environmental change and provide information about the overall environmental and ecological health of the harbour. Species of megafauna were not selected as indicators as there can be a long lag time between an environmental impact and a change in their condition. Additionally, their ranges will usually extend beyond the limits of Gladstone Harbour and may make it difficult to associate changes in condition to impacts within the harbour. This project deals exclusively with the suitability of existing datasets and monitoring programs to derive report card scores.

Infofish Australia performs an annual barramundi recruitment assessment for Gladstone Harbour and the Fitzroy River that could inform the barramundi indicator for the report card. They have also collected data for the two bream species of interest. The historical datasets, including recruitment data, provide details of surveys conducted in the estuarine regions from 1999 to the present. Data collection on individual tagged fish which contributes to the recruitment index began in 1990.

To assess the suitability of the Infofish data for developing report card scores and to provide recommendations for ongoing monitoring suitable for report card use, this project aims to achieve the following.

- In collaboration with Infofish review the utility of Infofish's barramundi data including:
    - documenting the data collection and analysis method
    - reviewing the statistical methods used to produce the recruitment indices
    - providing recommendations to Infofish on improved sampling and statistical methods used to calculate the barramundi recruitment index.
- Provide advice on the statistical methods to develop the GHHP report card barramundi indicator from the Infofish recruitment index and the methods used to combine the three indicators (barramundi and two bream species) into a report card fish score.
- Provide advice on the potential application of the barramundi statistical methods to the bream species data.

Reports and publications

Venables, W.N. (2015). *GHHP Barramundi Recruitment Index Project Final Report*. Gladstone Healthy Harbour Partnership, Gladstone.

Download the final report for this project.

ISP011 Gladstone Healthy Harbour Partnership seagrass pilot report card (Completed)

Centre for Tropical Water & Aquatic Ecosystem Research, Cairns

Seagrass meadows are one of the most important habitat types within Gladstone Harbour. Although the area and distribution of the seagrass meadows can vary annually, at peak distribution seagrass meadows can cover an area of approximately 12,000ha. This area can include intertidal, shallow, subtidal and deep-water habitats, in addition to providing a range of important ecosystem functions such as sediment stabilisation, nutrient cycling and carbon sequestration. The seagrass meadows can also provide nursery areas for juvenile fish, including barramundi, and food for dugongs and turtles.

The Gladstone Harbour Healthy Partnership (GHHP) Report Card objective for key ecosystems is to 'maintain/improve habitat function and structure of key ecosystems'. In order to measure progress against this objective for seagrass in the Gladstone Harbour report card, the GHHP required quality-assured seagrass data and ongoing annual monitoring of seagrass meadows within the harbour. This identified the baseline conditions needed to measure change against and to develop seagrass indicators and scores.

The Seagrass Ecology Group within TropWATER at James Cook University has been monitoring seagrass at least annually in Port Curtis and in Rodds Bay since 2002 and was engaged by GHHP to:

- develop a set of thresholds and five condition categories (grades) for the assessment of each of the seagrass indicators (area, biomass and species composition). This is based on the existing datasets.
- identify baseline conditions against which yearly assessments will be benchmarked to determine seagrass condition.

The results of this project are detailed in the project reports (below) and a summary of the 2016 project report appears in the body of this document.

Reports and publications

Bryant, C.V., Jarvis, J.C., York, P.H., & Rasheed, M.A. (2014). *Gladstone Healthy Harbour Partnership Pilot Report Card: ISP011 Seagrass Draft Report – October 2014*. Research Publication 14/53. Centre for Tropical Water & Aquatic Ecosystem, James Cook University.

Download the final report for this project.

Carter, A.C., Jarvis, J.C., Bryant, C.V., & Rasheed, M.A. (2015). *Gladstone Healthy Harbour Partnership 2015 Report Card ISP011: Seagrass final report*. Centre for Tropical Water & Aquatic Ecosystem Research Publication 15/29, James Cook University, Cairns.

Download the final report for this project.

Carter, A.C., Bryant, C.V., Davies, J.D. & Rasheed, M.A. (2016). *Gladstone Healthy Harbour Partnership 2016 Report Card ISP011: Seagrass final report*. Centre for Tropical Water & Aquatic Ecosystem Research Publication 15/29, James Cook University, Cairns.

Download the final report for this project.

ISP012 Cultural indicators pilot project (Completed)

Terra Rosa Consulting

The Cultural component of the report card consists of two indicator groups: 'sense of place' and cultural heritage. The 'sense of place' indicator group was assessed using computer-assisted telephone interviewing during 2014 and 2015. This project was initiated to address the cultural heritage indicator group of the report card from 2016. Working collaboratively with Port Curtis Capricorn Coast Tumara Coordinator, Gidarjil Development Corporation Ltd, this project will develop:

- an Indigenous Cultural Heritage Database for the Gladstone Harbour area that includes an assessment of the condition (intactness) and the size (physical space) and the type of registered cultural heritage site
- indicator option(s) to annually assess the 'number of registered cultural heritage sites protected along the waterways and harbour' for use in the Gladstone Harbour Report Card.

Reports and publications

Terra Rossa Consulting. (2016). *Gladstone Healthy Harbour Partnership Indigenous Cultural Heritage Indicators Milestone 1 Report.* Terra Rossa Consulting, Perth.

Terra Rossa Consulting. (2016). *Gladstone Healthy Harbour Partnership Indigenous Cultural Heritage Indicators Milestone 2* Report. Terra Rossa Consulting, Perth.

Terra Rossa Consulting. (2016). *Developing Cultural Heritage Indicators for the Gladstone Healthy Harbour Partnership: Project ISP012 Final Report.* Terra Rossa Consulting, Perth.

Download the final report for this project.

ISP013-2015 fish recruitment study (Completed)

Infofish Australia and Dr Bill Venables

'Fish and crabs' is one of the indicator groups under the Environmental component of the report card. These indicators are still under development.

In 2014, Gladstone Harbour Healthy Partnership (GHHP) commissioned a project (ISP010) to investigate the possibility of using existing fish recruitment data to devise a statistically robust and defensible barramundi recruitment index to include in the Gladstone Healthy Harbour Report Card (Venables, 2015). That project concluded that existing data were unsuited to developing a recruitment index for barramundi because:

- barramundi recruits were too rare in the existing dataset and their occurrence was too sporadic to enable a reliable index of recruit abundance
- barramundi recruits were not targeted by fishers, so their occurrence in the data was as bycatch
- there was no reliable way to standardise fishing effort, so no reliable way to estimate abundance from catch data (Venables, 2015).

At the same time, the GHHP commissioned a separate project (ISP013) to sample fish recruits, targeting barramundi but also collecting yellow-finned and pikey bream. This sampling was conducted in Gladstone Harbour and associated estuaries and inlets from December 2014 to May 2015. The ISP013 project identified that both bream species appeared to be sufficiently abundant and widespread to warrant investigation of their suitability as indicator species for the Gladstone Harbour Report Card. Therefore, Gladstone Harbour Healthy Partnership GHHP commissioned another project ISP013-2015 later in 2015 to:

- design an optimal, quantitative cast-net sampling program to collect fish recruits from Gladstone Harbour and its inlets and estuaries, from The Narrows to Rodds Bay
- conduct a cast-net sampling program based on the approved sampling design over the 2015–16 recruitment season
- undertake a statistical assessment of the new dataset in conjunction with existing datasets held by Infofish Australia to pilot preliminary recruitment indicators for yellow-finned bream (*Acanthopagrus australis*) and pikey bream (*A. berda*) in Gladstone Harbour.

GHHP intends that this project run for one year in the first instance. Subject to confirmation of ongoing funding, GHHP sees it being followed by a five-year study to collect data for successive report cards and to refine indicators of the abundance of fish recruits in each recruitment season.

Reports and publications

Sawynok, B., Parsons, W., Mitchell J., & Sawynok, S. (2015) *Gladstone fish recruitment 2015.* Report for the Gladstone Healthy Harbour Partnership, Gladstone.

Venables, W.N. (2015). *GHHP barramundi recruitment index project final report*. Gladstone Health Harbour Partnership.

Download the final report for this project.

ISP014 Coral indicator pilot project (Completed)

Australian Institute of Marine Science (AIMS), Townsville

Coral communities are iconic components of marine ecosystems in northern Australia. They have high biodiversity values and provide spawning, nursery and feeding areas for fish and a variety of other animals. These include sea turtles, crustaceans (such as prawns and crabs) and a large range of benthic organisms including echinoderms (sea stars, sea cucumbers and sea urchins), molluscs, sponges and worms. Reefs also provide important ecosystem services such as nutrient recycling and carbon and nitrogen fixation. In addition to their ecological values, coral reefs have considerable socio-economic importance.

Gladstone Harbour Healthy Partnership (GHHP) aims to establish a long-term coral monitoring program consistent with the report card objective for key ecosystems to 'maintain/improve habitat function and structure of key ecosystems'. Three indicators of coral health were measured to calculate the coral score for the Gladstone Harbour Report Card:

1. coral cover (%) – the combined cover of hard and soft corals relative to a baseline determined by the AIMS Reef Plan Marine Monitoring Program (MMP)
2. macroalgal cover (%) – the cover of macroalgae relative to a baseline consistent with the MMP
3. juvenile coral density (no.m^{-2}): density relative to the MMP baseline.

A fourth indicator, coral cover change, measures change in coral cover from the previous year. It may be added in subsequent report cards but cannot be included in the 2015 Gladstone Harbour Report Card as there is no baseline from which to measure it.

The results of this project are detailed in the AIMS project report (below) and a summary of the project appears in the body of this document.

Reports and publications

Thompson, A., Costello, P., & Davidson, J. (2015). *Development of coral indicators for the Gladstone Harbour Report Card, ISP014: Coral*. Australian Institute of Marine Science, Townsville.

Download the report for this project.

Thompson, A., Costello, P., & Davidson, J. (2016). *Development of coral indicators for the Gladstone Harbour Report Card, ISP014: Coral*. Australian Institute of Marine Science, Townsville.

Download the final report for this project

ISP015: Developing an indicator for mud crab (*Scylla serrata*) abundance in Gladstone Harbour. (To be completed in 2017)

Mud crabs are one of Gladstone Harbour's 'iconic species'. They were identified as a major community concern at workshops conducted by the Gladstone Harbour Healthy Partnership (GHHP). This is in part a result of reported high rates of rust spot disease in the harbour's population. Mud crabs spend most of their post-larval lives in burrows in estuarine mangrove habitats and their abundance, size distribution and health is related to environmental conditions within these habitats. Based on the development of conceptual models, Dambacher et al., (2013) indicated that the abundance of adult mud crabs was a highly interpretable variable and would be a meaningful indicator for the Gladstone Harbour Report Card. The report card framework nominated size distribution, abundance and visual health assessment as candidate indicators of mud crab status (McIntosh et al., 2014).

Mud crabs are important commercial species that are harvested using baited traps in estuarine waters throughout Queensland, including within Gladstone Harbour. Each licensed commercial fisher in Queensland has to record their daily fishing effort and catch in a logbook. Data from those logbooks are collated and recorded in the QFish database by the Queensland Government Department of Agriculture and Fisheries. The first component of this project was a review of the suitability of the data for developing report card indicators. This review concluded that logbook data were unsuitable (Brown, 2015). The report recommended that the GHHP develop and implement a fishery-specific logbook to record data on commercial catch and effort within Gladstone Harbour's mud crab fishery. These logbooks would be implemented to monitor the abundance, size distribution and health of mud crabs. The data would then be used to develop report card indicators.

Reports and publications

Brown, I.W. (2015). Comments on Gladstone Healthy Harbour Partnership (GHHP) proposed Project ISP015: Developing an indicator for mud crab *Scylla serrata* abundance in Gladstone Harbour. Report prepared for the Gladstone Healthy Harbour Partnership, Gladstone.

ISP016: GHHP Gladstone fish health research program (In progress)

Gladstone Harbour Healthy Partnership, Fisheries Research and Development Canberra, AusVet Animal Health Services, Australian Institute of Marine Sciences

When the Gladstone Healthy Harbour Partnership was established, the Management Committee has requested the Independent Science Panel (ISP) to develop priority research areas for identifying the cause of recent fish health issues in Gladstone Harbour and to develop approaches to enhance early detection of fish health issues. The broad goals of the Gladstone Harbour fish health research program are to better understand outstanding questions around causal links of fish ill health and other environmental or anthropogenic impacts and develop suitable approaches to enhance early detection of fish health issues in the harbour in the future.

To identify priority research projects an invitation-only Fish Health Workshop was conducted in Gladstone in 2015. The workshop involved a small panel of experts and was coordinated by the Fisheries Research and Development Corporation in conjunction with the ISP. This workshop resulted in three research projects ISP016a, ISP016b and ISP016c to guide the development of a tool for early detection of fish health issues in Gladstone Harbour. It is hoped that this research would be completed within five years from commencement and that the early detection tool would be available at its conclusion. Initially projects will have a research focus, however, it is expected that research outcomes will ultimately contribute to the annual Gladstone Harbour Report Card. Two projects were completed in 2016.

- ISP016a: Conduct a critical review of the literature on the use of fish health indices worldwide and their potential use in Gladstone Harbour fish health research program
- ISP016b: Conduct a critical review of the literature on the use of biomarkers in fish health assessment worldwide and their potential use in Gladstone Harbour

A scope of works for the ISP016c-Development of fish health indicators for the Gladstone Harbour Report Card was released in August in order to achieve following four objectives,

1) To review and identify suitable methods to monitor fish health in the Gladstone Harbour.
2) To develop and implement a data collection approach by the end of June 2018 to monitor fish health in the Gladstone Harbour that is both cost-effective and suitable for a fish health indicator.
3) To evaluate the potential to adapt and transfer the methods and indicators developed to monitor fish health in other estuaries and ports in northern Australia.
4) To develop fish health indicator(s) based on the data collected and apply them to the 2017-18 Gladstone Harbour Report Card.

Reports and publications

Fisheries Research Development Corporation. (2015). *Development of the Gladstone Healthy Harbour Partnership Fish Health Research Program.* FRDC, Canberra.

Download the final report for this project

Kroon, F.J., Streten, C., & Harries, S.J. (2016) *The Use of Biomarkers in Fish Health Assessment Worldwide and Their Potential Use in Gladstone Harbour.* Australian Institute of Marine Science, Townsville.

Download the final report for this project.

ISP017: Additional PAH monitoring 2015 (Completed)

Port Curtis Integrated Monitoring Program (PCIMP)

The Gladstone Harbour Healthy Partnership (GHHP) objective for water and sediment quality is to 'Maintain water and sediment quality at levels compliant with the appropriate guidelines.' In reviewing the sediment indicators available for use in the Pilot Report Card, the Independent Science Panel (ISP) identified measurement of polycyclic aromatic hydrocarbons (PAHs) as a clear omission. Appropriate guidelines do exist for PAHs (ANZECC/ARMCANZ 2000, Simpson et al., 2013). There are several potential sources of PAHs associated with Gladstone Harbour, including petrogenic (from fossil fuels – coal, oil and gas), pyrogenic (formed through incomplete combustion of organic matter – fossil fuels and biomass), and diagenic sources (formed through biological breakdown processes).

Previous surveys of PAHs in Gladstone Harbour sediments have reported either no detectable levels or generally low levels but with exceedances of the ANZECC/ARMCANZ (2000) guideline for the PAH naphthalene at six sites (WBM Oceanics, 2000). Previous studies have found that naphthalene was of potential ecological concern in Gladstone Harbour. Given this potential ecological concern, the ISP determined that there was a need to establish baseline levels of PAHs in the harbour and to develop an indicator for environmental health based on PAH concentrations in harbour sediments.

This project addresses these concerns by including annual PAH monitoring with the existing annual sediment monitoring conducted by PCIMP. Data analysis will be conducted by the National Measurement Institute (NMI) which is routinely used by PCIMP for the existing sediment monitoring program. Data will be supplied to GHHP for inclusion in the Annual Gladstone Harbour Report Card.

Reports and publications

The results of the PAH sediment sampling were included in the 2015 Gladstone Harbour Report Card and supporting technical report and website.

These GHHP products can be accessed here.

ISP018: Development of mangrove indicators for the Gladstone Harbour Report Card (Under development)

The health of mangrove communities can be impacted by both natural and anthropogenic processes, either separately or in combination. These processes include sediment deposition and erosion, nutrient enrichment, disease, hydrological and climatic changes, extreme events pollution, water extraction, changes to land use and land reclamation. Indicators of mangrove health are required to document changes over time in relation to interactions among these processes, or in response to them.

Mangroves were identified as an important indicator during the report card visioning process. The Independent Science Panel selected the following potential indicators for mangrove health for inclusion in the report card:

- aerial coverage
- changes in distribution
- changes in species composition.

To avoid duplication in data collection, a project is being developed to include mangroves in the 2017 report card using data collected as a component of the Port Curtis and Port Alma Coastal Habitat Archive and Monitoring Program (PCPA CHAMP) and other data as required. The aim of this project is to:

- develop mangrove health indicators, baselines and a suitable scoring system for report card use based on the annual data collected as a component of PCPA CHAMP
- provide report card grades and scores for the 2017 Gladstone Harbour Report Card with an accompanying project report which describes all methods employed and provides an overview of the current status of mangroves within the Gladstone Harbour Healthy Partnership reporting area.

ISP019: Coral coring in Gladstone Harbour to enable a comparison of pre- and post-industrial eras in Gladstone Harbour (In progress)

Australian Institute of Marine Science (AIMS), Townsville

The skeletons of long-lived massive corals (e.g. *Porites* and *Cyphastrea*) provide annually dated growth and records of environmental conditions. This information can extend existing observational records of the marine environment in which the corals grew.

Coral reef communities within Gladstone Harbour and the report card zone may be impacted by natural processes including floods, storms and biological interactions as well as historical and current human activity, including land use within the catchment area, dredging and other port-related activities.

The Gladstone Healthy Harbour Partnership (GHHP) requires a coral coring study to document pre-industrialisation conditions of Gladstone Harbour and document any changes over time. This study will be conducted in two stages. The first stage will involve surveys to identify suitable massive coral colonies in the region within and surrounding Gladstone Harbour. These colonies will need to be approximately 0.75 to 1.00m in height to obtain records that cover the pre-industrial history of the harbour dating back to the 1970s and beyond. A minimum of four in-harbour (sites considered to be influenced by the port) with a suitable number of corals, and four out-harbour sites (those sites not impacted by port activities) will be required. The CSIRO's 3D-hydrodynamic model of Gladstone Harbour may be employed to determine how much influence the port has on selected sites. If a sufficient number of suitable sites is not located, the project will not proceed beyond this point.

The second phase of this project will involve coral coring in Gladstone Harbour, analysis of the cores and a subsequent assessment of the results. If suitable sites are found within and outside the area that is influenced by the port, core analysis will reconstruct the continuous records of sediment inputs for the presence of heavy metals (Al, As, Zn, Pb, Mn and Cu), nutrient inputs ($\delta 15N$ as a proxy for nutrients), coral growth rates comparing pre- and post-industrial development levels and levels within and outside the harbour area.

AIMS was contracted in June 2016 to undertake this project. The final results will be available in early 2018.

ISP020: Development of R scripts to calculate, aggregate and integrate cultural heritage indicators with Bayesian model and Data Information Management System (Completed)

CSIRO/Bill Venables

The Cultural component of the report card consists of two indicator groups, 'sense of place' and cultural heritage. 'Sense of place' data are collected as a component of the computer-assisted telephone interviewing survey conducted annually to obtain data for the social and economic indicator groups. Information on Indigenous culture has been collected by Terra Rosa Consulting (see ISP012). The purpose of this project is to integrate these two indicators into the Data Information Management System (DIMS) workflow to calculate report card grades and scores. This project will:

- develop R scripts to calculate heritage indicator scores and grades using the documented methods endorsed by the Independent Science Panel
- integrate cultural heritage indicators with Bayesian network model (in R) and 'sense of place' indicator group to generate scores and grades at all levels of reporting in the Cultural component of the Gladstone Healthy Harbour Partnership Report.
- provide assistance to successfully integrate and implement the code base and data input module with the Gladstone Healthy Harbour Partnership DIMS.

Reports and publications

Pascoe, S. & Venables, B. (2016). *Draft report on the Development of R scripts to calculate, aggregate and integrate Cultural heritage indicators with GHHP Data Information Management System*. CSIRO, Brisbane.

Appendix 2: The role of the Independent Science Panel (ISP)

The Independent Science Panel (ISP) provides independent scientific advice, review and direction. Its role is to ensure that the environmental, social and economic challenges of policy, planning and actions as they relate to achieving the Gladstone Healthy Harbour Partnership (GHHP) vision are supported by credible science. This is a review and oversight role, and ISP project work will be carried out by collaborators or consultants with the ISP providing advice. This is reflected by the time commitment agreed to by ISP members. In this role, the panel will engage with stakeholders such as the Gladstone community and industry to ensure their participation in the process.

Chair of the ISP

The ISP Chair is responsible for championing the integrated and collaborative approach to research and monitoring. The Chair will be an ex-officio member of the GHHP Management Committee and will work with the GHHP to convene the ISP. The Chair is also responsible for managing conflict-of-interest issues that may arise among ISP members and is the ISP spokesperson.

The ISP will be supported by the Secretariat and a Science Convener. The role of the Science Convenor is to support the ISP including by coordinating the operations, recommendations and outputs from the panel (e.g. preparation, synthesis and collation of information). With the ISP Chair, the Science Convenor is also responsible for progressing the ISP deliverables by overseeing and managing ISP projects, keeping projects on task and reporting any delays or changes in project scope to the Chair.

Composition of the ISP

The ISP will comprise up to nine members (including the Chair and the Convenor) with expertise on one or more of the following:

- water quality
- ecosystem health
- marine biogeochemistry
- marine ecotoxicology
- decision support tools/modelling
- social science
- resource economics
- computational informatics, statistics, decision support and modelling
- marine biodiversity (including fish and seagrass).

Roles and responsibilities

The role of the ISP is to provide independent scientific advice on the piloting and system testing of the GHHP-endorsed Gladstone Harbour Report Card. This includes:

- the monitoring program to support the report card
- overseeing the synthesis work required to ascertain report card grades to ensure the independence of the grades

- overseeing the continued development of the Gladstone Harbour Model that will be used by the GHHP to underpin advice to policy, management and regulatory agencies, industry and other stakeholders
- research projects (if required) to improve the Gladstone Harbour Report Card
- monitoring improvement plans that may be needed to improve the efficiency and/or effectiveness of the Gladstone Harbour Report Card, its monitoring program and/or the Gladstone Harbour Model.

The ISP will also provide independent scientific advice when requested by the GHHP. The key output from the ISP in 2015 is the review of scientific reports commissioned by the GHHP and the review of the 2015 report card and associated material.

Other roles of ISP

Enhancement of research partnerships

The ISP will ensure that partnerships and collaboration are enhanced in the generation of science advice to GHHP. The ISP will facilitate the links with research partnerships and initiatives (e.g. research alliances, centres of excellence) and other researchers and academics (e.g. in-house industry scientists) to address scientific and technical key issues identified by the ISP and the GHHP. Leveraging of resources to address research questions will also be facilitated.

Scientific quality assurance

The ISP will ensure that the recommendations are based on science activities that are designed, conducted, coordinated, integrated and peer-reviewed in accordance with best practice in scientific community.

Effective scientific communication

The ISP will support stakeholder decision making through the provision and access to synthesised knowledge and, information and robust decision-support tools. The ISP will ensure, to the best of its capability, that a common science consensus/recommendation on any particular issue in relation to Gladstone Harbour will be presented to the GHHP and the community, as required. The ISP will work with GHHP to facilitate the effective communication of results and recommendations to the wider community as required.

Appendix 3: Water quality guidelines used to calculate water quality scores

Table A5.1: Water quality guidelines used to calculate water quality scores.

		Turbidity (NTU)		pH range (20-80%ile)														
	Level of protection	Dry (May-Oct) (50%ile)	Wet (Nov-Apr) (50%ile)	when conductivity <40mS/cm	when conductivity >40mS/cm	Ammonia (ug/L) (50%ile)[a]	Total N (ug/L) (50%ile)	Total P (ug/L) (50%ile)	NOx(ug/L) (50%ile)[a]	DO range (%) (20 and 80%ile)[a]	Orthophosphate (FRP) ug/L (50%ile)[a]	Chlorophyll-a (ug/L) (50%ile)	Aluminium (ug/L)[b]	Copper (ug/L)	Lead (ug/L)	Manganese (ug/L)[c]	Nickel (ug/L)	Zinc (ug/L)
The Narrows	HEV	7	15	7.2 - 8.2	7.4 - 8.3	3	170	20	3	87-95	3	1	24	1.3	4.4	140	7	15
Graham Creek	MD	8	13	7.2 - 8.2	7.4 - 8.3	3	170	20	3	83-94	4	1	24	1.3	4.4	140	7	15
Western Basin	MD	8	13	7.2 - 8.2	7.4 - 8.3	3	170	18	4	91-100	3	1	24	1.3	4.4	140	7	15
Boat Creek	MD	14	25	7.2 - 8.2	7.4 - 8.3	4	190	22	3	85-98	3	2	24	1.3	4.4	140	7	15
Inner Harbour	MD	8	13	7.2 - 8.2	7.4 - 8.3	3	160	21	5	93-98	3	1	24	1.3	4.4	140	7	15
Calliope Estuary	MD	11	11	7.2 - 8.2	7.4 - 8.3	6	175	22	3	91-100	4	1.7	24	1.3	4.4	140	7	15
Auckland Inlet	MD	6	8	7.2 - 8.2	7.4 - 8.3	6	160	16	6	93-100	3	1.9	24	1.3	4.4	140	7	15
Mid Harbour	MD	4	9	7.2 - 8.2	7.4 - 8.3	3	135	14	3	94-101	2	1	24	1.3	4.4	140	7	15
South Trees Inlet	MD	11	13	7.2 - 8.2	7.4 - 8.3	3	170	20	3	86-99	4	1.1	24	1.3	4.4	140	7	15
Boyne Estuary	MD	3	5	7.2 - 8.2	7.4 - 8.3	3	120	11	1	90-102	1	0.8	24	1.3	4.4	140	7	15
Outer Harbour	MD	3	7	8.0 - 8.2		4	130	13	3	94-100	1	1	24	1.3	4.4	140	7	15
Colosseum Inlet	HEV	3	7	7.2 - 8.2	7.4 - 8.3	3	130	10	3	86-97	1	1	24	1.3	4.4	140	7	15
Rodds Bay	All	4	5	7.2 - 8.2	7.4 - 8.3	3	160	13	1	93-98	1	1	24	1.3	4.4	140	7	15

[a] These measures were not included in 2016–17 report card.

[b] Aluminium guideline for moderately disturbed conditions (24ug/L, 95% species protection) is now applicable to all harbour zones.

[c] A single manganese guideline (140ug/L, 95% species protection and corals present) is applied to all harbour zones.

Appendix 4: The relationship between water quality guidelines and report card scores for two nutrients in the 2017 report card.

Water and sediment quality scores for individual measures (e.g. Total Nitrogen and Total Phosphorous) were calculated relative to zone specific guidelines determined by the Queensland Department of Environment and Heritage (DEHP, 2014a) using the scaled modified amplitude method (Logan, 2016). This method generates indices (report card scores) as an expression of the degree of deviation from the zone specific guideline value for a measure. Where the average concentration of a measure exceeds the guideline value it receives a low score and conversely where a measure is below a guideline value it receives a high score (Figure A1). A satisfactory score (C) is given when the average concentration of a measure meets the guideline value (0.50) or exceeds that value (0.50 – 0.64).

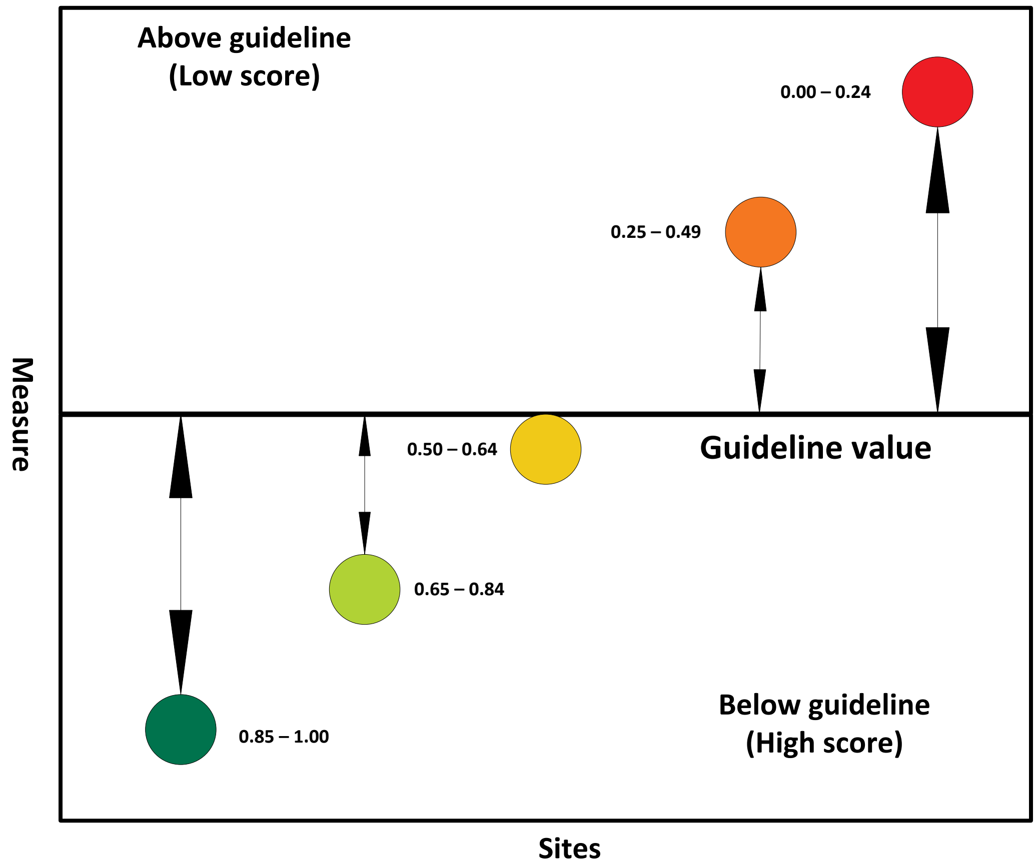

Figure A1: Water and sediment quality measures are scored relative to zone and measure specific guideline values.

The relationship between the zone specific water quality guidelines against the mean concentration of measures for nutrients for 2015–16 can be seen in Figures A2 and A3. Guideline values are shown in the black bars and the annual mean concentration for Total Nitrogen and Total Phosphorous are shown in the coloured bars. The colours in the measure bar indicate the grade achieved for each measure. For example it can be seen in Figure A1 that the annual mean value for Total Nitrogen in Zone 4 was 308 µg/L, well in excess of the guideline value of 190 µg/L. As a result this zone received a very poor report card score (0.00 – 0.24). Similarly, in Zone 2 in Figure A2 the zone specific value for Total Phosphorous is 20 µg/L compared to the annual mean value of 13 µg/L; consequently the zone received a good score (0.65 – 0.84) for this measure. The full range of water and sediment quality guidelines used to calculate report card scores are presented in Appendices 4 and 5.

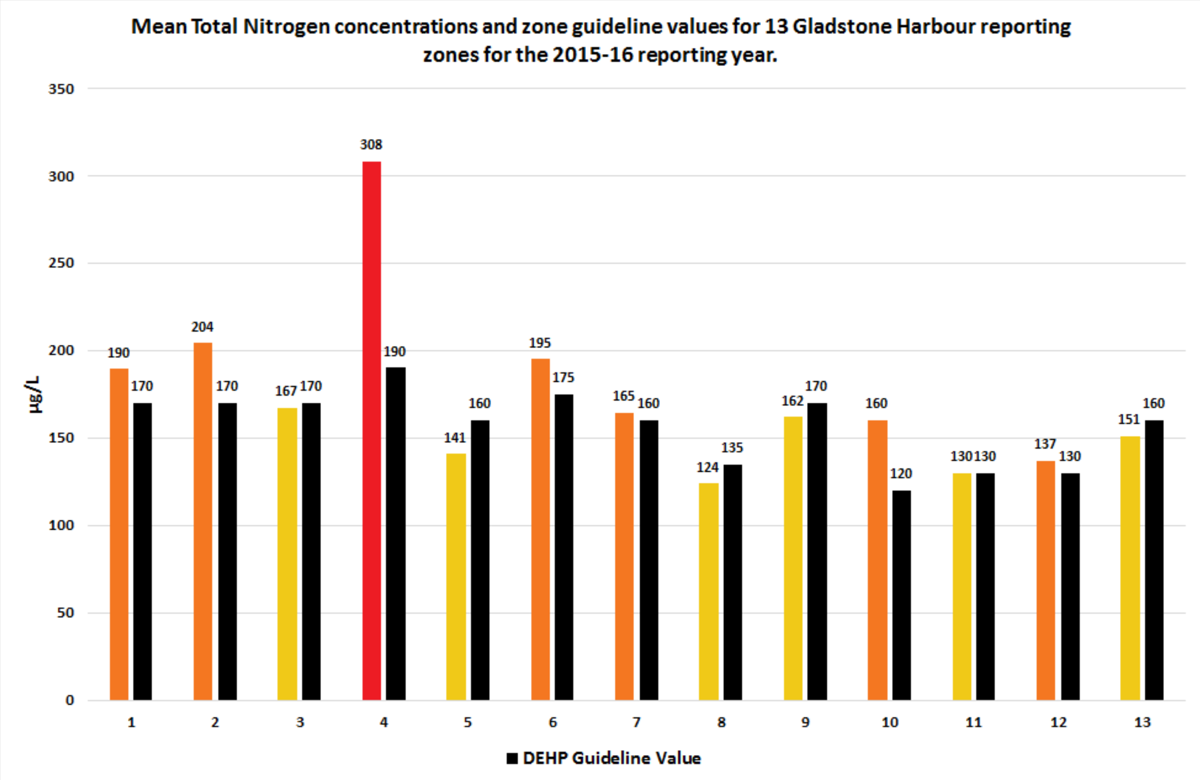

Figure A2: Mean values for total nitrogen concentrations (coloured bars) compared to the DEHP (2014a) guideline values (black bars) for the 13 GHHP reporting zones in the 2015-16 reporting year.

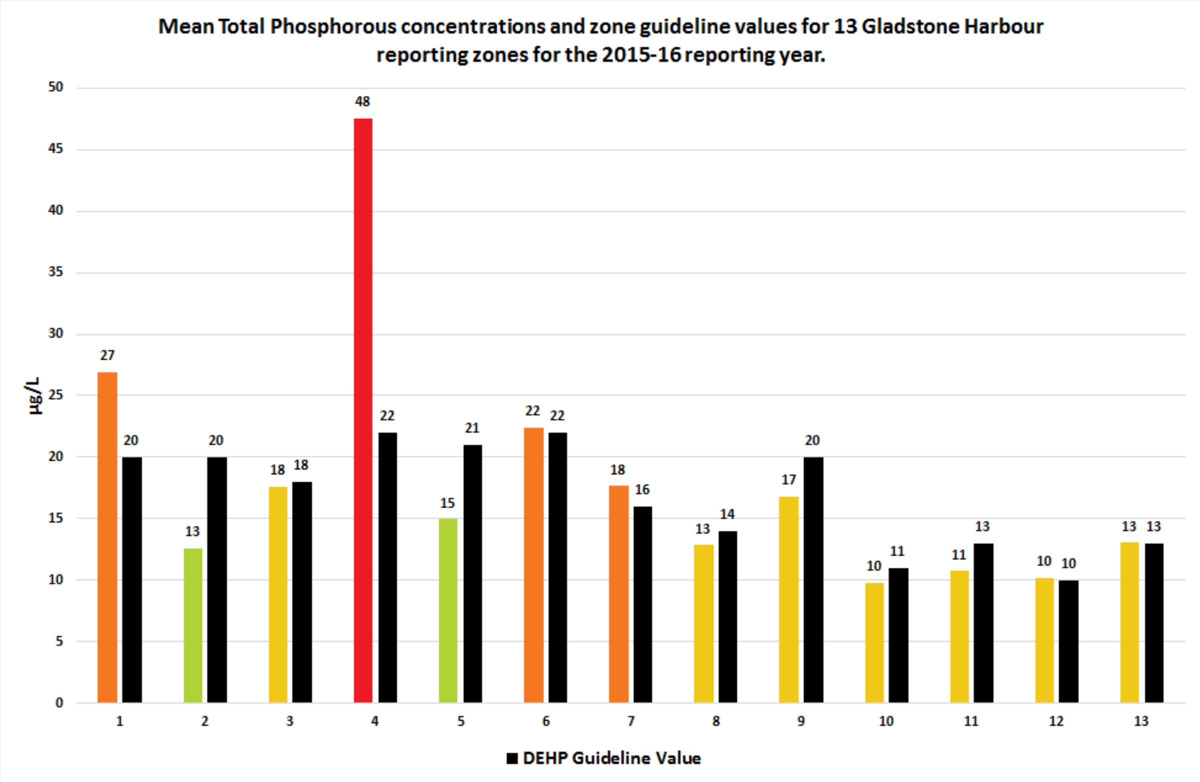

Figure A3: Mean values for total phosphorous concentrations (coloured bars) compared to the DEHP (2014a) guideline values (black bars) for the 13 GHHP reporting zones in the 2015-16 reporting year.

Appendix 5: Sediment quality guidelines used in the calculation of sediment quality scores

Table A6.1: Sediment quality guidelines used to calculate sediment quality scores.

Indicator group	Measure	Concentration (mg/kg)	Guideline based on
Metals and metalloid	Arsenic (As)	20	ANZECC/ARMCANZ, 2000
	Cadmium (Cd)	1.5	ANZECC/ARMCANZ, 2000
	Copper (Cu)	65	ANZECC/ARMCANZ, 2000
	Lead (Pb)	50	ANZECC/ARMCANZ, 2000
	Mercury (Hg)	0.15	ANZECC/ARMCANZ, 2000
	Nickel (Ni)	21	ANZECC/ARMCANZ, 2000
	Zinc (Zn)	200	ANZECC/ARMCANZ, 2000