Gladstone Healthy Harbour Partnership

TECHNICAL REPORT

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GLADSTONE HARBOUR REPORT CARD 2018

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

Australian Government, Australian Institute of Marine Science, Australian Pacific LNG, Boyne Smelters, CQG Consulting, Central Queensland University, CSIRO, Dhou Woolkoom, Fitzroy Basin Association, Gidarjil Development Centre, Gladstone Area Water Board, Gladstone Ports Corporation, Gladstone Regional Council, Gladstone Region Environmental Advisory Network, Griffith University, NRG, Orica, QGC, Queensland Alumina Limited, Queensland Government, Queensland Energy Resources, Rio Tinto, Santos GLNG, The University of Queensland, Wiggins Island Coal Export Terminal.

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Disclaimer

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Executive summary

Context

The 2018 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 2017 to 30 June 2018. Indicator scores range between 0.00 and 1.00 and are converted into grades (Figure 1).

A	**Very good** (0.85–1.0)
B	**Good** (0.65–0.84)
C	**Satisfactory** (0.50–0.64)
D	**Poor** (0.25–0.49)
E	**Very poor** (0.0–0.24)

Figure 1: Grading scheme used to convert scores to grades in the 2018 Gladstone Harbour Report Card for each component of harbour health.

Overall component grades

The overall component scores and grades for the 2018 report card were: Environmental 0.61 (C), Social 0.67 (B), Cultural 0.60 (C) and Economic 0.72 (B) (Figure 2). All overall component scores are similar to the scores recorded in 2017. However, owing to the addition of mangroves to the habitat indicator group, direct comparisons with the 2017 Environmental score are not possible.

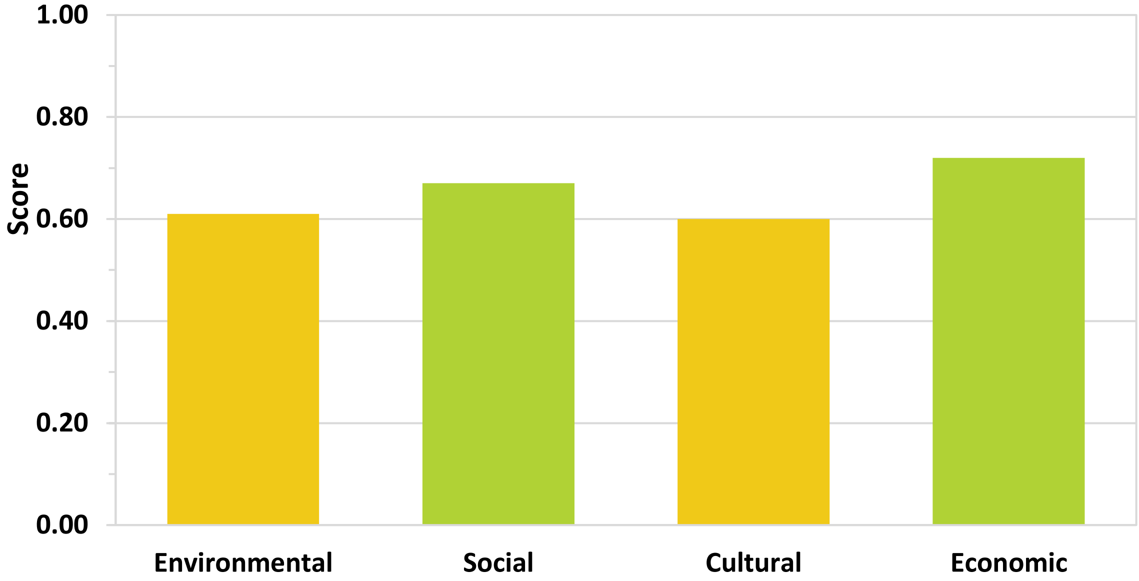

Figure 2: Overall scores for each of the four components of Gladstone Harbour Health in 2018.

Environmental health

Within the Environmental component, the water and sediment quality indicator group received a score of 0.86 (A), habitats 0.41 (D), and fish and crabs 0.58 (C). Water and sediment quality scores were similar to the previous year (0.87). Adding mangroves to the indicator group improved habitats from 0.33 in 2017 to 0.41 in 2018, but the overall grade remained poor (D). The score for fish and crabs was also similar to the score recorded in 2017 (0.63).

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, corals and mangroves)	Fish and crabs
1. The Narrows	0.80	0.49	0.62
2. Graham Creek	0.86	0.67	0.60
3. Western Basin	0.85	0.52	0.79
4. Boat Creek	0.77	0.63	0.56
5. Inner Harbour	0.88	0.26	0.58
6. Calliope Estuary	0.86	0.67	0.60
7. Auckland Inlet	0.83	0.68	0.86
8. Mid Harbour	0.88	0.43	0.59
9. South Trees Inlet	0.85	0.73	0.69
10. Boyne Estuary	0.88	0.41	0.52
11. Outer Harbour	0.94	0.42	NA
12. Colosseum Inlet	0.91	0.68	0.61
13. Rodds Bay	0.85	0.40	0.48
Harbour score	**0.86**	**0.41**	**0.58**

NA: not applicable (no fish or crab monitoring is conducted in the Outer Harbour)

Water and sediment quality

The water quality indicator group received a grade of 0.76 (B) and sediment quality a score of 0.95 (A). These were comparable to the 2017 results of 0.78 (B) and 0.95 (A). Since the first report card in 2015, water quality has consistently been rated as good and sediment quality has consistently been rated as very good.

Water quality

Water quality was relatively uniform across the harbour and all zones received a good or very good score except for Boat Creek which received a satisfactory grade (Table 2). Compared to the previous year, the score for the physico-chemical group improved in eight zones as a result of higher scores for turbidity. The overall grade for nutrients (0.47, D) was lower than the 2017 grade (0.50, C) as a result of the cumulative effects of lower scores in all zones for total nitrogen and chlorophyll-a.

Table 2: Overall water quality indicator scores for Gladstone Harbour zones (2015–2018).

Water quality	Physico-chemical score	Nutrients score	Dissolved metals score	Zone score 2018	*Zone score 2017*	*Zone score 2016*	*Zone score 2015*
1. The Narrows	0.77	0.39	0.95	0.71	*0.71*	*0.68*	*0.82*
2. Graham Creek	0.96	0.43	0.94	0.78	*0.88*	*0.75*	*0.86*
3. Western Basin	0.87	0.34	0.94	0.72	*0.77*	*0.70*	*0.82*
4. Boat Creek	0.77	0.17	0.90	0.63	*0.59*	*0.58*	*0.70*
5. Inner Harbour	0.93	0.54	0.94	0.80	*0.79*	*0.78*	*0.88*
6. Calliope Estuary	0.94	0.42	0.91	0.76	*0.77*	*0.71*	*0.86*
7. Auckland Inlet	0.83	0.47	0.92	0.74	*0.79*	*0.71*	*0.77*
8. Mid Harbour	0.92	0.56	0.94	0.81	*0.79*	*0.77*	*0.80*
9. South Trees Inlet	0.93	0.40	0.94	0.76	*0.84*	*0.79*	*0.85*
10. Boyne Estuary	0.93	0.49	0.94	0.79	*0.83*	*0.71*	*0.70*
11. Outer Harbour	1.00	0.82	0.95	0.92	*0.90*	*0.72*	*0.84*
12. Colosseum Inlet	0.99	0.58	0.94	0.83	*0.83*	*0.73*	*0.78*
13. Rodds Bay	0.79	0.47	0.94	0.74	*0.75*	*0.73*	*0.80*
Whole harbour	**0.89**	**0.47**	**0.93**	**0.76**	***0.78***	***0.72***	***0.81***

Sediment quality

Sediment quality has been uniformly very good (A) in all harbour zones since the first report card in 2015 (Table 3). This is a result of low concentrations of all measures (arsenic, cadmium, copper, lead, nickel and zinc). Although included in the 2017 report card, sediment mercury was not included in 2018. This is because the limit of reporting for this metal was above the guideline value, hence a score could not be determined. When different laboratory procedures were used in 2017, sediment mercury levels across the harbour were found to be very low and well below the guideline value.

Table 3: Overall sediment quality indicator scores for Gladstone Harbour zones (2015–2018).

Sediment quality	Zone score 2018	*Zone score 2017*	*Zone score 2016*	*Zone score 2015*
1. The Narrows	0.90	*0.92*	*0.92*	*0.94*
2. Graham Creek	0.94	*0.92*	*0.96*	*0.98*
3. Western Basin	0.98	*0.97*	*0.98*	*0.99*
4. Boat Creek	0.91	*0.98*	*0.90*	*0.96*
5. Inner Harbour	0.95	*0.93*	*0.94*	*0.98*
6. Calliope Estuary	0.95	*0.94*	*0.99*	*0.98*
7. Auckland Inlet	0.91	*0.87*	*0.94*	*0.94*
8. Mid Harbour	0.95	*0.95*	*0.97*	*0.99*
9. South Trees Inlet	0.94	*0.98*	*0.95*	*0.96*
10. Boyne Estuary	0.97	*0.97*	*0.98*	*1.00*
11. Outer Harbour	0.96	*0.97*	*0.96*	*0.96*
12. Colosseum Inlet	0.99	*0.99*	*1.00*	*1.00*
13. Rodds Bay	0.97	*0.95*	*0.99*	*0.98*
Harbour score	**0.95**	*0.95*	*0.99*	*0.98*

Habitats

Including mangroves in 2018 completes the habitat indicator group. Although still poor, this improved the overall grade for habitats from 0.33 in the previous year to 0.41 (D). The seagrass grade remained stable (0.40, D) compared to 2017 (when it was 0.39, D), but the coral grade was lower (0.24, E) than that recorded in 2017 (0.28, D). The overall grade for mangroves was (0.60, C).

Seagrass

Three seagrass sub-indicators—biomass, area and species composition—were assessed in six reporting zones. Unlike other indicators, the lowest score, rather than the average of the three sub-indicator scores, was applied because a poor score for any one of the three sub-indicators described a seagrass meadow in poor condition. Following a review of how meadow scores were calculated, a change in species composition scoring was adopted. The new method still defines overall meadow condition as the lowest sub-indicator score when this score is either meadow area or biomass, however where species composition is the lowest score, the overall meadow score is 50% of the species composition score and 50% of the next lowest score (area or biomass).

This change was applied to correct an anomaly noted in the 2017 report card where the Inner Harbour received a score of zero owing to a zero species composition score despite having very good and good biomass and area scores. The change acknowledges that the species composition is an important characteristic of a seagrass meadow in terms of defining meadow stability, resilience and ecosystem services, but is not as fundamental as having seagrass present.

The overall seagrass score in 2018 was 0.40 indicating a poor overall condition for seagrass. This result is similar to the poor results recorded in the three previous report cards (2015–2017). At the zone level, South Trees Inlet (0.85) improved from a B in 2017 to an A, while the Mid Harbour remained in a poor condition although the score improved. The Narrows (0.42) and the Western Basin (0.46) both changed from satisfactory to poor, Rodds Bay (0.10) declined from a poor to very poor and the Inner Harbour remains very poor (Table 4).

Multiple years of high rainfall, river flows, cyclone activity and other stressors may have reduced the resilience and capacity for recovery of seagrass communities in Gladstone an effect observed in other locations in Queensland. Despite their reduced biomass, in 2018 the total area of most meadows remained stable with some of the key foundation species remaining.

Table 4: Overall seagrass meadow, zone and harbour scores for the 2018 reporting year and overall zone scores from 2015 and 2016.

Zone	Meadow	Overall meadow score	Zone score 2018	Zone score 2017	*Zone score 2016*	*Zone score 2015*
1. The Narrows	21	0.42	0.42	*0.59*	*0.33*	*0.15*
3. Western Basin	4	0.48	0.46	*0.50*	*0.55*	*0.51*
	5	0.51				
	6	0.45				
	7	0.00				
	8	0.41				
	52–57	0.86				
5. Inner Harbour	58	0.09	0.09	*0.00*	*0.14*	*0.41*
8. Mid Harbour	43	0.42	0.47	*0.34*	*0.35*	*0.56*
	48	0.50				
9. South Trees Inlet	60	0.85	0.85	*0.75*	*0.48*	*0.52*
13. Rodds Bay	94	0.01	0.10	*0.19*	*0.25*	*0.45*
	96	0.23				
	104	0.07				
Harbour score			**0.40**	***0.39***	***0.35***	***0.43***

Corals

The overall grade for corals in 2018 was an E (0.24), a change in grade from the previous year when the overall coral grade was D (0.28). At the zone level, the Mid Harbour (0.27) received a poor score and the Outer Harbour (0.20) received a very poor score (Table 5). Scores for the four coral measures—coral cover, change in hard coral cover, macroalgal cover and juvenile density—remained broadly similar to the previous year. However, the cumulative effect of slightly lower scores across all four coral measures has resulted in the lower grade. Initial coral monitoring in 2015 noted very low coral cover, which reflected the severe impacts of the 2013 flooding. Subsequent monitoring, particularly that conducted in 2018, suggests that the combined impacts of the 2013 flooding and ongoing pressures including high macroalgal cover, high sea-surface temperatures and the influence of flooding in 2017, have slowed the recovery of coral communities in Gladstone Harbour.

A minor change to the juvenile density methodology was adopted. Prior to 2018, coral in the size classes 0–2cm, >2–5cm and >5–10cm were identified to the genus level and recorded. In 2018 the >5–10cm class was discontinued to realign the methodology with that used in the Marine Monitoring Program (MMP) for the Great Barrier Reef. This method was adopted by the MMP because limiting observations to the 0–5cm range more accurately focuses on juvenile rather than fragmented colonies or small colonies of slow growing corals which could be mistaken for juvenile corals but do not reflect recent recruitment and survivorship dynamics. Comparison of the two methods shows this change had little effect on the overall coral scores.

Table 5: Coral indicator scores for the two surveyed harbour zones from 2015 to 2018.

Zone	Coral cover	Change in hard coral cover	Macroalgal cover	Juvenile density	Zone score 2018	*Zone score 2017*	*Zone score 2016*	*Zone score 2015*
8. Mid Harbour	0.06	0.30	0.41	0.34	0.27	*0.33*	*0.15*	*0.23*
11. Outer Harbour	0.05	0.33	0.00	0.45	0.20	*0.21*	*0.14*	*0.15*
Harbour score					**0.24**	***0.28***	***0.15***	***0.18***

Mangroves

Indicators of mangrove health have been included for the first time in the 2018 Gladstone Harbour Report Card. Three mangrove measures were assessed in 2018—extent, canopy condition and shoreline condition. Mangrove extent, which calculates the proportion of mangroves in a tidal wetland, and canopy condition, which measures canopy health, were determined from satellite imagery. Shoreline condition, which assesses the proportion of dead mangroves within the shoreline trees, was determined from aerial photography.

The overall score for mangroves in Gladstone Harbour was 0.60 (C). Six zones were considered to be in good condition and five zones were considered satisfactory (Table 6). Two zones, Inner Harbour (0.43) and Boyne Estuary (0.41), received an overall poor grade. Severe flood impacts affecting the shoreline trees were observed in Boyne Estuary and notable shoreline dieback was observed at the Inner Harbour.

Table 6: Overall mangrove zone and harbour scores for the 2018 reporting year.

Zone	Mangrove extent	Mangrove canopy condition	Shoreline condition	Zone Score 2018
1. The Narrows	0.67	0.40	0.61	0.56
2. Graham Creek	0.82	0.47	0.71	0.67
3. Western Basin	0.74	0.60	0.38	0.57
4. Boat Creek	0.64	0.61	0.63	0.63
5. Inner Harbour	0.44	0.37	0.47	0.43
6. Calliope Estuary	0.85	0.59	0.56	0.67
7. Auckland Inlet	0.66	0.63	0.74	0.68
8. Mid Harbour	0.39	0.55	0.70	0.55
9. South Trees Inlet	0.77	0.49	0.58	0.61
10. Boyne Estuary	0.60	0.49	0.14	0.41
11. Outer Harbour	0.79	0.60	0.57	0.65
12. Colosseum Inlet	0.84	0.58	0.64	0.69
13. Rodds Bay	0.76	0.68	0.68	0.71
Harbour score	**0.69**	**0.54**	**0.57**	**0.60**

Fish and crabs

The overall grade for fish and crabs was satisfactory (0.58, C), similar to the grade recorded in 2017 when the overall grade was also satisfactory (0.63, C).

Fish

In 2018, the overall fish score has been determined from fish recruitment. Additional indicators for fish health are being developed and are expected to be included in the 2019 report card.

The overall grade for fish recruitment in 2018 was 0.66 (B). This was measured in two species: yellow-finned bream *Acanthopagrus australis* and pikey bream *Acanthopagrus pacificus*. The final scores (Table 7) were measured against a 2011–12 to 2017–18 baseline. The 2018 score for fish recruitment indicates a season with a higher recruitment rate (increased catch rate) relative to the mean reference level determined over the baseline period. For the first time, more pikey bream than yellow-finned bream were caught. Compared to 2017, numbers of yellow-finned bream decreased and numbers of pikey bream increased.

Table 7: Bream recruitment score for 12 harbour zones and the overall harbour score from 2015 to 2018.

Zone	2018	*2017*	*2016*	*2015*
1. The Narrows	0.58	*0.75*	*0.30*	*0.86*
2. Graham Creek	0.77	*0.58*	*0.44*	*0.72*
3. Western Basin	0.79	*0.78*	*0.36*	*Not surveyed*
4. Boat Creek	0.61	*0.47*	*0.36*	*0.80*
5. Inner Harbour	0.67	*0.64*	*0.33*	*0.80*
6. Calliope Estuary	0.70	*0.79*	*0.43*	*0.70*
7. Auckland Inlet	0.87	*0.91*	*0.53*	*0.80*
8. Mid Harbour	0.58	*0.71*	*0.29*	*Not surveyed*
9. South Trees Inlet	0.69	*0.71*	*0.43*	*0.72*
10. Boyne Estuary	0.52	*0.74*	*0.54*	*0.69*
11. Outer Harbour	Not surveyed	*Not surveyed*	*Not surveyed*	*Not surveyed*
12. Colosseum Inlet	0.61	*0.71*	*0.45*	*Not surveyed*
13. Rodds Bay	0.59	*0.74*	*0.58*	*Not surveyed*
Harbour average	**0.66**	***0.71***	***0.40***	***0.80***

Mud crabs

Three mud crab measures were assessed in 2018—abundance, prevalence of rust lesions and sex ratio. A fourth measure 'biomass' will be included in 2019 when sufficient data to determine a baseline are accumulated.

The overall mud crab grade, 0.49 (C), was calculated from monitoring in seven of the thirteen environmental monitoring zones. However, owing to a very low catch rate at Auckland Inlet, abundance was the only measure calculated and an overall score could not be calculated for this zone. The Narrows received a very good score for abundance (1.00), the Inner Harbour was satisfactory (0.52) and the remaining five zones were poor or very poor (Table 8). Owing to the variability that can occur in abundance data which are sensitive to local pressures, this measure is regarded as being of 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; hence, 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 poor to very poor.

Rust spots (shell lesions) were first reported in Gladstone Harbour by commercial fishers in 1994. In the report card, monitoring for these rust spots is determined by visual inspection. In 2018, all zones where this was measured received very good scores indicating very low levels of rust spots on mud crabs within the harbour.

Table 8: Mud crab score for seven harbour zones and the overall harbour score (2017 and 2018).

Zone	Sex ratio	Abundance (CPUE)	Prevalence of rust lesions	Zone score 2018	*Zone score 2017*
1. The Narrows	0.00	1.00	1.00	0.67	*0.66*
2. Graham Creek	0.03	0.30	1.00	0.44	*0.61*
4. Boat Creek	0.29	0.25	1.00	0.51	*0.70*
5. Inner Harbour	0.02	0.52	1.00	0.51	*0.87*
6. Calliope Estuary	0.11	0.47	1.00	0.52	*0.47*
7. Auckland Inlet	NC	0.00	NC	NC	*0.25*
13. Rodds Bay	0.06	0.20	0.90	0.38	*0.36*
Harbour scores	**0.09**	**0.46**	**0.98**	**0.49**	***0.55***

CPUE: catch per unit effort

NC: not calculated (due to small sample size)

Social health

The overall score for social health in 2018 was 0.67 (B) similar to the score received in 2017. This score was based on three indicators of social health, harbour usability (0.63, C), harbour access (0.67, B) and liveability and wellbeing (0.70, B) (Table 9). This year a new aesthetic value measure contributes to the liveability and wellbeing indicator.

All scores were similar to the 2017 scores and the overall social health of the harbour has remained stable since 2015—suggesting people living in the Gladstone Region continue to feel that Gladstone Harbour provides them with a positive living experience and quality of life.

Table 9: Scores for social indicator groups and indicators from 2015 to 2018.

Indicator groups	Social indicators	2018 Score	2018 Score	*2017 Score*	*2016 Score*	*2015 Score*
Harbour usability	Satisfaction with harbour recreational activities	0.70	0.63	*0.62*	*0.66*	*0.65*
	Perceptions of air and water quality	0.58				
	Perceptions of harbour safety for human use	0.61				
Harbour access	Satisfaction with access to the harbour	0.72	0.67	*0.66*	*0.65*	*0.62*
	Satisfaction with boat ramps and public spaces	0.66				
	Perceptions of harbour health	0.63				
	Perceptions of barriers to access	0.65				
Liveability and wellbeing	Liveability and wellbeing	0.70	0.70	*0.66*	*0.66*	*0.64*
Overall score			**0.67**	***0.66***	***0.66***	***0.64***

Cultural health

The overall grade for the Cultural health of Gladstone was 0.60 (C). Two indicator groups for Cultural health were assessed: 'sense of place' 0.65 (B) (Table 10) and Indigenous cultural heritage 0.54 (C).

The overall 'sense of place' score was identical to the 2017 score. This result suggests that the community expectations of the Gladstone Harbour area are mostly being met.

The overall Indigenous cultural heritage grade was 0.54 (C). The indigenous cultural heritage indicator framework was revised for the 2018 report card. The overall grade for Indigenous cultural heritage is a result of nine measures and based on physical condition and management strategies indicators. Data collected through previous surveys for The Narrows and Wild Cattle Creek zones were used to calculate 2018 scores and only sites at Gladstone Central and Facing Island were resurveyed. The new scoring structure takes into consideration the social, spiritual and scientific values of sites, includes anthropogenic and natural impacts on a number of Indigenous heritage resources and also acknowledges the constantly changing cultural landscape. Although not directly comparable, the overall cultural heritage for the 2018 report card remains at satisfactory, similar to the 2016 and 2017 grades (Table 11).

Table 10: Scores for the 'sense of place' indicator group, 2015 to 2018.

Indicator group	Indicators	2018 Score	2018 Score	*2017 Score*	*2016 Score*	*2015 Score*
'Sense of place'	Distinctiveness	0.56	0.65	*0.65*	*0.66*	*0.65*
	Continuity	0.53				
	Self-esteem	0.74				
	Self-efficacy	0.59				
	Attitudes to harbour	0.83				
	Values of harbour	0.65				

Table 11: Scores for Indigenous cultural heritage indicators and overall harbour score for the 2018 report card.

Zone	Physical condition			Management strategies						Zone score
	Intact.	Distur.	Threat.	Recor.	Cultural manage.	Stake.	Monit.	Access	Cultural resour.	
The Narrows	0.82	0.63	0.28	0.80	0.10	0.50	0.80	0.60	0.20	0.54
Facing Island	0.95	0.64	0.11	0.90	0.10	0.40	0.90	0.90	0.10	0.56
Wild Cattle Ck	0.67	0.59	0.24	0.80	0.10	0.60	0.70	0.60	0.10	0.49
Gladstone Central	0.85	0.44	0.50	1.00	0.10	0.40	1.00	0.60	0.10	0.57

(Intact. = Intactness of site features, Distur. = Extent of current disturbance, Threat. = Management of threats, Recor. = Recording, Cultural manage. = Cultural management, Stake. = Stakeholders, Monit. = Monitoring, Cultural resour. = Cultural resources)

Economic health

The overall grade for the Economic component of the 2018 report card was 0.72 (B), and similar to the scores received in the previous three report cards. The 2018 score was determined by the scores from three indicator groups: economic performance (0.90, A), economic stimulus (0.58, C) and economic value (0.74, B) (Table 12). While the overall economic health of Gladstone remained good, this grade was influenced by reduced employment opportunities, and a lower grade for socio-economic status associated with the end of the construction boom and a decline in the resources sector. Commercial fishing received a poor score owing to low gross value production and a lower net fishery productivity score. Shipping activity and tourism remained strong in 2018.

Table 12: Scores for the economic indicator groups from 2015 to 2018.

Indicator group	Indicators	2018 Score	2018 Score	*2017 Score*	*2016 Score*	*2015 Score*
Economic performance	Shipping activity	0.90	0.90	*0.90*	*0.87*	*0.79*
	Tourism	0.90				
	Commercial fishing	0.35				
Economic stimulus	Employment	0.44	0.58	*0.67*	*0.74*	*0.82*
	Socio-economic status	0.64				
Economic value (recreational)	Land-based recreation	0.76	0.74	*0.73*	*0.73*	*0.72*
	Recreational fishing	0.68				
	Beach recreation	0.75				
	Water-based recreation	0.75				
Overall score			**0.72**	***0.74***	***0.75***	***0.77***

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 25 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.

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.

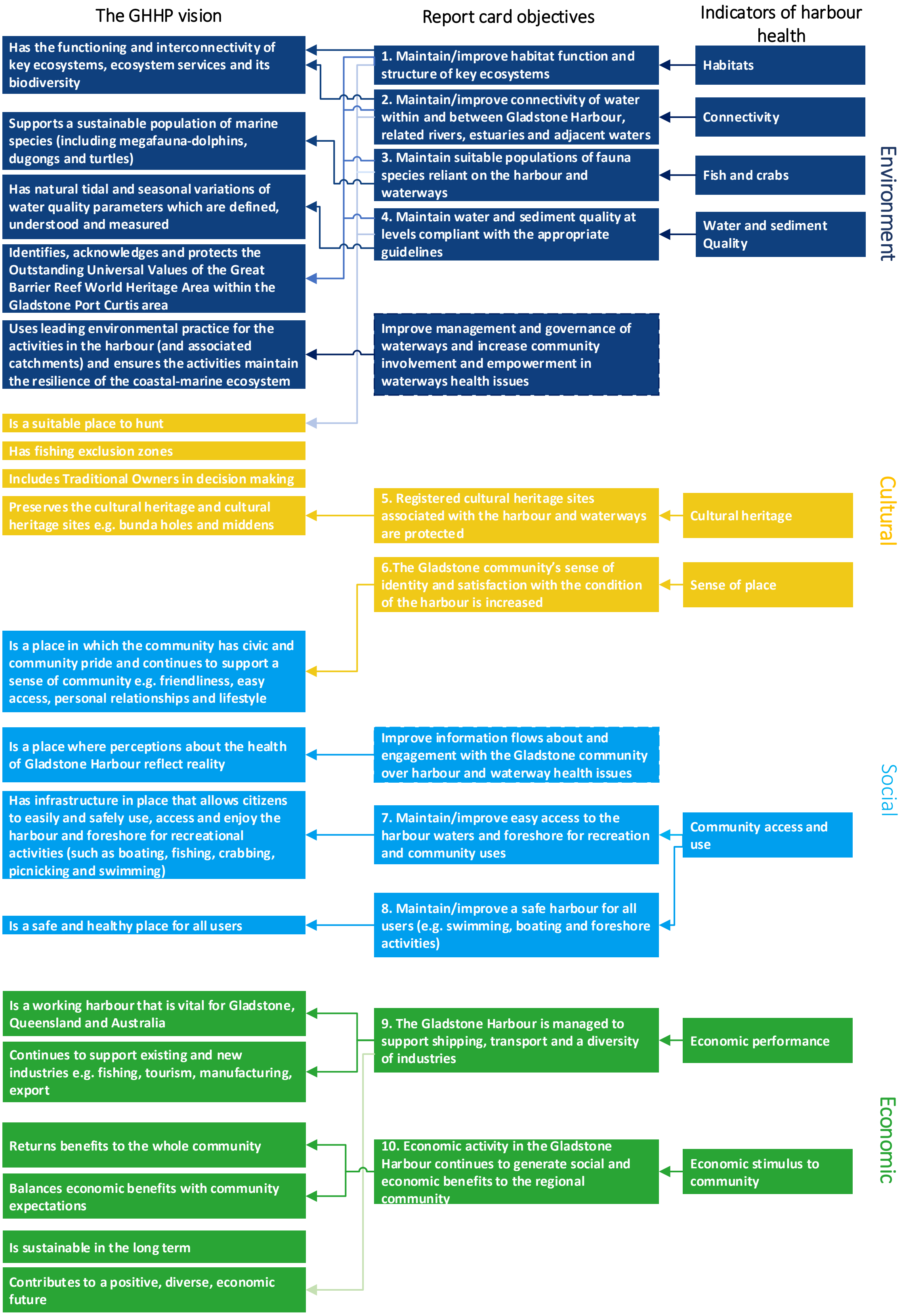

Figure 1.1: The Gladstone Harbour Report Card objectives and harbour health indicators were developed from the GHHP vision statements for the Environmental, Cultural, Social and Economic components of Gladstone Harbour health.

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.

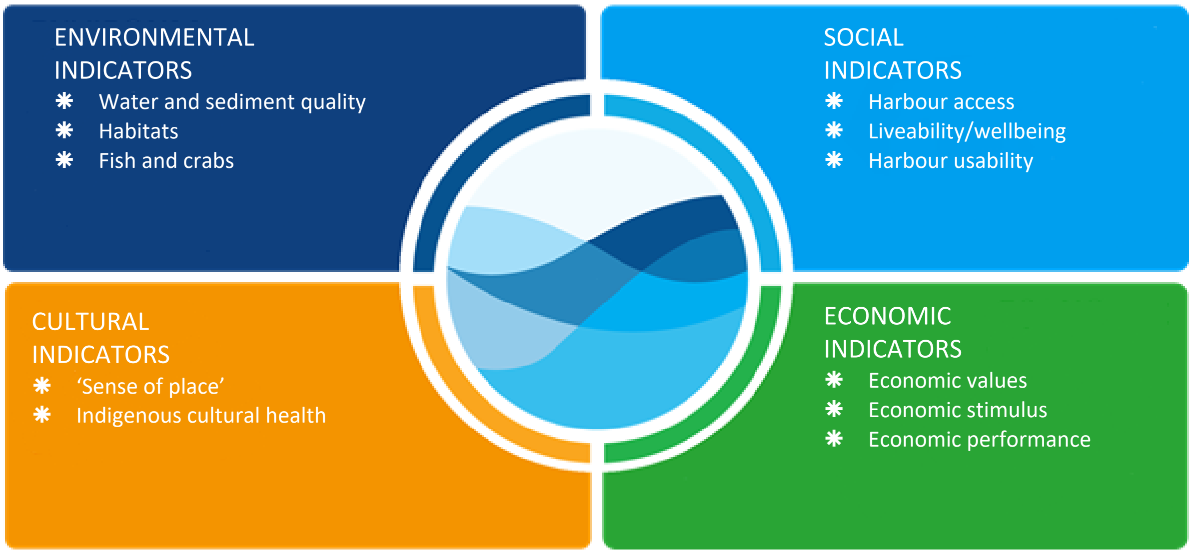

Figure 1.2: The four components of harbour health.

1.2. The science program

The GHHP science program commenced in 2013 and is now in its fifth 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 is available on the GHHP website. Refer to Appendix 1 for a list of GHHP projects.

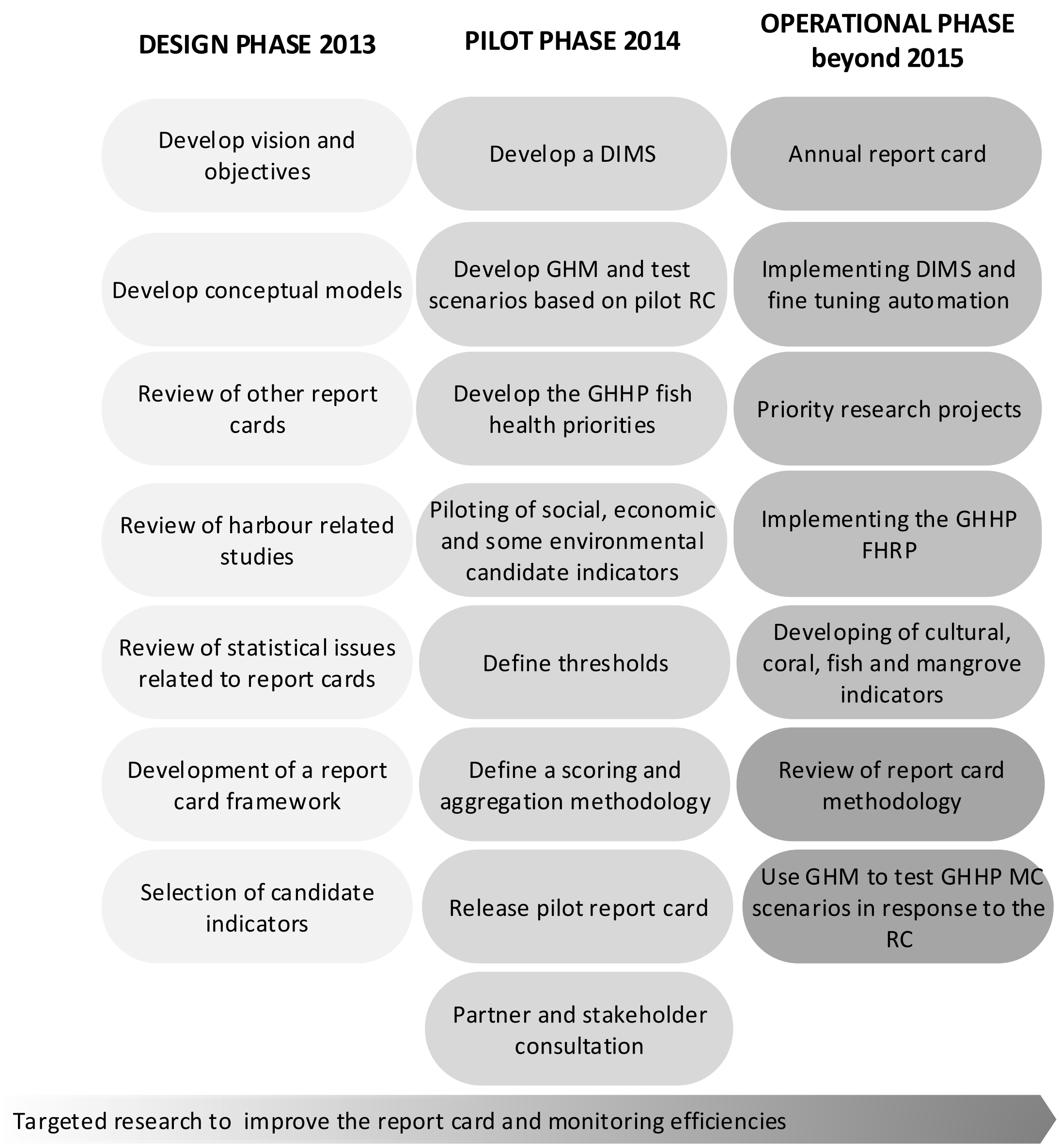

Figure 1.3: The three phases of the GHHP science program. DIMS = Data Information Management System, GHM = Gladstone Harbour Model, RC = Report Card, MC = Management Committee, FHRP = Fish Health Research Program.

1.3. Reporting periods

The reporting period for the 2018 Gladstone Harbour Report Card was 1 July 2017 to 30 June 2018. 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 2017–18 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

The hierarchy of score aggregation used to calculate the final grade for each component of harbour health can include up to five levels of aggregation: components, indicator groups, indicators, sub-indicators and measures (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 2018 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 0.0 and 1.0 (Figure 2.1). Scores are assigned to measurements that are then aggregated upwards towards a component.

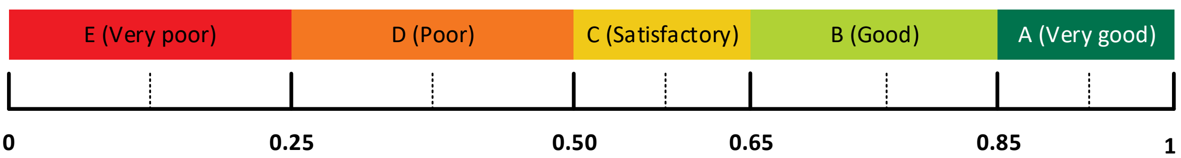

Figure 2.1: Grade ranges used in the 2018 Gladstone Harbour Report Card.

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 2017–18 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 2017–18 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 2.2–2.5). 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 2.6).

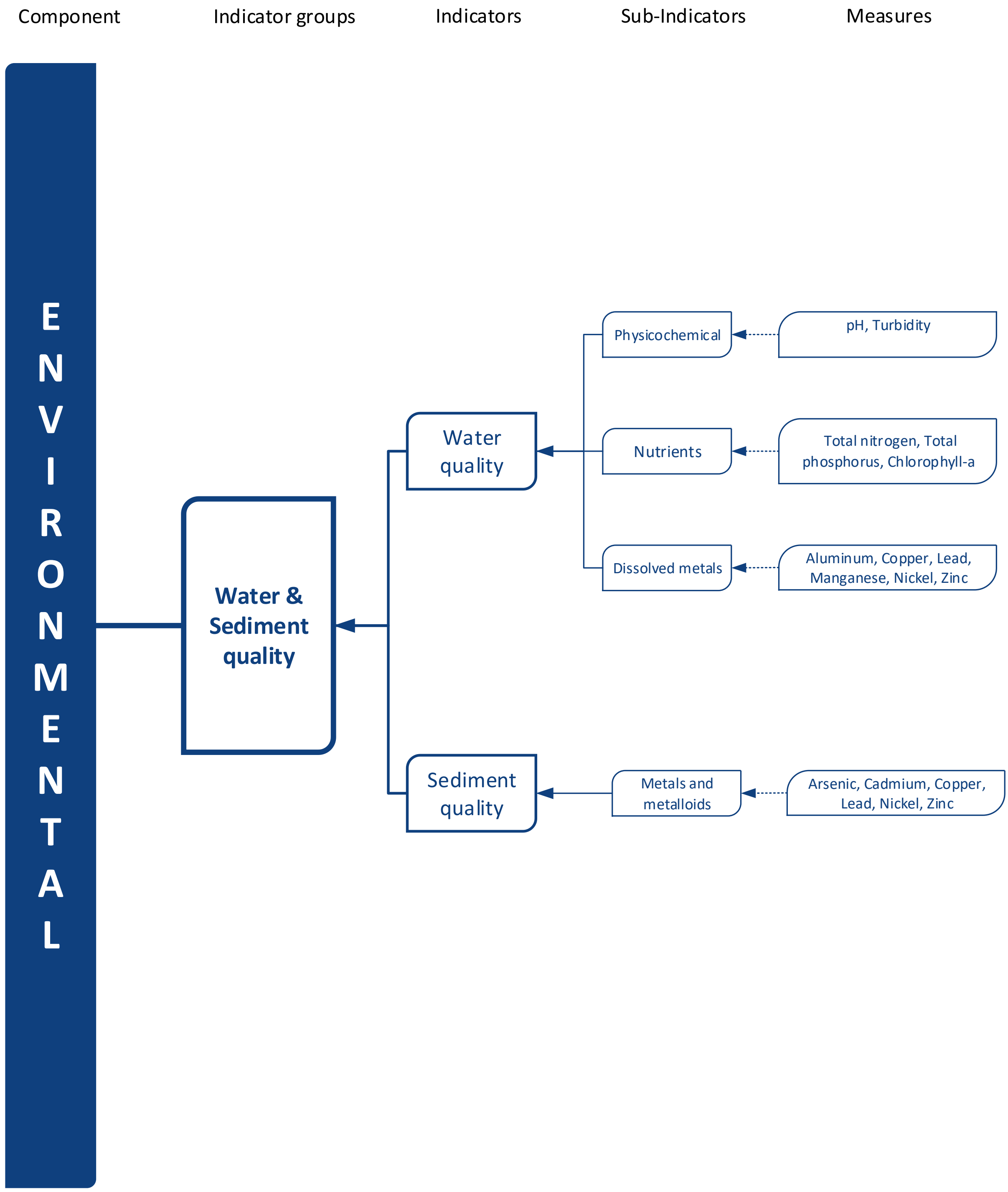

Figure 2.2a: The levels of aggregation used to determine the environmental scores and grades in the 2018 Gladstone Harbour Report Card. There are 3 environmental indicator groups, 6 Indicators, 15 sub-indicators and 29 measures.

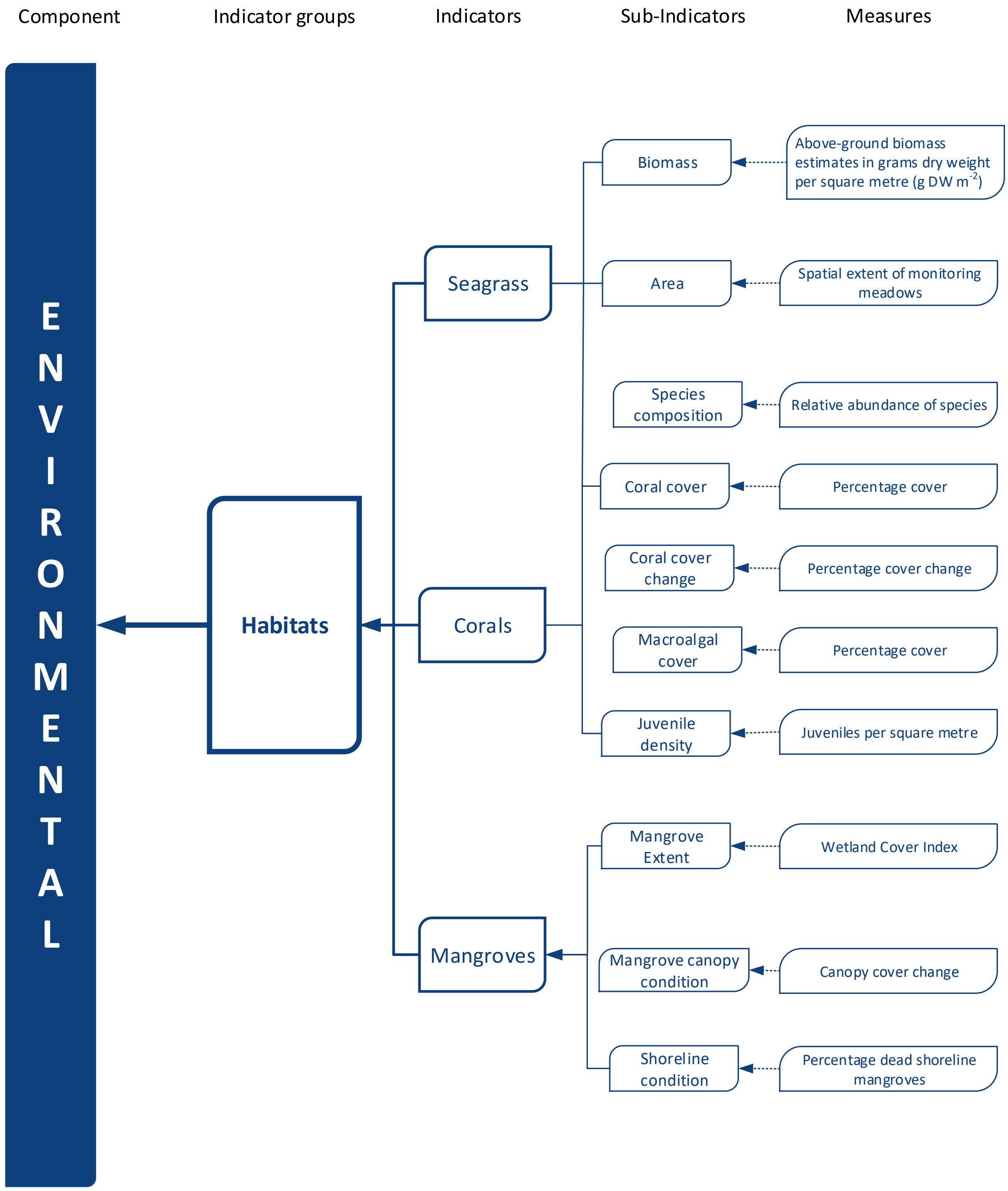

Figure 2.2b: The levels of aggregation used to determine the environmental scores and grades in the 2018 Gladstone Harbour Report Card. There are 3 environmental indicator groups, 6 Indicators, 15 sub-indicators and 29 measures.

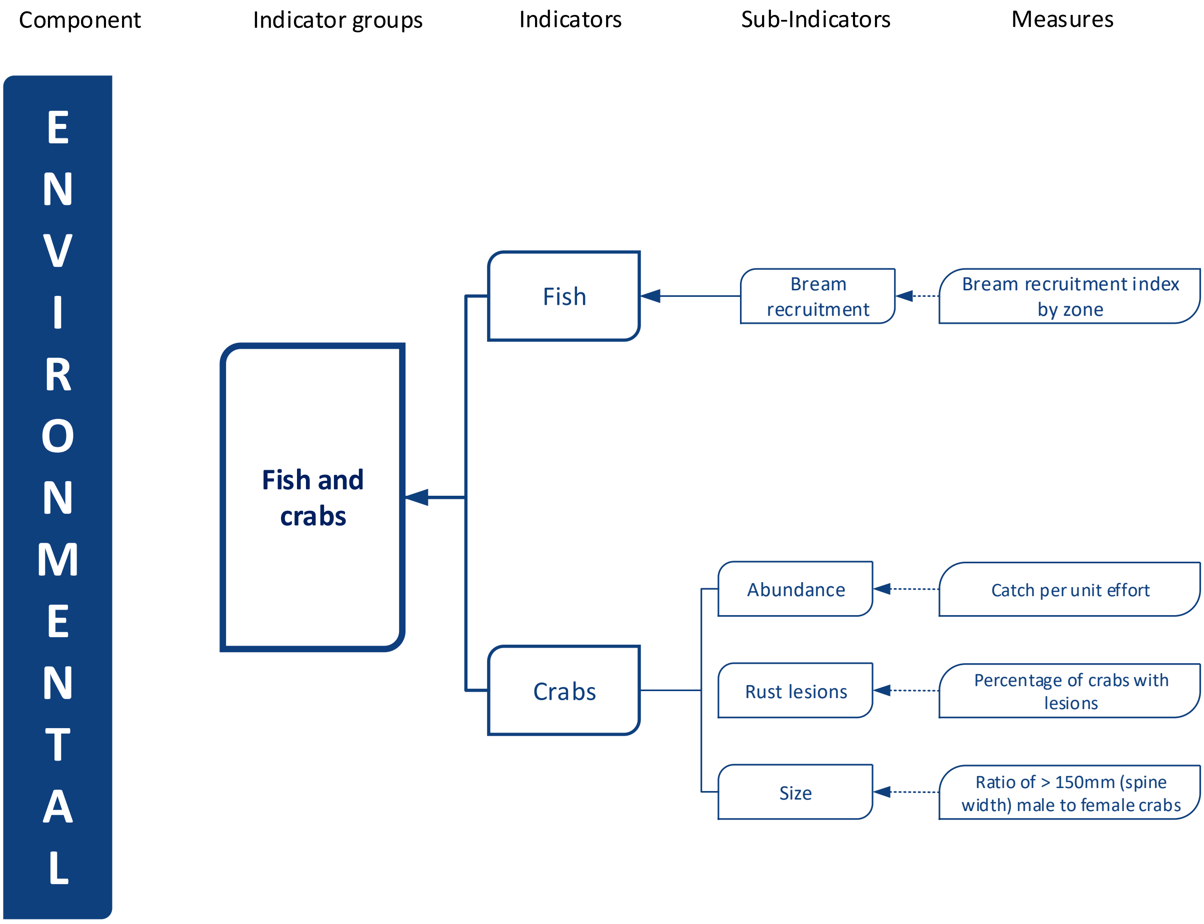

Figure 2.2c: The levels of aggregation used to determine the environmental scores and grades in the 2018 Gladstone Harbour Report Card. There are 3 environmental indicator groups, 6 Indicators, 15 sub-indicators and 29 measures.

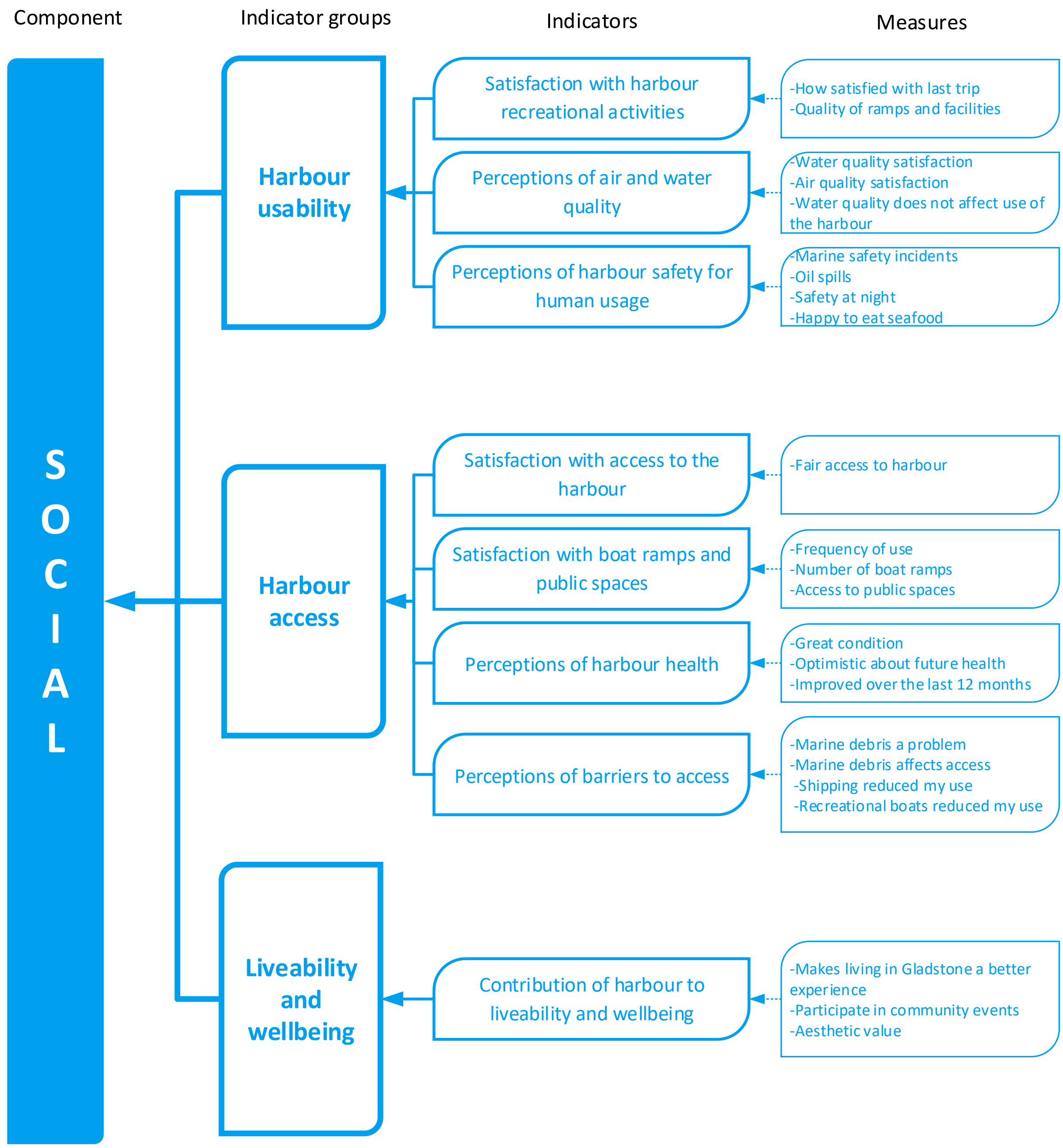

Figure 2.3: The levels of aggregation used to determine the social scores and grades in the 2018 Gladstone Harbour Report Card. There are 3 social indicator groups, 8 indicators and 23 measures.

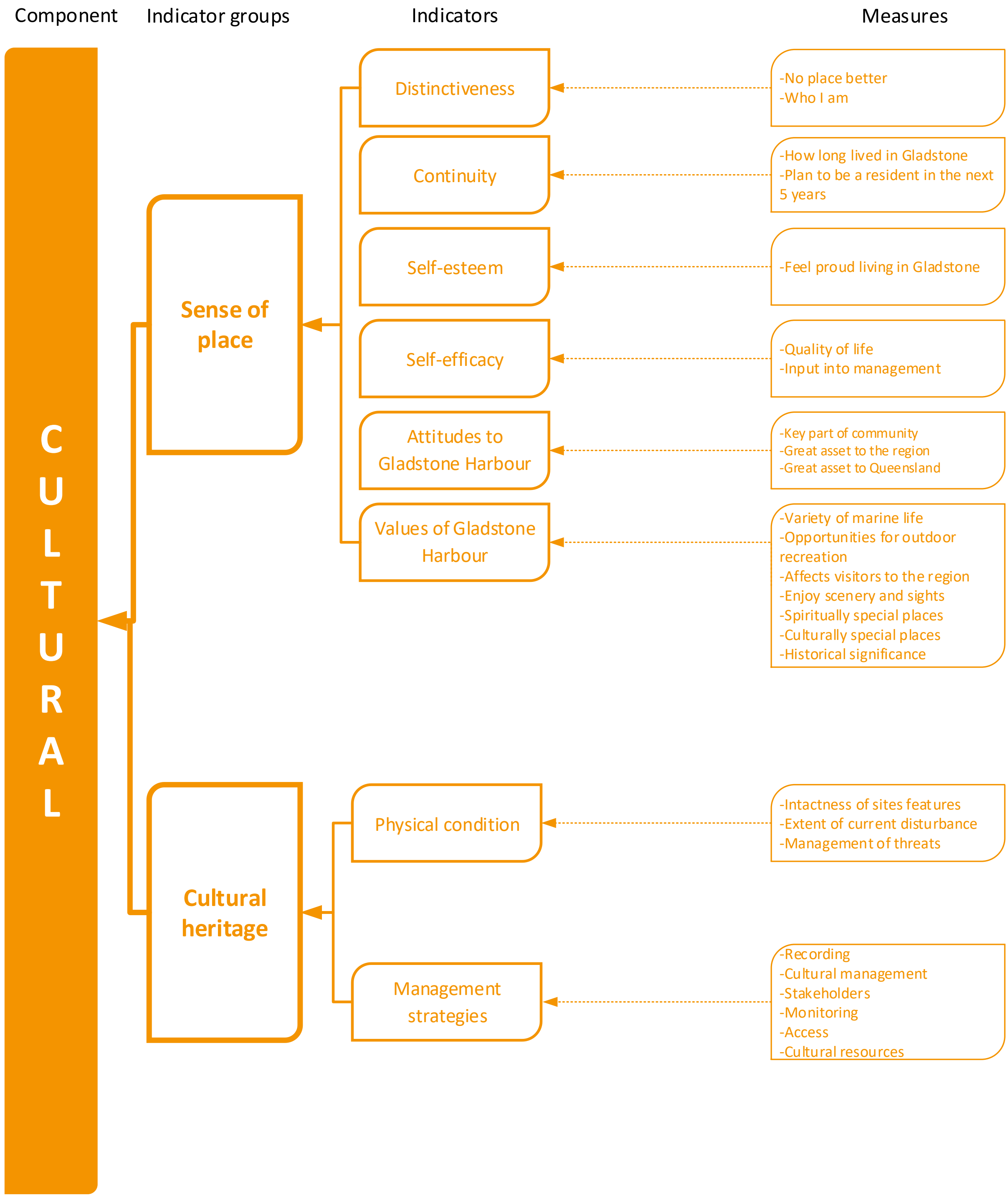

Figure 2.4: The levels of aggregation used to determine the cultural grades and scores in the 2018 Gladstone Harbour Report Card. There are 2 cultural indicator groups, 8 indicators and 26 measures.

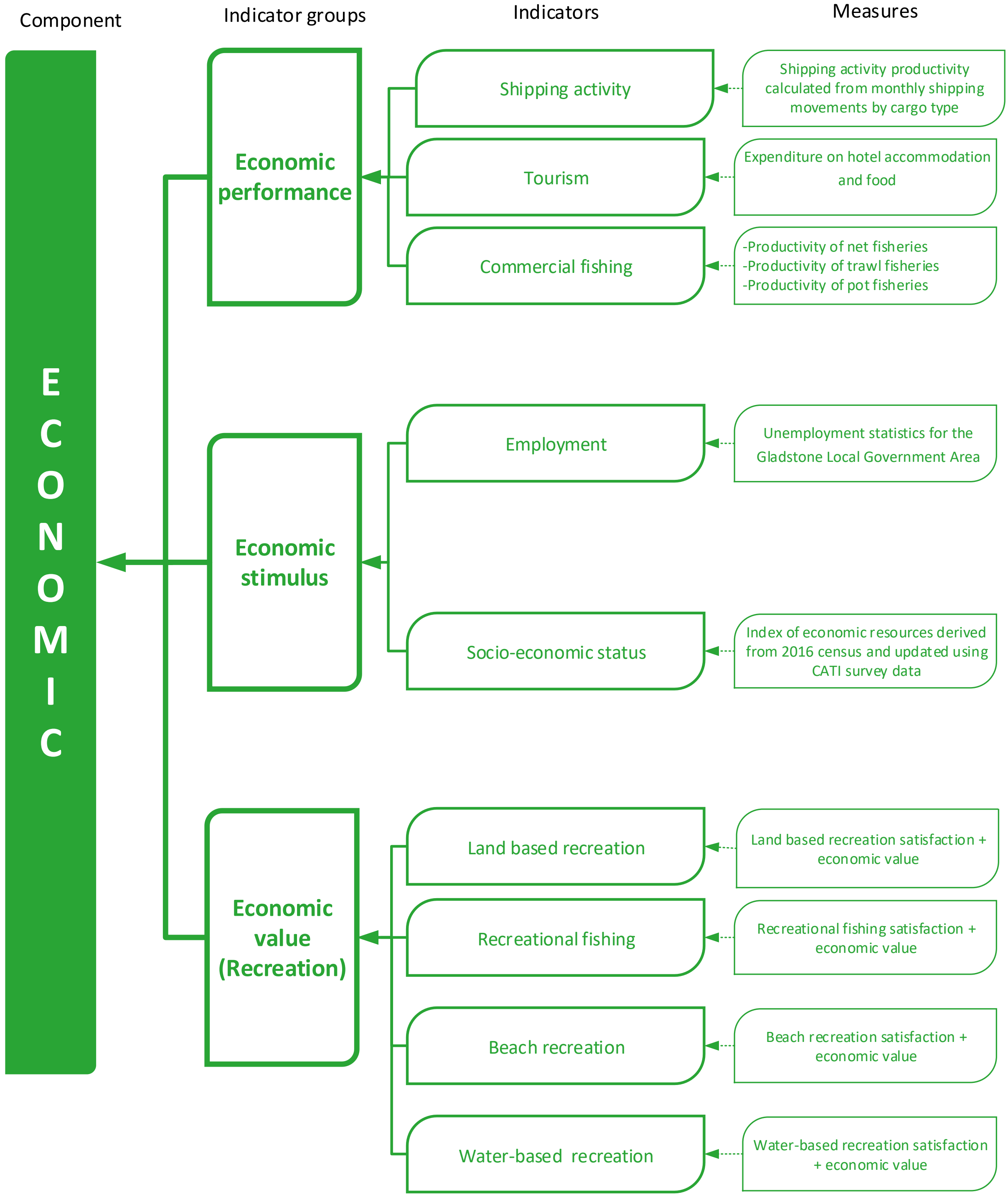

Figure 2.5: The levels of aggregation used to determine the economic scores and grades in the 2018 Gladstone Harbour Report Card. CATI = computer-assisted telephone interviewing. There are 3 economic indicator groups, 9 indicators and 11 measures.

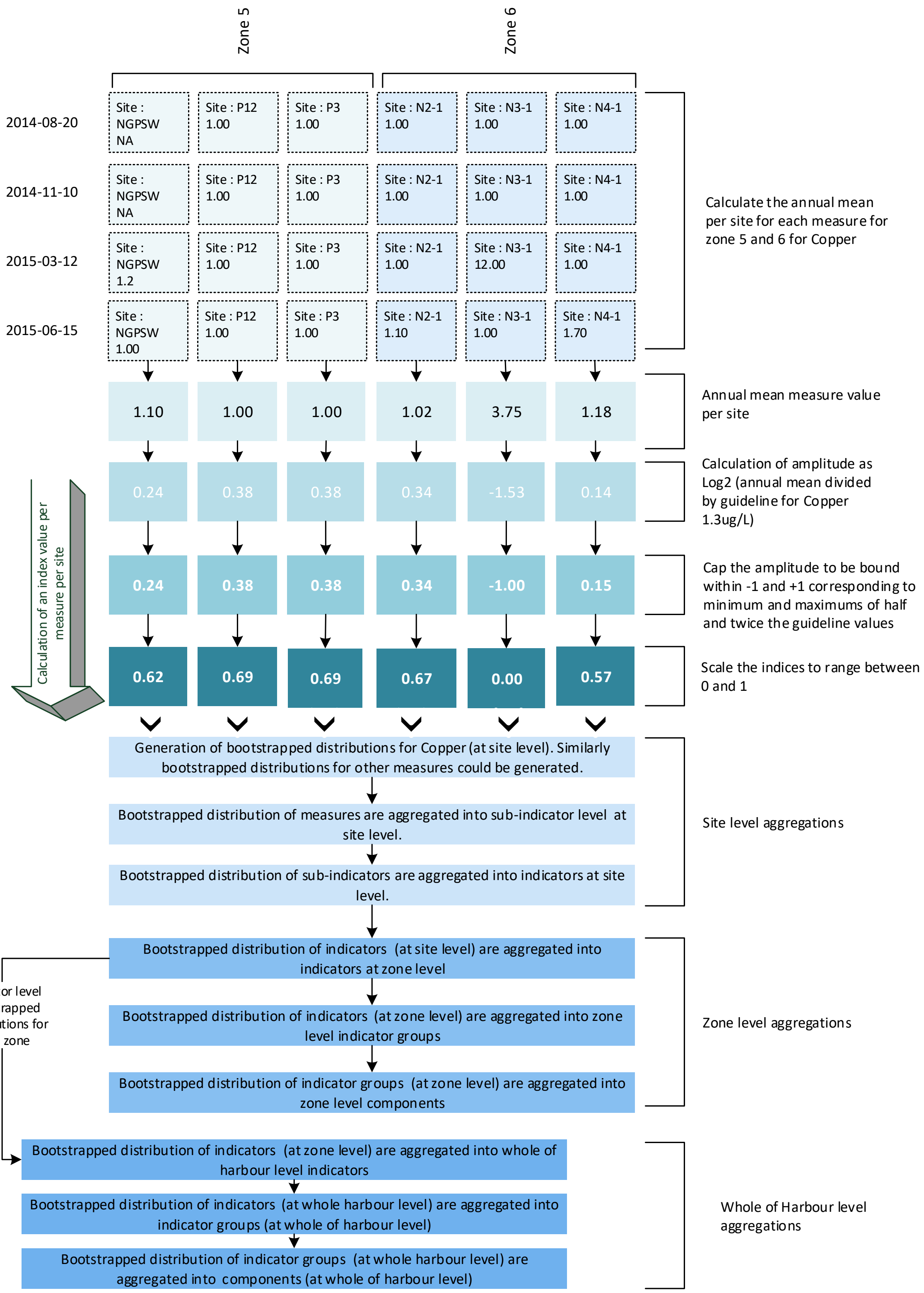

Figure 2.6: Aggregation of report card scores – a worked example using the water quality measure for copper in zones 5 and 6.

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 recruitment and crab data were regarded as reliable the full suite of indicators was not available for this year. Fish health indicators and the final mud crab measure are currently in development and when included will complete the Environmental component. The mud crab and mangrove indicators are relatively new but will become more robust over time. NO_x, and orthophosphate 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. Sediment mercury was not included for the same reason. Further limitations were that water quality sampling was only conducted on four occasions in the 2017–18 reporting year and only at 'far field' sites (sites that were 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 being reliable and repeatable and was improved in 2017 with the inclusion of 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 is the Gladstone Maritime Region which includes areas well beyond Gladstone Harbour. Despite these minor issues it was considered that overall the grade for the Social component was 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 2017. While there have been improvements in the Indigenous Cultural Heritage indicator including weighting the scores based on inputs from Traditional Owners and Elders, several issues remain. Not all sites surveyed in 2017 were resurveyed in 201 and the methodology to assess Indigenous Cultural Heritage in a report card framework is still relatively new. 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. However there are ongoing issues with the definition of a tourist and separating the effects of Gladstone Harbour from Gladstone City in the tourism indicator. 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 2018 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.

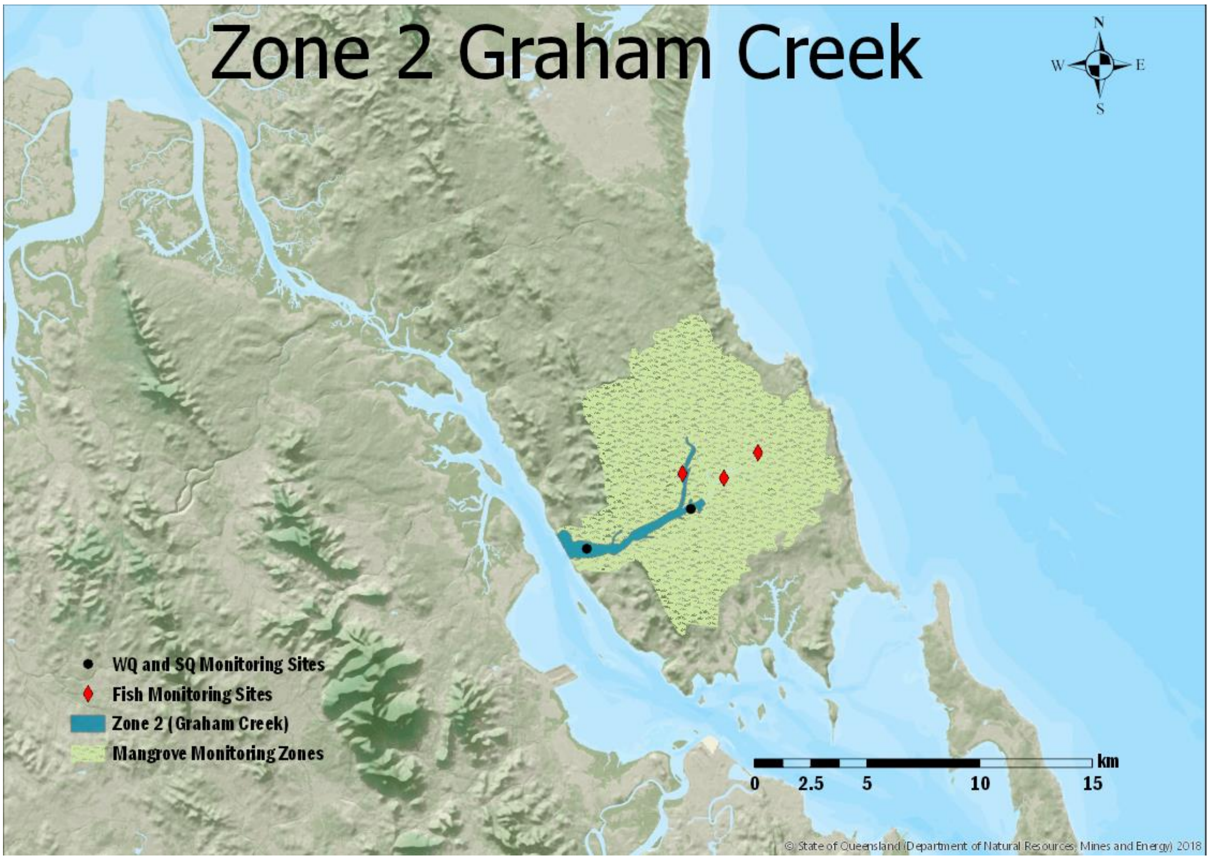

Figure 3.4: Habitat types and water and sediment quality sampling sites in Graham Creek.

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.

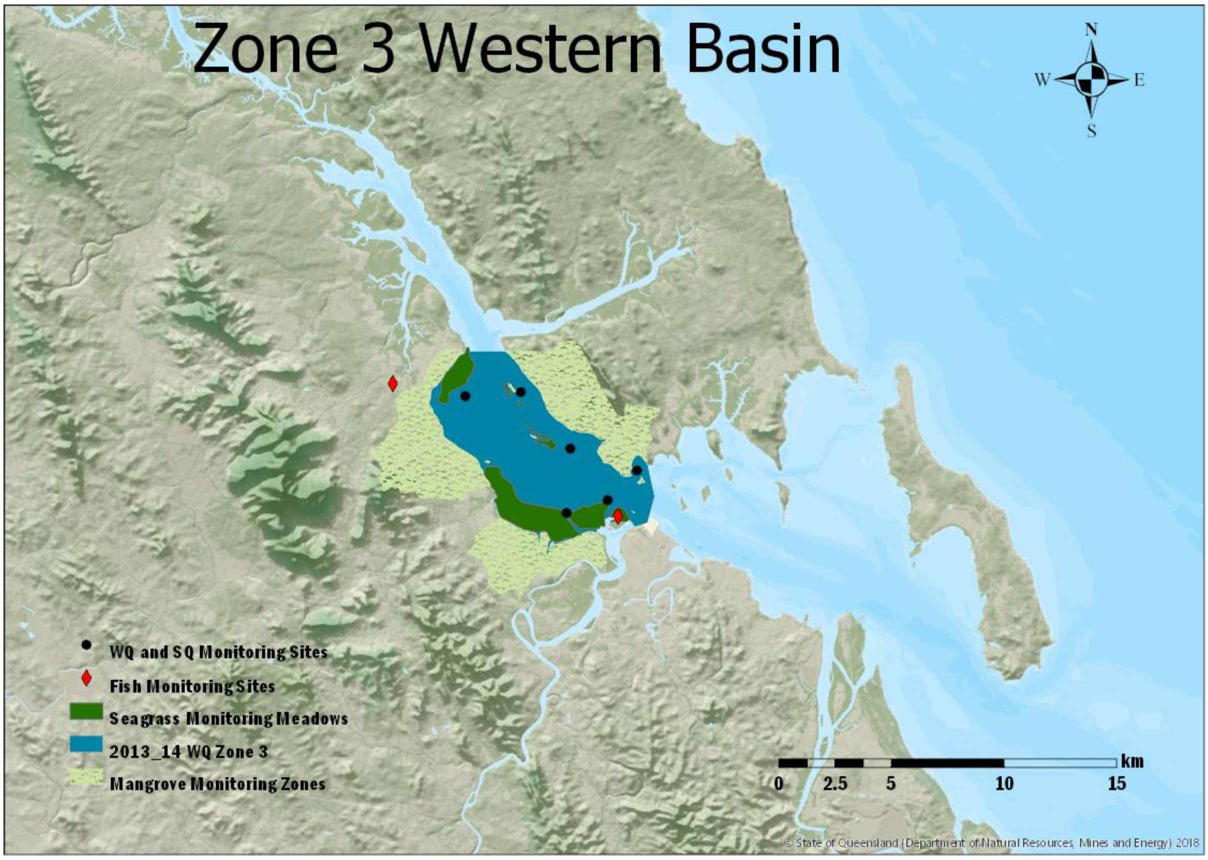

Figure 3.6: Habitat types and water and sediment quality sampling sites in the Western Basin.

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.

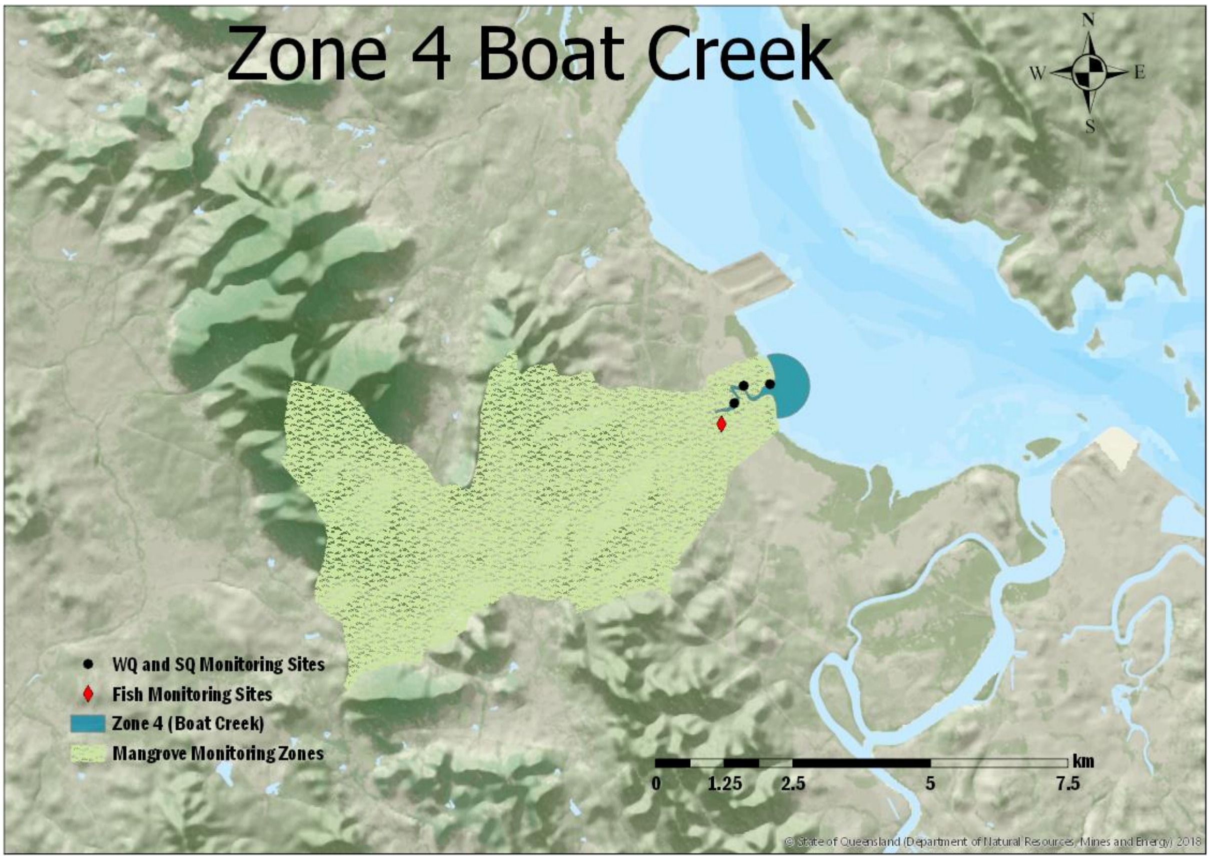

Figure 3.8: Habitat types and water and sediment quality sampling sites in Boat Creek.

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.

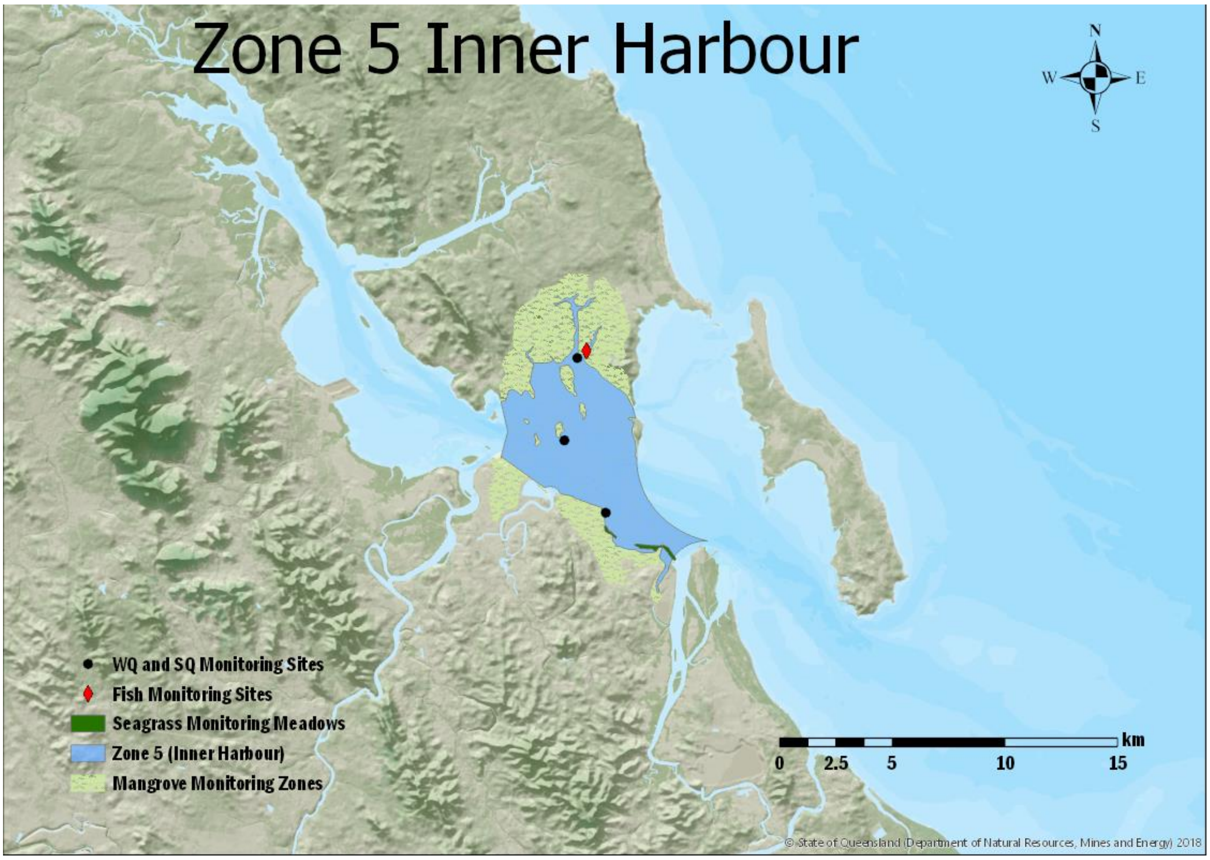

Figure 3.10: Habitat types and water and sediment quality sampling sites in the Inner Harbour.

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.

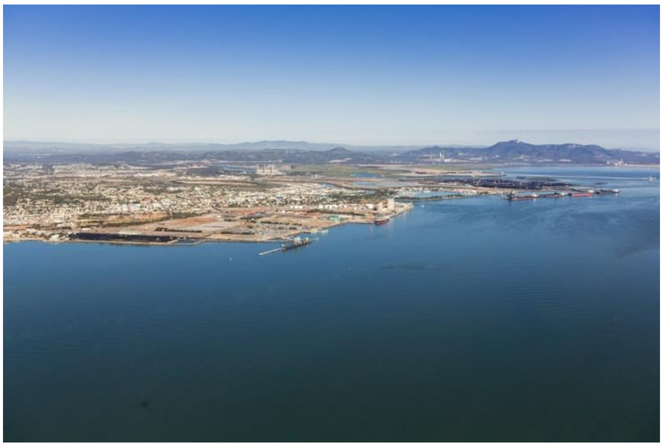

Figure 3.11: The Inner Harbour photographed from the north-east, with Auckland Point wharves and the City of Gladstone on the left and the RG Tanna coal loading facility on the right.

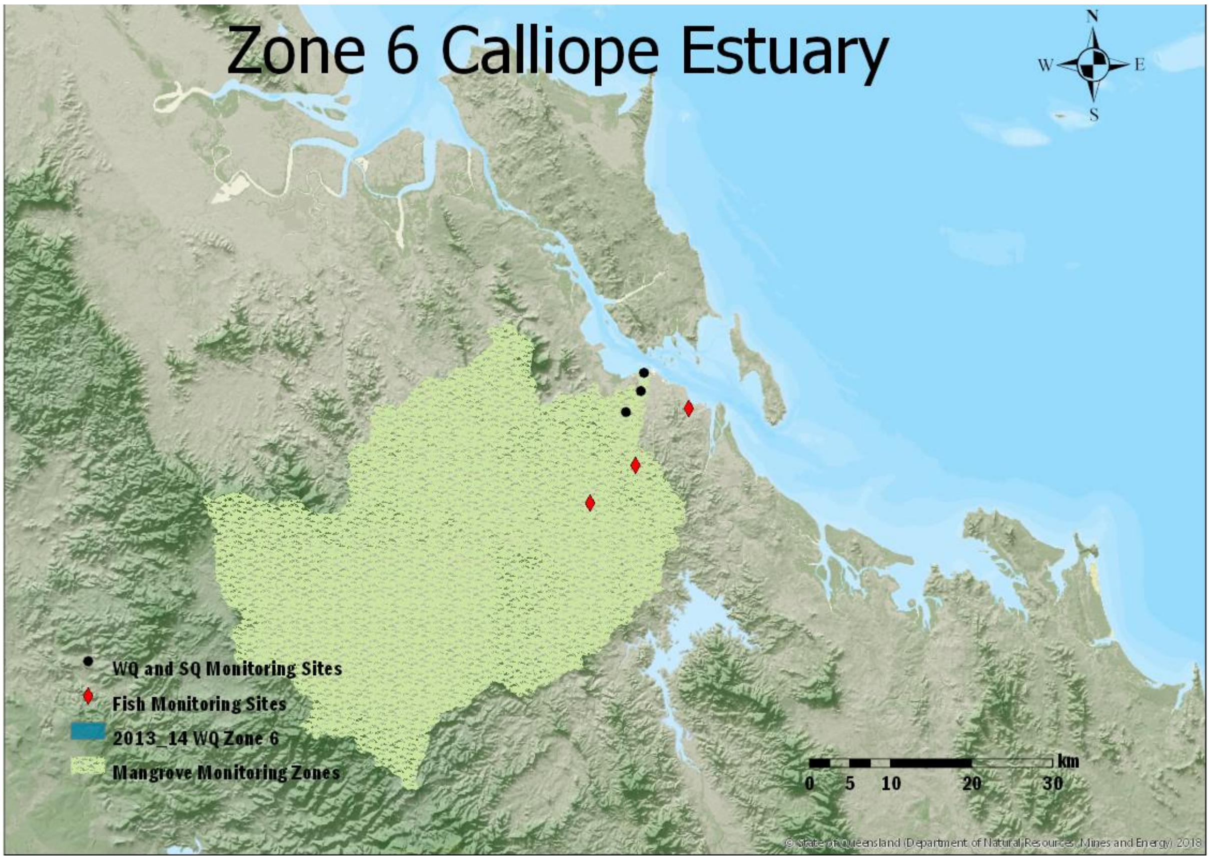

Figure 3.12: Habitat types and water and sediment quality sampling sites in Calliope Estuary.

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.

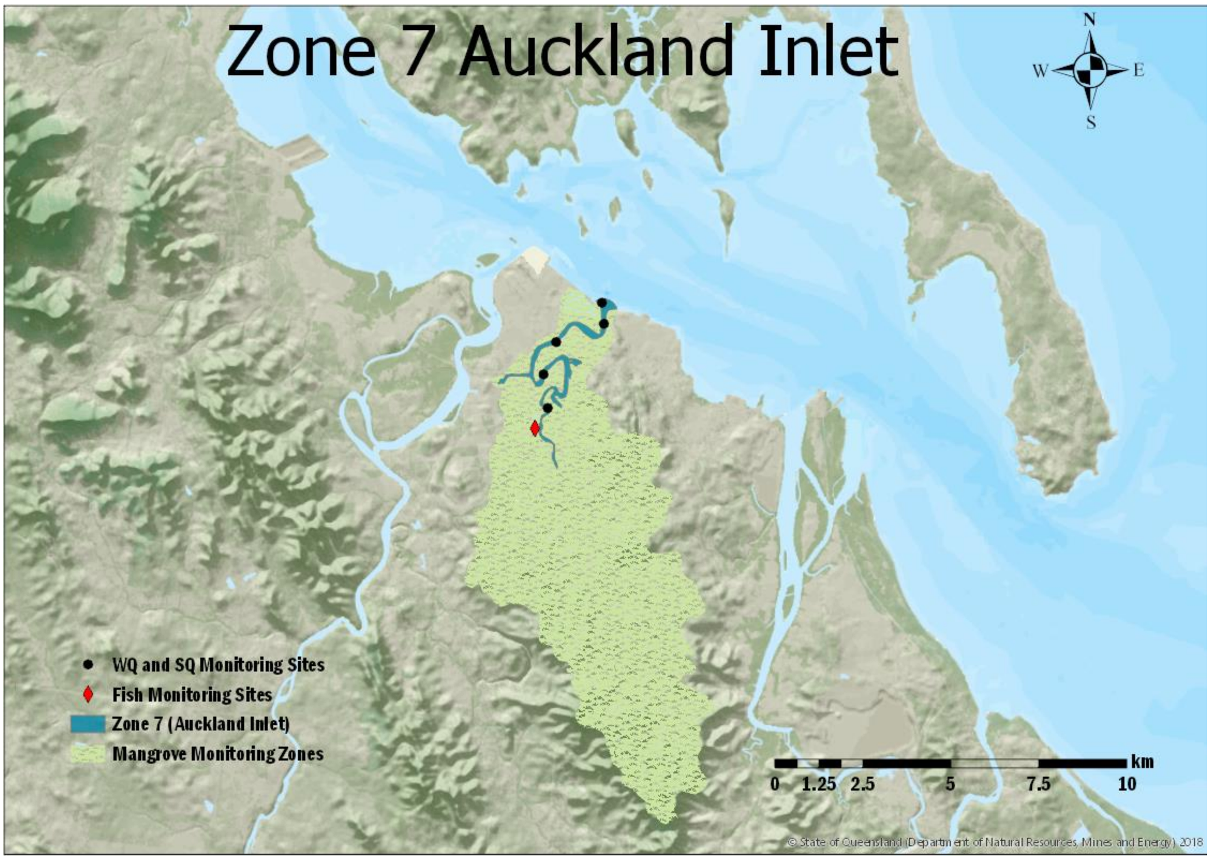

Figure 3.14: Habitat types and water and sediment quality sampling sites in Auckland Inlet.

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.

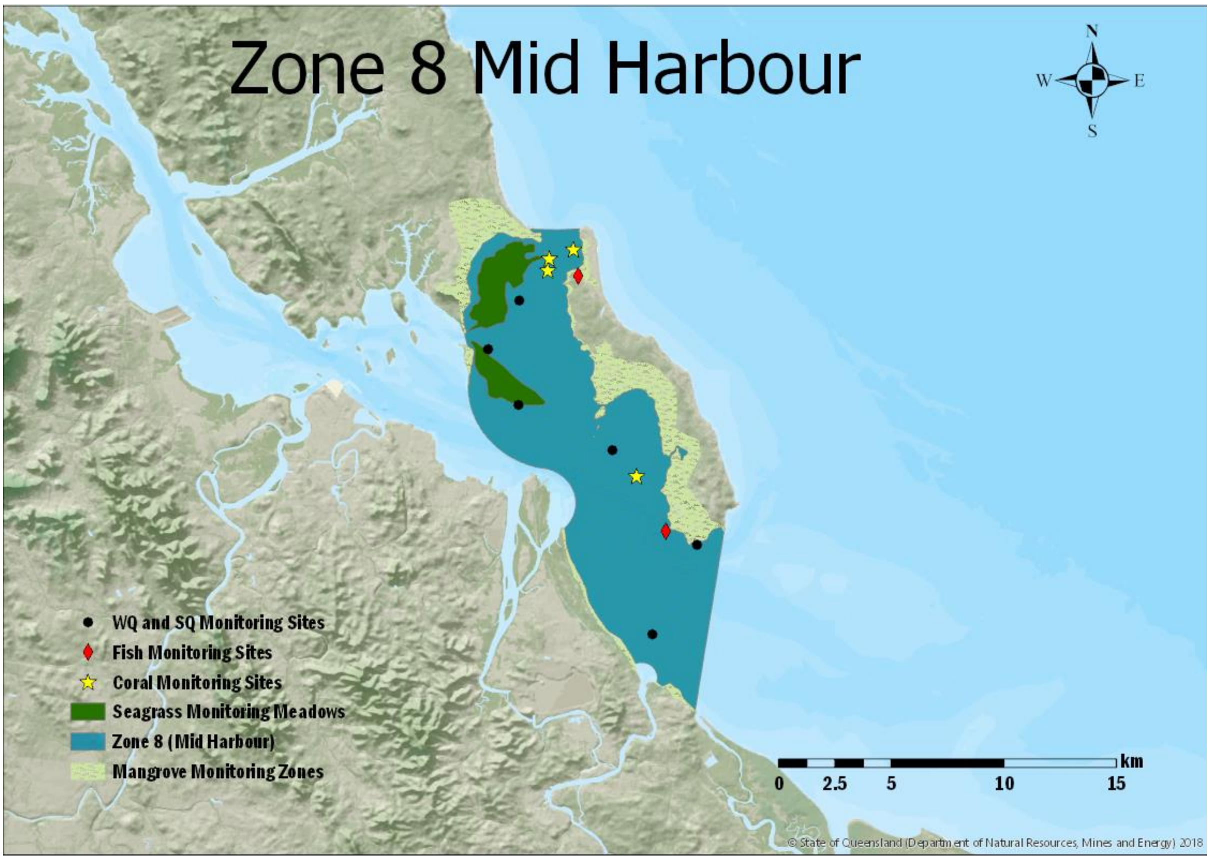

Figure 3.16: Habitat types and water and sediment quality sampling sites in the Mid Harbour.

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 are adjacent to the Great Barrier Reef Marine Park.

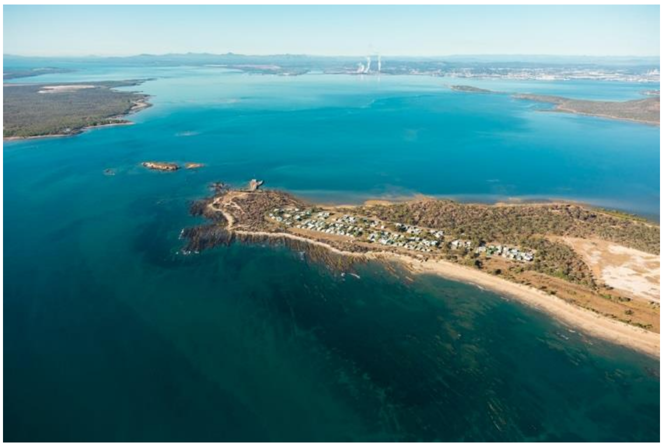

Figure 3.17: The Mid Harbour photographed from north-east. Curtis Island is in the foreground and the Inner Harbour is in the background.

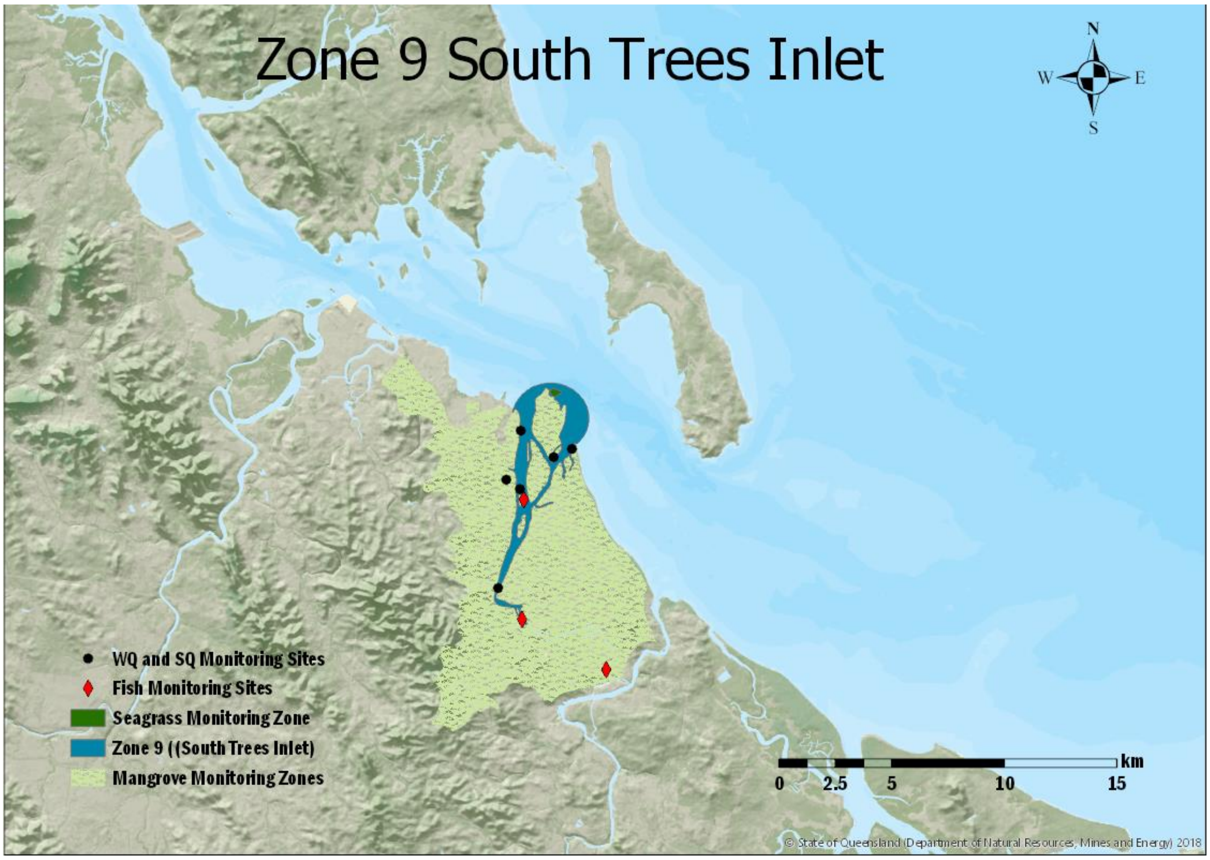

Figure 3.18: Habitat types and water and sediment quality sampling sites in South Trees Inlet.

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.

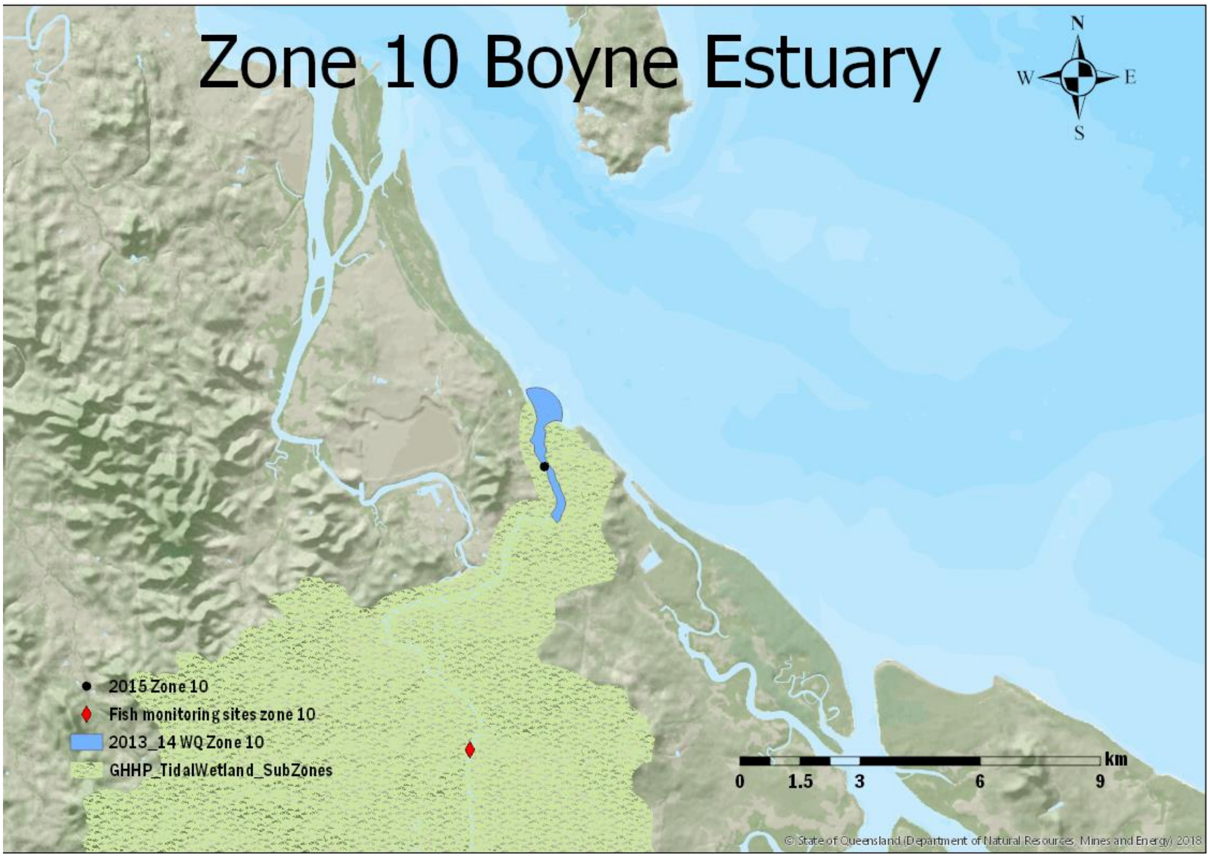

Figure 3.20: Habitat types and water and sediment quality sampling sites in Boyne Estuary.

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.

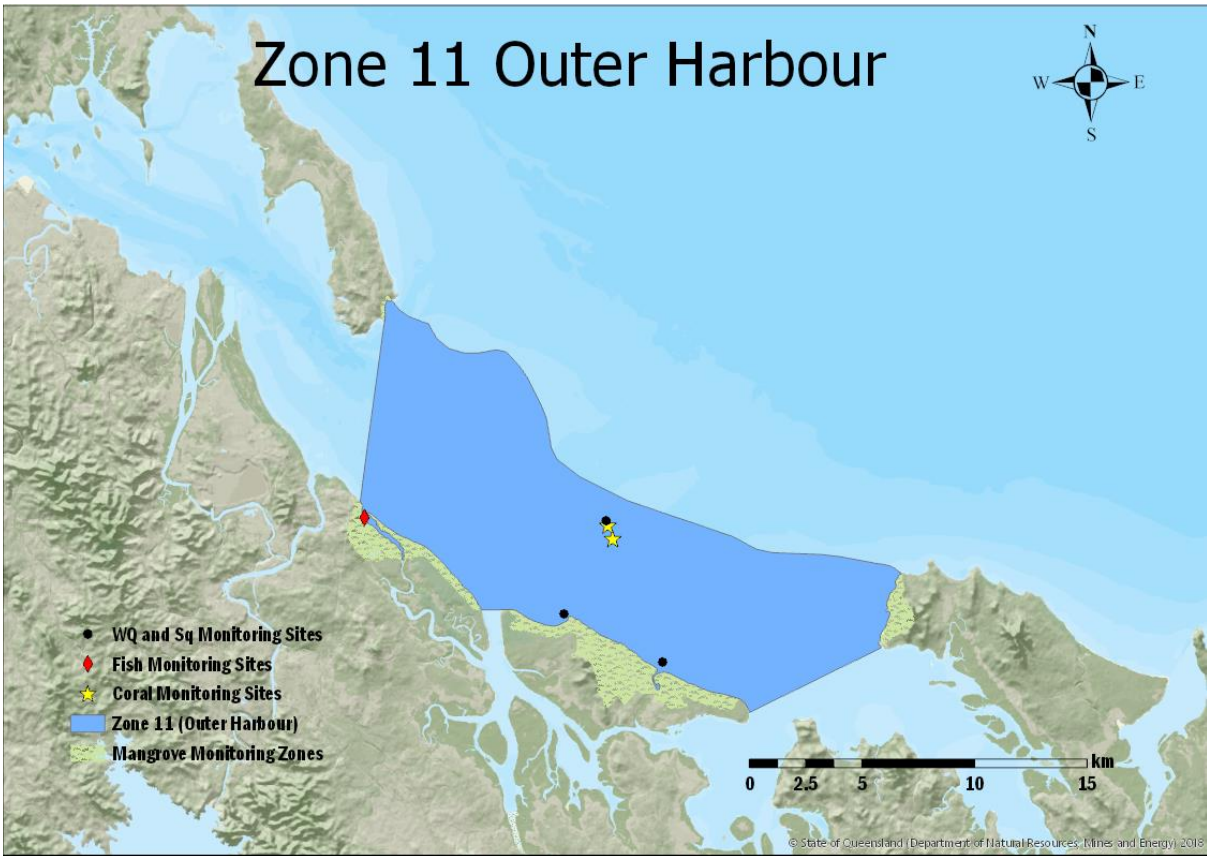

Figure 3.22: Habitat types and water and sediment quality sampling sites in the Outer Harbour.

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.

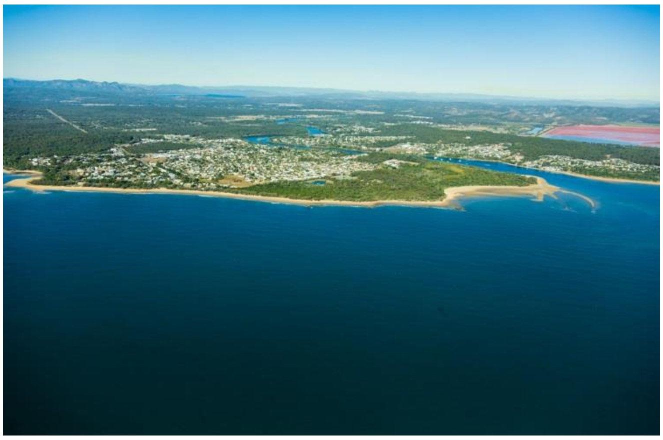

Figure 3.23: The Outer Harbour and Tannum Sands photographed from the north-east. Boyne Island and one of Gladstone's red mud (bauxite) dams are on the right.

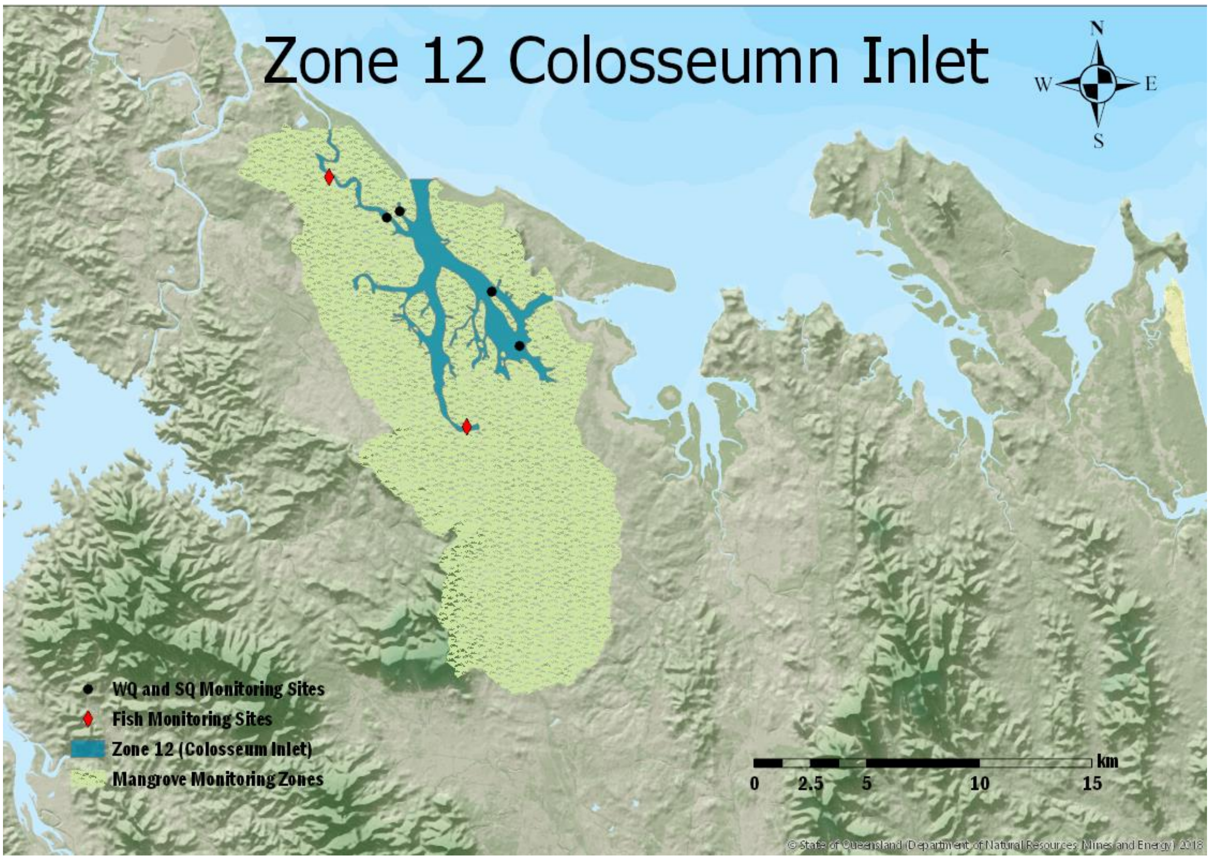

Figure 3.24: Habitat types and water and sediment quality sampling sites in Colosseum Inlet.

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.

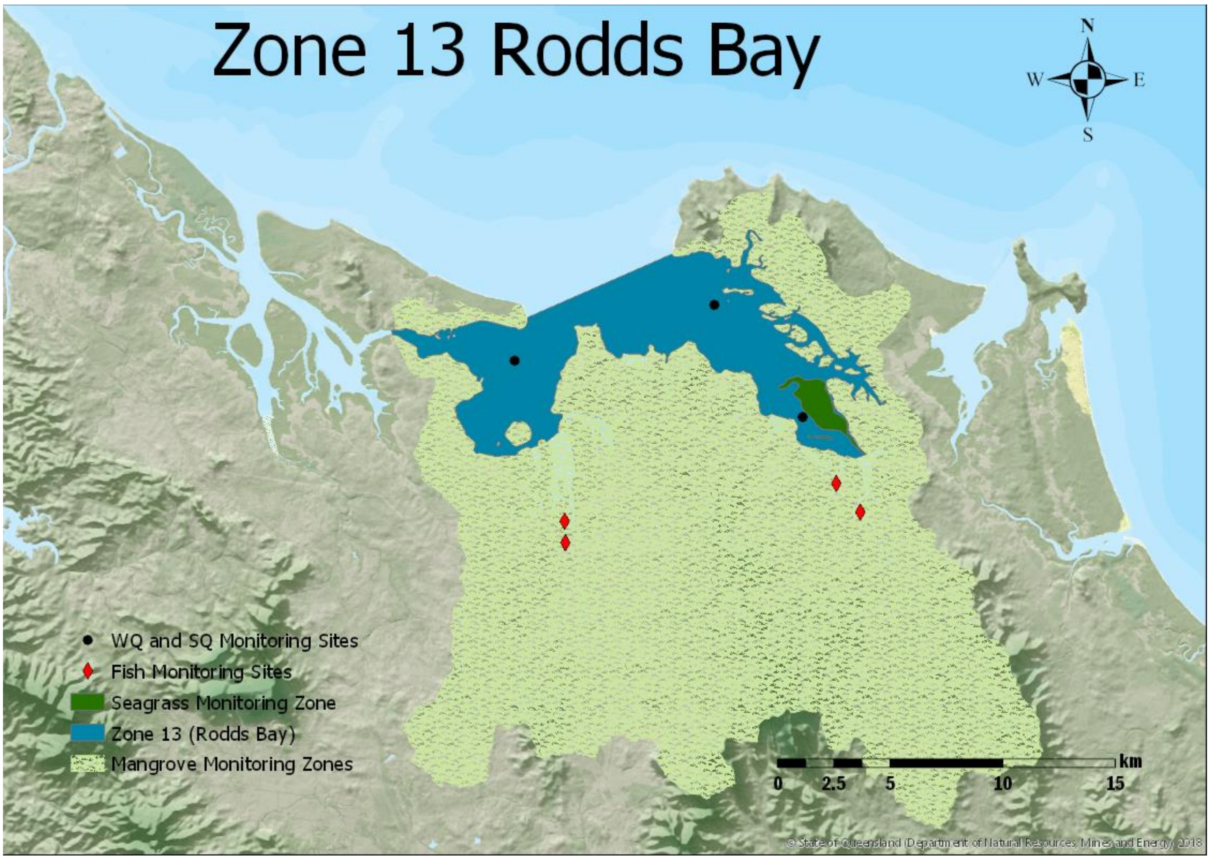

Figure 3.26: Habitat types and water and sediment quality sampling sites in Rodds Bay.

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 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 2018).

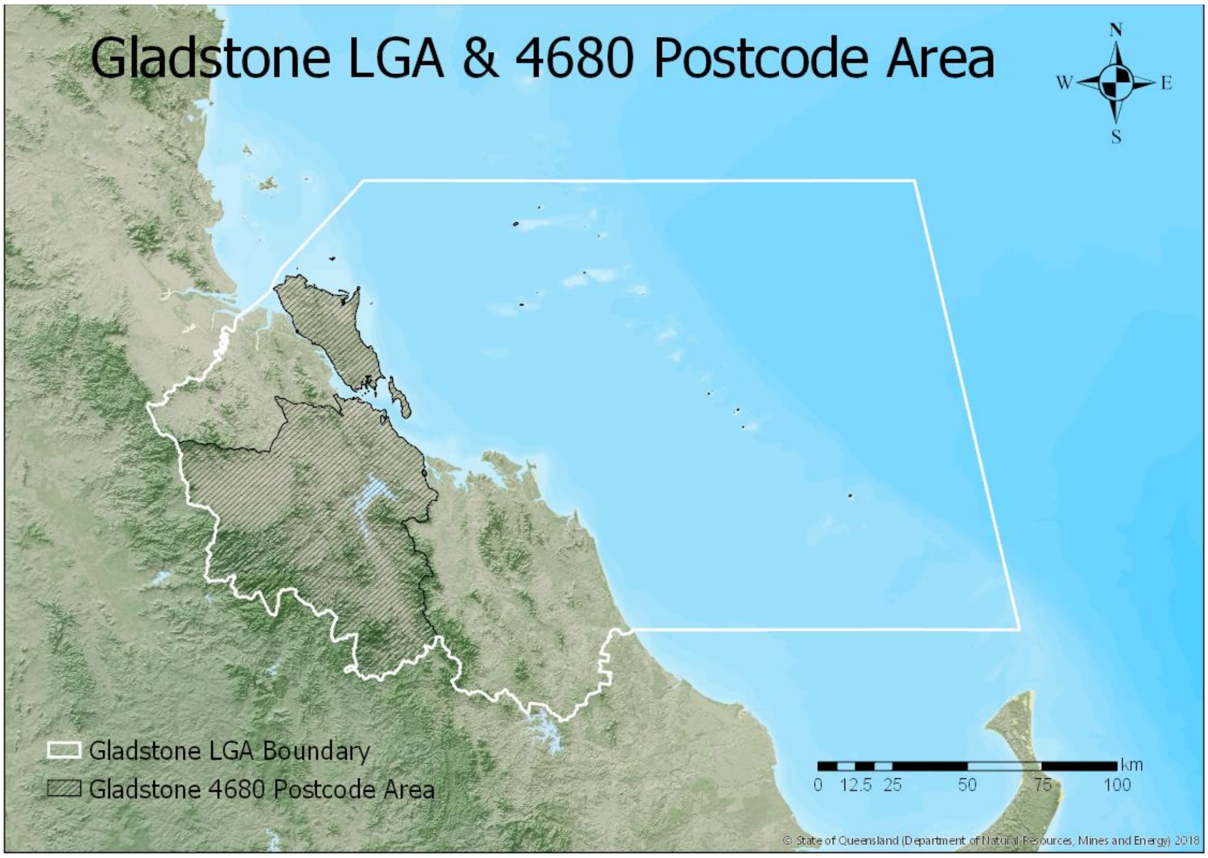

Figure 3.28: The Gladstone Region showing the mainland extent of the Gladstone Local Government Area (LGA) and the Gladstone 4680 postcode area. Both were used to define areas from which some social, cultural and economic data were collected.

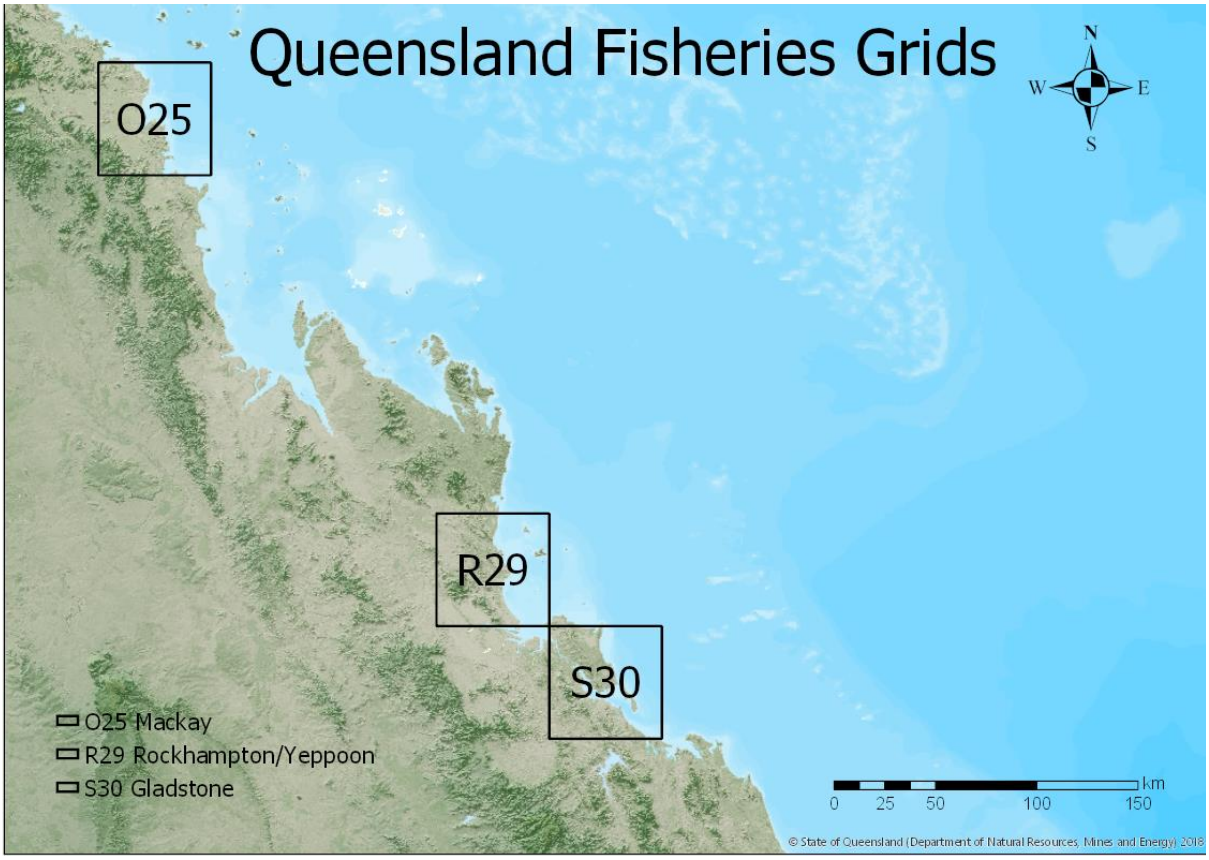

Figure 3.29: The Queensland Fisheries S30 (Gladstone), R29 (Rockhampton and Yeppoon) and O25 (Mackay) Grids. Data from these grids are used to calculate the commercial fishing indicator.

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. The score and the grade for the Narrows is based on 6 sites documented in 2016, 3 sites documented in 2017 and 1 site documented in 2018. The cultural locus site is a 2km 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 at Mt Larcom as of similar cultural significance, so weighted it 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. A total of seven sites have been identified in annual field surveys since 2016 and six sites within this zone have been resurveyed in 2018. 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 the 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. A total of six sites have been identified for annual surveys within this zone since 2016 of which 5 were revisited for the 2018 report card.

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. The 2018 scores and grades for Wild Cattle Creek are based on 11 sites documented in 2016 and 5 sites documented in 2017.

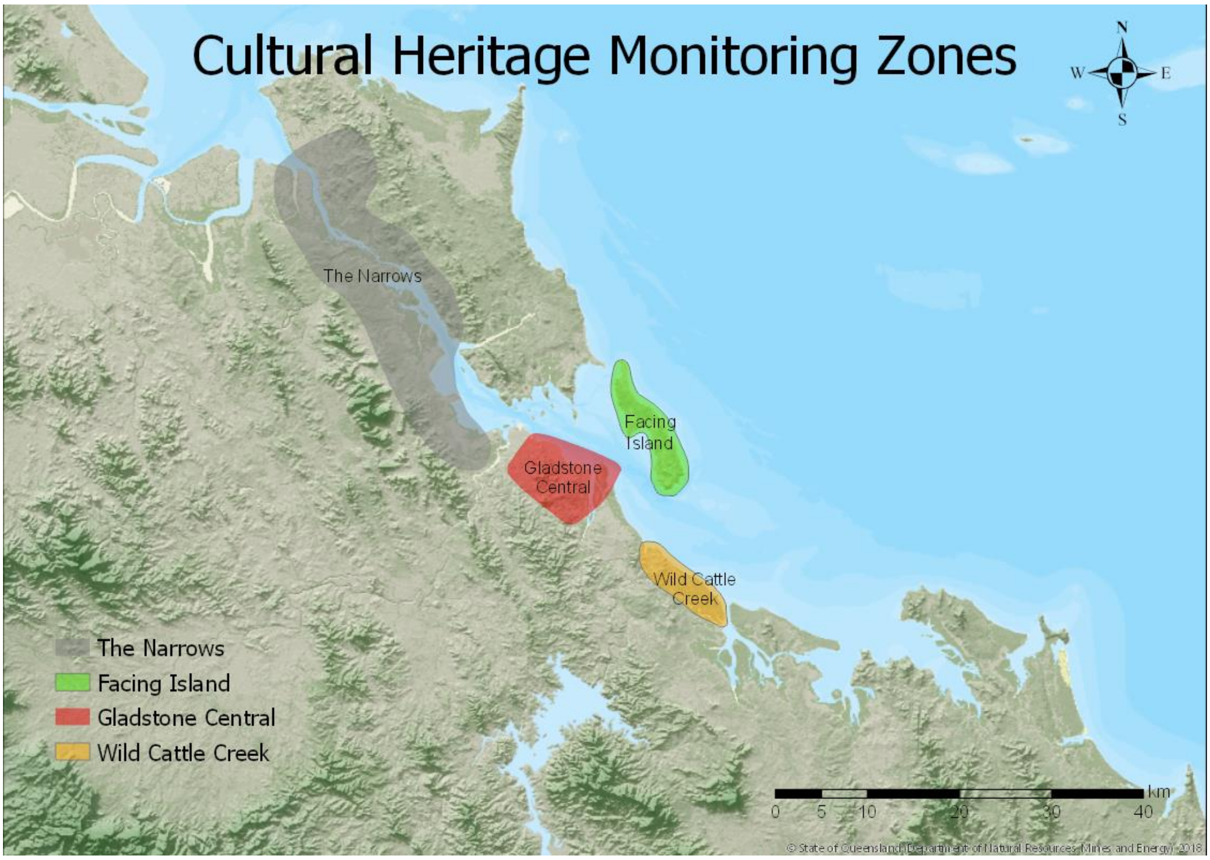

Figure 3.31: The four reporting zones from which data used to inform the Indigenous cultural heritage indicators for 2018 report card were collected.

4. The Environmental component

The Environmental component for the 2018 report card consists of three indicator groups: water and sediment quality, habitats and fish and crabs. The addition of mangroves to the habitat indicator group completes that group. In 2018, the fish and crabs indicator includes fish recruitment and mud crab health. 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 2018 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 3 and 5 for further details.

With the exception of metals, water quality guideline values differ among geographic zones within Gladstone Harbour (see Appendix 3 for values by zone). The aluminium guidelines developed by Golding et al. (2014) ranged from 2.1µg/L in high ecological value (HEV) zones in Gladstone Harbour (The Narrows, Colosseum Inlet, Rodds Bay) to 24µg/L in moderately disturbed (MD) zones (all other zones). This led to similar actual concentrations of aluminium being scored 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 24µg/L across all zones. For the same reason, the ISP also selected a consistent guideline of 140µg/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 20µg/L and 390µg/L depending on whether the zone was classified as HEV or MD and whether corals were present or absent.

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 2018 Gladstone Harbour Report Card. Those data were based on samples collected from 51 sites across the 13 harbour zones in August and November 2017 and March and June 2018 (Figures 3.1–3.27).

Eleven water quality parameters were assessed for the 2018 Gladstone Harbour Report Card: two physico-chemical measures, three nutrient measures and six dissolved metals (Table 4.1). Physico-chemical 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 0.45µm membrane filters in the field.

Vision Environment Queensland collected the field samples and prepared them for analysis by one of three 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 2018 Gladstone Harbour Report Card.

Indicator	Sub-indicator	Measure	Guideline source
Water quality	Physico-chemical	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 3 for a full list of water quality guidelines.

Sediment quality

The 2018 Gladstone Harbour Report Card assessed five 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 2018 Gladstone Harbour Report Card in June 2018. 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 2018 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
		Zinc (Zn)	ANZECC/ARMCANZ, 2000

See Appendix 5 for a full list of sediment guidelines.

What water and sediment quality measures were not included?

During early September 2018, the ISP held a meeting with the members of PCIMP to discuss QA/QC issues with the raw dataset for 2018 for the water and sediment quality data collected.

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

- 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 QA issues with contaminated field blanks in conjunction with values close to guideline values made it difficult to determine accurate measures.
- NO_x: raw data were not available consistently over four quarters
- orthophosphate: the 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 more than 50% 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. Physico-chemical 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 coral growth.

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 nutrient 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 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).

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 bioaccumulate 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: physico-chemical, nutrients and dissolved metals. The physico-chemical 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 2018 report card was a B (0.76). The Outer Harbour (0.92), received very good scores for overall water quality and Boat Creek (0.63) received a satisfactory score. The remaining zones had good scores for water quality (Table 4.3).

Table 4.3: Overall water quality, physico-chemical, nutrient and dissolved metal scores for the 13 zones in the 2018 Gladstone Harbour Report Card. Overall zone scores 2015 to 2017 are shown for comparison.

Water quality	Physico-chemical score	Nutrients score	Dissolved metals score	Zone score 2018	*Zone score 2017*	*Zone score 2016*	*Zone score 2015*
1. The Narrows	0.77	0.39	0.95	0.71	*0.71*	*0.68*	*0.82*
2. Graham Creek	0.96	0.43	0.94	0.78	*0.88*	*0.75*	*0.86*
3. Western Basin	0.87	0.34	0.94	0.72	*0.77*	*0.70*	*0.82*
4. Boat Creek	0.77	0.17	0.90	0.63	*0.59*	*0.58*	*0.70*
5. Inner Harbour	0.93	0.54	0.94	0.80	*0.79*	*0.78*	*0.88*
6. Calliope Estuary	0.94	0.42	0.91	0.76	*0.77*	*0.71*	*0.86*
7. Auckland Inlet	0.83	0.47	0.92	0.74	*0.79*	*0.71*	*0.77*
8. Mid Harbour	0.92	0.56	0.94	0.81	*0.79*	*0.77*	*0.80*
9. South Trees Inlet	0.93	0.40	0.94	0.76	*0.84*	*0.79*	*0.85*
10. Boyne Estuary	0.93	0.49	0.94	0.79	*0.83*	*0.71*	*0.70*
11. Outer Harbour	1.00	0.82	0.95	0.92	*0.90*	*0.72*	*0.84*
12. Colosseum Inlet	0.99	0.58	0.94	0.83	*0.83*	*0.73*	*0.78*
13. Rodds Bay	0.79	0.47	0.94	0.74	*0.75*	*0.73*	*0.80*
Whole harbour	**0.89**	**0.47**	**0.93**	**0.76**	***0.78***	***0.72***	***0.81***

The physico-chemical scores for pH were very good in all zones (Table 4.4). The scores for turbidity ranged from satisfactory to very good with the majority of zones being ranked good or above. Only three zones, The Narrows, Boat Creek and Rodds Bay, had satisfactory scores.

All zones had very good scores (0.90 – 0.95) for dissolved metals (Table 4.3). Scores for individual metal measures were predominantly very good, although manganese received a good score in Boat Creek (0.83). Scores for copper were lower than for the other metals, with six zones rated as good and six zones receiving a satisfactory score. The only zone to receive a poor score for this measure was Calliope Estuary (0.48) (Table 4.4).

Similar to previous report cards, nutrients (nitrogen, phosphorus and chlorophyll-a) received the lowest scores amongst the water quality sub-indicators. While the Outer Harbour had a good score for the nutrient sub-indicator and The Inner Harbour, Mid Harbour and Colosseum Inlet had satisfactory scores, all other zones had poor or very poor scores. This was a result of poor scores for total nitrogen (excluding Boat Creek which received a very poor score) and poor to very poor scores for chlorophyll-a. With one exception, Boat Creek (0.27), scores for total phosphorus were satisfactory to very good (Table 4.4).

Table 4.4: Scores for water quality measures for each of the 13 zones in the 2018 Gladstone Harbour Report Card.

Zone	Physico-chemical		Nutrients			Metals					
	pH	Turbidity	TN*	TP**	Chl-*a*#	Al	Copper	Lead	Mn	Nickel	Zinc
1. The Narrows	1.00	0.54	0.38	0.63	0.16	1.00	0.67	1.00	1.00	1.00	1.00
2. Graham Creek	1.00	0.92	0.40	0.82	0.06	1.00	0.65	1.00	1.00	1.00	1.00
3. Western Basin	1.00	0.74	0.32	0.56	0.14	1.00	0.62	1.00	1.00	1.00	1.00
4. Boat Creek	1.00	0.56	0.22	0.27	0.03	1.00	0.60	1.00	0.83	1.00	1.00
5. Inner Harbour	1.00	0.87	0.41	0.88	0.32	1.00	0.61	1.00	1.00	1.00	1.00
6. Calliope Estuary	1.00	0.88	0.34	0.73	0.21	1.00	0.48	1.00	1.00	1.00	1.00
7. Auckland Inlet	1.00	0.65	0.35	0.65	0.42	0.96	0.53	1.00	1.00	1.00	1.00
8. Mid Harbour	1.00	0.85	0.41	0.80	0.48	1.00	0.65	1.00	1.00	1.00	1.00
9. South Trees Inlet	1.00	0.86	0.36	0.69	0.15	1.00	0.64	1.00	1.00	1.00	1.00
10. Boyne Estuary	1.00	0.86	0.31	0.75	0.41	1.00	0.64	1.00	1.00	1.00	1.00
11. Outer Harbour	1.00	1.00	0.48	0.99	0.99	1.00	0.67	1.00	1.00	1.00	1.00
12. Colosseum Inlet	1.00	0.97	0.39	0.89	0.44	0.95	0.67	1.00	1.00	1.00	1.00
13. Rodds Bay	1.00	0.56	0.41	0.67	0.34	1.00	0.67	1.00	1.00	1.00	1.00

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

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4.1.3.2. Sediment quality

The overall sediment quality scores were derived from one sub-indicator—metals and metalloids. Five metals (cadmium, copper, lead, nickel and zinc) and the metalloid arsenic were assessed. The overall grade for sediment quality was an A (0.95) indicating concentrations that were well below the guideline values.

Zone scores for sediment quality were all very good and ranged from 0.90 in The Narrows to 0.99 in Colosseum Inlet (Table 4.5) indicating very low concentrations of sediment metals across the harbour. This was a result of low concentrations of all measures (arsenic, cadmium, copper, lead, nickel and zinc) (Table 4.6). Sediment mercury was in the 2017 report card, but it was not included in 2018. This is because the limit of reporting for this metal was above the guideline value. Hence a score could not be determined. When different laboratory procedures were used in 2017, sediment mercury concentrations across the harbour were found to be well below the guideline values.

Table 4.5: Sediment quality indicator scores for Gladstone Harbour zones in 2018, 2015 to 2017 are shown for comparison.

Sediment quality	Metals and metalloids score	Zone score 2018	*Zone score 2017*	*Zone score 2016*	*Zone score 2015*
1. The Narrows	0.90	0.90	*0.92*	*0.92*	*0.94*
2. Graham Creek	0.95	0.94	*0.92*	*0.96*	*0.98*
3. Western Basin	0.98	0.98	*0.97*	*0.98*	*0.99*
4. Boat Creek	0.91	0.91	*0.98*	*0.90*	*0.96*
5. Inner Harbour	0.95	0.95	*0.93*	*0.94*	*0.98*
6. Calliope Estuary	0.95	0.95	*0.94*	*0.99*	*0.98*
7. Auckland Inlet	0.91	0.91	*0.87*	*0.94*	*0.94*
8. Mid Harbour	0.95	0.95	*0.95*	*0.97*	*0.99*
9. South Trees Inlet	0.94	0.94	*0.98*	*0.95*	*0.96*
10. Boyne Estuary	0.97	0.97	*0.97*	*0.98*	*1.00*
11. Outer Harbour	0.97	0.96	*0.97*	*0.96*	*0.96*
12. Colosseum Inlet	0.99	0.99	*0.99*	*1.00*	*1.00*
13. Rodds Bay	0.97	0.97	*0.95*	*0.99*	*0.98*
Whole harbour	**0.95**	**0.95**	***0.95***	***0.99***	***0.98***

Table 4.6: Scores for sediment quality measures for each of the 13 zones in the 2018 Gladstone Harbour Report Card.

Zone	Metals and metalloids					
	Arsenic	Cadmium	Copper	Lead	Nickel	Zinc
1. The Narrows	0.74	1.00	1.00	1.00	0.66	1.00
2. Graham Creek	0.83	1.00	1.00	1.00	0.83	1.00
3. Western Basin	0.91	1.00	1.00	1.00	0.95	1.00
4. Boat Creek	0.76	1.00	1.00	1.00	0.76	1.00
5. Inner Harbour	0.72	1.00	1.00	1.00	1.00	1.00
6. Calliope Estuary	0.88	1.00	1.00	1.00	0.87	1.00
7. Auckland Inlet	0.84	1.00	1.00	1.00	0.75	1.00
8. Mid Harbour	0.71	1.00	1.00	1.00	1.00	1.00
9. South Trees Inlet	0.78	1.00	1.00	1.00	1.00	1.00
10. Boyne Estuary	0.81	1.00	1.00	1.00	1.00	1.00
11. Outer Harbour	0.79	1.00	1.00	1.00	1.00	1.00
12. Colosseum Inlet	0.93	1.00	1.00	1.00	1.00	1.00
13. Rodds Bay	0.84	1.00	1.00	1.00	1.00	1.00

4.1.4. Water and sediment quality conclusions

Scores for the water quality indicator have remained high since the first Gladstone Harbour Report Card in 2015, receiving a good grade (B) in all years (Figure 4.1). Water quality was relatively uniform across the harbour and all zones received a good or very good grade except for Boat Creek which received a satisfactory grade. Compared to the previous year, the score for the physico-chemical group improved in eight zones as a result of higher scores for turbidity. Similar to previous report cards, nutrients (nitrogen, phosphorus and chlorophyll-a) received the lowest scores amongst the water quality sub-indicators. While the Outer Harbour had a good score for the nutrient sub-indicator and the Inner Harbour, Mid Harbour and Colosseum Inlet had satisfactory scores, all other zones had poor or very poor scores. This was a result of poor to very poor scores for total nitrogen and poor to very poor grades for chlorophyll-a, except Outer Harbour which received a very good score. With one exception, Boat Creek, scores for total phosphorus were satisfactory to very good. Catchment run-off is a major source of nutrients in estuarine waters such as Gladstone Harbour. The level of nutrients entering the harbour can be influenced by land use and climatic condition with the nutrient load expected to increase with wet season run-off. As nutrients can bind to fine sediments, the resuspension of sediments associated with tidal movements or wave action can also lead to increased nutrient levels.

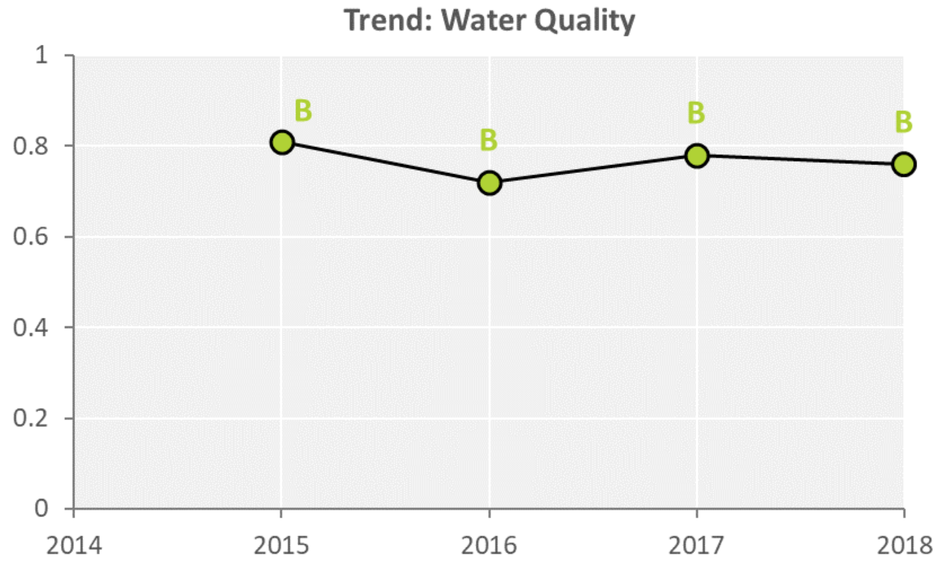


Figure 4.1: Changes in the water quality grade 2015 – 2018.

Sediment quality scores were uniformly very good (A) across all Gladstone Harbour reporting zones as it has been in all previous report cards (Figure 4.2). This is a result of low concentrations of all measures (arsenic, cadmium, copper, lead, nickel and zinc). PAHs were not monitored in 2018 due to the very low concentrations recorded in the 2015 sediment monitoring.

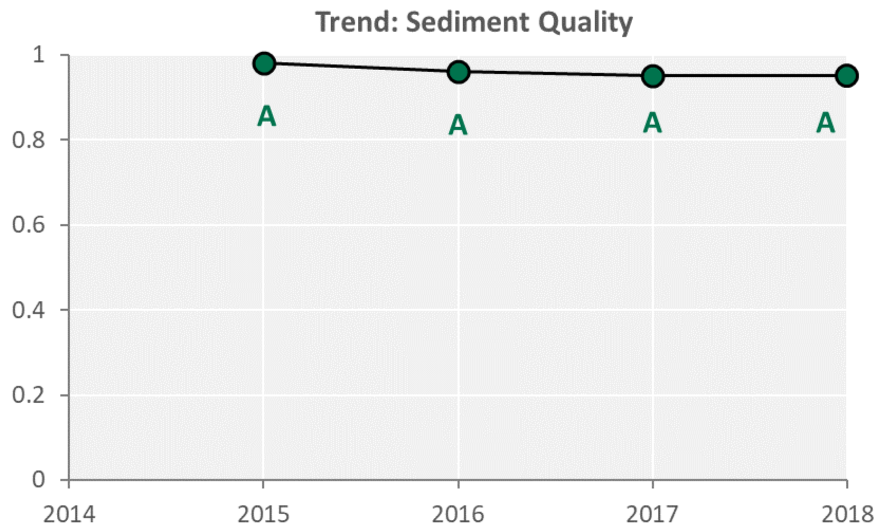


Figure 4.2: Changes in the overall sediment quality grade 2015–2018.

4.2. Habitats

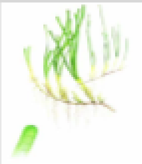
4.2.1. Seagrass

What is seagrass?

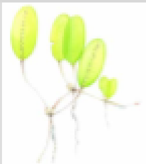
Seagrasses are the only flowering plants that can live submerged in the marine environment; and they play an important roles in the marine ecosystem. A range of marine species including turtles, dugongs, crabs, sea-cucumbers and some fish species graze on seagrass. There are four families of seagrass 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,

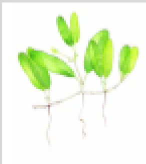
Zostera muelleri
Halophila ovalis
Halophila decipiens
Halophila spinulosa
Halodule uninervis



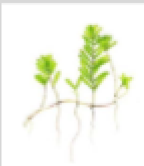
Zostera muelleri



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 scores and 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.

4.2.2. 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

Why species composition is important

Figure 4.3: Seagrasses at low tide.

Fisheries habitat – Fish species display a distinct preference for particular seagrasses. A shift in species composition can lead to a change in the abundance and diversity of fish, crabs and prawns.

Benthic invertebrate diversity – The abundance and diversity of benthic invertebrates differs between seagrass species. Changes in the benthic invertebrate community can result in the loss of important habitat functions and a decline in the secondary productivity of the meadow.

Coastal protection – Stiffness, biomass, density, leaf length and morphology all influence the coastal protection value of seagrass. Long-lived, slow-growing species provide the greatest protection.

Carbon sequestration – Species composition is a known variable for carbon sequestration. Larger bodied species are generally associated with higher sedimentary organic carbon stocks.

Resistance to disturbance – Larger bodied, persistent species generally have a higher physiological resistance to disturbance, while small-bodied colonising species have the ability to rapidly recover.

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 were 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

4.2.3. 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. 4). 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).

Between 2015 and 2017 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. A review in 2018 of how meadow scores were calculated led to a change of this method. The new method still defines overall meadow condition as the lowest indicator score when this score is either meadow area or biomass; however, where species composition is the lowest score, the overall meadow score is 50% of the species composition score and 50% of the next lowest score (area or biomass). This change was applied to correct an anomaly noted in the 2017 report card where the Inner Harbour received a score of zero owing to a 0 species composition score despite having very good and good biomass and area scores. The change acknowledges that the species composition is an important characteristic of a seagrass meadow in terms of defining meadow stability, resilience, and ecosystem services, but is not as fundamental as seagrass present.

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.

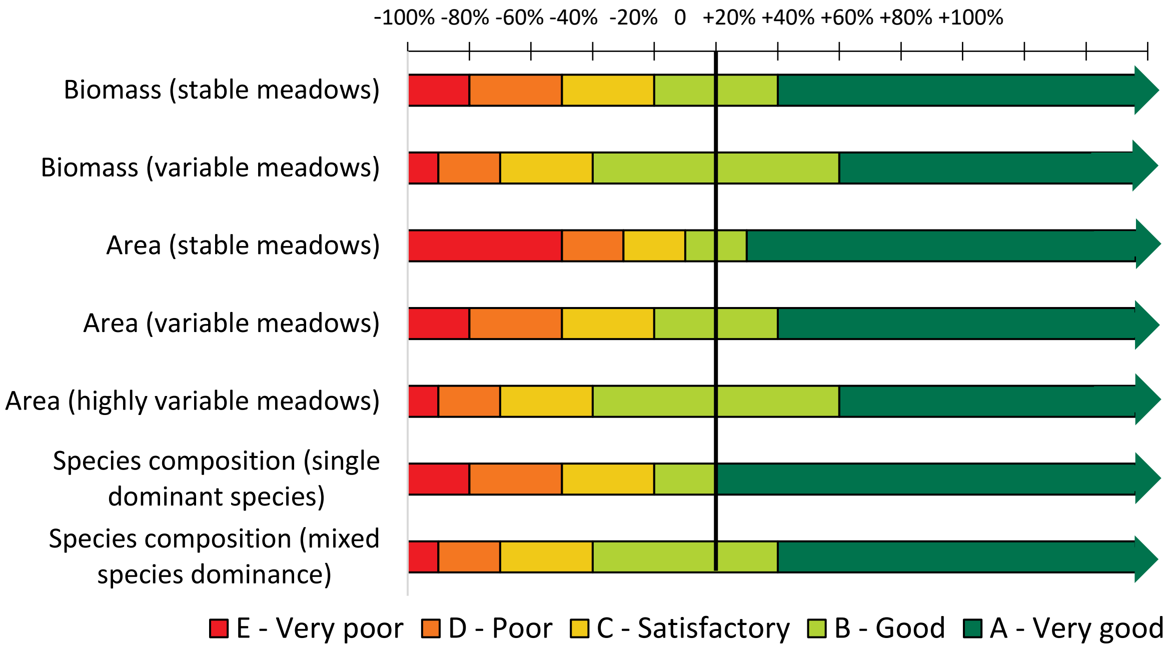


Figure 4.4: Threshold values between grades A to E varied for the seagrass meadow types for each of the three seagrass indicators (biomass, area and species composition). Each grade was determined by the percentage difference from a baseline of the 10-year mean.

4.2.4. Seagrass results

The overall seagrass score in 2018 was 0.40 indicating a poor overall condition for seagrass. This result is similar to the poor results recorded in the three previous report cards (2015–2017). At the zone level, South Trees Inlet (0.85) improved from a B in 2017 to an A; the Mid Harbour remained in poor condition although the score improved. The Narrows (0.42) and the Western Basin (0.45) both changed from a satisfactory to a poor condition, Rodds Bay (0.10) and the Inner Harbour remain in a very poor condition (Table 4.8).

Table 4.8: Scores for seagrass indicators (biomass, area and species composition) and overall meadow, zone and harbour score for the 2018 and overall zone scores for 2015–2017.

Zone	Meadow	Biomass score	Area score	Species composition score	Overall meadow score	Zone score 2018	*Zone score 2017*	*Zone score 2016*	*Zone score 2015*
1. The Narrows	21	0.42	0.74	0.66	0.42	0.42	*0.59*	*0.33*	*0.15*
3. Western Basin	4	1.00	0.80	0.16	0.48	0.45	*0.50*	*0.55*	*0.51*
	5	0.67	0.74	0.35	0.51				
	6	0.58	0.96	0.31	0.45				
	7	0.00	0.00	CR	0.00				
	8	0.87	0.53	0.29	0.41				
	52–57	1.00	0.86	1.00	0.86				
5. Inner Harbour	58	0.18	0.83	0.00	0.09	0.09	*0.00*	*0.14*	*0.41*
8. Mid Harbour	43	0.42	0.61	0.71	0.42	0.46	*0.34*	*0.35*	*0.56*
	48	0.68	0.89	0.32	0.50				
9. South Trees Inlet	60	0.85	0.97	1.00	0.85	0.85	*0.75*	*0.48*	*0.52*
13. Rodds Bay	94	0.01	0.19	0.71	0.01	0.10	*0.19*	*0.25*	*0.45*
	96	0.23	0.85	0.55	0.23				
	104	0.07	0.08	0.15	0.07				
Harbour score						**0.40**	***0.39***	***0.35***	***0.43***

CR: calculation restriction (A species composition score was not calculated because seagrass was absent.)

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 declined from satisfactory (0.59) in 2017 to poor (0.42) in 2018, owing to a poor biomass score. Meadow area improved from a satisfactory (0.59) condition in 2017 to a good condition (0.74) in 2018 with a ~30ha expansion from the previous year. Species composition also changed from satisfactory (0.63) to good (0.66) due to an increase of the dominant species *Zostera muelleri* subsp. *capricorni*. This is the first year that species composition has reached a good condition since 2012.

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 subtidal meadow. The overall score zone score declined from satisfactory (0.50) in 2017 to poor (0.45) in 2018. This was a result of poor or very poor species composition scores in four meadows and the disappearance of Meadow 7. When present, this monospecific meadow is comprised entirely of *Halophila decipiens*. This meadow is extremely variable owing to the marginal light and sensitivity of the species that occur in the subtidal environment. This meadow was last absent in 2011. Meadow 52–57 received very good scores for all measures, with biomass (1.00) at the highest level recorded since monitoring of the meadow began in 2009.

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 2018 zone score (0.09) was determined by species composition indicating a very poor condition. 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. Biomass (0.18) was very poor, and a substantial decline from the previous year when it was good. Area (0.83) was good, although this was very good in the previous year.

Zone 8 – Mid Harbour

The Mid Harbour has two monitored meadows 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 one where all three indicators have been classified as stable. Pelican Banks is intertidal, while Meadow 48 contains both intertidal and subtidal areas.

The overall score for the Mid Harbour in 2018 was 0.46 indicating a poor condition for seagrass in this zone. This was a result of a poor biomass score for Meadow 43 (0.42) and a poor species composition score for Meadow 48 (0.32). This is the third successive year that this zone has been in a poor condition. The area score for Meadow 43 (0.61) was similar to the satisfactory score (0.66) recorded in 2017. Meadow 48's area score (0.89) was very good and improved from 0.54 in the previous year as a result of an area increase to over 300ha, well above the baseline of 240ha. In 2017, both meadows 43 and 48 received satisfactory scores for species composition. However, in 2018, Meadow 43 improved to a good condition (0.71) with *Zostera muelleri* making up over 80% of the species biomass. Species composition in Meadow 48 declined to a poor condition (0.32) as the meadow was dominated by *Halophila spinulosa* and *Halophila ovalis* rather than the more persistent baseline species *Halophila uninervis*.

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. It is an intertidal meadow of aggregated patches of seagrass. The overall condition of this meadow has improved for the second year in succession moving from 0.48 in 2016 to 0.75 in 2017 and 0.85 in 2018, indicating a very good condition. The overall score for the meadow was determined by biomass which was at a level not seen since 2008.

The area score 0.97 was very good and similar to the score of 0.96 received in 2017, these scores indicate an area >20% above the baseline value. Species composition was 1.00 indicating a very good condition for this indicator and was similar to the score of 0.98 received in 2017. The meadow was almost entirely made up of *Z. muelleri* subsp. *capricorni* (99%) with the remaining fraction *H. uninervis.*

Zone 13 – Rodds Bay

There are three intertidal meadows in Rodds Bay comprising aggregated patches dominated by *Z. muelleri subsp. capricorni*. In 2018, the overall zone score was 0.10 indicating a very poor condition for this zone. A similar very poor condition was observed in the previous year. All three meadows have been affected by declines in biomass and over time these meadows have moved from areas of continuous seagrass cover to aggregated patches.

All biomass scores were very poor and lower than those recorded in the previous year. Meadow's 94 and 104 had very poor area scores, 0.19 and 0.08 respectively; these scores were similar to the scores recorded in 2017 when both meadows also received very poor scores. Meadow 96 (0.85) received a very good area score, an improvement from 2017 when it received a good score (0.65). Species composition scores were good (0.71) for Meadow 94, satisfactory (0.55) for Meadow 96 and very poor for Meadow 104 (0.15).

4.2.5. Seagrass conclusions

There were limited signs of seagrass recovery across the harbour between 2017 and 2018. The overall poor condition of the seagrass meadows for five consecutive years indicates the seagrass in Gladstone Harbour remains in a stable but vulnerable state (Figure 4.5). The overall seagrass condition for 2017 was poor (0.40) and similar to last year's score of 0.39. Overall zone condition declined in three zones and improved in three zones. The Narrows (0.42) and the Western Basin (0.45) both declined from a satisfactory condition to a poor condition and South Trees Inlet (0.85) improved from a good condition to a very good condition. The Mid Harbour (0.46) remained in a poor condition and the Inner Harbour and Rodds Bay remained in very poor condition. Seagrass condition is reported as the lowest of the three measure scores, biomass, area and seagrass composition. In the 2018 reporting year, species composition was responsible for overall meadow condition in 7 of the 14 monitored meadows, while biomass was responsible for the low scores in six meadows and area in one. However, seagrass biomass was the main determinant of overall meadow condition between 2002 and 2015, with the exception of the Western Basin, where lower scores for area and species composition have had a greater influence since 2010.

Since monitoring commenced in 2002, seagrass in Gladstone has undergone significant declines from 2010 (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's limits, just over 50km from Western Basin. Declines in seagrass biomass were also associated with high flows in the Calliope River, with the strongest associations occurring at monitored meadows closest to the river mouth (e.g. Wiggins Island in the Western Basin). Additional stressors to the seagrass communities may include grazing by dugongs and turtles; sediment changes may also be contributing to more recent declines.

The timing of flood-related seagrass declines in 2010 and 2011 prior to the start 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, cyclone activity and other stressors may have reduced the resilience and capacity for recovery of seagrass communities in Gladstone as it has in other locations in Queensland. The most recent assessment of seed banks in Gladstone Harbour, conducted in 2016 (Reason et al. 2017) found that they were substantiality reduced in comparison to previous studies. With diminishing seed reserves, the recovery of seagrass meadows may rely more heavily on remnant plants. Despite their reduced biomass, in the 2018 reporting year the total area of most monitoring meadows remained stable and at least some of the key foundation species remain. If favourable conditions for seagrass growth prevail, recovery can be rapid (Rasheed, 1999). Any anthropogenic activities in the region that cause additional stressors to seagrass meadows such as high turbidity, poor water quality or low light can delay any recovery.

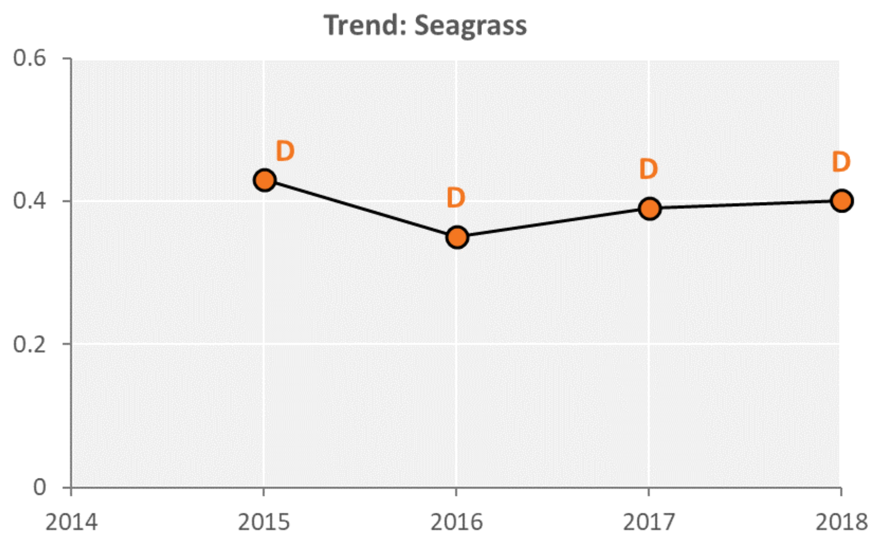


Figure 4.5: Changes in the overall seagrass grade 2015–2018.

Table 4.9: Grades for individual seagrass monitoring meadows from annual (November) surveys, 2002–2017 (Source: Bryant et al., 2018).

Zone	Meadow	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
1. The Narrows	21								A	B	C	C	E	E	D	C	D
3. Western Basin	4	B		C	D	B	A	B	A	E	D	C	D	D	C	B	D
	5	C		D	C	B	B	A	C	D	D	C	E	D	D	C	C
	6	B		D	C	C	B	B	A	E	E	D	D	B	B	C	D
	7	B		B	E	A	D	B	D	E	E	E	D	C	B	D	E
	8	A		E	E	B	B	C	B	C	E	D	E	D	D	E	D
	52–57								B	E	E	B	B	B	C	B	A
5. Inner Harbour	58	B		D	C	D	B	B	B	E	D	C	E	D	E	E	E
8. Mid Harbour	43	B		B	A	C	C	B	B	B	C	C	C	C	D	E	D
	48	B		C	B	A	A	B	E	D	D	D	C	C	D	C	C
9. South Trees Inlet	60	A		E	E	B	A	A	C	D	E	C	D	C	D	B	A
13. Rodds Bay	94	A		D	A	B	A	A	E	E	E	E	E	D	E	E	E
	96	B		D	C	B	A	A	B	D	E	D	E	D	D	D	E
	104	B		D	B	B	A	A	C	E	E	E	E	C	D	E	E

4.2.6. 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 Hill 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 sub-indicators of coral health were measured to calculate the coral score for the 2018 Gladstone Harbour Report Card.

1. Coral cover (%): the combined cover of hard and soft corals observed at the monitored reefs
2. Macroalgal cover (%): the cover of macroalgae observed at the monitored reefs
3. Juvenile coral density (no.m^{-2}): observed at the monitored reefs
4. Change in hard coral cover, averaged over three years to give the rate at which hard coral cover increases.

4.2.7. 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 2018 report card was conducted on 5 May 2018 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 5cm 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 or 2–5cm. 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.

4.2.8. Development of coral sub-indicators and grades

Each of the four coral sub-indicators was scored against a baseline founded on expert opinion and data from the MMP for inshore reefs. The baseline for each of the four sub-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 4.9 and Figure 4.6). The lowest score of 0.00 was set to represent the worst condition that could be expected in the local environment (Table 4.10 and Figure 4.6). 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.

A detailed description of the development of the critical values and thresholds for coral cover are presented in Thompson et al. (2015). The values and thresholds used for the combined coral cover are based on two prior assessments of coral cover on nearshore reefs. A broad-scale survey of nearshore reefs between Cape Tribulation and the Keppel islands conducted in 2004 using the same sampling methods as the Gladstone Harbour surveys returned a mean hard coral cover of 33% and 5% cover for soft corals (Sweatman et al., 2007). This 38% mean was observed after severe loss of corals owing to thermal bleaching in 1998 and 2002 and is considered too low for a threshold that would indicate a good condition (Thompson et al., 2015). A summary of coral surveys from over 100 sites between Cape Flattery and the Keppel Islands in 1996 prior to the bleaching events found a mean coral cover of hard corals of approximately 48% when the results were corrected to be consistent with MMP methods (Thompson et al., 2015). Allowing for some soft coral cover and rounding to an even percentage a 50% threshold for coral cover was proposed for the MMP and adopted for use in the Gladstone Harbour report card. Correcting for the differences in the grading schemes between the Reef Report Card and the Gladstone Harbour Report Card a 40% threshold is applied (Table 4.10). A figure consistent with surveys conducted in Gladstone Harbour (Mid Harbour) prior to 2009 where a mean hard coral cover of 39% was reported (BMT WBM, 2013). Although the BMT WBM (2013) report did not provide a mean estimate for soft coral cover, Figure 4.7 of that report indicates soft coral cover in the middle harbour ranged between ~4% and 40%.

However, it should be noted that while the thresholds and bounds were originally selected to be consistent with MMP reporting, changes to the thresholds and bounds for coral cover (Thompson et al., 2016a) mean that these thresholds are no longer consistent.

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 sub-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).

Owing to changes in the calculation of macroalgae scores in the MMP, including the use of reef specific water quality conditions (Thompson et al., 2016a), a direct comparison of macroalgae scores between the MMP and the Gladstone Harbour Report Card is not possible.

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 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 (Rogers, 1990) and a high cover of macroalgae (Foster et al., 2008 Mumby et al., 2008) will also negatively impact the number of juvenile colonies observed. This shows that juvenile coral density can indicate a reef's potential for recovery from disturbance given the current conditions.

Prior to 2018, coral in three size classes (0–2cm, > 2–5cm and > 5–10cm) were identified to the genus level and recorded. In 2018, the > 5–10cm class was discontinued to realign the methodology with that used in the MMP (Thompson et al., 2016a). This method was adopted by the MMP because limiting observations to the 0–5cm range more accurately focuses on juvenile rather than fragmented colonies or small colonies of slow growing corals, which may be mistaken for juvenile colonies and do not reflect recent recruitment and survivorship dynamics.

Thresholds for juvenile coral density 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 0 and 13 juvenile colonies per m^2 respectively (Table 4.10).

While the threshold has been adjusted to suit the grading scheme used in the Gladstone Harbour Report Card (Gladstone Harbour Threshold = 0.5, MMP threshold = 0.4), the thresholds and bounds are broadly consistent with those used in the MMP (see Thompson et al., 2016a).

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 sub-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 (sub-indicator score 0.5) and those not meeting the lower confidence interval of the predicted change received an sub-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.

While the threshold has been adjusted to suit the grading scheme used in the Gladstone Harbour Report Card (Gladstone Harbour Threshold = 0.5, MMP threshold = 0.4), the thresholds and bounds are broadly consistent with those used in the MMP (see Thompson et al., 2016a).

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

Sub-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	4.6 m^{-2}	13 m^{-2}	0 m^{-2}
Change in hard coral cover	Lower 95% confidence interval	Twice the upper 95% confidence interval	Twice the lower 95% confidence interval

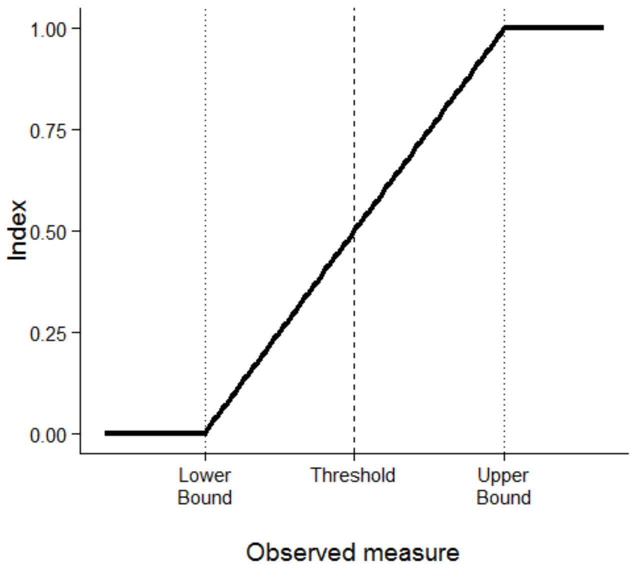


Figure 4.6: Generic scoring of the coral sub-indicators based on the threshold and bounds outlined in Table 4.9.

Aggregation of sub-indicator scores

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

4.2.9. Coral results

The overall grade for the 2018 report card was an E (0.24). This was a result of 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 cover. While coral cover (0.05), juvenile density and macroalgae cover received similar scores to 2017, the change in hard coral cover declined from 0.40 in 2017 to 0.32 in 2018. The Mid Harbour received a poor zone score (0.27), while the Outer Harbour received a very poor score (0.20), primarily a result of a very low score for macroalgal cover (Table 4.11).

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 in previous surveys. In 2009, a mean cover of 39% was recorded for hard corals in the Mid Harbour zone (BMT WBM, 2013). Although this figure does take into account soft coral cover, estimates of soft coral cover within the report range between 4 and 40% for the Mid Harbour. A visual estimate of hard coral cover at Seal Rocks North (Outer Harbour) in December 2012 was around 50% (R.C. Babcock, personal communication in Thompson et al., 2015).

The mean cover of macroalgae remains high resulting in an overall very poor score (0.22) for the fourth consecutive year (4.11). Farmers Reef (0.17), Manning Reef (0.00), and north (0.00) and south Seal Rocks received very poor scores (Table 4.12). Farmers Reef declined from a very good score in 2017, whereas the other three reefs were in very poor condition in 2017. Rat Island received a very good score (1.00), consistent with the very good score it received in 2017. Facing Island 2 received a poor score (0.46) similar to the poor score in 2017. Macroalgae communities in the Outer Harbour continue to be dominated by the brown macroalgae genera, *Sargassum* and *Lobophora*. Species composition in the Mid Harbour has been more variable, and this year was dominated by the red macroalgae *Asparagopsis* at Farmers and Manning reefs and the brown macroalgae *Lobophora* at Facing Island.

The size for juvenile corals 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. Over three years of monitoring (2015–2017) there has been a steady increase in juvenile density recorded at the harbour level. The average number of juvenile corals ≤5cm was 3.70 per square metre in 2015, increased to 4.23 per square metre in 2017 and then declined in 2018 to 3.68 per square metre in 2015 (Table 4.14).

Scores for juvenile coral density ranged from very poor at Facing Island 2 (0.16) to satisfactory at Farmers Reef (0.53). All other reefs—Manning (0.40), Rat Island (0.28) and Seal Rocks north (0.42) and south (0.48)—had poor scores. The score for juvenile coral density was similar to that recorded in 2016 and 2017 (Table 4.12).

The overall change in hard coral cover score remained poor 0.32, compared to 0.40 in 2017. The coral cover scores at Mid Harbour (0.30) and Outer Harbour (0.33) also remained poor (Table 4.11). Scores at the reef level were uniformly poor. Facing Island 2 (0.33), Farmers Reef (0.33), Manning Reef (0.27) and Seal Rocks South (0.33) all declined from a satisfactory condition in 2017. Seal Rock North (0.34) remained in a poor condition and Rat Island (0.26) was the only reef with an improved grade moving from a very poor condition in 2017 to a poor condition (Table 4.12).

Table 4.11: Coral indicator scores for the Mid Harbour and Outer Harbour and overall zone and harbour scores (Costello et al., 2018).

Zone	Coral cover	Change in hard coral cover	Macroalgal cover	Juvenile density	Overall score
8. Mid Harbour	0.06	0.30	0.41	0.34	0.27
11. Outer Harbour	0.05	0.33	0.00	0.45	0.20
Harbour score	**0.05**	**0.32**	**0.22**	**0.39**	**0.24**

Table 4.12: Individual coral indicator scores site level (Costello et al., 2018).

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	8.75	0.11	–1.0	0.33	14.50	0.46	1.46	0.16
Farmers Reef	3.0	0.04	–4.13	0.33	18.00	0.17	5.15	0.53
Manning Reef	0.13	0.00	–0.13	0.27	37.50	0.00	3.64	0.40
Rat Island	7.00	0.09	0.52	0.26	1.50	1.00	2.62	0.28
Seal Rocks North	0.63	0.01	0.38	0.34	63.13	0.00	3.87	0.42
Seal Rocks South	6.88	0.09	–2.63	0.33	42.13	0.00	4.4	0.48

Table 4.13: Number of juvenile hard coral colonies in two size classes (Costello et al., 2018).

Zone	Reef	Year	Size-class categories	
			< 2cm	2–5cm
			Estimated age	
			~1 year	1–2 years
8. Mid Harbour	Facing Island 2	*2015*	*107*	*28*
		2016	*67*	*58*
		2017	*32*	*58*
		2018	19	20
	Farmers Reef	*2015*	*32*	*17*
		2016	*37*	*26*
		2017	*64*	*39*
		2018	56	39
	Manning Reef	*2015*	*52*	*6*
		2016	*55*	*40*
		2017	*49*	*29*
		2018	46	45
	Rat Island	*2015*	*19*	*23*
		2016	*48*	*43*
		2017	*44*	*28*
		2018	30	26
11. Outer Harbour	Seal Rocks North	*2015*	*111*	*31*
		2016	*80*	*48*
		2017	*55*	*64*
		2018	42	69
	Seal Rocks South	*2015*	*52*	*30*
		2016	*27*	*55*
		2017	*58*	*58*
		2018	32	64

Table 4.14: Overall juvenile density values and scores 2015–2018 based on juvenile colonies in the 0–2cm and 2–5cm size classes.

Whole harbour	Year	Juvenile density (m^2)		Report card score
		Mean	SD	
	2015	*3.70*	*0.71*	*0.28*
	2016	*3.90*	*0.06*	*0.40*
	2017	*4.23*	*0.41*	*0.42*
	2018	3.68	0.65	0.39

4.2.10. Coral conclusions

The overall grade for corals declined from a D (0.28) in 2017 to an E (0.24) in 2018 (Figure 4.7, Table 4.11). While all four coral indicator scores remained broadly similar to the previous year, the cumulative effect of slightly lower scores across these indicators has resulted in the shift of grade. Initial coral monitoring in 2015 noted very low coral cover which reflected the severe impacts of the 2013 flooding. Subsequent monitoring, particularly that conducted in 2018, suggests that the cumulative impacts of the 2013 flooding and ongoing pressures, including high macroalgal cover have reduced the potential for the recovery of coral communities in Gladstone Harbour.

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 2013 where 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.

While scores for juvenile density improved between 2015 and 2017, they declined for the first time in 2018 (Table 4.14). The high cover of macroalgae may be affecting coral recruitment processes by occupying available space for juvenile settlement. Ongoing competition between coral and macroalgae also contributes to the poor score for the change in hard coral cover. The widespread presence of the bio-eroding sponge *Cliona orientalis* continues to be the most significant contributor to coral mortality within the harbour (Table 4.16) and is also contributing to the poor score for the change in the hard coral cover sub-indicator.

In the broader context of inshore reefs on the Great Barrier Reef, the Coral Index for reefs in Gladstone Harbour falls in the bottom 25% of those monitored by the MMP. The conditions of reefs in the harbour are comparable with those in the inshore areas of Keppel Bay where extremely low coral cover, high macroalgae cover and low juvenile densities are also inhibiting the recovery of coral communities (Thompson et al., 2018).

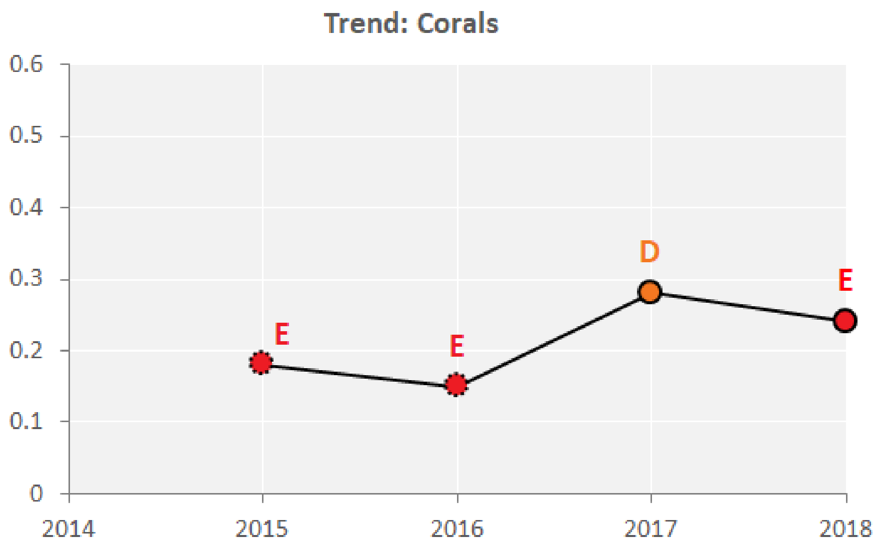


Figure 4.7: Changes in the overall coral grade 2015–2018.

Table 4.15: A comparison of coral indicator scores for the Mid Harbour and Outer Harbour for surveys conducted from 2015 to 2018 (Costello et al., 2018).

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*
		2018	0.11	0.33	0.16	0.46	0.27
	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*
		2018	0.04	0.33	0.53	0.17	0.27
	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*
		2018	0.00	0.27	0.40	0.00	0.17
	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*
		2018	0.09	0.26	0.28	1.00	0.41
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*
		2018	0.01	0.34	0.42	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*
		2018	0.09	0.33	0.48	0.00	0.22

Table 4.16: Causes of coral mortality at the time of the 2015 to 2018 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. Bio-eroding sponge is primarily *Cliona orientalis* (Thompson et al., 2016b; Costello et al. 2017; Costello et al., 2018).

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
		2018	Bio-eroding sponge	*Cyphastrea*	1
				Porites	13
	Farmers Reef	*2015*	Bio-eroding sponge	*Cyphastrea*	4
				Favia	1
		2016	Bio-eroding sponge	*Cyphastrea*	9
		2017	Bio-eroding sponge	*Cyphastrea*	9
				Favia	1
		2018	Bio-eroding sponge	*Cyphastrea*	12
				Plesiastrea	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*	8
		2018	Bio-eroding sponge	*Cyphastrea*	6
				Turbinaria	5
11. Outer Harbour	Seal Rocks South	*2015*	Bio-eroding sponge	*Turbinaria*	3
		2016	*Atramentos necrosis* (coral disease)	*Turbinaria*	1
			Bleaching	*Pocillopora*	2
			Bio-eroding sponge	*Turbinaria*	4
			Unknown	*Turbinaria*	1
		2017	Bio-eroding sponge	*Turbinaria*	6
			White syndrome (Coral disease)	*Turbinaria*	6
				Psammocora	1
			Bleaching	*Montipora*	1
		2018	Bio-eroding sponge	*Turbinaria*	5
			Bleaching	*Montipora*	1
	Seal Rocks North	*2017*	Bleaching	*Montipora*	1

4.2.11. Mangroves

Mangroves occur in the tidal wetlands of all 13 GHHP environmental reporting zones. Their total extent in 1999 was around 5,013 ha (Duke et al., 2003) for all zones minus Colosseum Inlet, Outer Harbour and Rodds Bay (as GHHP zones 1 to 10). These coastal ecosystems consist of flowering trees and shrubs adapted to marine and estuarine tidal conditions. Adaptions to cope with salt-saturated soils and tidal inundation include; exposed above ground breathing roots, salt-excreting leaves, and live water-dispersed propagules (Duke 2011). In addition to providing valuable habitat and nursery areas for aquatic species such as barramundi, mud crabs and prawns. The canopy, woody stems, shaded mud flats and exposed roots provide numerous niches for birds and other species. Mangroves preform a number of vital ecosystem services. Coastal mangroves protect seagrass and coral communities by filtering catchment runoff and limiting shoreline erosion by reducing wave energy. Mangroves are highly productive and have a high capacity for carbon storage or export (UNEP, 2014).

Mangroves and tidal saltmarsh vegetation have changed considerably across the Port Curtis region since the 1940s especially around the central port area where there has been substantial urban and port development resulting in the loss of tidal wetland areas. Throughout this region (GHHP zones 3 to 10) there was a total loss of mangrove area of 1470 hectares (38%) between 1941 and 1999 and a total loss of 1342 hectares 34% over the same time period (Duke et al. 2003). Primarily these losses were associated with reclamation, particularly around the mouths of the Calliope and Boyne Rivers and Auckland Inlet. However natural fluctuations in climate have also resulted in changes to tidal wetland areas as a result of depositional gain or loss, and ecotone shifts (Duke et al. 2003). While these changes are historically important it is impractical to use a 1940s distribution of mangroves as a baseline for the Gladstone Harbour Report Card, both in terms of collecting suitable data and in being able to return to a past distribution. Hence the baseline adopted for two of the three mangrove indicators (mangrove extent and canopy condition) is the five-year period from 2013–14—the year in which the Gladstone Harbour Pilot Report Card was released (GHHP 2014). The third indicator, shoreline condition, is based on the current condition.

4.2.12. Mangrove data collection

Mangrove assessment area

Unlike the other environmental indicators, which are aquatic, mangroves exist in tidal wetlands which are not included in the 13 GHHP environmental reporting zones. To report on mangroves, the existing zones have been expanded to include the tidal wetland areas. As mangrove health can be influenced by the surrounding catchment area, the expanded zones are split where necessary to conform to the sub-catchment areas derived from the Queensland Government drainage sub-basin areas (Department of Natural Resources Mines and Energy, 2009). This results in the expanded zones being split into a total of 22 sub-zones (Table 4.17, Figure 4.8). For all mangrove indicators the zone score is calculated as the average of the sub-zone scores.

Table 4.17: GHHP environmental reporting zones and mangrove monitoring sub-zones.

Existing GHHP Environmental monitoring zone	Mangrove monitoring zones
1. The Narrows	1a The Narrows
	1b The Narrows
2. Graham Creek	2 Graham Creek
3. Western Basin	3a Western Basin
	3b Western Basin
4. Boat Creek	4 Boat Creek
5. Inner Harbour	5a Inner Harbour, Enfield Creek
	5b Inner Harbor Barney Point
6. Calliope Estuary	6 Calliope Estuary
7. Auckland Inlet	7 Auckland Inlet
8. Mid Harbour	8a Mid Harbour, Curtis Island
	8b Mid Harbour, Facing Island
	8c Mid Harbour, West
9. South Trees Inlet	9 South Trees Inlet
10. Boyne Estuary	10 Boyne Estuary
11. Outer Harbour	11a Outer Harbour, Wild Cattle Creek
	11b Outer Harbour, Split End
12. Colosseum Inlet	12a Colosseum Inlet, Main
	12b Colosseum Inlet, Hummock Hill
13. Rodds Bay	13a Rodds Bay, East
	13b Rodds Bay, West
	13c Rodds Bay, Pancake Creek
	13d Rodds Bay, Hummock Hill

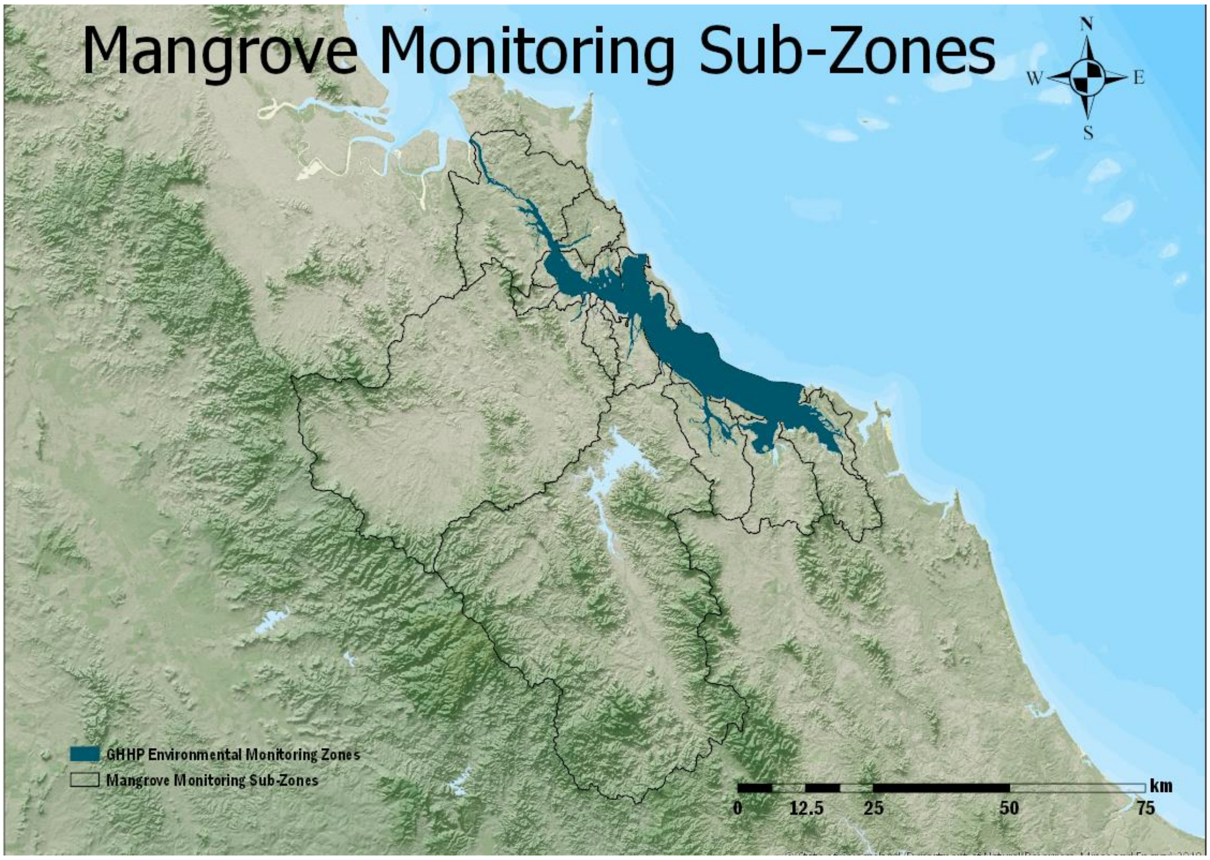


Figure 4.8: Mangrove sub-zones.

Mangrove data collection

All mangrove data used to derive the report card grades and scores for the three mangrove indicators was derived from either satellite imagery (extent and canopy) or aerial photography (shoreline) following the Shoreline Video Assessment Method (Mackenzie et al., 2016). Baselines for extent and canopy were derived from satellite imagery and no baseline was used for shoreline as the metric is derived statistically from the 2017–18 aerial imagery (Table 4.18).

Table 4.18: Mangrove indicators and data used to calculate the 2018 mangrove grades and scores.

Indicator	2018 data	Baseline data
Extent Change in the WCI from the 5 year mean and the year before	2017–18 satellite imagery (Landsat 8)	2013–14 to 2017–18 satellite imagery (Landsat 8)
Canopy Variation in NDVI from the 5 year mean and the year before	2017–18 satellite imagery (Landsat 8)	2013–14 to 2017–18 satellite imagery (Landsat 8)
Shoreline Percent live/dead tress each 50m interval of mangrove shoreline	June 2018 helicopter filming of 22 sub-zones	No baseline, score calculated statistically (see Table 4.20)

Satellite imagery

To determine scores for the extent and canopy sub-indicators Landsat 8 images with a 30m spatial resolution (Gladstone Harbour: path 91, row 76. Rodds Bay: path 91, row 7) for the 2013–14 to 2017–18 period were used. Masks and models created in a previous study were used (Duke et al., 2017) to analyse the satellite imagery.

Aerial photography

An aerial shoreline survey of shorelines bordering the 22 mangrove sub-zones was undertaken in June 2018. Either a Nikon D800E or D850 camera with a 50mm lens was used to take overlapping high-resolution photographs of the shoreline. All images were taken from an open R44 helicopter flying perpendicular to the shoreline at an altitude of approximately 150m.

4.2.13. Development of mangrove indicators and grades

Mangrove extent

Tidal wetlands within the Gladstone Region often occupy soft sediment tidal slopes between mean sea level and highest tide level. These tidal wetlands can consist of mangroves, saltmarsh and saltpans with the relative proportion of area occupied being influenced by climate, particularly rainfall, and sea level. Changes in the spatial extent of mangroves, saltmarsh and saltpans measured as the total area occupied by each vegetation type, are readily evident after extreme events such as severe flooding and storms, large oil spills or larger scale reclamation work. However, while this is an important aspect of change, it can be an insensitive measure and difficult to determine along ecotones where different vegetation types meet. To track the subtle and ongoing changes that are likely to occur along habitat ecotones, a percent cover ratio, the Wetland Cover Index (WCI), is used.

The raw WCI score is calculated as the relative proportion of mangrove within the tidal wetland area in each mangrove sub-zone (Table 4.19, Figure 4.8) determined from 2017 mapping.

The area of mangrove and saltmarsh/saltpan within the mangrove sub-zones was determined from 2017–18 Landsat 8 imagery. A minimum mangrove normalised difference vegetation index (NDVI) value threshold ($Mang_{MIN}$) was determined as less than two standard deviations from the mean 2017 mangrove NDVI value (0.39). A point layer ($30m^2$ Landsat 8 pixel centroids) was created for the tidal wetland areas within the mangrove sub-zones. Points were classified as either mangrove, saltmarsh/saltpan or open water.

To determine mangrove loss and gain, the 2017–18 NDVI classification (number of points that were mangrove or saltmarsh/saltpan) was compared to the 2013–14 maximum value for all points as follows.

Mangrove loss: NDVI 2013–14 ≥ $Mang_{MIN}$ and the 2017 SPOT classification = saltmarsh/saltpan or water.

Mangrove gain: NDVI 2013–14 < $Mang_{MIN}$ and the 2017 SPOT classification = Mangrove

Percent change represents the relative nett change in mangrove area between 2013–14 and 2017–18, with the values adjusted to reflect tidal area loss owing to erosion.

The grading system for mangrove extent (Table 4.19) is based on the WCI score for 2017–18 and the observed change between 2013–14 and 2017–18.

Table 4.19: Mangrove extent scoring classification system.

	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)
Wetland Cover Index (WCI) 2017–18	WCI = 0.85– 1.00	WCI = 0.65–0.84	WCI = 0.50–0.64	WCI = 0.25–0.49	WCI = 0.00–0.24
Mangrove loss 2013–14 to 2017–18	0–1.5% Loss	1.6–3.5% Loss	3.6–5.0% Loss	5.1–7.5% Loss	>7.5% Loss
Wetland Cover Index nett mangrove extent change (gain & loss) 2013–14 to 2017–18	0–1.5% Deviation	1.6–3.5% Deviation	3.6–5.0% Deviation	5.1–7.5% Deviation	>7.5% Deviation

Canopy condition

Mangrove canopy density measured at a forest scale can indicate mangrove condition and, when measured over time, can predict a forest's capacity to recover from disturbances. Healthy forests typically have a dense canopy cover. However, local or regional stressors such as long-term rainfall and sea-level variability, localised herbivory, altered hydrological regimes, increased sediment and nutrient loads, and localised pollution events, such as oil spills, can cause mangrove health to decline.

Exposure of mangroves to these stressors can lead to a loss of plant productivity and reduced leaf production. Removing a stressor can result in remnant living trees increasing leaf production and gaps created by dead trees being occupied by mangrove seedlings. Plant productivity is expressed as canopy density and forest resilience can be measured as the rate and extent to which a forest recovers from a stress event.

The canopy condition measure uses the NDVI which measures the relative absorption and reflectance of red and near-infra red light. Healthy forests with a dense canopy cover and high leaf chlorophyll content absorb high levels of red light and reflect near-infra red light and will have a high NDVI value. Conversely, forests in poorer condition—fewer leaves and sparser canopies—will have lower NDVI values.

To determine the relationship between NDVI value and mangrove health, a 2016 mangrove extent layer for the mangrove sub-zones was generated from multiple available sources (see Duke et al., 2017). ArcGIS 10.5.1 was used to divide the mangrove extent layer into a 30m^2 grid consistent with the 30m^2 pixel size of the Landsat 8 satellite imagery used to derive the NDVI values. A point layer was generated from the centroids of the 30m^2 squares.

Google Earth engine was used to generate an NDVI value from all available cloud-free Landsat 8 imagery for each of the $30m^2$ satellite pixels that were within the mangrove extent layer across five, one-year periods (2013–14 to 2017–18) from 1 July to 30 June. This one-year period corresponds with the report card year and the annual time frame captures peak mangrove seasonal productivity which occurs in the Gladstone Region between March and April (Duke, 2002; Duke & Burns, 2003; Duke et al., 2000 cited in Duke & Mackenzie., 2018).

Greenest pixel values (maximum NDVI value) were derived at each point of the point layer. For each point, a total of five greenest pixel values were derived for each year. A mangrove extent layer presented in Duke et al. (2017), which had high classification accuracy but high degrees of omission error, was used to derive a threshold of mangrove NDVI values. Based on the standard deviation of the mean mangrove NDVI values, it was determined that 0.3 was the minimum mangrove NDVI value for the GHHP region. A maximum value for NDVI 0.75 was determined and this range was used to derive the report card grades and scores range (Table 4.20).

Three NDVI measures were used to determine the overall canopy condition score for each mangrove sub-zone and each of the 13 environmental reporting zones (average of the sub-zone scores).

1) A mean mangrove point 2017–18 NDVI value was used to compare spatial differences between zones.
2) A mean annual change in mean mangrove NDVI point value between 2016–17 and 2017–18 was used to compare short-term temporal change.
3) The five-year mean mangrove NDVI point value between 2013–14 and 2017–18 was used to compare temporal change.

The grade range for the inter-annual comparison (1) was calculated by dividing the identified range of mangrove NDVI values. Scores for the inter-annual NDVI comparisons (2 & 3) were determined using a z-test to compare sub-zone values with a regional mean. Where sub-zone mean inter-annual NDVI difference values were significantly greater or less than the regional expected mean value, Cohen’s d was used as a measure of relative effect size to determine the extent to which values deviated from the mean (Table 4.19). The regional mean value was used to reflect that climatic conditions are likely to affect all mangroves across all zones between years, causing overall declines or improvements in mangrove NDVI.

The overall mean of the three NDVI indicators was used to generate the final canopy condition score for each of the 13 environmental reporting zones.

Table 4.20: Classification of canopy condition scores derived from NDVI values 2013–14 to 2017–18.

<table>
<tr><th></th><th>A Very good (0.85–1.00)</th><th>B Good (0.65–0.84)</th><th>C Satisfactory (0.50–0.64)</th><th>D Poor (0.25–0.49)</th><th>E Very poor (0.00–0.24)</th></tr>
<tr><td>Mean NDVI 2017–18</td><td>0.81–0.73</td><td>0.72–0.63</td><td>0.62–0.55</td><td>0.54–43</td><td>0.42–0.30</td></tr>
<tr><td>Mean NDVI change 2016–17 to 2017–18</td><td rowspan="2">Mean inter-annual NDVI difference significantly (p<0.05) greater than regional mean and effect size (Cohen’s d) > 0.70</td><td rowspan="2">Mean inter-annual NDVI difference significantly (p<0.05) greater than regional mean and effect size (Cohen’s d) 0.69 to 0.30</td><td rowspan="2">Mean inter-annual NDVI difference not significantly (p>0.05) different from regional mean.
OR
Mean inter-annual NDVI difference significantly (p<0.05) greater than regional mean and effect size (Cohen’s d) 0.29 to 0.0</td><td rowspan="2">Mean inter-annual NDVI difference significantly (p<0.05) less than regional mean and effect size (Cohen’s d) –0.01 to –0.50</td><td rowspan="2">Mean inter-annual NDVI difference significantly (p<0.05) less than regional mean and effect size (Cohen’s d) –0.51 to –1.0</td></tr>
<tr><td>Mean 5-year NDVI change 2013–14 to 2017–18</td></tr>
</table>

Shoreline condition

Shoreline mangroves can respond rapidly to changes in tidal conditions, water quality and climate. They provide high ecosystem service value by protecting shorelines from episodic severe erosion events such as storms and flooding. As such their status is a useful indication of shoreline condition.

Shoreline condition was assessed and scored using the Shoreline Video Assessment Method developed by Mackenzie et al. (2016). This method matches high resolution oblique aerial photographs with shoreline sampling points at 50m intervals created from the 0-metre contour line using a 5m digital elevation model (Geosciences Australia, 2018). At each sampling point the presence or absence of individual dead mangroves along the shoreline or within the shoreline fringing zone was noted.

The oblique aerial image assessment provided a representation of the proportion of shoreline fringe mangrove forest with dead mangroves present within each of the GHHP water quality zones. A chi-square goodness-of-fit analysis with unequal proportions was conducted on dead mangrove frequency using SPSS v.24 to test the hypothesis that the frequency of observations of shoreline mangrove with dead individuals in each mangrove sub-zone was the same as the expected frequency for the overall study area. Where the observed frequency of fringing mangroves with dead mangrove individuals present in the target zone (O) was significantly higher or lower than the expected overall frequency (E), Cramér’s V (SQRT(X2/n) was calculated as a measure of effect size. The effect size based on the value of Cramér’s V was classified following Cohen (1988), where scores less than 0.5 represent low to moderate effect size and scores greater than or equal to 0.5 represent a large effect size. Scores were assigned based on the results of the chi-square analysis and the resulting Cramér's V following Table 4.21.

Table 4.21: Classification of shoreline condition scores.

	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)
Shoreline condition score (Dead mangrove frequency)	0–7.5%	7.6–17.5%	17.6–25%	25.1–37.5%	>37.5%
Seasonally adjusted Shoreline condition score (Relative dead mangrove frequency)	Observed dead mangrove frequency significantly greater than expected harbour value (p<0.05), Cramér's V 1.0 to 0.7	Observed dead mangrove frequency significantly greater than expected harbour value (p<0.05), Cramér's V 0.69 to 0.30	Observed dead mangrove frequency not significantly different from expected harbour value (p<0.05) OR Observed dead mangrove frequency significantly greater than expected harbour value (p<0.05), Cramér's V 0.29 to 0.0	Observed dead mangrove frequency significantly less than expected harbour value (p<0.05), Cramér's V < 0.30 to 0.69	Observed dead mangrove frequency significantly less than expected harbour value (p<0.05), Cramér's V 0.7 to 1.0

4.2.14. Mangrove results

The overall grade for mangroves in Gladstone Harbour was 0.60 (C). Six zones were considered to be in good condition and five zones were considered satisfactory (Table 4.22). Two zones Inner Harbour (0.43) and Boyne Estuary (0.41) received an overall poor grade—a result of a very poor shoreline condition score (0.14) in Boyne Estuary. Severe flood impacts, affecting the shoreline trees, were observed in this zone. The remaining six zones all had a satisfactory overall condition.

Table 4.22: Overall mangrove zone and harbour scores for the 2018 reporting year.

Zone	Mangrove extent	Mangrove canopy condition	Shoreline condition	Zone score 2018
1. The Narrows	0.67	0.40	0.61	0.56
2. Graham Creek	0.82	0.47	0.71	0.67
3. Western Basin	0.74	0.60	0.38	0.57
4. Boat Creek	0.64	0.61	0.63	0.63
5. Inner Harbour	0.44	0.37	0.47	0.43
6. Calliope Estuary	0.85	0.59	0.56	0.67
7. Auckland Inlet	0.66	0.63	0.74	0.68
8. Mid Harbour	0.39	0.55	0.70	0.55
9. South Trees Inlet	0.77	0.49	0.58	0.61
10. Boyne Estuary	0.60	0.49	0.14	0.41
11. Outer Harbour	0.79	0.60	0.57	0.65
12. Colosseum Inlet	0.84	0.58	0.64	0.69
13. Rodds Bay	0.76	0.68	0.68	0.71
Harbour score	**0.69**	**0.55**	**0.57**	**0.60**

Mangrove extent

This indicator is derived from estimates to changes to mangrove canopy cover between 2013–14 and 2017–18 relative to saltmarsh and saltpan within tidal wetlands. Mangrove extent scores, indicate a nett gain in mangrove area relative to saltmarsh and saltpan within the sub-zone. Calliope Estuary (0.85) had a very good score, and ten zones had good or satisfactory scores. Only two zones, Inner Harbour (0.44) and Mid Harbour (0.39), had poor scores indicating a nett loss of mangroves (Table 4.23).

Table 4.23: Wetland cover index, change scores and overall zone scores for mangrove extent.

Zone	Mangrove sub-zone	WCI 2017–18	WCI change score	Mangrove loss score	Sub-zone score	Zone extent score
1. The Narrows	1a. Mainland	0.61	0.93	0.78	0.77	0.67
	1b. Curtis Island	0.61	0.61	0.50	0.57	
2. Graham Creek	2. Graham Creek	0.75	0.91	0.79	0.82	0.82
3. Western Basin	3a. Mainland	0.44	0.76	0.86	0.69	0.74
	3b. Curtis Island	0.66	0.88	0.86	0.80	
4. Boat Creek	4. Boat Creek	0.37	0.68	0.86	0.64	0.64
5. Inner Harbour	5a. Enfield Creek	0.54	0.98	0.77	0.75	0.44
	5b. Barney Point	0.17	0.22	0.00	0.13	
6. Calliope Estuary	6. Calliope Estuary	0.83	0.97	0.76	0.85	0.85
7. Auckland Inlet	7. Auckland Inlet	0.72	0.47	0.80	0.66	0.66
8. Mid Harbour	8a. Curtis Island	0.24	0.58	0.00	0.27	0.39
	8b. Facing Island	0.23	0.94	0.40	0.52	
9. South Trees Inlet	9. South Trees Inlet	0.60	0.91	0.80	0.77	0.77
10. Boyne Estuary	10. Boyne Estuary	0.76	0.85	0.18	0.60	0.60
11. Outer Harbour	11a. Wild Cattle Creek	0.96	0.98	0.91	0.95	0.79
	11b. Split End	0.47	0.63	0.77	0.62	
12. Colosseum Inlet	12a Colosseum Creek	0.72	0.91	0.85	0.85	0.84
	12b. Hummock Hill	0.72	0.80	0.82	0.83	
13. Rodds Bay	13a. East	0.75	0.90	0.87	0.87	0.76
	13b. West	0.68	0.83	0.79	0.79	
	13c. Pancake Creek	0.63	0.93	0.80	0.80	
	13d. Hummock Hill	0.35	0.89	0.57	0.57	
Harbour score						**0.69**

Canopy condition

This indicator was calculated from estimates for the NDVI value of mangrove forest canopies within the 13 environmental reporting zones. Rodds Bay (0.68) had a good canopy condition, seven zones were satisfactory (0.50 – 0.65) and The Narrows (0.40), Graham Creek (0. 47), the Inner Harbour (0.37), South Trees Inlet (0.49) and Boyne Estuary (0.49) had poor canopy condition (Table 4.24).

Table 4.24: Canopy condition, NDVI scores, one and five-year change and overall scores for canopy condition.

Zone	Mangrove sub-zone	2018 NDVI score	1-year change	5-year change	Sub-zone score	Zone score
1. The Narrows	1a. Mainland	0.61	0.38	0.40	0.46	0.40
	1b. Curtis Island	0.57	0.34	0.14	0.34	
2. Graham Creek	2. Graham Creek	0.60	0.45	0.35	0.47	0.47
3. Western Basin	3a. Mainland	0.63	0.51	0.70	0.62	0.60
	3b. Curtis Island	0.64	0.39	0.65	0.57	
4. Boat Creek	4. Boat Creek	0.62	0.50	0.71	0.61	0.61
5. Inner Harbour	5a. Enfield Creek	0.60	0.33	0.34	0.42	0.37
	5b. Barney Point	0.51	0.00	0.56	0.32	
6. Calliope Estuary	6. Calliope Estuary	0.61	0.57	0.59	0.59	0.59
7. Auckland Inlet	7. Auckland Inlet	0.54	0.55	0.87	0.63	0.63
8. Mid Harbour	8a. Curtis Island	0.60	0.37	0.86	0.61	0.55
	8b. Facing Island	0.57	0.29	0.65	0.49	
9. South Trees Inlet	9. South Trees Inlet	0.61	0.42	0.44	0.49	0.49
10. Boyne Estuary	10. Boyne Estuary	0.57	0.44	0.50	0.49	0.49
11. Outer Harbour	11a. Wild Cattle Creek	0.62	0.64	0.16	0.48	0.60
	11b. Split End	0.59	0.62	0.96	0.72	
12. Colosseum Inlet	12a Colosseum Creek	0.63	0.55	0.53	0.58	0.59
	12b. Hummock Hill	0.64	0.48	0.64	0.59	
13. Rodds Bay	13a. East	0.67	0.73	0.72	0.72	0.68
	13b. West	0.62	0.78	0.73	0.73	
	13c. Pancake Creek	0.63	0.59	0.64	0.64	
	13d. Hummock Hill	0.59	0.50	0.62	0.62	
Harbour score						**0.54**

Shoreline condition

Across the 13 environmental reporting zones, 7,229 shoreline points were assessed for the presence of dead mangroves. Mangroves were identified at 5,288 points (87%) and the overall proportion of shoreline with dead mangroves present was 16%. The proportion of shoreline mangroves with dead mangroves present in the mangrove sub-zones ranged from 43% at Boyne Estuary to 7% at Auckland Inlet (Table 4.25). At a zone level Boyne Estuary (0.14), Western Basin (0.38) and Inner Harbour (0.47) had a significantly higher frequency of dead mangroves present compared to the harbour and received very poor to poor scores. Graham Creek (0.71), Auckland Inlet (0.74), Mid Harbour (0.70) and Rodds Bay (0.68) all had significantly fewer observations of dead mangroves compared to the overall harbour frequency and all received good scores (Table 4.26).

Table 4.25: Percent mangrove cover within each mangrove sub-zone and percentage of dead mangroves.

Zone	Mangrove sub-zone	Percent mangroves in shoreline zones assessed (sub-zone)	Percent mangroves with dead trees (sub-zone)
1. The Narrows	1a. Mainland	99	23
	1b. Curtis Island	99	6
2. Graham Creek	2. Graham Creek	98	9
3. Western Basin	3a. Mainland	99	31
	3b. Curtis Island	86	26
4. Boat Creek	4. Boat Creek	95	13
5. Inner Harbour	5a. Enfield Creek	97	18
	5b. Barney Point	28	29
6. Calliope Estuary	6. Calliope Estuary	89	19
7. Auckland Inlet	7. Auckland Inlet	86	7
8. Mid Harbour	8a. Curtis Island	93	6
	8b. Facing Island	58	13
9. South Trees Inlet	9. South Trees Inlet	96	17
10. Boyne Estuary	10. Boyne Estuary	82	43
11. Outer Harbour	11a. Wild Cattle Creek	83	17
	11b. Split End	15	18
12. Colosseum Inlet	12a Colosseum Creek	92	15
	12b. Hummock Hill	77	11
13. Rodds Bay	13a. East	86	5
	13b. West	81	15
	13c. Pancake Creek	96	12
	13d. Hummock Hill	86	9

Table 4.26: Estimates of shoreline condition for harbour environmental monitoring zones and sub-zones.

Zone	Mangrove sub-zone	Dead mangrove frequency score	Seasonally Adjusted dead mangrove frequency score	Sub-zone shoreline condition score	Zone shoreline condition score
1. The Narrows	1a. Mainland	0.54	0.40	0.47	0.61
	1b. Curtis Island	0.88	0.64	0.76	
2. Graham Creek	2. Graham Creek	0.83	0.60	0.71	0.71
3. Western Basin	3a. Mainland	0.38	0.29	0.33	0.38
	3b. Curtis Island	0.49	0.37	0.43	
4. Boat Creek	4. Boat Creek	0.73	0.53	0.63	0.63
5. Inner Harbour	5a. Enfield Creek	0.64	0.50	0.57	0.47
	5b. Barney Point	0.42	0.32	0.37	
6. Calliope Estuary	6. Calliope Estuary	0.63	0.50	0.56	0.56
7. Auckland Inlet	7. Auckland Inlet	0.86	0.62	0.74	0.74
8. Mid Harbour	8a. Curtis Island	0.88	0.63	0.76	0.70
	8b. Facing Island	0.74	0.54	0.64	
9. South Trees Inlet	9. South Trees Inlet	0.66	0.50	0.58	0.58
10. Boyne Estuary	10. Boyne Estuary	0.15	0.13	0.14	0.14
11. Outer Harbour	11a. Wild Cattle Creek	0.64	0.50	0.57	0.57
	11b. Split End	0.67	0.50	0.58	
12. Colosseum Inlet	12a Colosseum Creek	0.77	0.56	0.67	0.64
	12b. Hummock Hill	0.69	0.50	0.60	
13. Rodds Bay	13a. East	0.90	0.65	0.77	0.68
	13b. West	0.69	0.51	0.60	
	13c. Pancake Creek	0.77	0.56	0.66	
	13d. Hummock Hill	0.82	0.59	0.77	
Harbour score					**0.57**

4.2.15. Mangrove conclusions

The mangrove indicators have been selected to represent a range of pressures on mangroves in Gladstone Harbour. These pressures include environmental conditions such as annual rainfall variability, rising sea levels, the effects of floods or storms (cyclones) or anthropogenic impacts related to changing land use including, land reclamation, increased sediment and nutrient loads or localised pollution events. The indicators are capable of elucidating trends in mangrove health over time and confidence in this indicator will improve as the dataset grows over time.

In 2018, the zones with the highest overall scores were Rodds Bay (0.71), Colosseum Inlet (0.69), Outer Harbour (0.65), Auckland Inlet (0.68) and Calliope Estuary (0.67). All of which were considered to be in a good condition (Table 4.22). The condition of mangroves observed at Auckland Inlet and Calliope Estuary is likely to have been improved by higher levels of nutrients that occur in urban estuarine waters (Figure 4.8). However, it is important to note that these areas are being measured from a 2013–14 baseline and considerable clearing and other habitat modification has occurred in these areas in the past (Duke et al., 2003).

Rodds Bay, Colosseum Inlet, and Outer Harbour benefit from being further removed from direct impacts of clearing and development which result in fragmentation of the extant mangrove forest (Figure 4.9).

Figure 4.8: Healthy mangroves at Auckland Inlet possibly enhanced by relatively high levels of nutrients.

Figure 4.9: Healthy mangroves in Rodds Bay benefit from being away from direct human influence.

Two zones, Inner Harbour (0.43) and Boyne Estuary (0.41) received poor scores (Table 4.22). Severe flood impacts, affecting the shoreline trees, were observed in Boyne Estuary (Figure 4.10) and notable shoreline dieback was observed at the Inner Harbour.

Figure 4.10: Flood impacts affecting shoreline mangrove condition observed at Boyne Estuary during the 2017–18 mangrove surveys.

The remaining five zones all had a satisfactory overall condition; however, The Narrows, Graham Creek, Inner Harbour, South Trees Inlet and Boyne Estuary all received poor scores for mangrove canopy condition (Table 4.22). Dieback at the saltpan ecotone and shoreline has contributed to this score in The Narrows and this change may be indicative of a longer term decrease in rainfall

(Figure 4.11). Shoreline dieback has also contributed to the low canopy score in the Inner Harbour and dust has resulted in the browning of canopy foliage at South Trees Inlet.

Figure 4.11: Dieback marking the retreat of mangroves corresponding with a low canopy condition score observed in the Narrows (Curtis Island).

Dieback of upland trees at the terrestrial-upper tidal ecotone was observed over the course of the mangrove surveys particularly at the Western Basin (Figure 4.12) and Colosseum Inlet. This terrestrial retreat is marked by bank erosion, dead terrestrial edge trees, mangrove seedling establishment and upper saltpan scouring. This appears indicative of rising sea levels across the entire study area. This process is also recognisable in the change direction imagery where the retreat of mangroves is observed across three fronts simultaneously as loss of frontal edge mangrove trees, terrestrial retreat and saltpan scouring.

Figure 4.12: Terrestrial dieback and retreat of mangroves marked by lines of dead upland trees in the Western Basin.

4.3. Fish and crabs

4.3.1. 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 and Venables, 2016[a]). 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 ?

Yellow-finned bream

Yellow-finned 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. Yellow-finned 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. Yellow-finned 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.

Yellow-finned bream
(*Acanthopagrus australis*)

Pikey bream
(*Acanthopagrus berda*)

(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 2017–18 reporting year and data from this survey are reported here.

4.3.2. Fish recruitment data collection

Data for the two bream species were collected monthly from 26 sites across 12 harbour zones between December 2017 and March 2018. The Outer Harbour zone was excluded from the surveys as there were no suitable bream habitats (Table 4.27). Where possible within each zone, a minimum of two sites were selected to cover the upper tidal limit and another selected 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 (Sawynok and Sawynok, 2018). The fork length profiles of both species for key periods across the reporting year are shown in Figure 4.13.

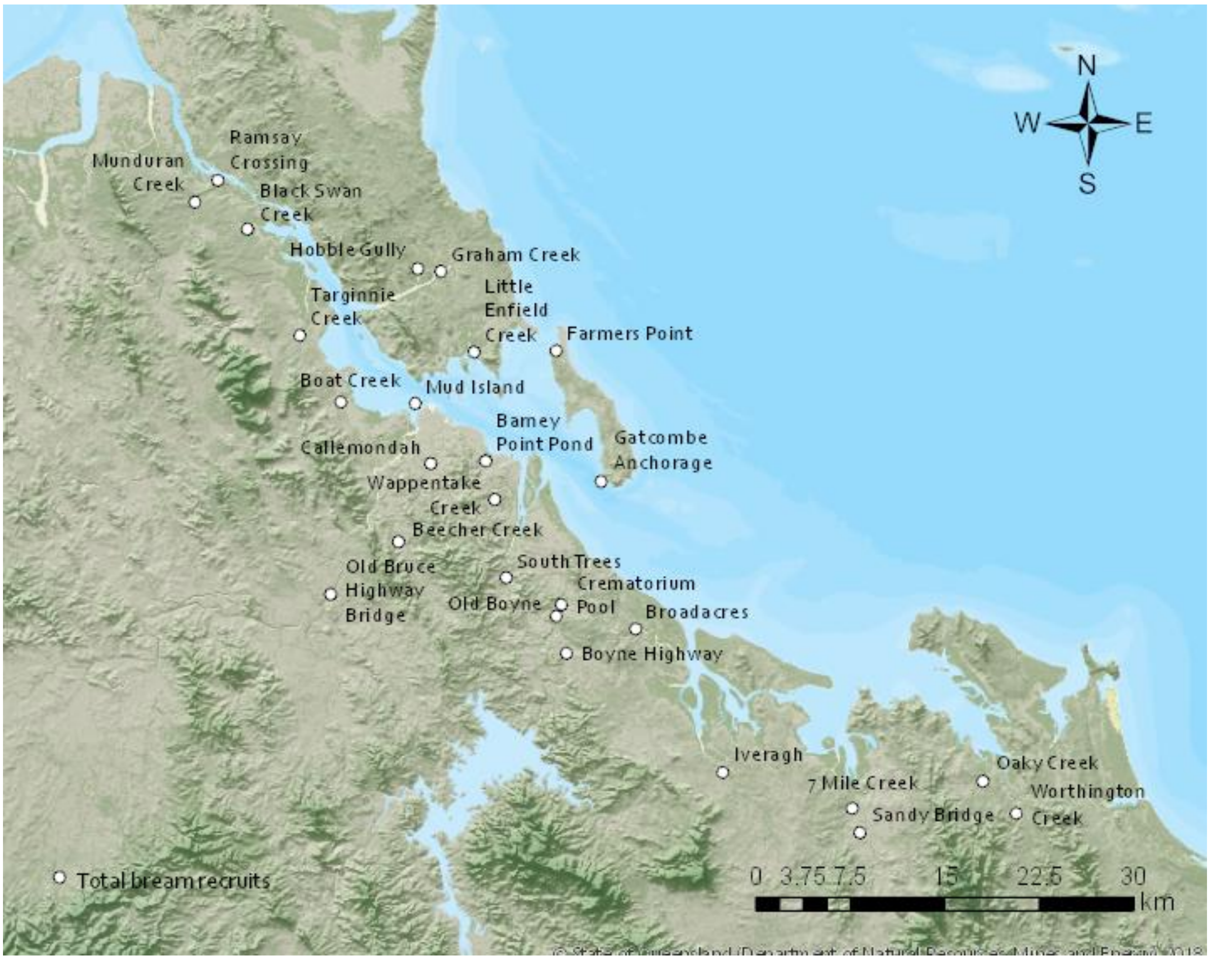


Figure 4.13: Bream nursery habitats surveyed around Gladstone Harbour between December 2017 and March 2018.

Each site was sampled 20 times using a standard castnet (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 substrata, vegetation and site photographs were recorded at each site. Surveys were not done if the water temperature exceeded 32°C. Three experienced castnetters were involved in surveys (Sawynok et al., 2018) (Figure 4.14).

Figure 4.14: Fish recruitment surveys using in castnets (Photos courtesy Bill Sawynok).

Table 4.27: Number of sites surveyed in each zone to collect bream recruitment data.

Harbour zone	Sites	Yellow-finned bream	Pikey bream
Zone 1. The Narrows	Ramsay Crossing	9	56
	Munduran Creek	15	0
	Black Swan Creek	4	22
	Targinnie Creek	21	6
Zone 2. Graham Creek	Graham Creek	0	24
	Hobble Gully	2	53
Zone 3. Western Basin	Mud Island	2	8
Zone 4. Boat Creek	Boat Creek	4	2
Zone 5. Inner Harbour	Little Enfield Creek	1	30
	Barney Point Pond	1	1
Zone 6. Calliope Estuary	Beecher Creek	12	2
	Old Bruce Highway Bridge	76	12
Zone 7. Auckland Inlet	Callemondah	20	57
Zone 8. Mid Harbour	Farmers Point	6	3
	Gatcombe Anchorage	4	1
Zone 9. South Trees Inlet	Wappentake Creek	10	1
	South Trees	11	44
	Crematorium Pool	35	14
Zone 10. Boyne Estuary	Old Boyne	20	6
	Boyne Highway	29	1
Zone 11. Outer Harbour	*Not surveyed*	*Not surveyed*	*Not surveyed*
Zone 12. Colosseum Inlet	Broadacres	9	31
	Iveragh	8	1
Zone 13. Rodds Bay	Oaky Creek	15	4
	7 Mile Creek	6	35
	Worthington Creek	8	13
	Sandy Bridge	18	2
Total	**26 sites**	**346**	**429**

4.3.3. 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 (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]). 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.

4.3.4. Fish recruitment results

The total number of bream caught in 2018 (775) was slightly lower than the total catch of bream in the previous year (910) (Figure 4.15). The pikey bream recruits also increased over the last three years. There were 104 surveys conducted over four months catching 346 (574 previous monitoring year) yellow-finned bream and 429 (336 previous monitoring year) pikey bream. The total number of casts in 2018 (2080) is similar to the previous monitoring year.

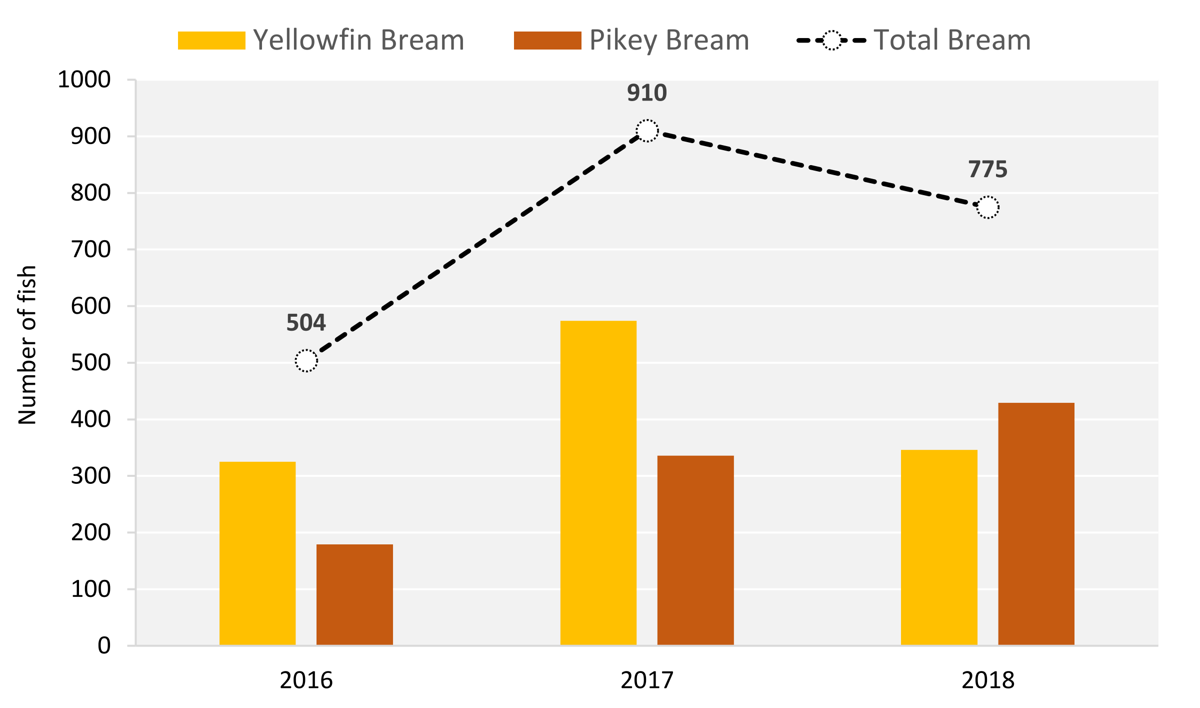


Figure 4.15: Yellow-finned and pikey fin bream recruits for 2016, 2017 and 2018 fish recruitment surveys.

The pikey bream recruits reported in the castnet surveys have slightly increased over the past three years although the total bream recruits declined by about 14% in 2017–18 compared to 2016–17 monitoring year (Figure 4.16). 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). In adding 2016–17 data, the model has become more stable and should be able to compare results in future report cards.

Table 4.28: Fish recruitment scores for all harbour zones and overall harbour score for fish recruitment.

Zone	2018	*2017*	*2016*	*2015**
1. The Narrows	0.58	*0.75*	*0.30*	*0.86*
2. Graham Creek	0.77	*0.58*	*0.44*	*0.72*
3. Western Basin	0.79	*0.78*	*0.36*	*Not surveyed*
4. Boat Creek	0.61	*0.47*	*0.36*	*0.80*
5. Inner Harbour	0.66	*0.64*	*0.33*	*0.80*
6. Calliope Estuary	0.70	*0.79*	*0.43*	*0.70*
7. Auckland Inlet	0.86	*0.91*	*0.53*	*0.80*
8. Mid Harbour	0.59	*0.71*	*0.29*	*Not surveyed*
9. South Trees Inlet	0.69	*0.71*	*0.43*	*0.72*
10. Boyne Estuary	0.52	*0.74*	*0.54*	*0.69*
11. Outer Harbour	Not surveyed	*Not surveyed*	*Not surveyed*	*Not surveyed*
12. Colosseum Inlet	0.61	*0.71*	*0.45*	*Not surveyed*
13. Rodds Bay	0.59	*0.74*	*0.58*	*Not surveyed*

Harbour average	0.66	*0.71*	*0.40*	*0.80*

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

Overall the fish recruitment score in the 2018 report card was 0.66 (B), indicating a good result. Of the 12 zones monitored, six zones indicated satisfactory scores and one zone had a very good scores (Table 4.28). Although some zones indicated a better recruitment than the previous year, the score for about eight zones declined.

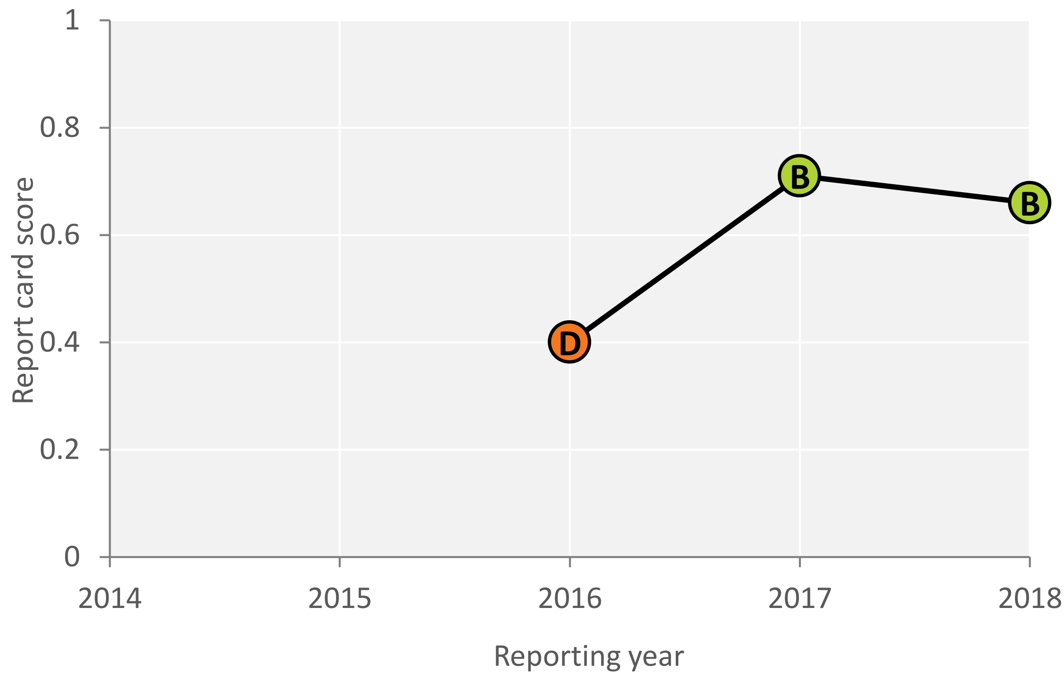


Figure 4.16: Fish recruitment overall harbour grade in the report card for three monitoring periods since 2016.

4.3.5. Fish recruitment conclusions

Recruitment plays a key role in a fishery population. The 2018 score of 0.66 equates to a grade of B for fish recruitment across all harbour zones and means that there is an increased catch rate relative to the median reference level. The 2017–18 bream catch was lower than for the previous reporting year, but was higher than the long-term average after adjusting for important environmental and temporal variables. The grade for each monitoring period closely follows the total bream caught in the harbour zones for 2016, 2017 and 2018 (Figure 4.16 and Table 4.28) monitoring years.

4.3.6. 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 4.17: 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 (Figure 4.17). 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.

4.3.7. 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. 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 selected for future report card monitoring. (Table 4.29). 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 4.29: GHHP zones assessed as permanent report card mud crab monitoring sites in 2017. From the nine sites assessed seven were included in the report card and recommended for ongoing 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

2018 Mud crab monitoring

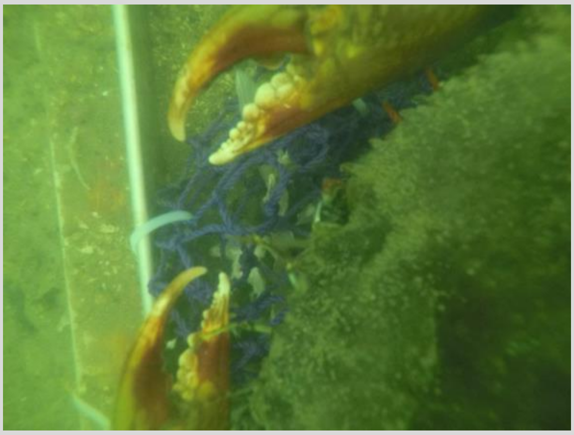
Two rounds of mud crab monitoring were conducted in 2018—a summer (warm, wet season) survey from 25–28 February and a winter (cool, dry season) survey from 22–25 June.

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 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).

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.



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.

4.3.8. Development of mud crab indicators and grades

A literature search for potential mud crab indicators identified nine classes of potential mud crab indicators (Table 4.30). 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 4.30: 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 (Flint et al., 2017a) and four indicators were selected for the report card:

1. Sex ratio based on legal size limit

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

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 sex ratio, abundance and visual health were calculated and compared to a benchmark and a worst-case scenario (Table 4.31). 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 or 2018 report cards. This indicator will be included once sufficient data are collected through the mud crab monitoring program to inform on 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, an accumulating average of the 75th percentile will be used for up to 10 years to account for natural variability. Using the accumulating average the benchmark for 2018 is 2.5. 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 4.31: Calculation of mud crab scores for the 2018 report card.

Measure	Benchmark	Worst-case scenario	Method
Sex ratio	Male:female sex ratio of 2:1 from an unfished mud crab population reported in Butcher, 2004 and Pillans et al., 2005	25th percentile of Long Term Monitoring Program data (0.25)	1–((x-B)/(WCS-B)) Where: x=recorded CPUE B=benchmark (2) WCS=worst-case scenario (0.25)
Abundance (CPUE)	75th percentile of the combined 2017 & 2018 data (2.5)	Catch rate of < 1 crab per allowable 4 pots (0.25)	1–((x-B)/(WCS-B)) Where: x=recorded CPUE B=benchmark (2.5) WCS=worst-case scenario (0.25)
Prevalence of rust lesions	25th percentile of the 2018 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 was set using 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 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 2:1 reported for unfished populations in northern NSW and an unfished section of Moreton Bay were used in 2018 (Butcher, 2004 & Pillans et al., 2005). This replaces the benchmark used in 2017 of 3:1 reported for unfished populations in Micronesia (Alberts-Hubatsch et al., 2016). A GHHP/CQU study of sex ratios at Eurimbula Creek (an un-crabbed estuary in Central Queensland) being conducted in 2018–19 may also influence this benchmark when it is completed. As the Long-Term Monitoring

Program data are the longest time series available, the worst-case scenario was set from this data at the 25th percentile (0.25).

4.3.9. Mud crab results

The overall grade for the 2018 report card was a D (0.49). This a result of predominantly very poor to poor scores for sex ratio (0.00–0.29), very good scores for prevalence of rust lesions (0.90–1.00) and abundance scores that ranged from very poor to very good (0.20–1.00) (Table 4.32).

Table 4.32: Mud crab indicator scores for the 2018 Gladstone Harbour Report Card the 2017 zone scores are shown for comparison.

Zone	Sex ratio	Abundance (CPUE)	Prevalence of rust lesions	Biomass	Zone score 2018	*Zone score 2017*
1. The Narrows	0.00	1.00	1.00		0.66	*0.66*
2. Graham Creek	0.03	0.30	1.00		0.44	*0.61*
4. Boat Creek	0.29	0.25	1.00		0.51	*0.70*
5. Inner Harbour	0.02	0.52	1.00		0.52	*0.87*
6. Calliope Estuary	0.11	0.47	1.00		0.52	*0.47*
7. Auckland Inlet	NC	0.00	NC		NC	*0.25*
13. Rodds Bay	0.06	0.20	0.90		0.38	*0.36*
Harbour scores	**0.09**	**0.46**	**0.98**		**0.49**	***0.55***

NC: Not calculated owing to small sample size (< 5)

Sex ratio based on legal size limits

In 2018, five zones received very poor scores (0.00 to 0.11) for sex ratio. The Narrows had the lowest score (0.00) based on a sex ratio of 0.07 males to 1 female crab. Boat Creek had the highest score for this measure, 0.29, based on a ratio of 0.75 males to 1 female (Tables 4.32 and 4.33).

Abundance: catch per unit effort (CPUE)

Abundance was measured as the total number of mud crabs caught during the two mud crab monitoring surveys in 2018 for the seven harbour zones. The highest catch rate was recorded in The Narrows, which was the only zone to have a very good score (1.00) based on an average catch of 3.5 mud crabs per pot for the two sampling periods. The Inner Harbour received a satisfactory score (0.52) based on an average catch of 1.5 crabs per pot. Three zones, Graham Creek, Boat Creek and Calliope

Estuary had poor scores and the remaining two zones, Auckland Inlet and Rodds Bay, had very poor scores (Tables 4.32 and 4.34).

Table 4.33: Size and sex of mud crabs caught and released during the 2018 mud crab monitoring.

Zone	Males >143mm	Females >143mm	Sex ratio	Males >143mm	Females >143mm	Sex ratio
1. The Narrows	3	44	0.07	3	39	0.08
2. Graham Creek	4	10	0.40	1	7	0.14
4. Boat Creek	3	4	0.75	3	4	0.75
5. Inner Harbour	4	11	0.36	3	13	0.23
6. Calliope Estuary	2	4	0.50	5	12	0.42
7. Auckland Inlet	2	0.0	NC	0	1	0.0
13. Rodds Bay	2	2	1	3	12	0.25
Harbour average			**0.51**			**0.27**

NC: Not calculated

Table 4.34: Catch per unit effort (CPUE) for pots set in seven harbour zones during the February and June 2018 mud surveys.

Zone	February 2018			June 2018		
	Pots	Crabs caught	CPUE	Pots	Crabs caught	CPUE
1. The Narrows	20	70	3.5	20	60	3.0
2. Graham Creek	20	28	1.4	20	11	0.55
4. Boat Creek	16	13	0.82	17	15	0.88
5. Inner Harbour	20	29	1.5	20	28	1.4
6. Calliope Estuary	20	23	1.2	20	29	1.5
7. Auckland Inlet	20	2	0.1	20	2	0.1
13. Rodds Bay	20	10	0.5	20	19	0.95

Visual health: prevalence of rust lesions

A very low incidence of rust lesions was recorded across the harbour resulting in very good scores for all zones assessed. Owing to the low number of crabs caught in Auckland Inlet (Table 4.32) a score for prevalence of rust lesions was not calculated for this zone, however no crabs caught in this zone had any lesions (Table 4.35).

Table 4.35: Percentage of mud crabs with external lesions (rust spot) recorded during the February and June 2018 mud crab monitoring.

Zone	February 2018			June 2018		
	Mud crabs without lesions	Mud crabs with lesions	% with lesions	Mud crabs without lesions	Mud crabs with lesions	% with lesions
1. The Narrows	67	3	4.3	59	1	1.7
2. Graham Creek	26	1	3.7	10	0	0
4. Boat Creek	13	0	0	13	1	7.7
5. Inner Harbour	29	0	0	28	0	0
6. Calliope Estuary	23	0	0	29	0	0
7. Auckland Inlet	2	0	0	2	0	0
13. Rodds Bay	9	0	0	17	2	11.8

4.3.10. Mud crab conclusions

The mud crab indicators have been selected to represent a 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. While the overall score (0.49) was similar to the overall score recorded in 2017 (0.55) it did result in a grade change from C to D (Table 4.32).

As only four mud crabs were caught in Auckland Inlet over the February and June sampling periods, scores for sex ratio, prevalence of rust lesions and an overall score were not calculated for this zone owing to the very small sample size (Table 4.33).

In 2018, the zone with the highest overall grade was The Narrows (0.66), this was a result of a very good grades for abundance (1.00) and prevalence of rust lesions (1.00), however in common with the majority of zones, The Narrows had a very poor score (0.00) for sex ratio. Three zones, Boat Creek (0.51), Inner Harbour (0.52) and Calliope Estuary (0.52) received satisfactory zone grades and two zones, Graham Creek (0.44) and Rodds Bay (0.38), received poor scores (Table 4.32).

In Queensland mud crab fisheries it is illegal to take female crabs, hence change 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 a potential for changes in ecosystem processes 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.

In 2018, Boat Creek (0.29) received a poor score for sex ratio and all other zones, where sex ratio could be calculated, received very poor scores (Table 4.32). Where a sex-based fishery is enforced, changes in the ratio of males to females that can't be explained by biological factors such as spawning migrations may be indicative of changes in fishing pressure. Presently the timing and population effect of the female spawning migration is not well understood and the possibility that this may be influencing the observed scores cannot be ruled out. A decrease in female numbers owing to a spawning migration would though result in lower scores. The pattern observed in 2017 and again in 2018 suggests that fishers are observing regulations for the release of female crabs.

Abundance scores ranged from very good (1.00) in The Narrows to very poor at Auckland Inlet (0.00) and Rodds Bay (0.20), the overall harbour score for this measure was poor (0.46) (Table 4.32). Even under the new benchmark, with the exception of The Narrows, all zone scores were lower than those recorded in 2017. However, caution is required in interpreting the abundance scores as CPUE data can be highly variable. This can arise as a result of capture technique, sampling area and time, or from differences in crab distribution, growth or survival related to habitat and environmental conditions (Alberts-Hubatsch et al., 2016). When these factors are controlled, 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. All six of the zones where this measure could be calculated received very good scores (Table 4.32). These scores indicate a very low prevalence of rust spot lesions across the harbour. The average incidence of rust spot lesions across the seven monitored zones was 2.4% for the combined February and June survey periods, 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).

4.4. Environmental component and indicator groups results

The overall Environmental component score for the 2018 report card was 0.61 (C). This was derived by aggregating the three environmental indicator groups (water and sediment quality, habitats, and fish and crabs) using the bootstrapping methodology (Logan, 2016).

The indicator group score was derived from by aggregating the water and sediment quality indicator scores, whereas for habitats this was derived by aggregating seagrass, coral and mangrove scores, and fish and crabs was derived from the aggregated fish and crabs scores. The overall harbour grades for the three indicator groups were: water and sediment quality 0.86 (A), habitats 0.41 (D) and fish and crabs (0.58) (Table 4.36).

The zone scores for the habitat indicators group only include the habitat indicators present in each zone. While mangroves are present in all zones, coral is only present in two zones and seagrass is present in six zones. The health of other important habitat types, such as benthic habitat which occurs in all zones, was not measured. Fish sampling was conducted in all zones except the Outer Harbour, while mud crab monitoring was conducted in six zones. Water and sediment quality was conducted in all zones.

Table 4.36: Environmental indicator group scores and overall environmental scores and grades for the 13 harbour zones and the overall harbour scores.

Zone	Indicator groups		
	Water and sediment quality	Habitats (seagrass, corals and mangroves)	Fish and crabs
1. The Narrows	0.80	0.49*	0.62~
2. Graham Creek	0.86	0.67	0.60~
3. Western Basin	0.85	0.52*	0.79
4. Boat Creek	0.77	0.63	0.56~
5. Inner Harbour	0.88	0.26*	0.58~
6. Calliope Estuary	0.86	0.67	0.60~
7. Auckland Inlet	0.83	0.68	0.86
8. Mid Harbour	0.88	0.43*#	0.59
9. South Trees Inlet	0.85	0.73*	0.69
10. Boyne Estuary	0.88	0.41	0.52
11. Outer Harbour	0.94	0.42#	NA
12. Colosseum Inlet	0.91	0.68	0.61
13. Rodds Bay	0.85	0.40*	0.48~
Harbour score	**0.86**	**0.41**	**0.58**

As indicated these zones included: # coral monitoring, * seagrass monitoring, ~mud crab monitoring

5. The Social component

Report cards have become an increasingly popular way to document environmental condition. The 2018 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). This year a new aesthetic value measure is added to the liveability and wellbeing indicator group.

Table 5.1: The indicator groups, indicators and measures used to determine social grades and scores for the 2018 report card (Source: Windle et al., 2018).

Indicator groups	Indicators	Measures	Data source	Baseline
Harbour usability	Satisfaction with harbour recreational activities	How satisfied with last trip	CATI survey (average of Q11b, 12b1, 15b and 25)	10-point scale
		Quality of boat 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 2017 by Department of Transport and Main Roads, Maritime safety Queensland	10-year moving average (Data from 2008–17 calendar year – rate of incidents in Gladstone Maritime Region as compared to other ports in Queensland)
		Oil spills	Marine pollution data 2002–18 Queensland Department of Transport and Main Roads	10-year moving average (Data from 2008–17 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.): The indicator groups, indicators and measures used to determine social grades and scores for the 2018 report card (Source: Windle et al., 2018).

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 harbour health	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
		Aesthetic value	CATI survey (Q45a, 45b)	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 appropriate measures to evaluate these candidate indicators were identified by the ISP and through a workshop with experts in social science and economics (Pascoe et al., 2014). ‘Appropriateness’ was based on a measure’s relationship with the indicator, indicator group and its measurability.

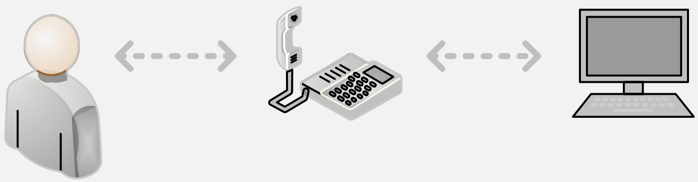
A Computer Assisted Telephone Interview (CATI) survey of 400 residents from the Gladstone 4680 postcode area was conducted during the first two weeks of June 2018 (Figure 3.28). Participants were contacted using a random dialling technique. Both landline and mobile phone users were contacted for the surveys. Note that prior to 2016, the CATI survey was restricted to landlines. Trained research interviewers administered the survey, which had been thoroughly monitored for data QA/QC. The survey questions were largely qualitative and related to the GHHP social, cultural (sense of place) and economic objectives. All questions were designed to be answered on a 10-point agree–disagree scale. In the CATI survey, participants were asked a specific question 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 (Figure 5.9, more details in Pascoe et al. 2014).

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 (e.g. Social and Economic Long-Term Monitoring Program for the Great Barrier Reef) and to elicit trends over time (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. The report card scores are derived from a distribution of responses (weighted average) across the A to E grades thus differ from the mean scores that are reported in the results from the CATI survey.

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 randomization 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 annul 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.

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 reflects 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 a scoring-based method was used for weighting as it had the lowest variance (Pascoe et al., 2014).

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. A 10-year moving average was used as the baseline for both marine safety incidents and oil spill measures.

There were minor changes in the marine incidents and oil spill data since 2014. The marine safety incidents measure in 2014 and 2015 were estimated using the ratios of incidents, with both recreational and commercial vessels registered within each maritime region. However, in 2016 due to new regulations relevant to jurisdictional changes, Queensland reporting included only details of Queensland-regulated ships (99.8% recreational vessels) and not commercial vessels. Therefore, rates of oils spills and incident rates were available for recreational vessels only, and commercial vessel counts were not included in the assessment. This method was repeated in 2018 so that grades and scores of both years become comparable. The rate has been calculated as per 10,000 Queensland regulated ships.

Harbour access

The harbour access indicator group comprised four indicators: satisfaction with access to the harbour, satisfaction with boat ramps and public spaces, perceptions of harbour health, and perceptions 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

The indicator for the harbour's contribution to liveability and wellbeing in Gladstone was assessed using four questions in the CATI survey. The liveability and wellbeing survey questions related to: (i) whether Gladstone Harbour makes living in Gladstone a better experience, and (ii) the level of participation in community events.

In 2018, a new indicator aesthetic value has been added to the liveability and wellbeing indicator group because:

- the aesthetic values of Gladstone Harbour are important but have not been captured in the current indicator framework
- the previous word cloud analysis conducted based on the CATI survey questions highlighted the importance of the 'aesthetic aspect' of the harbour to Gladstone residents although there was no separate indicator related to the aesthetic aspect in the indicator framework.

This new indicator is based on two additional questions that were included in the CATI survey about the participants' satisfaction related to the aesthetic value of the harbour. This new measure will complement the liveability and wellbeing indicator group and the results of the word-cloud analysis. By adding this new indicator, it is expected that the score of the indicator group will improve slightly, as aesthetic value is likely to attract a relatively high score. This will mean the score for the indicator group will not be fully comparable with previous years.

5.3. Results

A total of 400 respondents participated in the 2018 CATI survey with 90% (58% in 2017) contacted via mobile phones and 10% (42% in 2017) via landlines. There were equal numbers of female and male respondents. Since the first report card in 2014, there has been a steady increase in the representation by respondents in the 25–34 age group and a decline in the 65+ group. The representation by the younger age group (18–24) improved in 2018 but remains low as in previous years. This is well below the figures (11%) provided by the Australian Bureau of Statistics (ABS) for the same age group for Gladstone (Figure 5.1).

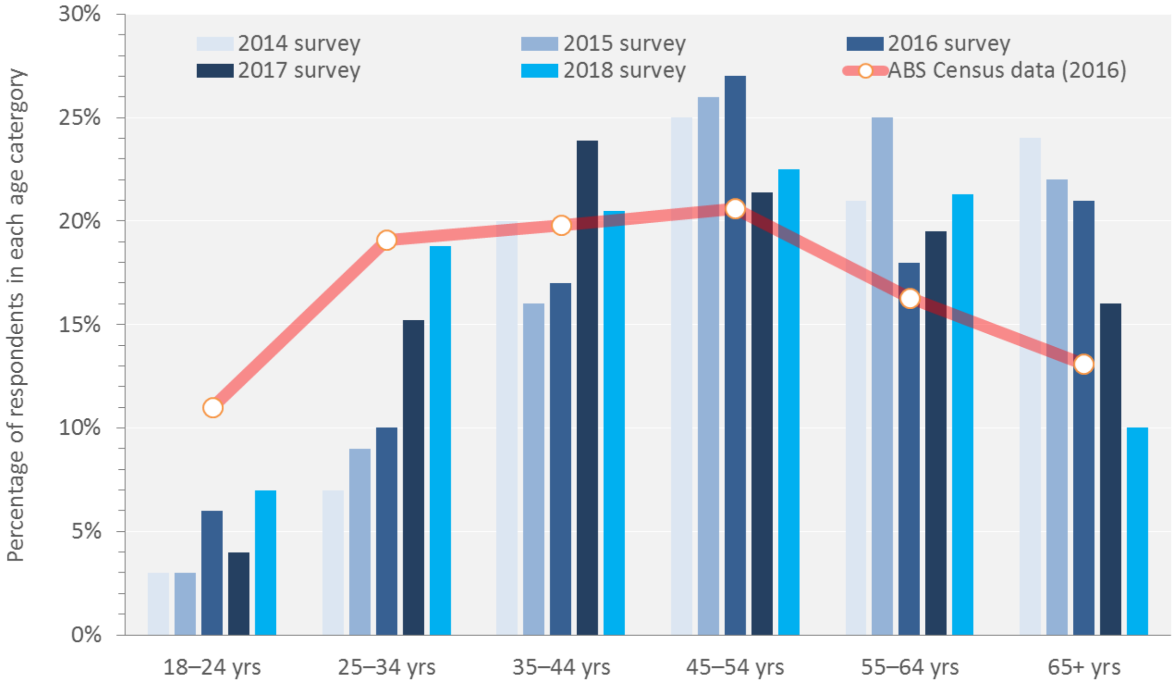


Figure 5.1: Distribution of age groups of the CATI participants since monitoring began in 2014.

The Traditional Owner representation in the 2018 CATI survey was 10% (2017 – 13%, 2016 – 11%, 2015 – 13%). This is higher than the representation of Indigenous residents in Gladstone who make up 4% of the population, based on 2016 ABS census data. In 2018, the highest annual income household bracket in Gladstone was $78,000–$103,999. In 2014, 2015 and 2016 reporting years the highest representation was in the over $156,000 annual household income bracket (Windle et al., 2017). The income brackets were changed during the 2016 ABS Census and now contain fewer categories (7 income categories) than the 2011 census (9 income categories). A majority of respondents own their home without a mortgage (27%) or with a mortgage (43%). The proportion of respondents renting increased from 22% in 2017 to 30% in 2018.

The overall grade for the Social component in the 2018 Gladstone Harbour Report Card was 0.67 (B) and similar to the previous year. The overall social health of Gladstone Harbour has gradually increased from 0.58 (C) in the 2014 Pilot Report Card, 0.64 (C) in the 2015 report card, 0.66 (B) in 2016 report card and 0.66 (B) in 2017 report card.

Of the three indicator groups, harbour access received a score of 0.67 (B), liveability and wellbeing a score of 0.70 (B) and harbour usability received a score of 0.63 (C) (Figure 5.2). The scores for harbour access increased from 2017 (0.66 to 0.67), the score for liveability and wellbeing increased from 0.66 in 2017 to 0.70 in 2018, and the score for harbour usability increased from 0.62 in 2017 to 0.63 in 2018.

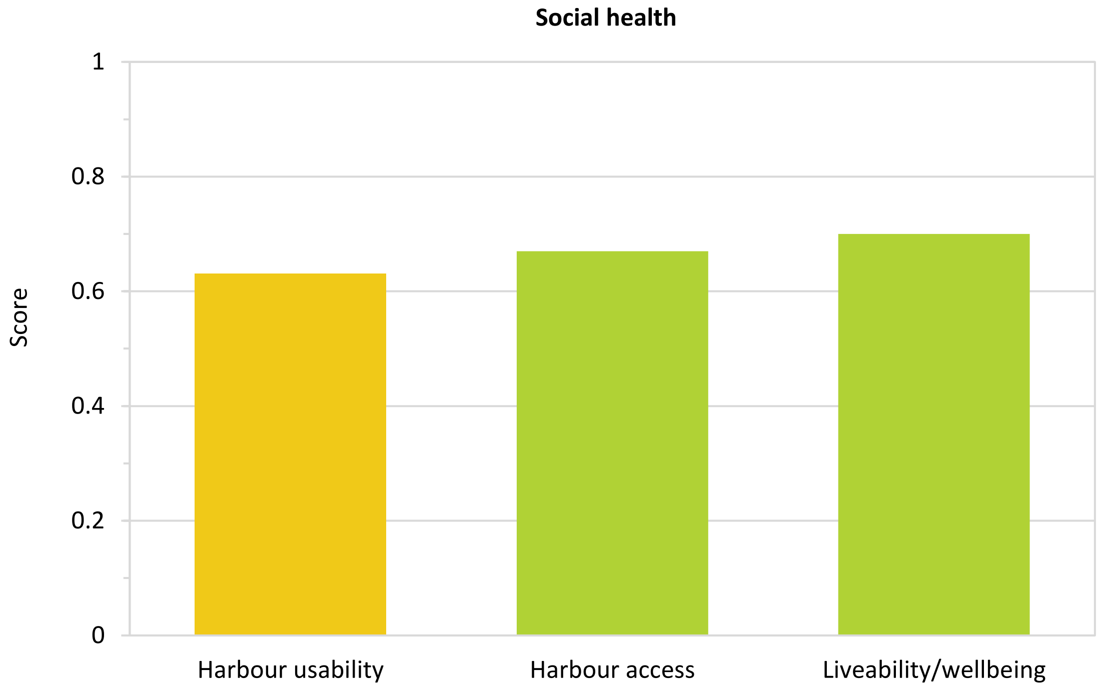


Figure 5.2: Indicator group scores within the Social component of harbour health in the 2018 Gladstone Harbour Report Card.

Harbour usability

The scores for the three indicators of harbour usability ranged from 0.58 (C) for perceptions of *air and water quality*, up to 0.61 (C) and 0.70 (B) for *perceptions of harbour safety* and *satisfaction with harbour recreational activities* respectively (Figure 5.3).

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 measure and two CATI questions for the latter. Overall the indicator score increased from 0.69 to 0.70 in 2018.

The score for the *perceptions of air and water quality* has steadily increased since monitoring started and remained at 0.58 in 2018 (0.46 in 2014, 0.52 in 2015, 0.55 in 2016, 0.56 in 2017). The *water quality* satisfaction score increased in 2018 (0.58 in 2017 to 0.61 in 2018), while the satisfaction score for *air quality* (0.47 in 2017) remained similar to 2017.

The score for *perceptions of harbour safety for human use* indicator improved in 2018 (0.61) compared to 2017 (0.60) and the resulting grade remains satisfactory (C), as in 2017. This indicator has two measures based purely on the secondary data and another two based on satisfaction ratings from the annual CATI survey. Both *marine safety incidents* (0.54) and *oil spill* (0.56) scored satisfactory results, although the former declined a grade (from B in 2017 to a C in 2018), whereas the latter improved a grade (from D in 0.38 to a C in 2018). The *marine safety incidents* also increased in 2017 (72) compared to 64 in 2016 resulting in a decline in the score from 0.76 (2017) to 0.54 (2018). However, the number of oil spills reported for the Gladstone Maritime Region declined to 11 (2017) compared to 18 in 2016. The most commonly reported incidents included collision between ships, groundings, collision with objects, and capsizing (Department of Transport and Main Roads, 2017). The other two measures in this indicator *safety at night* and *happy to eat seafood* measures improved in 2018.

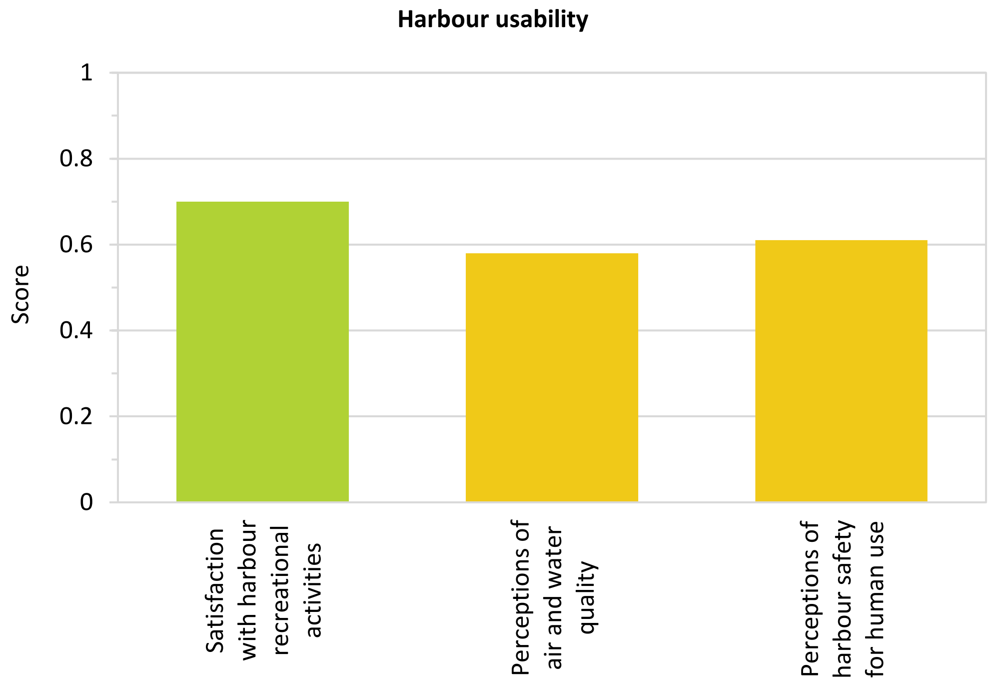


Figure 5.3: Scores for the three indicators of harbour usability in the 2018 Gladstone Harbour Report Card.

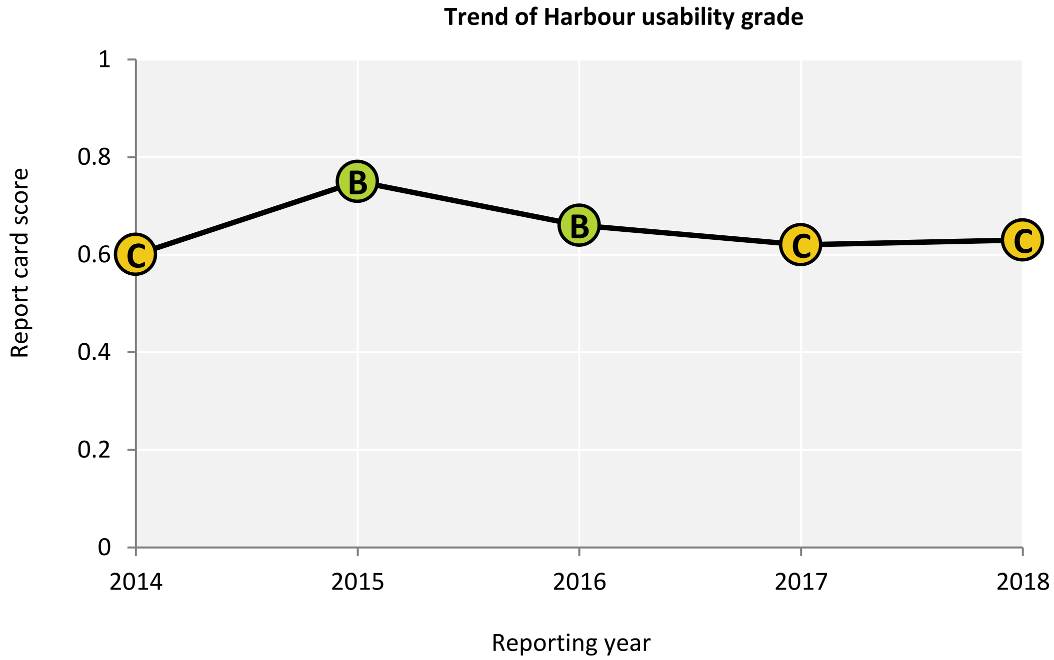


Figure 5.4: The trend of grade received for harbour usability indicator group since year 2014.

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 5.5). The indicator score for *satisfaction with boat ramps and public spaces* increased, while scores for all other indicators remained unchanged from last year. As in 2017, three out of four measures used to assess this indicator scored well.

All four harbour access indicator scores have been increasing since the pilot report card in 2014 (Figure 5.6).

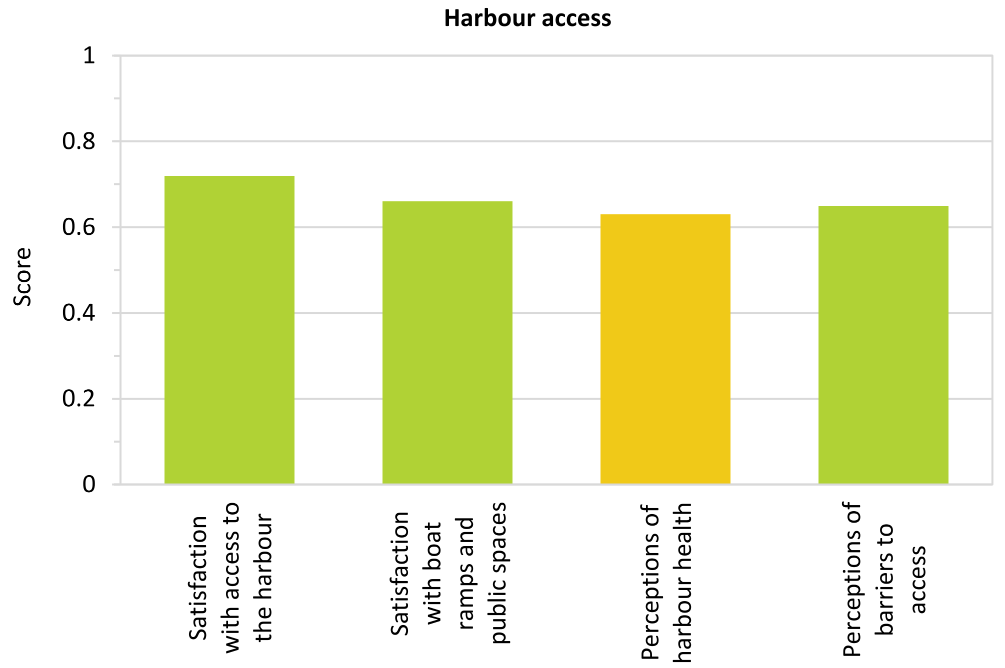


Figure 5.5: Scores for the four indicators of harbour access in the 2018 Gladstone Harbour Report Card.

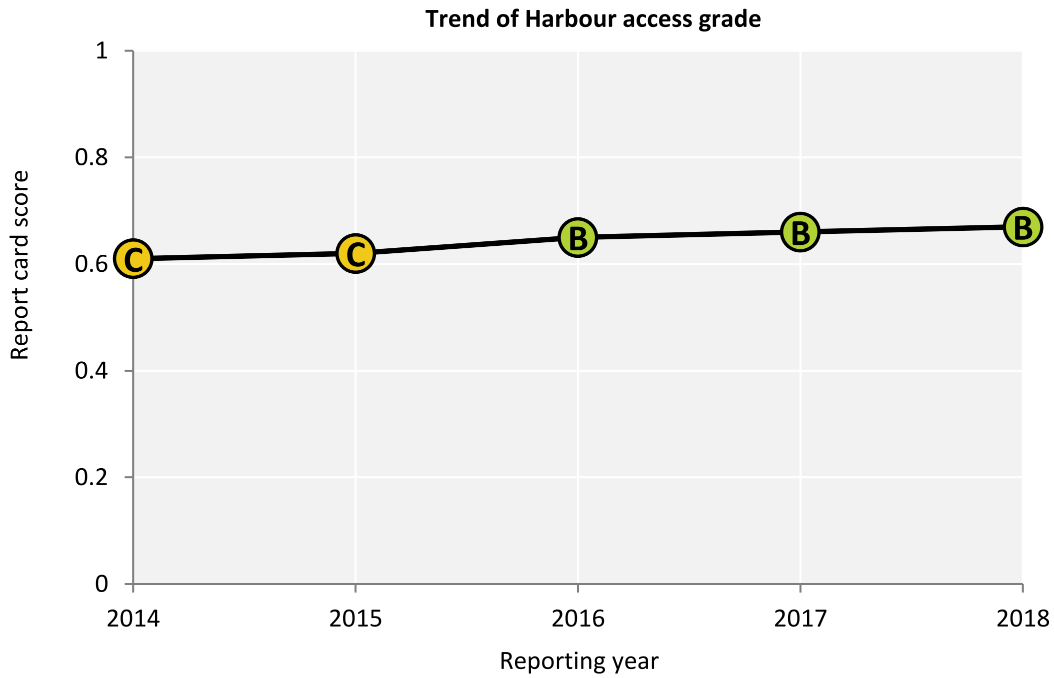


Figure 5.6: The trend of grade received for harbour access indicator group since year 2014.

Liveability and wellbeing

The contribution of Gladstone Harbour to the liveability of Gladstone and wellbeing was scored at 0.70 (B) (Figure 5.7). 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). In 2018, a new measure *aesthetic value* also contributed to the overall score, improving it from 0.66 to 0.70 in 2018. The overall score has increased slightly since the monitoring began in 2014 and has been stable over the last three years (Figure 5.8).

There were two survey questions used to assess the liveability and wellbeing indicator group—*Gladstone harbour makes living in Gladstone a better experience* and *I regularly participate community events in the Gladstone Harbour area*. About 90% (86% in 2017, 87% in 2016, 70% in 2015) of people surveyed implied they were satisfied, responding with a score of 6 and above, indicating that Gladstone Harbour makes living in Gladstone a better experience. About 56% (61% in 2017, 60% in 2016, 53% in 2015) of the respondents implied they agreed, responding 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 that they will increasingly participate in community events in the harbour area.

About 89% and 85% respondents respectively implied they were satisfied with the aesthetic value of the harbour area, responding with a score of 6 or above for the relevant questions: *I enjoy going to the harbour because it is beautiful to look at* and *I enjoy going to the harbour because of its natural beauty.*

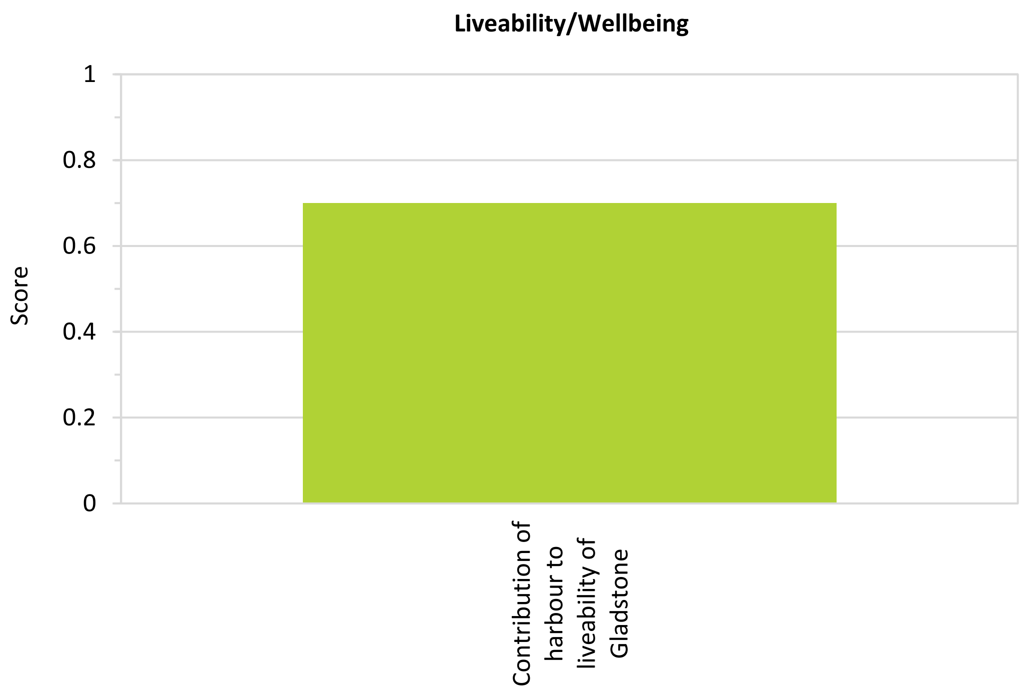


Figure 5.7: Score for the contribution of Gladstone Harbour to the liveability and wellbeing of Gladstone in the 2018 Gladstone Harbour Report Card.

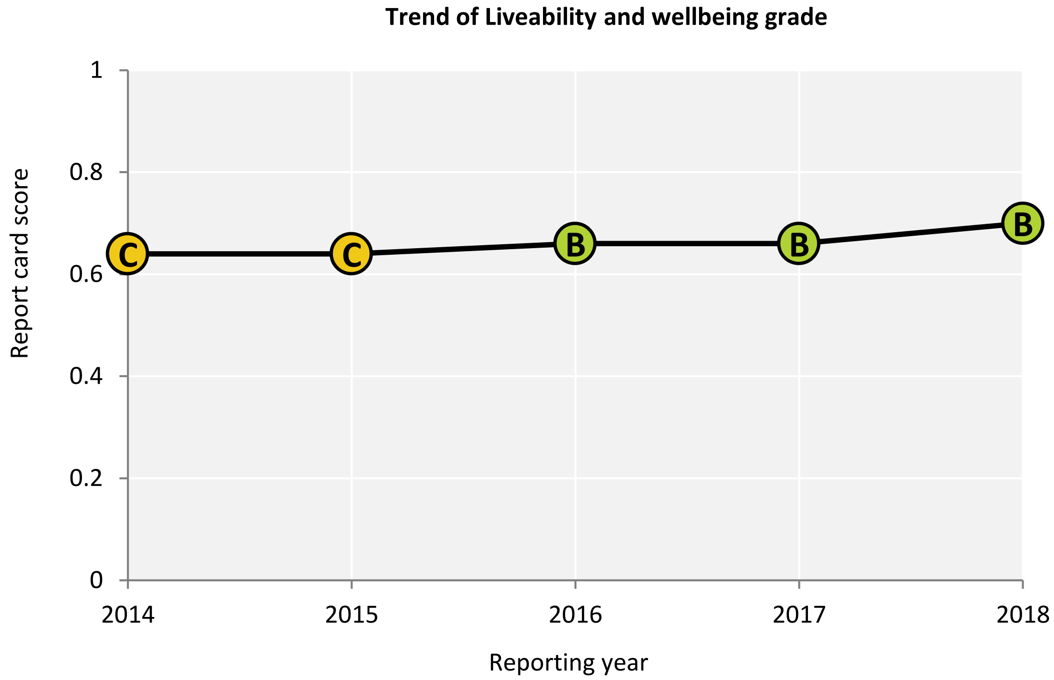


Figure 5.8: The trend of grade received for the liveability and wellbeing indicator group since year 2014. Grades prior to 2018 were based on two measures. The third measure *aesthetic value* was added to the indicator group in 2018.

Word-cloud analysis

Figure 5.9: Word-cloud analysis of the 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 2018 remained similar to previous reporting years. The sizes of the words relates to the word frequency when participants responded to the CATI survey.

Overall, the responses indicate that most respondents continue to perceive the harbour area positively as the word ‘beautiful’, ‘busy’, ‘fishing’ and ‘industrial’ appeared in all five years.

In 2017, word cloud references to geographical locations adjacent to the harbour such as East-shore and Spinnaker Park became prominent than in 2016. The CATI respondents continue to use words such as ‘pretty’, ‘clean’, ‘nice’, ‘great’ and ‘good’ to indicate a positive association with the harbour, and words such as ‘polluted’ and ‘dirty’ to indicate negative association.

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 similar to previous year (Table 5.3). The overall grade remained unchanged from the 2017 reporting year.

Harbour usability

Overall, the harbour usability score improved from the previous year.

The harbour usability scores fluctuated between satisfactory and good grades since the monitoring began in 2014. This year, the indicator improved slightly compared to 2017 but maintained its grade as satisfactory. The *air quality satisfaction* measure had the lowest scores amongst the other measures within this indicator, similar to previous years. This measure has consistently received a low score since 2014. On the other hand *satisfaction with the last recreational trip* has received a good grade since the monitoring began. The *marine safety* incidents increased in 2017 (72) compared to 2016 (64), but the impact on the score was offset by the number of *oil spills* reported for the Gladstone Maritime Region, declining to 11 (2017) compared to 18 in 2016.

Similar to 2017, a 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 usability of the harbour area and its resources to the community. 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 overall harbour access score has improved from the previous year.

The harbour access has been stable over the last three years and resulted in good grades in 2018. The score of one out of four indicators (*satisfaction with boat ramps and public spaces)* slightly increased in 2018 compared to 2017.

The 2018 harbour access results indicate that residents continue to enjoy accessing the harbour, public spaces and boat ramps, and that perceptions of harbour health have not changed since 2017. Residents further agreed that they have fair access to the harbour compared to its other users, with an increase in the frequency of harbour use over the previous year (9 times in 2018, 8 times 2017). Residents' perceptions around barriers to access remained the same as in 2017. However, respondents continue to perceive that marine debris and litter is a problem in Gladstone Harbour, although they did not see the amounts of marine debris, commercial shipping and recreational boating activity as hindrances to harbour access. The harbour environment is viewed positively by many residents and they believe this will continue into the future.

Liveability and wellbeing

There has been very little change in this indicator over the past five years. However, adding the new aesthetic value related measure improved the overall liveability and wellbeing score for the Gladstone Harbour.

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 and Boyne-Tannum Hook Up, that are held in and around the harbour area. Overall, respondents enjoyed going to the harbour due to its natural beauty.

Table 5.3: Social indicator group scores of reporting years.

		2018	*2017*	*2016*	*2015*	*2014*
Indicator group	**Harbour usability**	0.63	*0.62*	*0.66*	*0.65* [a]	*0.60*
Indicators	Satisfaction with harbour recreational activities	0.70	*0.69*	*0.67*	*0.69* [b]	*0.70*
	Perceptions of air and water quality	0.58	*0.56*	*0.55*	*0.52*	*0.46*
	Perceptions of harbour safety for human use	0.61	*0.6*	*0.76*	*0.72*	*0.38*
Indicator group	**Harbour access**	0.67	*0.66*	*0.65*	*0.62*	*0.61*
Indicators	Satisfaction with access to the harbour	0.72	*0.72*	*0.69*	*0.68*	*0.67*
	Satisfaction with boat ramps and public spaces	0.66	*0.65*	*0.64*	*0.62*	*0.60*
	Perceptions of harbour health	0.63	*0.63*	*0.62*	*0.58*	*0.53*
	Perceptions of barriers to access	0.65	*0.65*	*0.65*	*0.61*	*0.64*
Indicator group	**Liveability and wellbeing**	0.70 [c]	*0.66*	*0.66*	*0.64*	*0.64*
Overall harbour score		0.67	*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 in 2016, 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.
[c] Liveability and wellbeing score in 2018 was determined with an additional measure 'aesthetic value'.

6. The Cultural component

To assess the cultural health of the harbour, the 2018 report card uses six ‘sense of place’ indicators and two Indigenous cultural heritage indicators. The Indigenous cultural heritage indicators have been developed and piloted during 2016, with further refinement to the indicator framework in 2018.

Indigenous cultural heritage values associated with the land and waterways adjacent to the harbour play a key role in the cultural health of Gladstone Harbour. This diverse and living heritage reflects the rich Indigenous heritage values and various cultural aspects of the First Australians in connection to the country. Including Indigenous cultural heritage related indicators in the report card acknowledges and recognises this ongoing connection of the Traditional Owners. The importance of monitoring cultural health together with social, economic and environmental health was further highlighted by the Gladstone community when the Gladstone Healthy Harbour Partnership developed a community vision in 2013.

In the report card, two indicators assess the Indigenous cultural heritage—the physical condition of sites and management strategies of zones. These indicators were chosen to address two report card objectives: ‘registered cultural heritage sites associated with the harbour and waterways are protected’ and ‘the Gladstone community’s sense of identity and satisfaction with the condition of the harbour is increased’, which were derived from a community vision developed for the Gladstone Harbour.

6.1. Data collection

‘Sense of place’

The CATI survey of 400 people conducted in June 2018 to assess social health also 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 Facing Island and Gladstone Central completed in July (Table 6.2). The Wild Cattle Creek Zone was not resurveyed in 2018. However, two sites in The Narrows were assessed. The physical condition related indicators were assessed at site level, whereas the indicators related to the management strategy were assessed at zone level.

Sites are referred to as areas of concentrated group-of-heritage features within the landscape. One or more monitoring stations are established as key locations within sites from which the heritage features heritage elements and non-heritage features are monitored (Terra Rosa, 2018). Overall, 11 new sites have been revisited during the 2017–18 reporting period, which included two new sites which haven’t been assessed before (Table 6.2).

Table 6.1: Indicator groups, indicators and measures used to determine cultural grades and scores for the 2018 Gladstone Harbour Report Card.

Indicator group	Indicators	Measures	Data source	Baseline
'Sense of place'	Distinctiveness	No place better	CATI survey (Q30)	10-point scale
		Who am I	CATI survey (Q51)	10-point scale
	Continuity	How long lived in the area	CATI survey (Q3)	Proportion of life lived in the area (0–100%)[a]
		Plan to be a resident in the next five years	CATI survey (Q53)	10-point scale
	Self-esteem	Feel proud living in Gladstone	CATI survey (Q50)	10-point scale
	Self-efficacy	Quality of life	CATI survey (Q52)	10-point scale
		Input into management	CATI survey (Q47)	10-point scale
	Attitudes to Gladstone Harbour	Key part of the community	CATI survey (Q54)	10-point scale
		Great asset to the region	CATI survey (Q58)	10-point scale
		Great asset to Queensland	CATI survey (Q59)	10-point scale
	Values of Gladstone Harbour	Variety of marine life	CATI survey (Q55)	10-point scale
		Opportunities for outdoor recreation	CATI survey (Q56)	10-point scale
		Attracts visitors to the region	CATI survey (Q57)	10-point scale
		Enjoy scenery and sights	CATI survey (Q60)	10-point scale
		Spiritually special places	CATI survey (Q61)	10-point scale
		Culturally special places	CATI survey (Q62)	10-point scale
		Historical significance	CATI survey (Q63)	10-point scale
Indigenous cultural heritage	Physical condition	Intactness of site features	Field survey	10-point scale
		Extent of current disturbance	Field survey	10-point scale
		Management of threats	Field survey	10-point scale
	Management strategies	Recording	Field survey	10-point scale
		Cultural management	Field survey	10-point scale
		Stakeholders	Field survey	10-point scale
		Monitoring	Field survey	10-point scale
		Access	Field survey	10-point scale
		Cultural resources	Field survey	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)

Data collection involved recording the health of various heritage aspects relevant to the cultural health (e.g. knapping floor, chopper tools, signage, gravestones and monuments) in relation to a pre-defined criteria (Terra Rosa, 2018). Similar to previous year, a series of 360° panoramic imagery was also captured during the surveys and used 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). Data collected in 2016, 2017 and 2018 were used in the score calculation for the 2018 report card.

Similar to the previous year, Traditional Owners and Elders from Gooreng Gooreng and Byellee groups assisted the field studies.

Table 6.2: Sites within each zone surveyed during 2016, 2017 and 2018 monitoring years.

Zone	***Sites surveyed in 2016***	***Sites surveyed in 2017***	**Sites surveyed in 2018**		**Total sites in the database**
			New	**Revisited**	
The Narrows	*6*	*3*	1	1	10
Facing Island	*6*	*0*	1	5	7
Wild Cattle Creek	*11*	*5*	0	0	16
Gladstone Central	*3*	*3*	0	5	6
Total	***26***	***11***	**2**	**11**	**39**

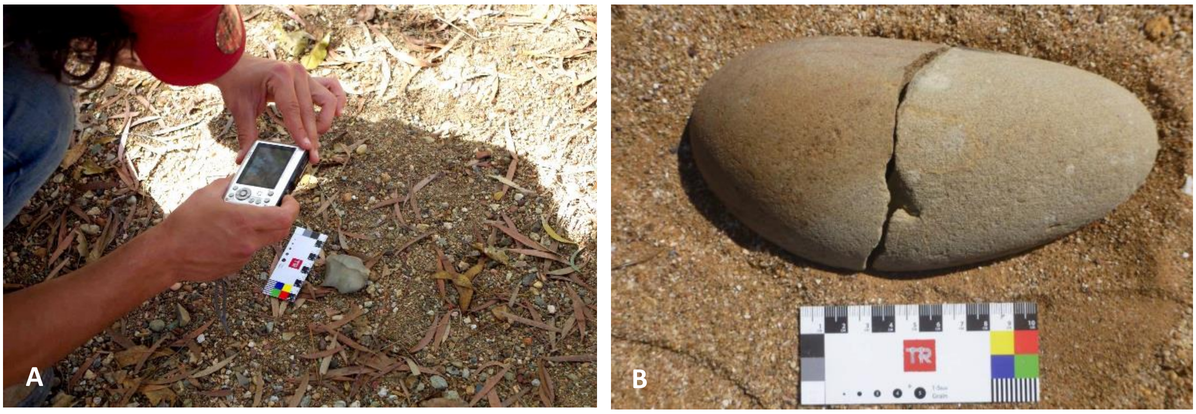


Figure 6.2: A – Photographing site features, B – Grinding stone at Facing Island (Source: Terra Rosa, 2018)

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’ assesses the attitudes of people in Gladstone with particular emphasis on its importance as a great asset to the local community and Central Queensland.

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

Indigenous cultural heritage

The Indigenous cultural scores for the 2018 report card are based on three physical condition measures assessed at site level and six management strategies measures assessed at zone level (Figure 6.1). The new framework simplifies the assessment and calculation of the Indigenous cultural heritage indicators, although the scores and grades calculated through the new framework may not be fully comparable to 2016 and 2017 grades.

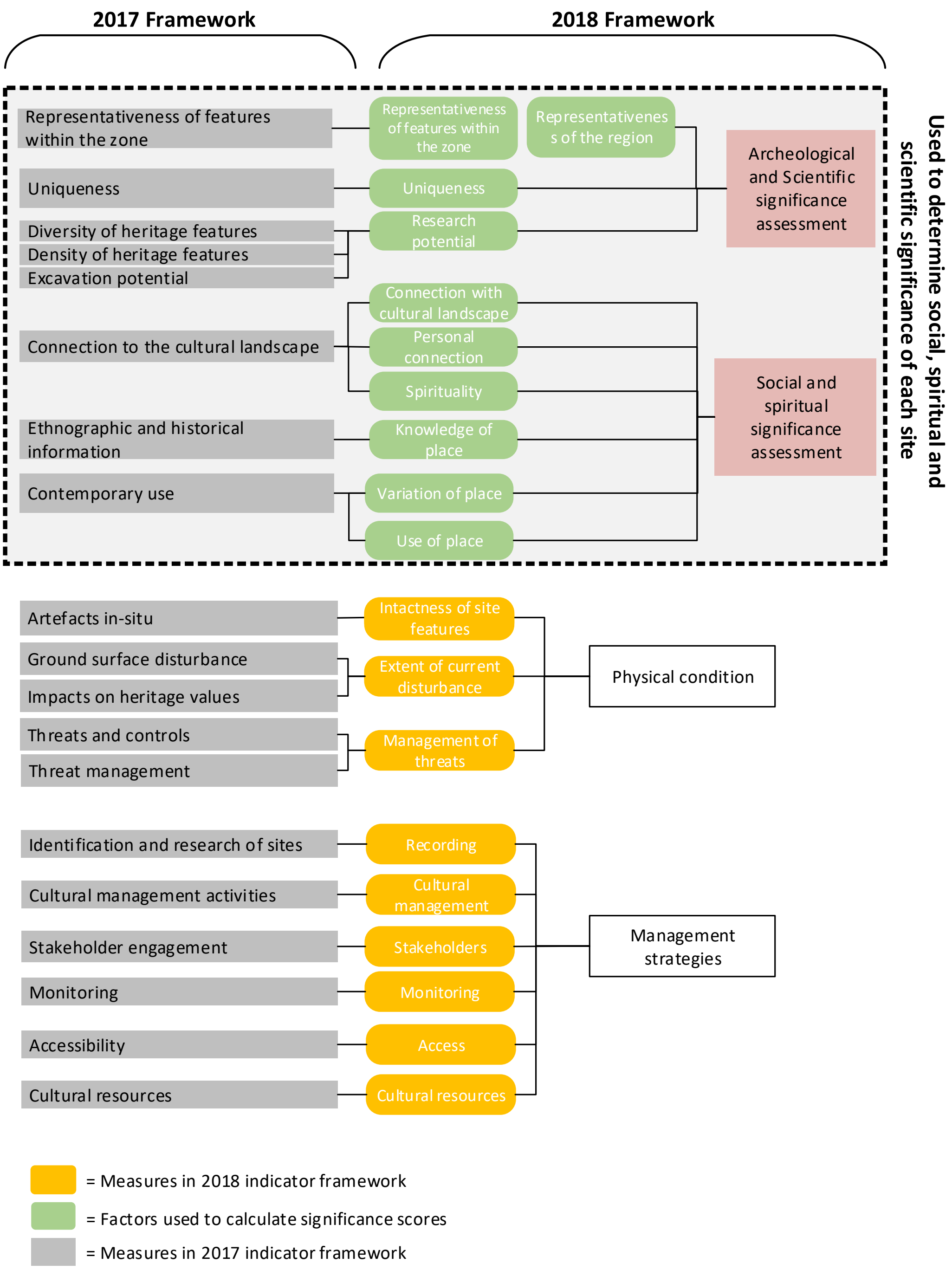


Figure 6.1: 2017 Indigenous cultural health indicators are mapped to the 2018 indicator framework. Two measures which were in the 2017 framework—site registration and developmental pressure measures—are no longer assessed in the 2018 framework.

The physical condition indicator uses three measures:

- Intactness of site features – relates to heritage features within the site being undisturbed and artefacts are *in situ*. A score of 10 is allocated when over 90% of the features are intact.
- Extent of current disturbance – relates to the percentage of site currently being disturbed by human and natural processes such as vehicle damage, erosion processes, animal or trampling

impacts, dumping rubbish and camping. A site attracts a score of 10 if less than 10% of a site is subjected to current or active disturbances.

- Management of threats – is based on a threats assessment for the site and identifying any management strategies that are in place to minimise the impacts or threats to the site. When a site has management strategies in place to minimise over 90% of threats it receives a score of 10.

The management strategies indicator uses six measures:

- Recording – examines whether sites have been further researched and investigated during monitoring. A score of 10 is given when all sites were revisited in the zone and new monitoring stations were established.

- Cultural management – relates to preparing and implementing a cultural heritage management plan. A zone would receive a score of 10 if a heritage management plan is implemented for the zone and all management activities are in progress.

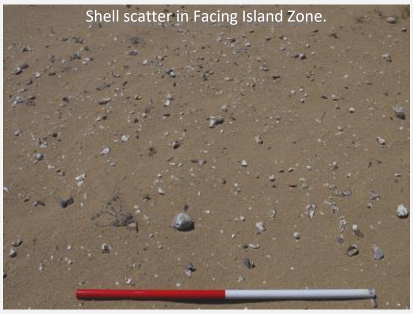
What are heritage elements and heritage features?

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)

- Stakeholders – relates to the engagement of various stakeholders towards a long-term management plan for the zone. A score of 10 reflects representatives from all stakeholder groups are actively engaged and support ongoing activities.

- Monitoring – relates to the annual monitoring of each site each year. A score of 10 is given when all monitoring stations have been revisited.

- Access – relates to the percentage of sites within a zone that can be easily accessed for heritage management. A score of 10 is allocated for this measure when all sites within the zone are easily accessible for heritage management activities.

- Cultural resources – relates to the availability of both physical and digital resources that store knowledge of cultural heritage within a zone. A score of 10 reflects that all sites within a zone have both physical and digital interpretive resources.

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 were selected following an in-depth literature review and extensive consultation with the Gidarjil Development Corporation in 2016 (Terra Rosa Consulting, 2016). Information related to the cultural heritage sites documented in the 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. Some sites from this list were revised and new sites were surveyed in 2018 with the help of Gooreng Gooreng and Byellee Traditional Owners and Elders for the 2018 report card.

The indicators of Indigenous cultural heritage were assessed based on a range of cultural heritage elements and features. Each measure was assessed based on 10 pre-defined criteria and given a score between 1 and 10 (see Terra Rosa 2018 for details of the criteria). GHHP grading thresholds were only applied to aggregated scores.

The indicators under physical condition were weighted on a spatial scale. The processes involved determining the social, spiritual and scientific significance of all sites based on 10 factors (see green boxes in Figure 6.1). The average values were then used as a guide together with cultural knowledge of the Traditional owners and Elders to determine the weightings for cultural locus site. The determination of social, spiritual and scientific significance of sites was completed in 2017 through consultation with the Gooreng Gooreng and Byellee Elders and investigation of sites (Terra Rosa, 2018).

A cultural locus site is considered to be the most important for ongoing monitoring and management of that zone (Terra Rosa, 2017). There is one cultural locus site for each monitoring zone. The health of the cultural locus sites was assessed independently and then used to benchmark other sites within each zone (Figure 6.3). The management strategies indicators were given fixed weightings at sub-indicator level.

Data aggregation was done using simple averages.

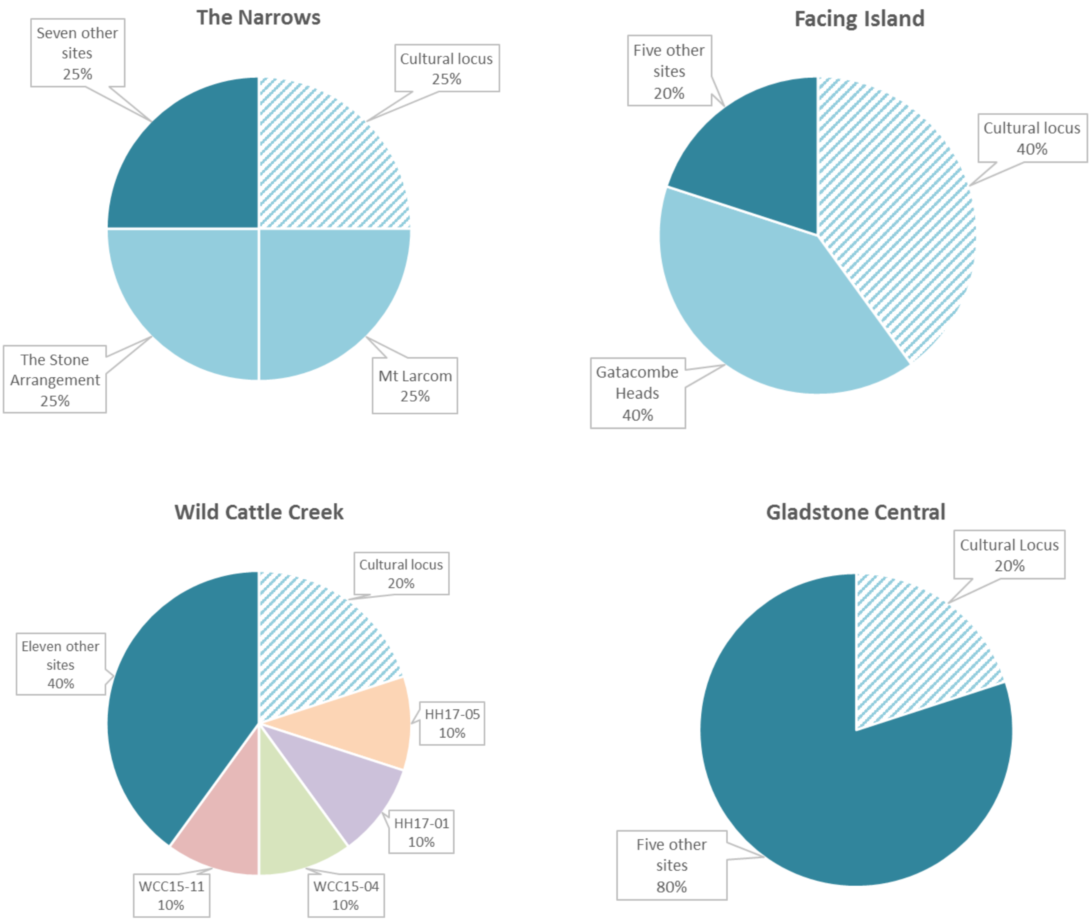


Figure 6.3: Weightings derived from ethnographic consultation for cultural locus and other sites within each zone for cultural health indicators.

6.3. Results

The overall score for the Cultural component of the Gladstone Harbour Report Card for 2018 was 0.60 (C). This comprised two indicator groups, 'sense of place' and Indigenous cultural health (Figure 6.4). 'Sense of place' received a score of 0.65 (B) and Indigenous cultural heritage received a score of 0.54 (C). This final score and the grade was based on six 'sense of place'-related indicators and two Indigenous cultural heritage indicators.

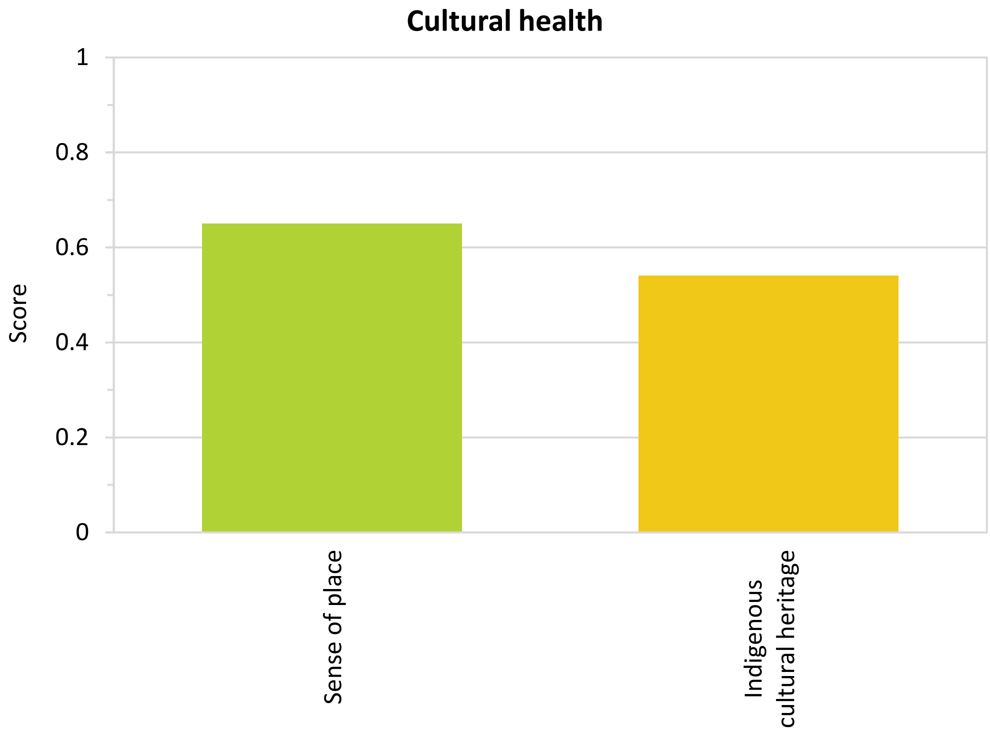


Figure 6.4: Indicator group scores within the Cultural component of the 2018 Gladstone Harbour report card.

'Sense of place'

The 'sense of place' indicator scores ranged from 0.53 (C) for continuity to 0.83(B) for attitudes to the harbour (Figure 6.5). Distinctiveness (0.56) and self-efficacy (0.59) received similar scores; self-esteem (0.74), attitudes to harbour (0.83) and values of Gladstone harbour (0.65) all received good scores. All scores were similar to 2017 and did not result in a change in the grade.

The highest score of 0.83 received for attitudes to the harbour was driven by three measures which received equally high scores (*key part of community* – 0.82, *great asset to region* – 0.82 and *great asset to Queensland* – 0.81). The lowest score of 0.53 for continuity was influenced by a low score (*how long lived in the area* – 0.41) and a high score (*plan to stay the next 5 years* – 0.65).

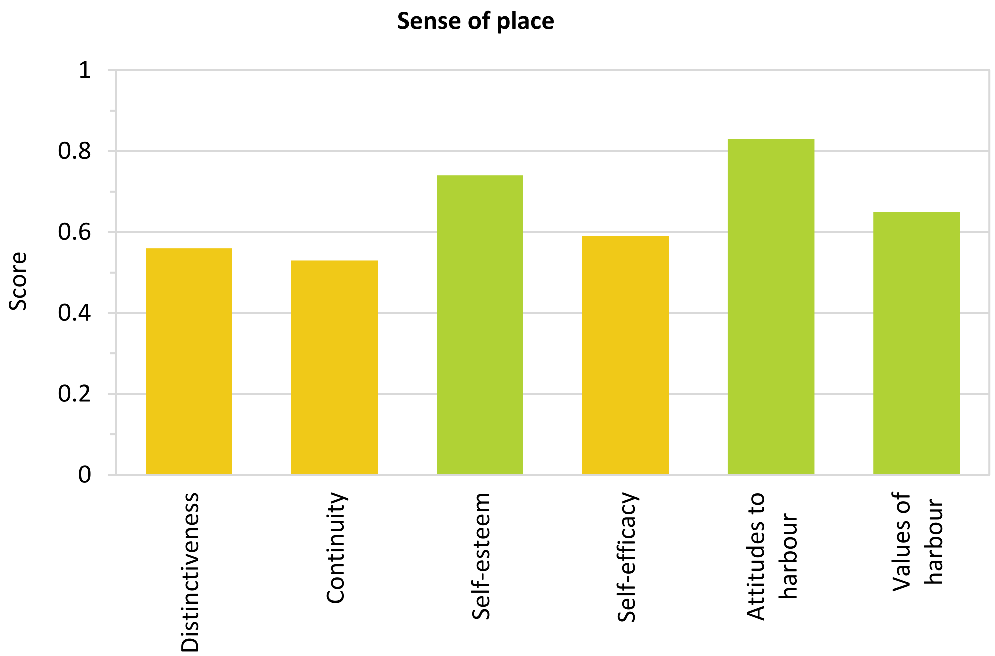


Figure 6.5: Indicator scores for 'sense of place' indicator group used for cultural health in the 2018 Gladstone Harbour Report Card.

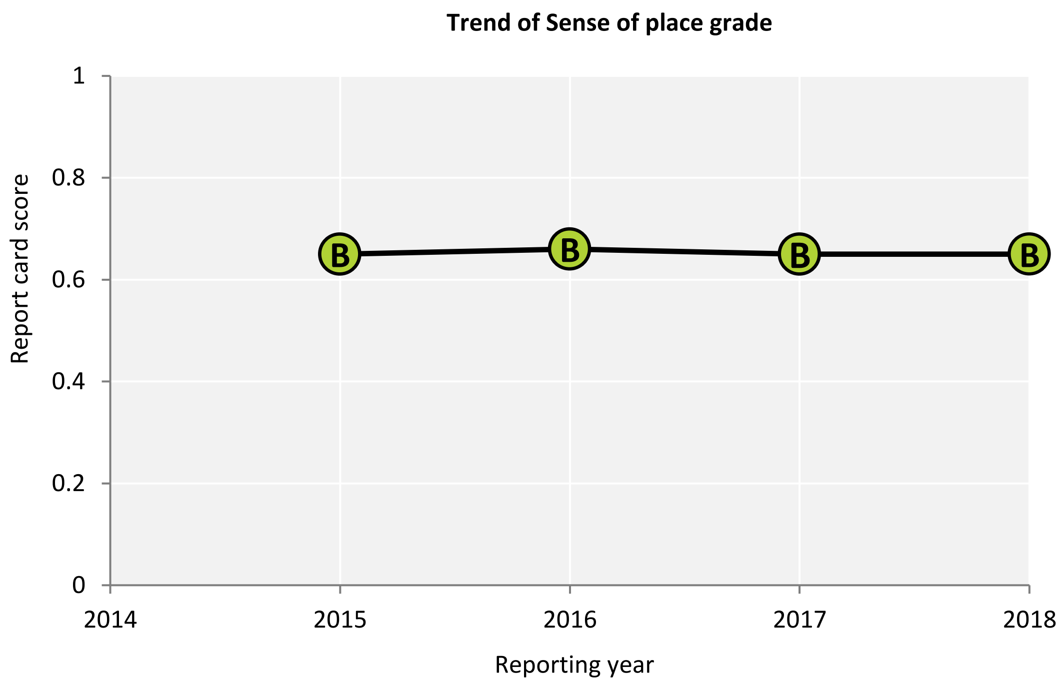


Figure 6.6: The trend of grade received for 'sense of place' indicator group since year 2014.

Indigenous cultural heritage

The overall harbour score for Indigenous cultural heritage was 0.54 (C) and very similar to the 2017 score of 0.55 (C). This score is based on the satisfactory scores received for physical condition (0.56) and management strategies (0.52) indicators. Overall, the physical condition and management strategies scores remain satisfactory for all zones except for the Wild Cattle Creek, which received a poor score of 0.48 (D) for management strategies (Figure 6.7).

Figure 6.7: Indicator scores for physical condition and management strategies across four reporting zones in the 2018 Gladstone Harbour Report Card.

The physical condition is based on three measures—*intactness of site features, extent of current disturbance* and *management of threats* (Table 6.3).

The *intactness of site features* received good to very good scores for all zones. When over 50% of the cultural features within a zone are undisturbed and artefacts are *in situ* good to very good results are likely. Although *intactness of site features* received high scores, if management strategies are not implemented properly, further disturbance continue to occur resulting in a lower score for this measure over time. The *management of threats* measure scores in the Facing Island and Wild Cattle Creek were very poor; The Narrows received a poor score and Gladstone Central received a satisfactory score, indicating the disturbed nature of the sites. The poor scores reflect a range of anthropogenic and natural impacts and threats on the cultural elements and features at each site. Some of these impacts and threats include off-road vehicle use, trampling, camping, rubbish, development, wind erosion, inundation and weeds (Figure 6.8) (Terra Rosa, 2018).

Table 6.3: Overall scores for physical condition scores across four zones.

	Physical condition		
	Intactness of site features	Extent of current disturbance	Management of threats
The Narrows	0.82	0.63	0.28
Facing Island	0.95	0.64	0.11
Wild Cattle Creek	0.67	0.59	0.24
Gladstone Central	0.85	0.44	0.50

Figure 6.8: A – Police Creek site in Gladstone Central zone – The area has high cultural and historical significance due to its association with a native police camp in 1854 and Aboriginal fringe camp in 1890. The field team has noticed chainsaw marks along the base of one of the scar trees at Police Creek. B – FAC15-01 site in Facing Island zone – Highly disturbed by vehicle tracks running through the site. The field team recommended establishing signage, fencing and designated tracks to inform the visitors and residents about the cultural significance of the area and to minimise further damage.

Within the cultural management strategies indicators, *cultural management* and *cultural resources* measures received very poor scores across all zones (Table 6.4). The *cultural management* score is based on the availability of a heritage management plan and evidence of a range of active cultural management activities occurring within the zone. The *cultural resources* score is based on the availability of physical and digital interpretive elements. The poor scores reflect the lack of a cultural management plan, lack of cultural management activities, and minimal availability of physical and digital interpretive elements in the monitoring zones. If these scores are to be improved, a proactive heritage management plan is needed. Although not directly comparable, the poor cultural maintenance scores received for all zones for 2016 and 2017 reflect the non-availability of a proactive cultural management plan in the monitoring zones.

Recording and *monitoring* measures received very high scores for all zones. Scores for The Narrows and the Wild Cattle Creek zones are based on sites revisited last year. Overall the good scores for the *monitoring* measure indicate that a good proportion of existing monitoring stations have been revisited.

The *stakeholder engagement* scores were satisfactory to poor highlighting the need for improved engagement activities with all key stakeholders relevant to site and zone management. When there is a good relationship with stakeholders, agreements can be put in place to mitigate the impacts of development on cultural sites within the zone, and stakeholders can be effectively engaged in conversations regarding management strategies, which will improve scores over time (Terra Rosa, 2018). The *access* measure for Facing Island received very good score meaning that all sites within the zone are easily accessible for heritage management activities.

Table 6.4: Overall scores for management strategies across four zones. Scores for The Narrows and Wild Cattle Creek zones are based on data collected for the previous year.

	Management strategies					
	Recording	Cultural management	Stakeholder engagement	Monitoring	Access	Cultural resources
The Narrows	0.80	0.10	0.50	0.80	0.60	0.20
Facing Island	0.90	0.10	0.40	0.90	0.90	0.10
Wild Cattle Creek	0.80	0.10	0.60	0.70	0.60	0.10
Gladstone Central	1.00	0.10	0.40	1.00	0.60	0.10

6.4. Cultural indicator conclusions

'Sense of place'

Overall the score for 'sense of place' remains at 0.65 (C) and is similar to previous years (0.65 in 2015, 0.66 in 2016 and 0.65 in 2017) (Table 6.5). Although some scores for indicators fluctuated slightly compared to the previous year, there was no change in the grades, suggesting that the community's expectations of the Gladstone Harbour area are mostly being met. The 'sense of place' indicators showed relatively little temporal variation compared with the previous report card scores.

Overall scores for three indicators, *distinctiveness*, *continuity* and *values of harbour* declined compared to the previous year.

The declined *distinctiveness* measure suggests people possess only a moderate identity with the harbour. The scores received for *distinctiveness* declined compared to 2016 and 2017 scores, indicating reduced engagement with, and appreciation of, the harbour-related activities.

The *continuity* indicator continued to decline compared to previous years and suggests that many of the respondents had moved to Gladstone in recent years. *Continuity* also received the lowest score out of all 'sense of place' indicators. This indicator was assessed through 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 (0.41) for the former question indicates that many respondents had not lived in Gladstone all their lives; however, the high score of the latter (0.65) indicates that community is becoming less transient and more stable (this may reflect the downturn in construction work in the region). The average time respondents had lived in the Gladstone Region further declined from 23.9 years in 2017 to 20.29 years in 2018 (26.5 years in 2016).

The score for the *attitudes to Gladstone harbour* improved slightly although remain very stable compared to previous years (Table 6.5). This shows that residents continue to have a positive outlook for the harbour area and what it provides to the community.

The *self-esteem* score has increased from 0.72 in 2015 to 0.74 in 2018, indicating that residents continue to feel proud living in the Gladstone community.

The *values of Gladstone harbour* indicator scores declined slightly but remain similar to previous years, suggesting that overall community perceptions around harbour values remain stable. Residents in the Gladstone Region continue to 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. However, fewer residents valued Gladstone Harbour highly based on its spiritual, cultural and historical significance.

The *self-efficacy* indicator increased slightly indicating that residents continue to feel their quality of life has improved. The community input into management measure received a satisfactory score, similar to the previous year.

Table 6.5: Comparison of 'sense of place' indicator grade and score between 2015 and 2018 report cards.

		2018	*2017*	*2016*	*2015*
Indicator group	'Sense of place'	0.65	*0.65*	*0.66*	*0.65*
Indicators	Distinctiveness	0.56	*0.57*	*0.59*	*0.55*
	Continuity	0.53	*0.54*	*0.59*	*0.57*
	Self-esteem	0.74	*0.72*	*0.74*	*0.72*
	Self-efficacy	0.59	*0.58*	*0.58*	*0.56*
	Attitudes to Gladstone harbour	0.83	*0.81*	*0.81*	*0.8*
	Values of Gladstone harbour	0.65	*0.66*	*0.66*	*0.64*
Overall harbour score		**0.65**	***0.65***	***0.66***	***0.65***

Indigenous cultural heritage

The Indigenous cultural heritage indicator framework was revised for the 2018 report card. The overall grade for Indigenous cultural heritage is a result of 9 measures (21 measures in the previous framework) and based on physical condition and management strategies indicators (these were further subdivided into six sub-indicators as in the previous framework). The new scoring structure takes into consideration the social, spiritual and scientific values of sites, includes anthropogenic and natural impacts on a number of Indigenous heritage resources, and also acknowledges the constantly changing cultural landscape. Although not directly comparable, the overall cultural heritage for 2018 report card remains at satisfactory, similar to the 2016 and 2017 grades.

The overall physical condition of the zones remained satisfactory. However, the ongoing natural (e.g. erosion, inundation) and anthropogenic (e.g. off-road vehicle use, development) disturbance and threats to the sites are evident in *management of threats* measures for three out of four zones surveyed (Table 6.3).

Similar to previous years, the lack of proactive cultural heritage management plan and heritage management activities in monitoring zones resulted in very poor scores for *cultural management* and *cultural resources* indicators for all zones (Table 6.4). The very poor scores could be greatly improved by focusing on a range of heritage management activities such as fencing, weed control, dune rehabilitation, imposing restrictions on 4WD access, installing cultural signage, and introducing or improving heritage management plans.

The stakeholder engagement scores ranged from satisfactory to poor, highlighting the need for improved engagement activities with all key stakeholders relevant to site and zone management.

Table 6.3: Overall harbour scores for Cultural component.

Zone	Overall		
	2018[a]	*2017*	*2016*
The Narrows	0.54	*0.56*	*0.53*
Facing Island	0.56	*0.55*	*0.57*
Wild Cattle Creek	0.49	*0.50*	*0.44*
Gladstone Central	0.57	*0.60*	*0.59*
Overall harbour score	0.54	*0.55*	*0.53*

[a] Indigenous cultural indicator framework has been simplified in 2018 and some new measures are not directly comparable with previous years' measures.

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).

In comparison to 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 the 2017 reporting year. To improve the quality of the indicator framework, minor modifications were made by:

- using 2016 national census data to calculate socio-economic status indicator (scores for this indicator prior to 2018 were based on 2011 census data)

- removing the line fishing measure from the commercial fishing indicator due to considerable data gaps in the database

- adding a new indicator 'water-based recreation' to the economic value (recreation) indicator group.

Table 7.1: Data sources and baselines employed to derive the economic scores and grades for the 2018 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 (2017–18 financial year)	Gladstone Ports Corporation	10-year average 2008–18
	Tourism expenditure	Gladstone Region's total tourism expenditure output and estimated spending from cruise ship passengers and crew	Expenditure on hotel accommodation (for 2007–08 to 2012–13 financial years) Expenditure on hotel accommodation and food (2013–14 financial year to present) from Gladstone Regional Council – REMPLAN Economic Profile (2017) AEC (2016). Economic Impact Assessment of the Cruise industry in Australia, 2015–16. Report for the Australian Cruise Association.	10-year average 2007–17
	Commercial fishing	Productivity of net (fish) fisheries Productivity of trawl (otter) fisheries Productivity of pot (mud crabs) fisheries	**Prices (average $/kg for fish prawns and crabs)** ABARES – Australian fisheries and aquaculture statistics 2016 (published in December 2017) **Production (fishing effort)** Queensland Fishing (QFish), Queensland Department of Agriculture and Fisheries	10-year average 2008–18[1]

[1] At the time of reporting, data for all months in the 2017–18 financial year were incomplete and three months data for April to June 2018 were unavailable.

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 (2018 March quarter)	Australian Department of Employment, *Small Area Labour Markets*	Queensland 2018 distribution for March quarter
	Socio-economic status	Index of Economic Resources derived from 2016 ABS census and updated using the community CATI survey	CATI survey; Australian Bureau of Statistics, 2016 census	Australian 2016 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
	Water-based recreation	Water-based recreation satisfaction and economic value	Satisfaction from CATI survey and economic value from Windle et al., 2017	10-point scale

Figure 7.1: Left – A ship being loaded with coal at Wiggins Island Coal Terminal. Right – A ship docked at Curtis Island prior to being loaded with LNG (Photo courtesy Uthpala Pinto).

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 the three activities of 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 (DEA).

A 10-year baseline data from 2008–18 was used in the analysis. Prior to 2017, a 20-year array was used. The shipping activity is weighted higher than the other two sectors due to its greater contribution to the 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 2007 to 2017 in the Gladstone Region. This information is sourced from an annual input–output analysis conducted by the REMPLAN consultancy group and the latest estimates were for 2016–17 financial year. The REMPLAN consultancy group estimated the output of tourism using an input–output analysis 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. Similar to the previous year,

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, reduction in market demand, reduced 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 as a technique to measure the performance or relative efficiency of organisations such as banks, hospitals and schools. During the analysis, a reference is set, including the best-performing organisations, which is called an 'efficiency frontier'. The 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 within the efficiency frontier are considered less than 100% efficient. This analysis is very important when we need to compare organisations with multiple inputs and outputs and need a special software tool to calculate the efficiency scores. The DEA analysis is performed on the capacity utilisation measures in two of the report card 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 2018 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.

the tourism indicator was supplemented with expenditure made by passengers and crew members of six (four in previous years) cruise ships docked at Gladstone port in the 2016–17 financial year.

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 three sectors: the net (fish), pot (mud crab) and otter trawl (prawns) fisheries in Gladstone Harbour relative to a 10-year average starting from 2008–09. Production figures come from the three grids, but prices are Queensland state-wide estimates (Figure 3.29 in Section 3.2).

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 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 was 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 data for April–June was not included in the analysis for the 2017–18 monitoring year as this information was not available in the QFish database at the time of report preparation, similar to last year.

The total value of commercial fishing was estimated based on catch data by fishing method data from the QFish database and average prices for each species group (fish, prawns and crabs) was derived from the most recent Australian fisheries and aquaculture statistics published by ABARES statistics (Mobsby and Koduah 2017, p. 102).

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., 2018).

A capacity utilisation approach is applied and the measures of relative productivity were estimated using the DEA. The three fisheries 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 2018 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 14 variables including income extremes (both high and low) in a population, household ownership, cost of living and other indicators relevant to economic wellbeing in the community. The IER was calculated using 2016 Australian census data. A system of weightings (ABS, 2018) for the 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.

Economic value (Recreation)

The economic value (recreation) indicator group was assessed through four indicators: land-based recreation, recreational fishing, beach-based recreation and water-based recreation (non-fishing). The water-based recreation indicator is new to the Economic component and based on the trip value estimated in 2017.

Two components of the recreational values can be assessed:

- the commercial value of the recreation and tourism (estimated based on financial records of commercial tourist operators)
- the 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).

While the former is already captured in the economic performance indicator, the latter is included in the economic value (recreation) indicator group.

The scores for the four 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 400 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 of 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) were estimated (Pascoe et al., 2014). Additional information was collected in 2015 and 2017 to estimate the value of a recreational fishing trip ($141) and water-based recreation ($95) (Cannard et al., 2015; Windle et al., 2017). The per-trip recreational values 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 four types of recreational activities are also collected from the CATI survey.

The indicator scores for land-based recreation, recreation fishing, beach recreation and water-based 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 ranged from satisfactory to very good yielding an overall good score of 0.72 for the Economic component of the 2018 Gladstone Harbour Report Card (Figure 7.2). Of those indicator groups, economic performance received the highest score of 0.90 (A), economic value of recreation received a score of 0.74 (B) and economic stimulus received a score of 0.58 (C).

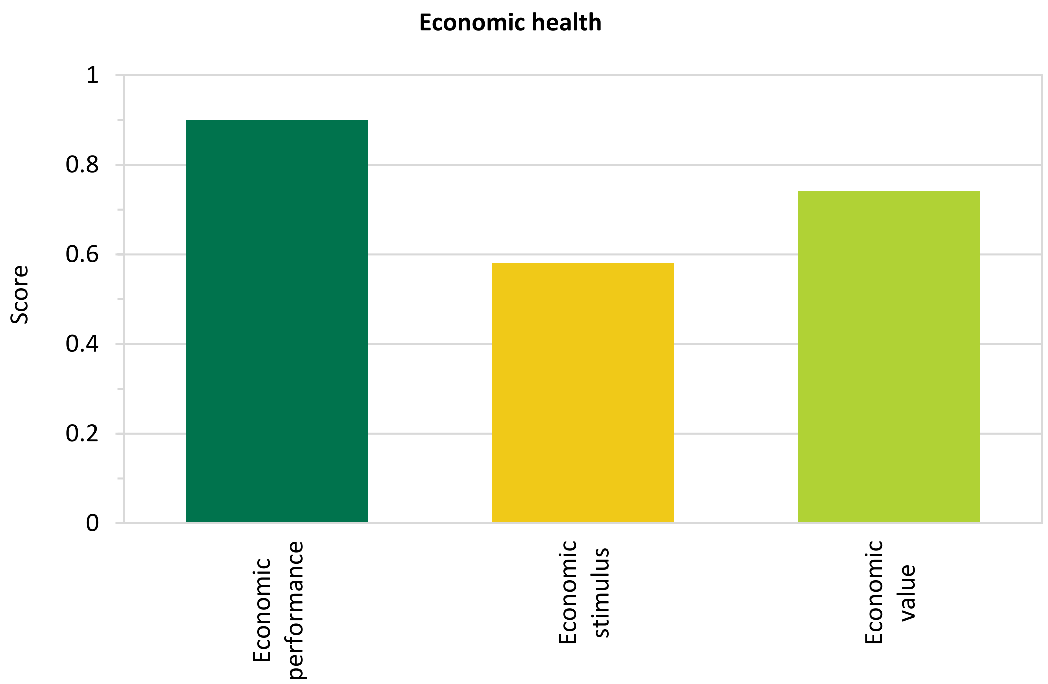


Figure 7.2: The scores for each of the three economic indicator groups in the 2018 Gladstone Harbour Report Card.

Economic health

Economic performance

The economic performance of Gladstone Harbour remains in a very good state (0.90) in 2018, the same score as in 2017.

Within the economic performance indicator group, shipping activity received the highest score of 0.90 (0.90 in 2017), followed by tourism 0.90 (0.90 in 2017). Commercial fishing received the lowest score of 0.35 (0.35 in 2017) and continues to be in poor state (Figure 7.3).

Similar to previous years, the overall economic performance score was strongly influenced by the high scores for shipping activity and tourism, and has remained very good since 2016 (Figure 7.4)

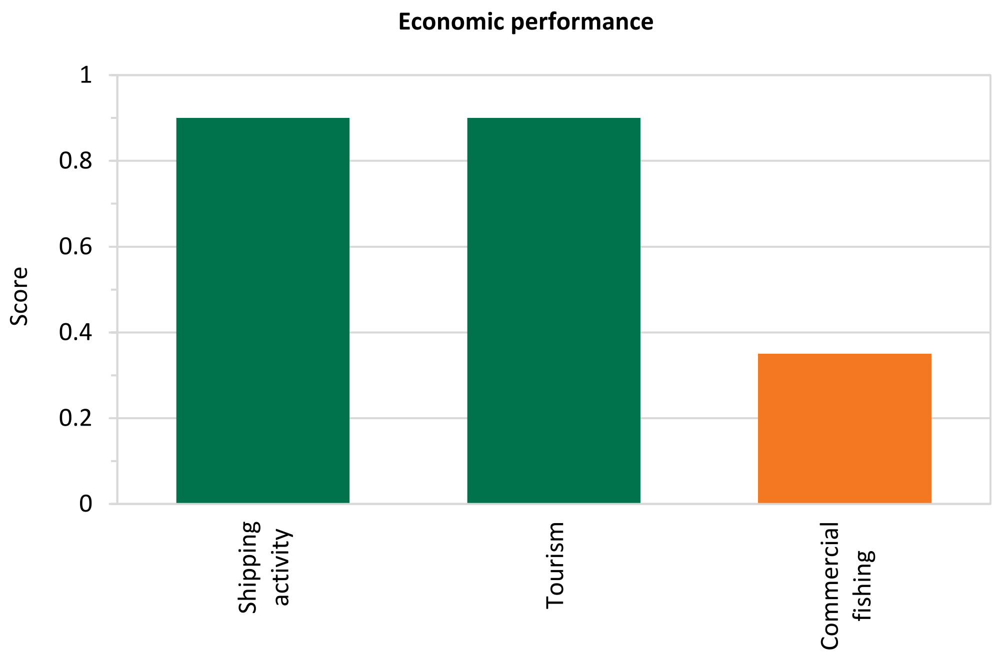


Figure 7.3: Scores for the three indicators of economic performance in the 2018 Gladstone Harbour Report Card.

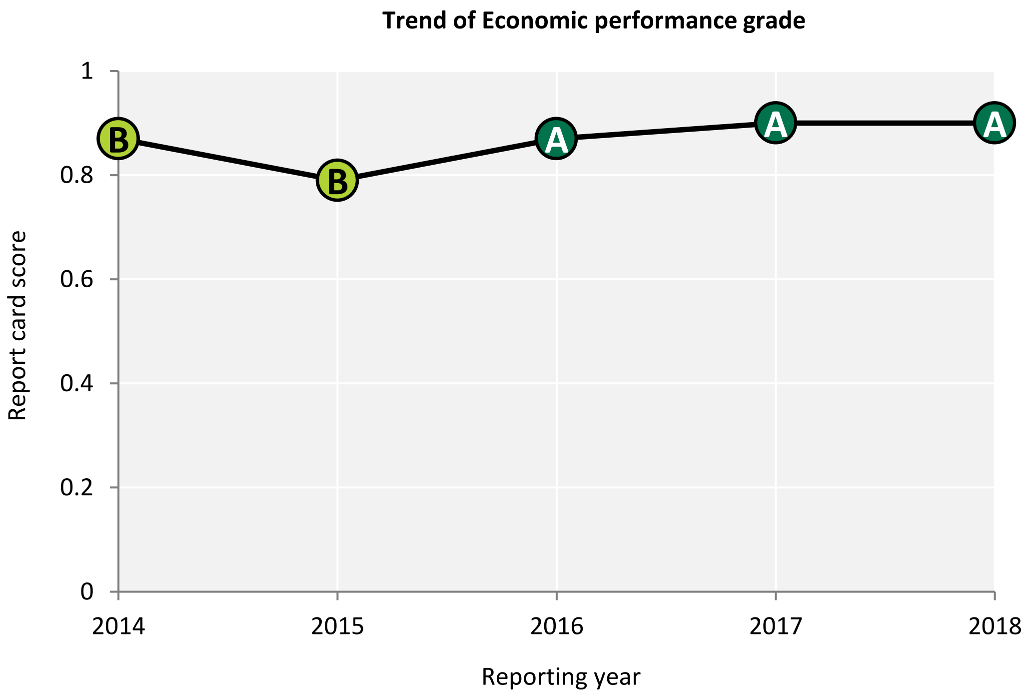


Figure 7.4: Economic performance grades from 2014 report card.

Shipping activity

The shipping activity indicator, based on the movement of shipping by cargo type in Gladstone Harbour, remained very good 0.90 (A), as in 2017. The total income generated by the Gladstone Ports

Corporation in 2016–17 was $471 million, a slight decrease from $479 million in 2015–16 and this is an increase from $453 million in 2014–15.

Coal exports (the dominant shipping activity) in Gladstone fluctuated over the reporting months, while LNG exports remained stable during the 2017–18 reporting year. The alumina exports, which historically have been the second largest export from Gladstone Harbour, remained low over the reporting period (Figure 7.5). The total ship movements in and out of the harbour was similar to 2017 with a total annual count exceeding 100 vessels (Figure 7.6). Overall capacity utilisation remains similar to the previous year resulting in a similarly high score for the shipping indicator.

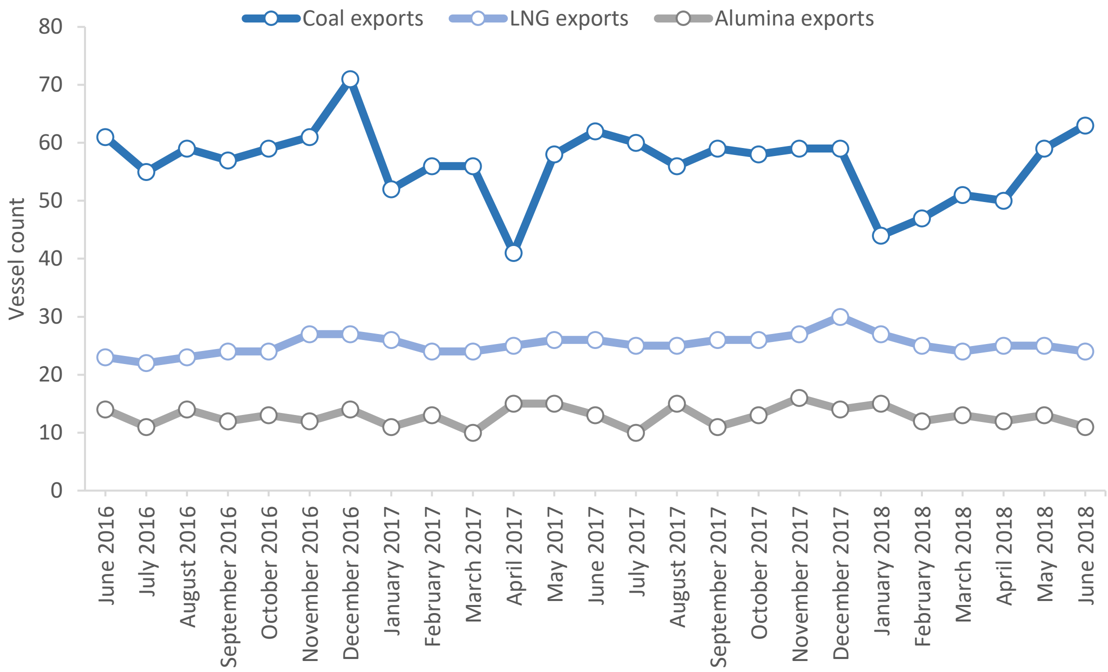


Figure 7.5: Trends in the three main commodity exports from Gladstone Harbour (Source: Gladstone Ports Corporation trade statistics prepared by Windle et al., 2018).

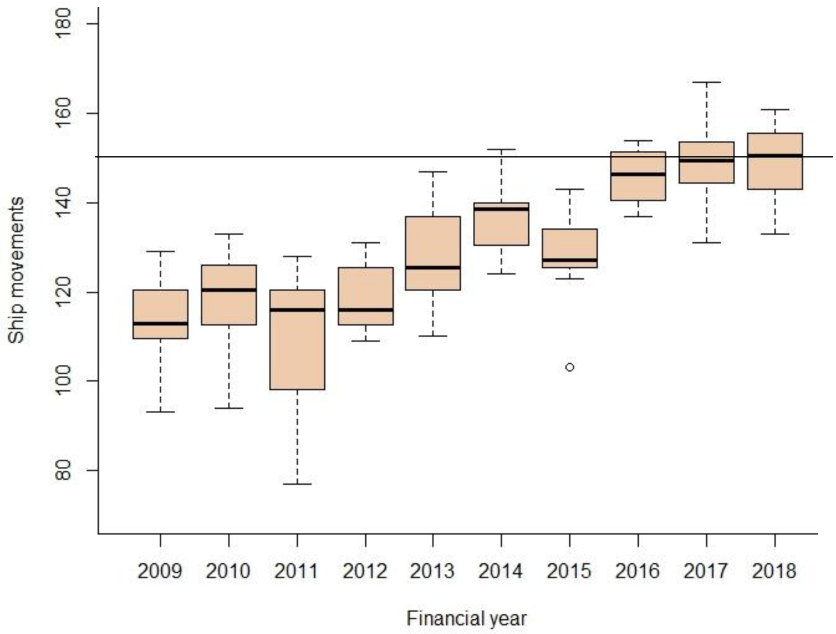


Figure 7.6: Trends in annual shipping movements in and out of the since 2009 (Source: Gladstone Ports Corporation trade statistics prepared by Windle et al., 2018).

Tourism

The tourism indicator remains 0.90 (A) in 2018, the same as in 2017.

Expenditure on tourism (accommodation, food and other local services) in the Gladstone Region was $341 million in 2016–17, up from previous years ($317 million in 2015–16, $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 has increased over time.

For the 2016–17 financial year, six cruise ships docked at Gladstone Port. The passengers and the crew spent an estimated $0.48 million in Gladstone (Windle et al., 2018). This contribution is approximately 0.1% of the total tourism expenditure in the region. The tourism expenditure from cruise ships has been added to the overall Gladstone Region estimate of $340.19 million in tourist expenditure for the 2016–17 financial year (Windle et al., 2018).

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

Commercial fishing

The commercial fishing indicator remained poor (0.35, D) in 2018 and the same as in 2017. Two factors likely contributed to this: the decline in GVP compared to the previous year and the three months of missing data related to fishing production (fishing effort based on number of licences and number of days fished) at the time of the score calculation.

The calculated GVP for Gladstone Harbour fisheries for 2017–18 was $1.64 million, a decrease from 2016–17 ($1.93 million), 2015–16 ($2.83 million) and 2013–14 ($4.68) estimates (Figure 7.7b). The GVP in Gladstone has been declining since 2014. Note at the time of completion of the analysis, the

GVP data for April to June 2017 were not available in the QFish database, as was the case for data for the 2017 report (Windle et al., 2018).

Although the productivity of commercial fisheries in Gladstone has declined considerably since 2014, the commercial fishing productivity in Gladstone ($3.37million[2]) remained relatively strong compared with the neighbouring regions of Mackay ($1.89 million[2]) and Yeppoon ($131 million[2]) with similar fisheries (Figure 7.7). The fisheries prices for fish, prawns and crabs (Queensland state-wide estimation) also remained relatively steady since 2012 (Figure 7.8).

The low score for the commercial fishing indicator was influenced by low productivity scores for net fisheries (0.25) and trawl fisheries (0.29). Pot fisheries productivity improved compared to the previous year from 0.62 to 0.64.

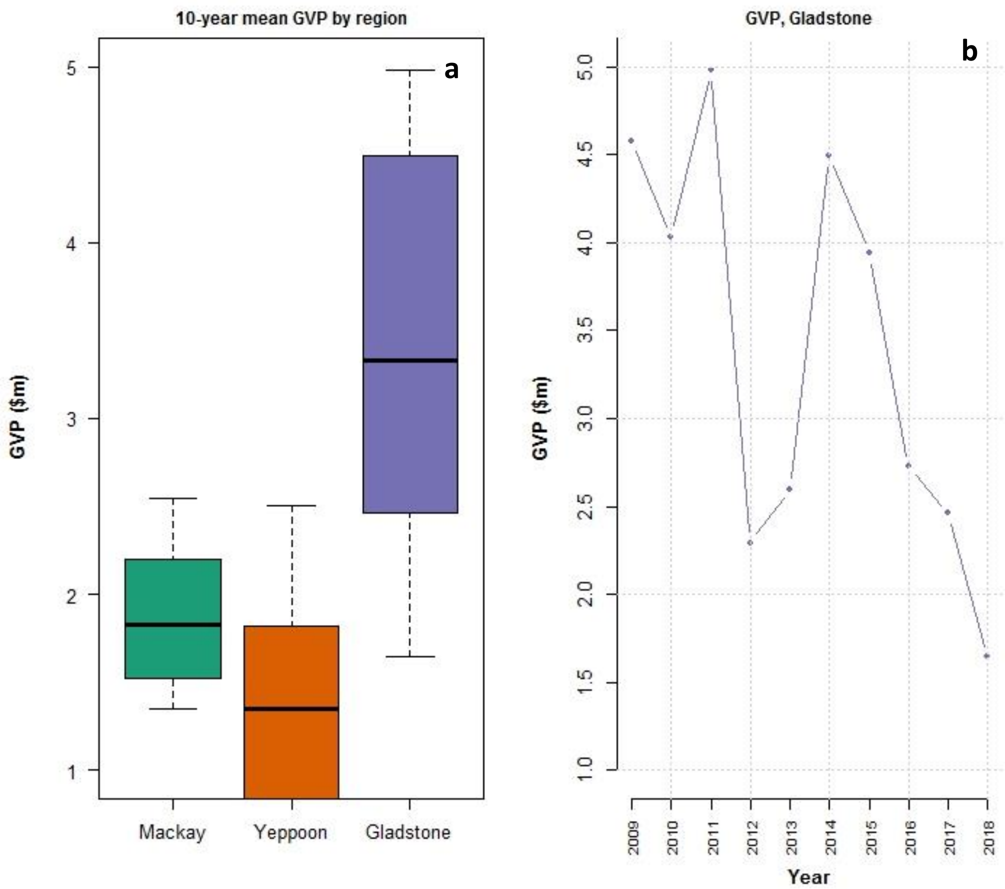


Figure 7.7: The 2008–16 gross value production for: (a) the regions of Mackay, Yeppoon and Gladstone (b) and change in GVP Gladstone, 2009–2018 (Source: Windle et al., 2018).

[2] 10-year mean GVP for the region

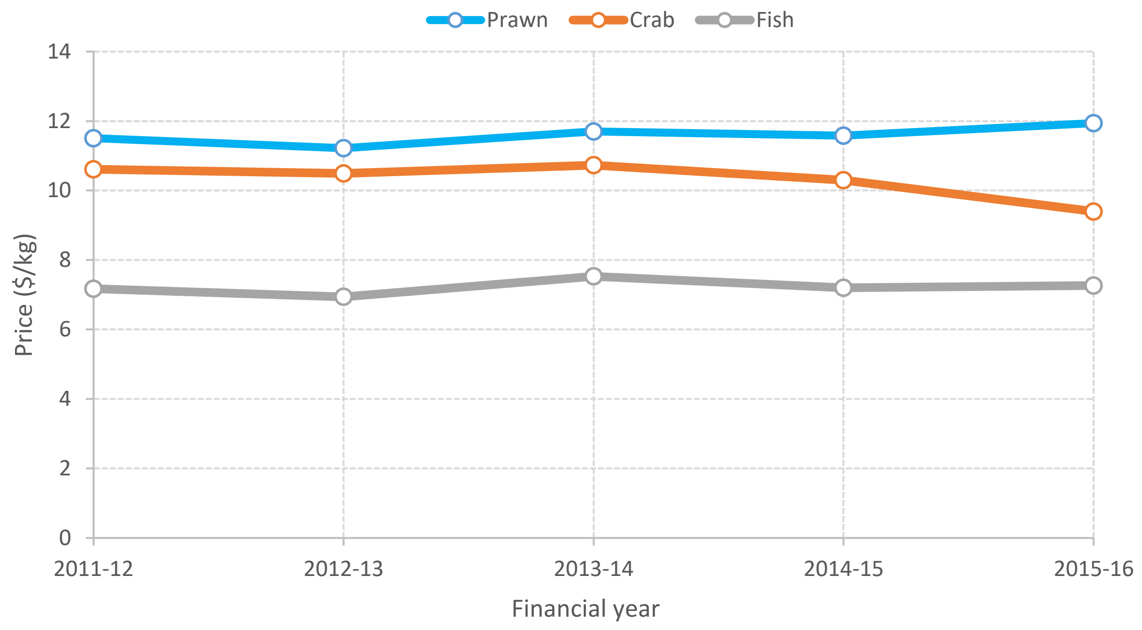


Figure 7.8: Price changes over time for prawns (otter), mud crabs (pot) and fish (net) from the 2011–12 to the 2015–16 financial year (Source: Windle et al., 2018).

Economic stimulus

The score for economic stimulus of 0.58 (C) was aggregated from the scores of two indicators: employment 0.44 (D) and socio-economic status 0.64 (C) (Figure 7.9). The employment and socio-economic status considerably declined compared to the previous year and changed the grade from C to a D for employment, and B to a C for socio-economic status. The overall economic stimulus scores have been steadily declining since the monitoring began in 2014 (Figure 7.10).

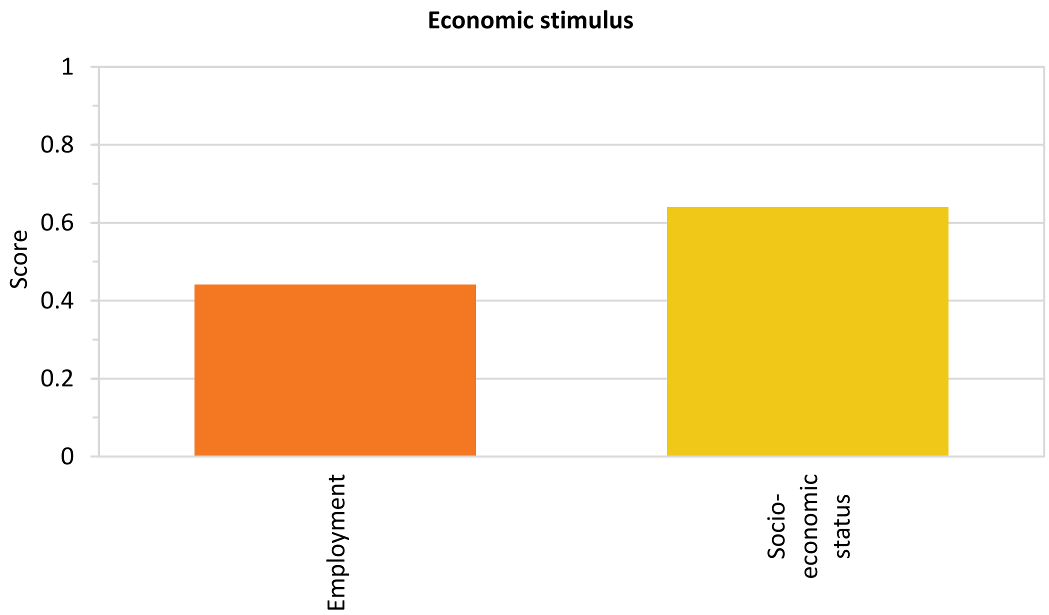


Figure 7.9: Scores for the two indicators of economic stimulus in the 2018 Gladstone Harbour Report Card.

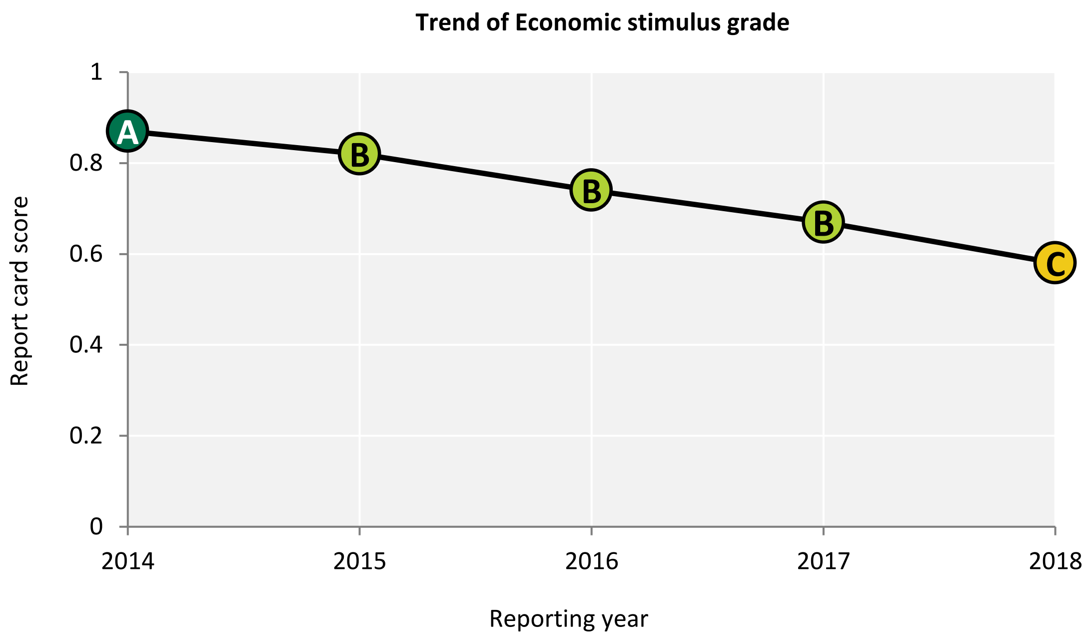


Figure 7.10: Trend of economic stimulus indicator since 2014 report card.

The unemployment rate of 8.0% for the 2018 March quarter was higher than the 2017 rate of 7% for the same period and higher than the state average of 6%. Over the past 12 months, the relative position of Gladstone deteriorated slightly compared to other LGAs in Queensland. The score for employment declined steadily from 0.53 in 2017 to 0.44 in 2018.

The socio-economic status score for 2018 (0.64, C) has declined slightly for the Gladstone Region from a score of 0.70 (B) in 2017. Overall, the low scores reported for socio-economic status reflect the impact of job losses and increased unemployment in the Gladstone Region. However, the socio-economic index used census data from the 2016 national census, thereby making the direct comparison of this score somewhat limited as previous scores were based on 2011 census data (Windle et al., 2018).

Economic value (Recreation)

The overall economic value received a score of 0.74 (B) and the grade remained the same as previous reporting years (0.73 in 2017, 0.73 in 2016, 0.72 in 2015). Similarly good scores were received for land-based recreation (0.76), recreational fishing (0.68), beach recreation (0.75) and water-based recreation (0.75) (Figure 7.11).

Both the beach recreation indicator (0.75 in 2018 and 0.74 in 2017) and the recreational fishing score (0.68 in 2018 and 0.65 in 2017) increased slightly from the previous year, but the grade B remained the same as 2017 (Figure 7.12).

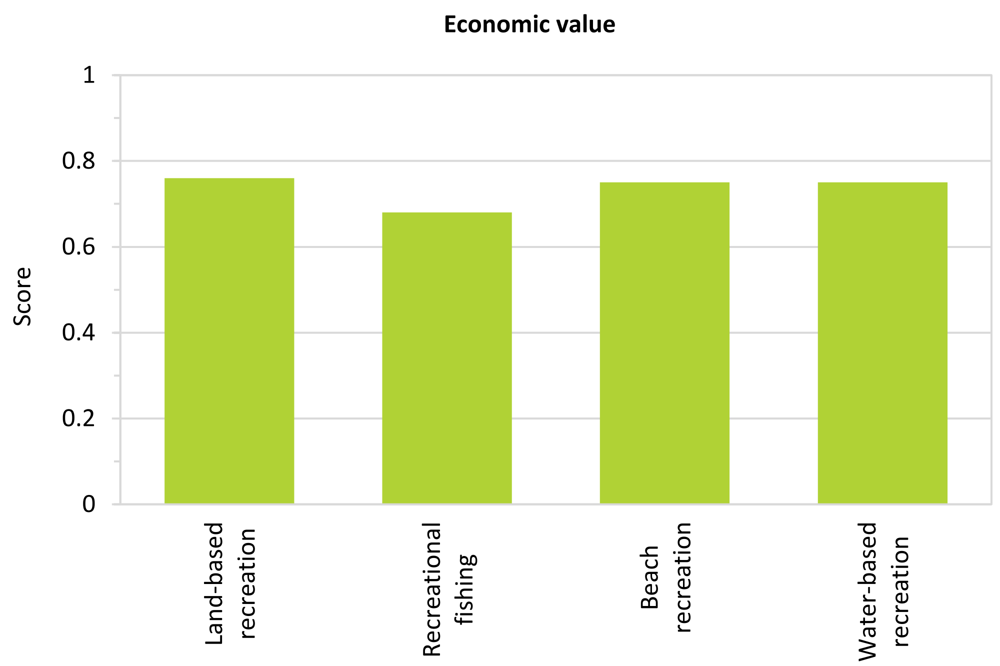


Figure 7.11: Scores for the three indicators of economic value (recreation) in the 2018 Gladstone Harbour Report Card.

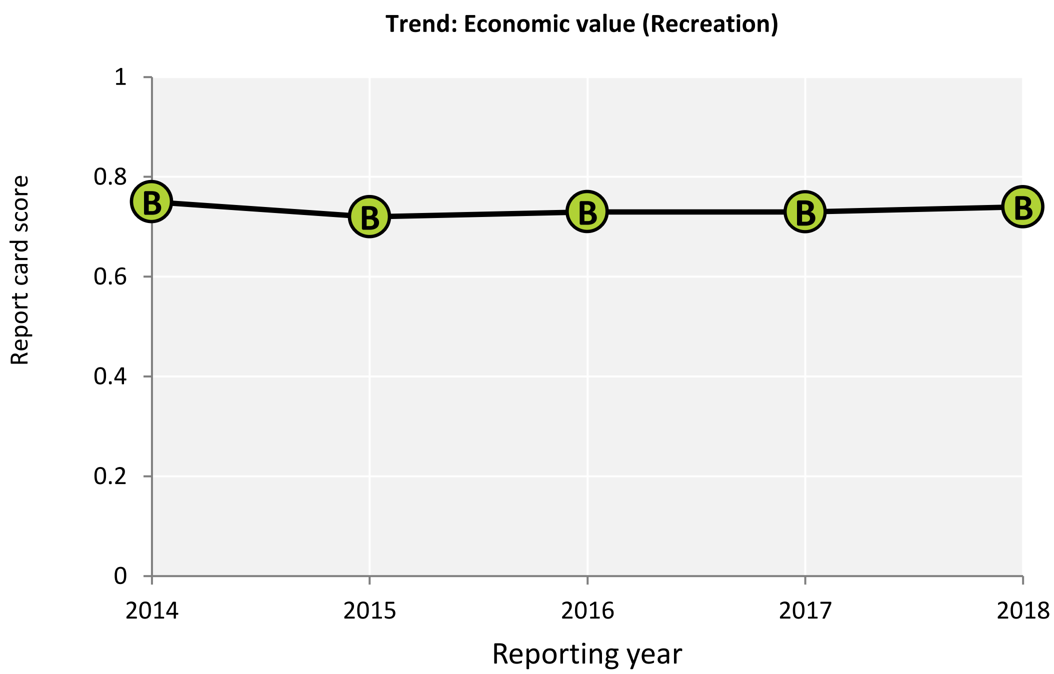


Figure 7.12: Trend of economic value (recreation) from 2014. Note that in 2018, the overall grade was calculated based on an additional indicator water-based recreation value which was not part of the 2017 assessment.

According to the CATI survey, the most popular land-based activities along the shores of Gladstone Harbour were walking (similar to 2017 and 2016), picnicking or barbecuing, and relaxing by the water. The most popular beaches visited by the survey participants were the same as last year, being Tannum Sands followed by Spinnaker Park artificial beach and Boyne Island. Land-based and beach recreational activity were much more prevalent than recreational fishing and other water-based recreation. The average satisfaction ratings for three types of recreational activities by CATI respondents were similar in 2016 and 2017—8.22 for beach recreation, 8.26 for land-based recreation and 7.36 for recreational fishing (Windle et al., 2018).

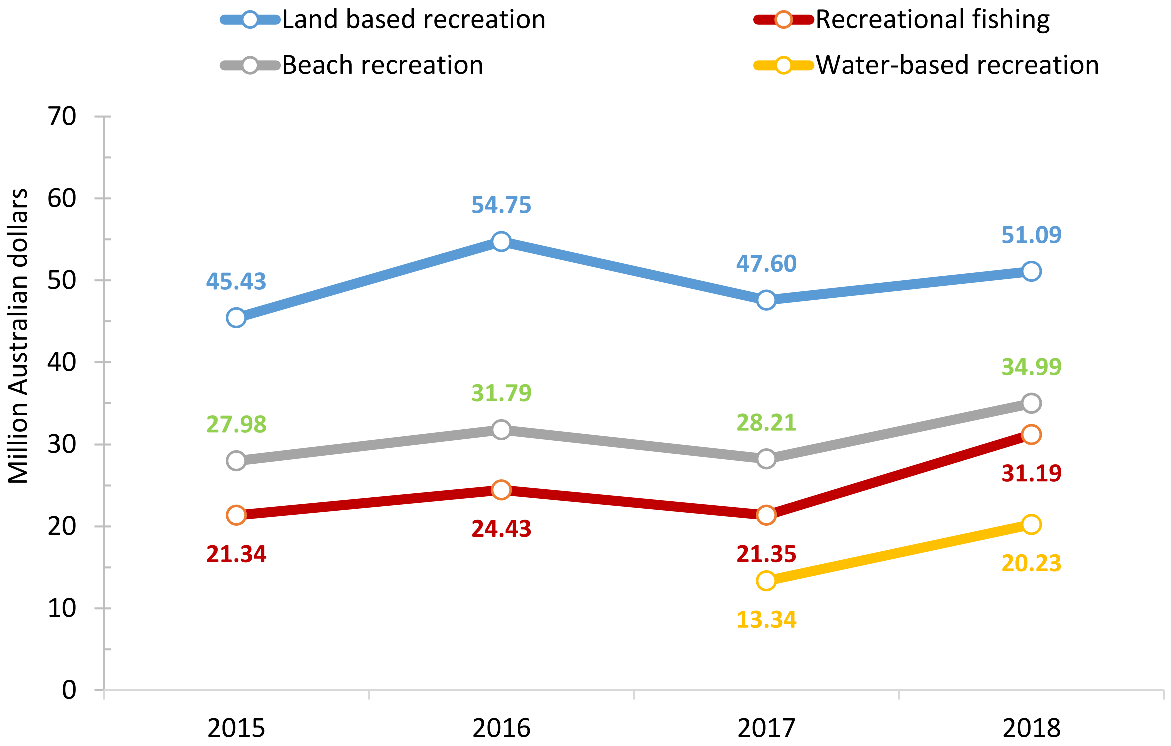


Figure 7.13: The estimated average annual value of recreational trips from 2015–2018. (Note that the 2017 estimates vary slightly from those presented in the 2017 report to align with the change in the source of Gladstone population data for 2018, Windle et al., 2018)

The highest average annual economic value of $51.09 million ($47.60 million in 2017) was reported for land-based recreation followed by $34.99 million for beach recreation ($28.21 million in 2017) and $31.19 million for recreational fishing ($21.35 million in 2017). Overall, the economic value estimates for 2018 were higher than the 2017 values (Figure 7.13).

The land-based recreation trip value increased by about $3.5 million from 2017. However, the average satisfaction rating for land-based recreation decreased from 8.31 (2017) to 8.26 in 2018. As a result, the score remained unchanged compared to the previous year.

The recreational fishing trip value increased from 2017 ($21.35 million) to 2018 ($31.19 million). The average satisfaction rating on recreational fishing trips also increased, from 6.99 in 2017 to 7.36 in 2018. The beach recreation trip value increased by $6.78 million in 2018, and the average satisfaction with the last beach respondents had visited in the Gladstone Harbour area for recreation increased (8.11 in 2017 and 8.22 in 2018). Accordingly, the score for the recreational fishing and beach-based recreation values increased in 2018.

Recreational fishing had a higher per trip value ($143) than beach ($40), land-based ($61) and water-based ($95) recreation. The annual total value of the recreational trip was $137 million, which was higher than in 2017, mainly due to the addition of the value for water-based recreational activities.

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 2018 was strongly influenced by:

- reduced employment opportunities
- declined socio-economic status associated with the end of construction boom and decline in resources sector
- high volume of shipping activity
- increased tourism activities in the region
- adding the value of water-based recreation in Gladstone
- missing data in the commercial fishing indicator.

Economic performance

Economic performance assesses the performance of three key industries based on Gladstone Harbour. The performance of these three industries underpins the stimulus 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 scores continue to remain low. This result must be interpreted cautiously as there have been some missing data in the QFish database that have affected data for both the current and previous years. The measure for line fishing was also removed from the assessment as it contained multiple data gaps and was a very small fishery. However, the low grade is largely driven by lower activity in the net and trawl sectors.

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 employment and socio-economic indicator scores continue to decrease.

The score for socio-economic status declined from good to satisfactory this year. This indicates declined economic stimulus from harbour-based industries that was flowing through the local economy to create some income and wealth and provide satisfactory access to economic resources such as housing. The flow-on effects from increased unemployment in Gladstone means a decline in mean household income also resulted in a lower socio-economic status score in 2018 compared with 2017.

Economic value

Economic value (recreation) assesses how the community generates economic value from the harbour through recreational activities. 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 2018. This pattern was the same as was observed in 2017.

Table 7.2: Economic indicator scores compared for report cards from 2014 to 2018.

		2018	2017	2016	2015	2014
Indicator group	**Economic performance**	0.90	0.90	0.87	0.79	0.83
Indicators	Shipping activity	0.90	0.90	0.87	0.82	0.83
	Tourism	0.90	0.90	0.72	0.64	0.6
	Commercial fishing	0.35[d]	0.35	0.43	0.63	0.66
Indicator group	**Economic stimulus**	0.58	0.67	0.74	0.82[a]	0.87
Indicators	Employment	0.44	0.53	0.62	0.64	0.72
	Socio-economic status	0.64[c]	0.70	0.8	0.95[b]	0.90
Indicator group	**Economic value (Recreation)**	0.74	0.73	0.73	0.72	0.75
	Land-based recreation	0.76	0.76	0.76	0.73	0.76
	Recreational fishing	0.68	0.65	0.66	0.71	0.67
	Beach recreation	0.75	0.74	0.75	0.7	0.71
	Water-based recreation	0.75	NA	NA	NA	NA
Overall harbour score		**0.72**	**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.

[c] In 2018, the socio-economic status was based on the 2016 census data, whereas socio-economic scores prior to 2018 were based on 2011 national census data.

[d] In 2018, the commercial fishing indicator was calculated without the line fishing measures. This measure is excluded in 2018 and future assessments due to data gaps.

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 2018, a total of 150 roosts were surveyed over six days at Port Curtis, Fitzroy Estuary, North Curtis Island, Western Basin reclamation area, Rodds Peninsula, Mundoolin Rocks and Colosseum Inlet. These surveys recorded 12,986 migratory shorebirds from 19 species. This was 1017 less than the 2017 surveys and 5% more than the overall average for the summer counts (2011–2018). The 10 most abundant species accounted for 97% of the birds observed and this was similar to previous years. These species in order of abundance were: red-necked stint *Calidris ruficollis,* bar-tailed godwit *Limosa lapponica,* grey-tailed tattler *Tringa brevipes,* terek sandpiper *Xenus cinereus,* whimbrel *Numenius phaeopus,* lesser sand plover *Charadrius mongolus,* eastern curlew *Numenius madagascariensis,* great knot *Calidris tenuirostri,* greater sand plover *Charadrius leschenaultia* and grey plover *Pluvialis squatarola* (Wildlife Unlimited, 2018).

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 2017 to July 2018, acute climatic events, such as flooding and cyclones, and changes to economic circumstances did not influence the report card grades.

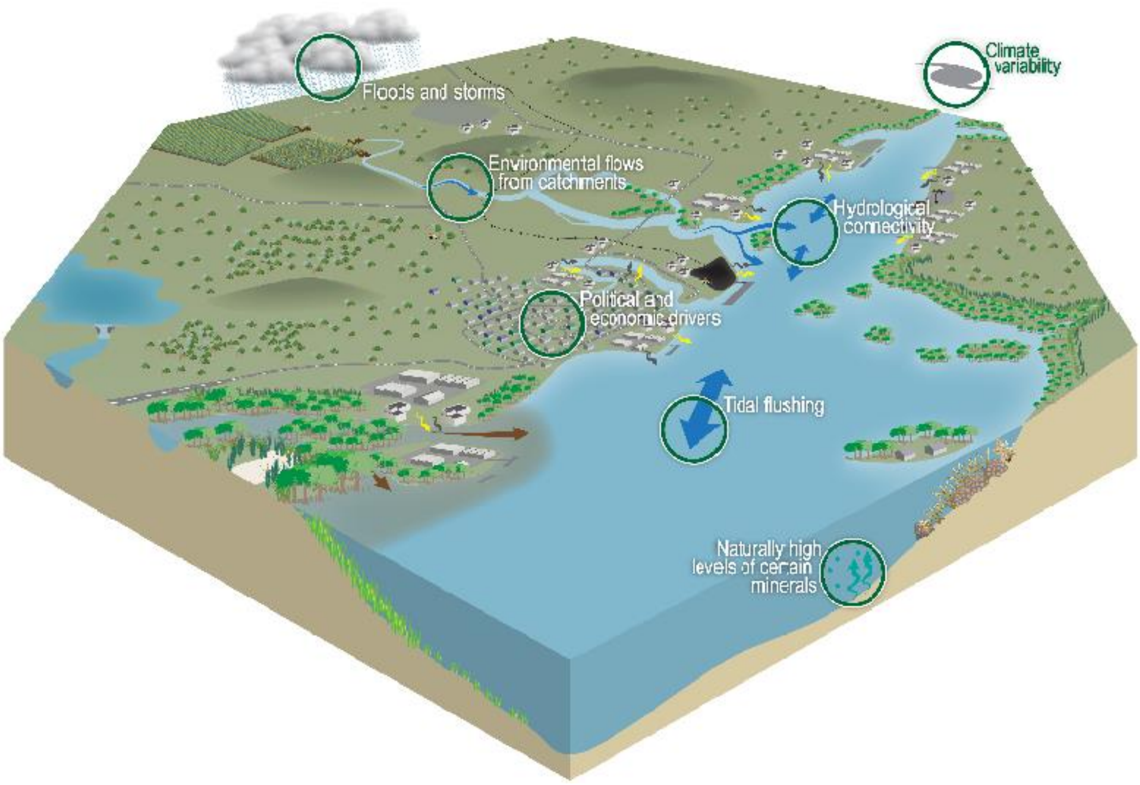


Figure 9.1: Major drivers of environmental change within Gladstone Harbour (Source: McIntosh et al., 2014).

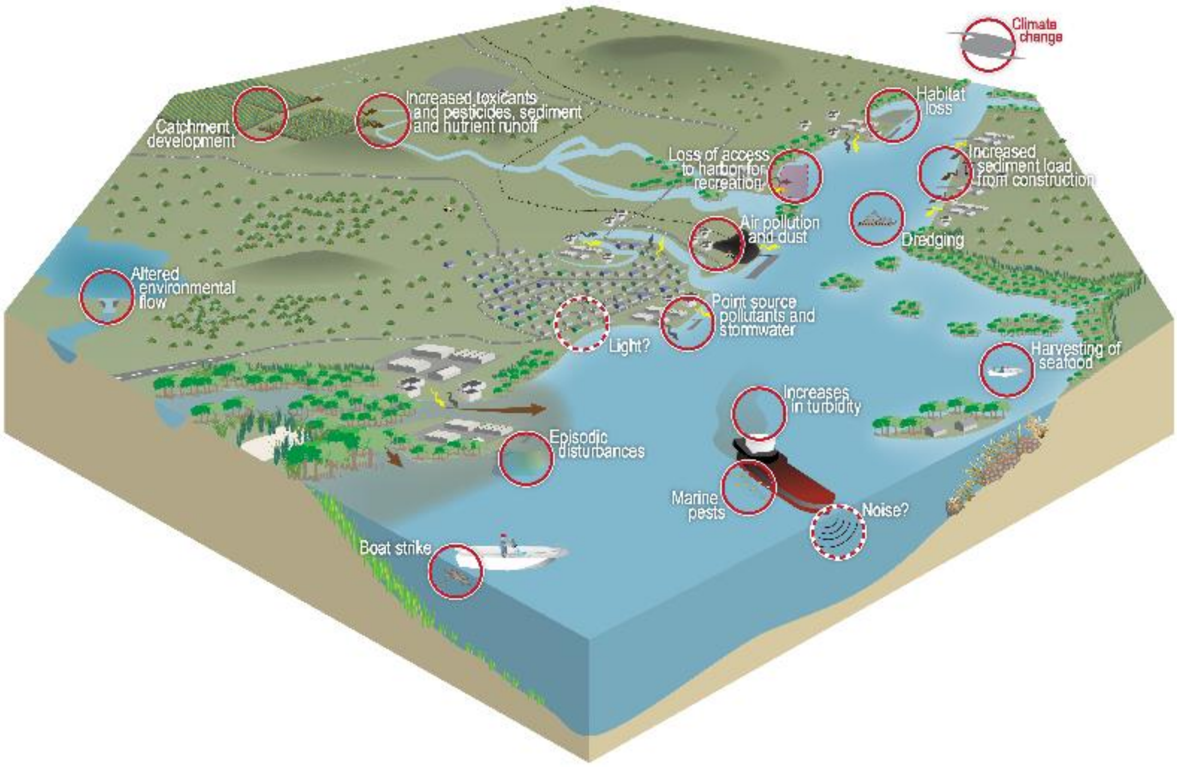


Figure 9.2: Pressures which can drive environmental change within Gladstone Harbour (Source: McIntosh et al., 2014).

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 1994–2018 was 882mm. 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.

2017–18 rainfall

In the 2017–18 reporting year (July 2017 to June 2018), total rainfall recorded at Gladstone Airport was 754mm, which is below the annual average of 882mm (Figure 9.4). Total monthly rainfall for all months except July, October and February were below the monthly average over the past 24 years. The total October 2017 rainfall of 215mm was nearly four times the October average of 58mm. No rainfall was recorded in September 2017 and the period between March and June was also dry, with total rainfall below the average in all months (Figure 9.5).

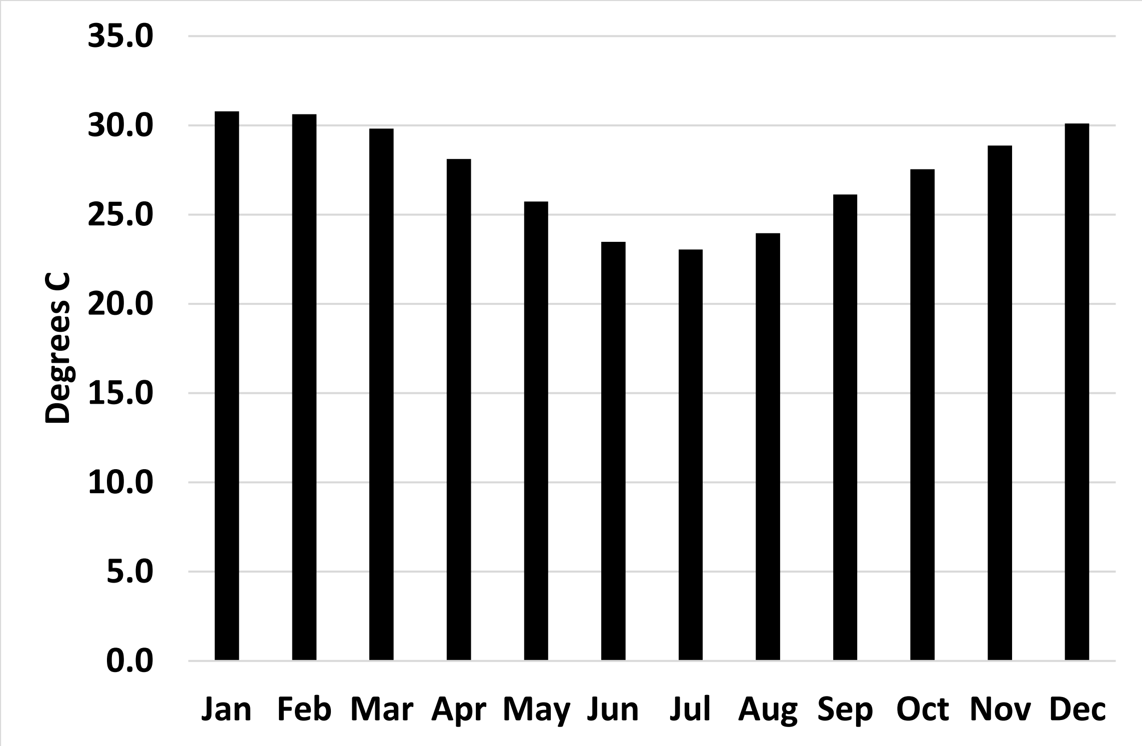


Figure 9.3: Average maximum monthly temperatures at the Gladstone Airport weather station from 1994–2018. Annual average = 27.3° C (Australian Bureau of Meteorology data).

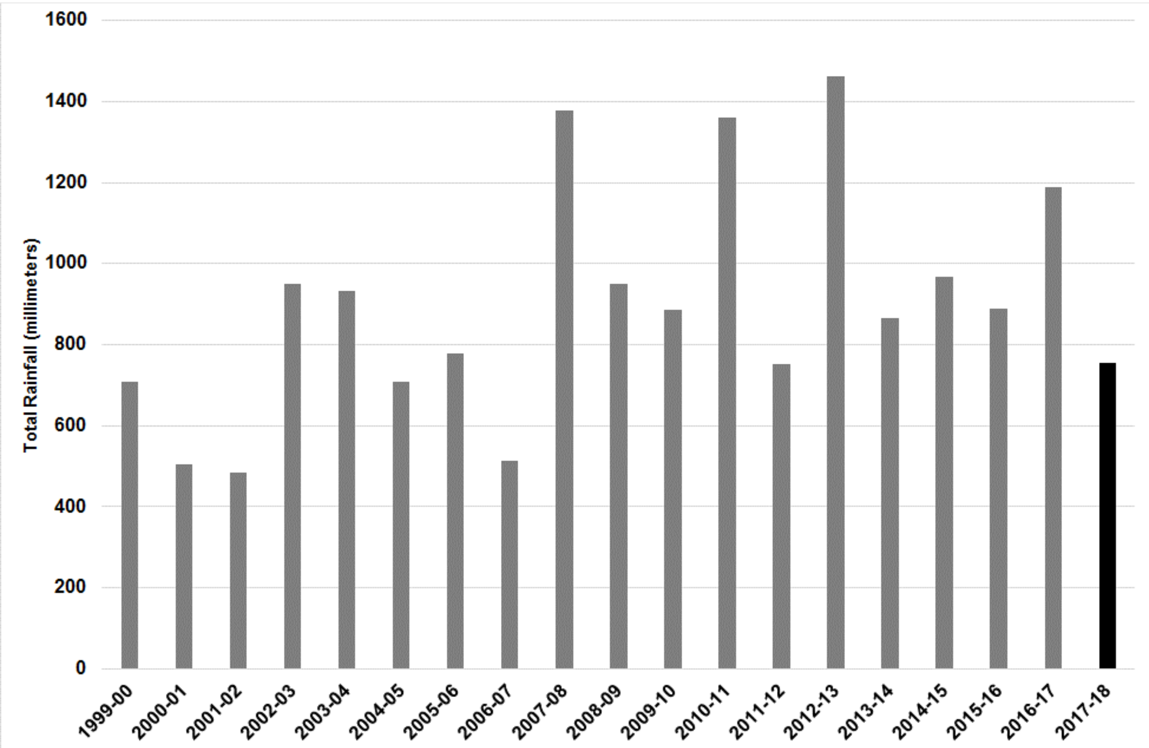


Figure 9.4: Annual rainfall (reporting year) at the Gladstone Airport weather station from 1999–2000 to 2017–2018 (Australian Bureau of Meteorology data).

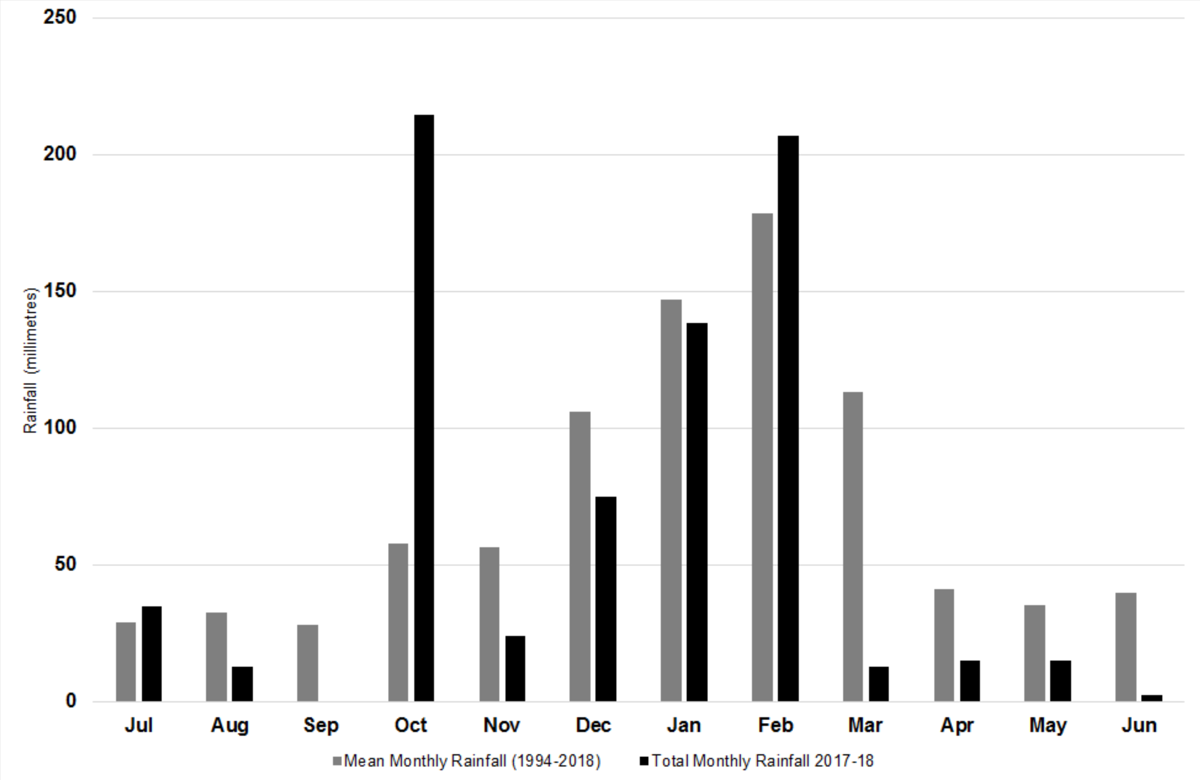


Figure 9.5: Mean monthly rainfall (mm) at the Gladstone Airport weather station (1994–2018) compared to total monthly rainfall for the 2017–18 reporting year (Australian Bureau of Meteorology data).

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 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 2018 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 to a median daily flow of 24ML/day form February 1974 to July 2018 period (DNRM Water Monitoring Information Portal).

Table 9.1: Streamflow summary for the Boyne River (1984–85 to 2011–12) and the Calliope River (1938–39 to 2016–17) (DNRM Water Monitoring Information Portal downloaded 17/07/18).

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 2016–17)			
Annual streamflows (ML)		December streamflows	
Mean	165,603	Mean	21,659
Median	102,113	Median	3,061
Maximum flow (Total flow 2012–13)	916,693	Maximum flow (Total flow December)	401,837

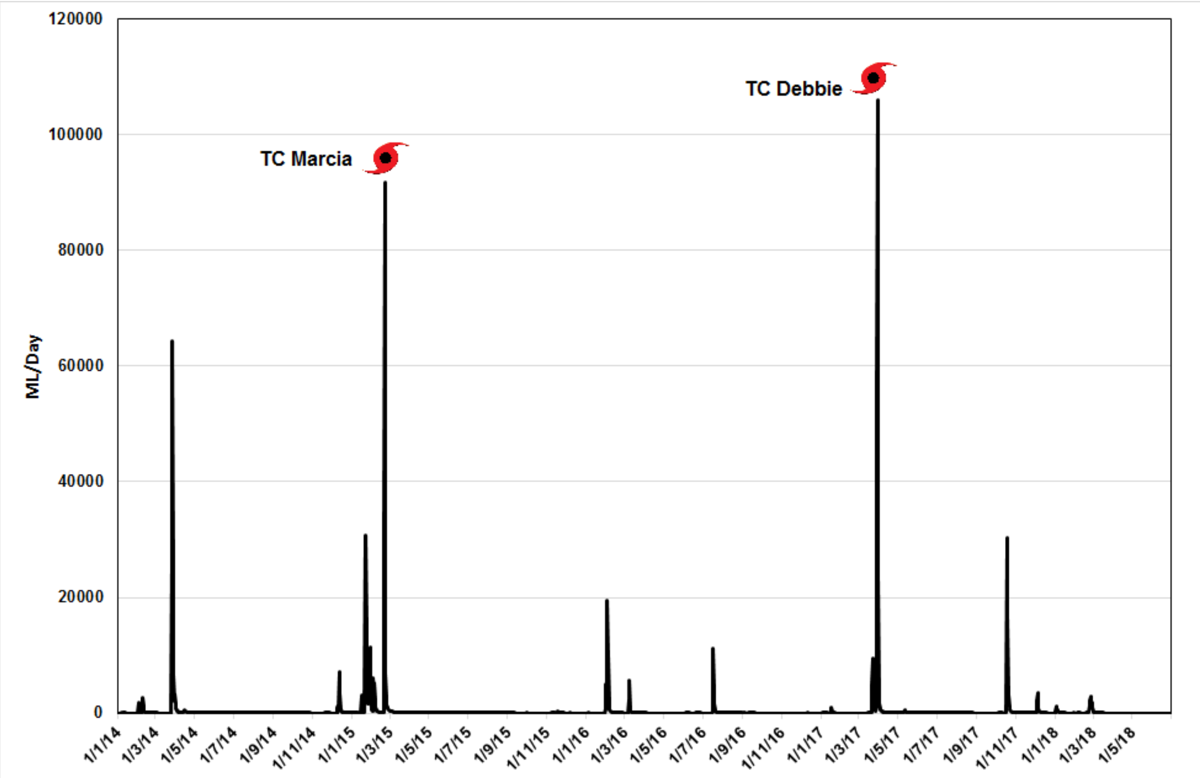


Figure 9.6: Calliope River flows recorded at Castlehope between January 2014 and June 2018. A flow of 91,666ML/day was recorded on 21 February 2015 in association with the passage of Tropical Cyclone (TC) Marcia and a flow of 105,980ML/day was recorded on 30 March in association with the passage of TC Debbie. These peak flows compare with a daily median flow of 34ML/day for the same time period (DNRM Water Monitoring Information Portal downloaded 17/07/18).

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 six times—in 2002, 2010, 2013, 2015, 2017 and in the 2017–18 reporting year in October 2017 (Table 9.2 and Figure 9.7). The October 2017 overtopping was caused by above average rainfall in that month. 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 (01/01/2018) and 2017 overtopping levels compared to the largest overflow recorded in 2013 (Source: Gladstone Area Water Board).

Storage level	Date	Level (m AHD)	Volume (ML)	Capacity (%)	Surface area (ha)
Current storage	31-Jan-18	39.88	768,765	98.96	6,732
Level one year ago	31-Jan-17	37.82	638,301	82.16	5,938
Last overflow of 40m spillway	18-Oct-17	40.80	832,263	107.14	7,101
Highest level	27-Jan-13	48.3	1,498,586	192.9	10,810

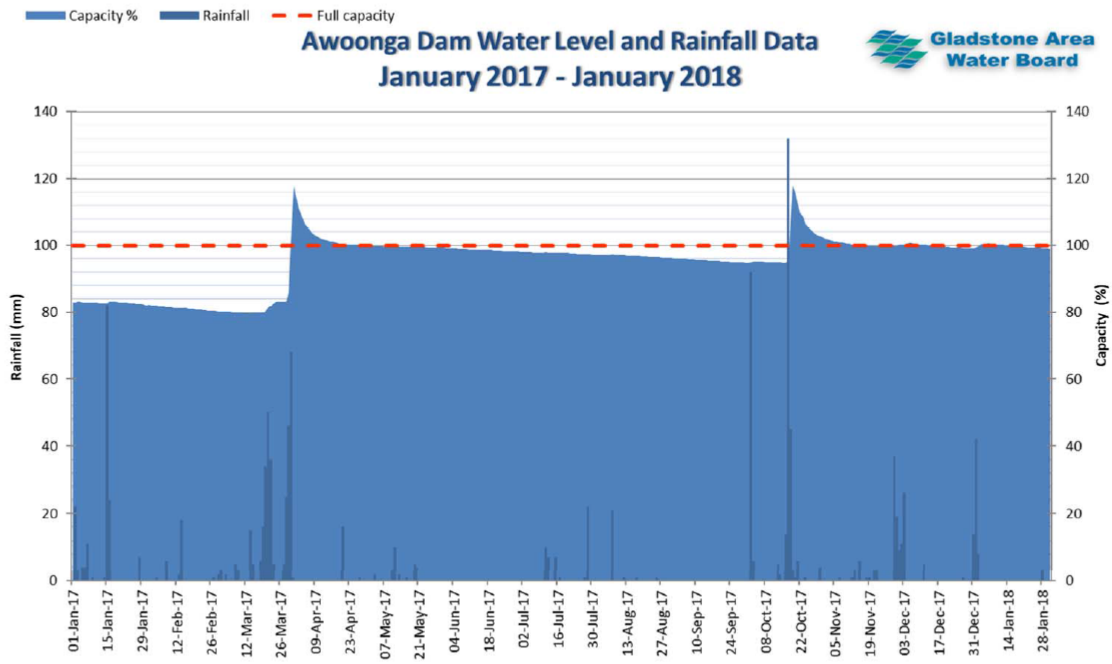


Figure 9.7: Awoonga Dam levels January 2017 to January 2018 (Source: Gladstone Area Water Board).

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.

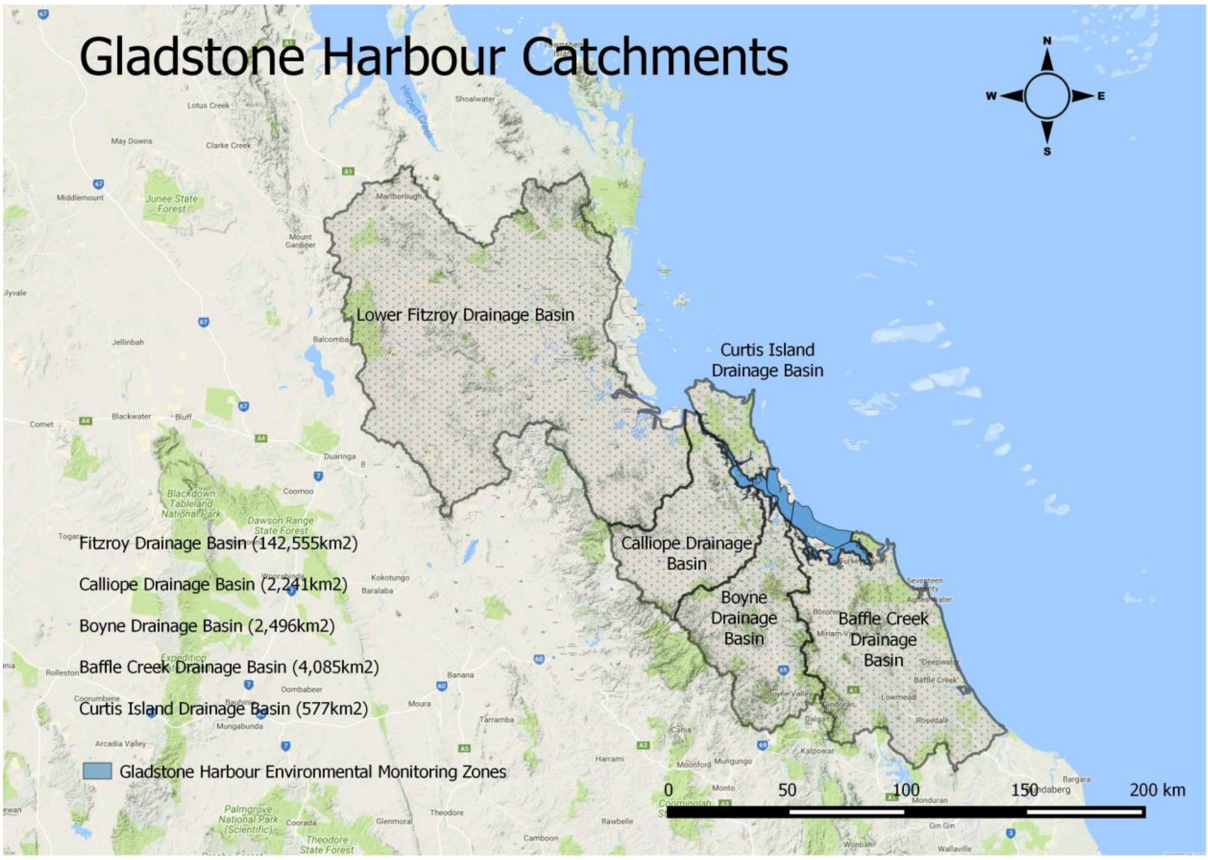


Figure 9.8: Drainage basins surrounding the Gladstone Harbour Environmental Monitoring Zones.

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 (kilotonnes 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%

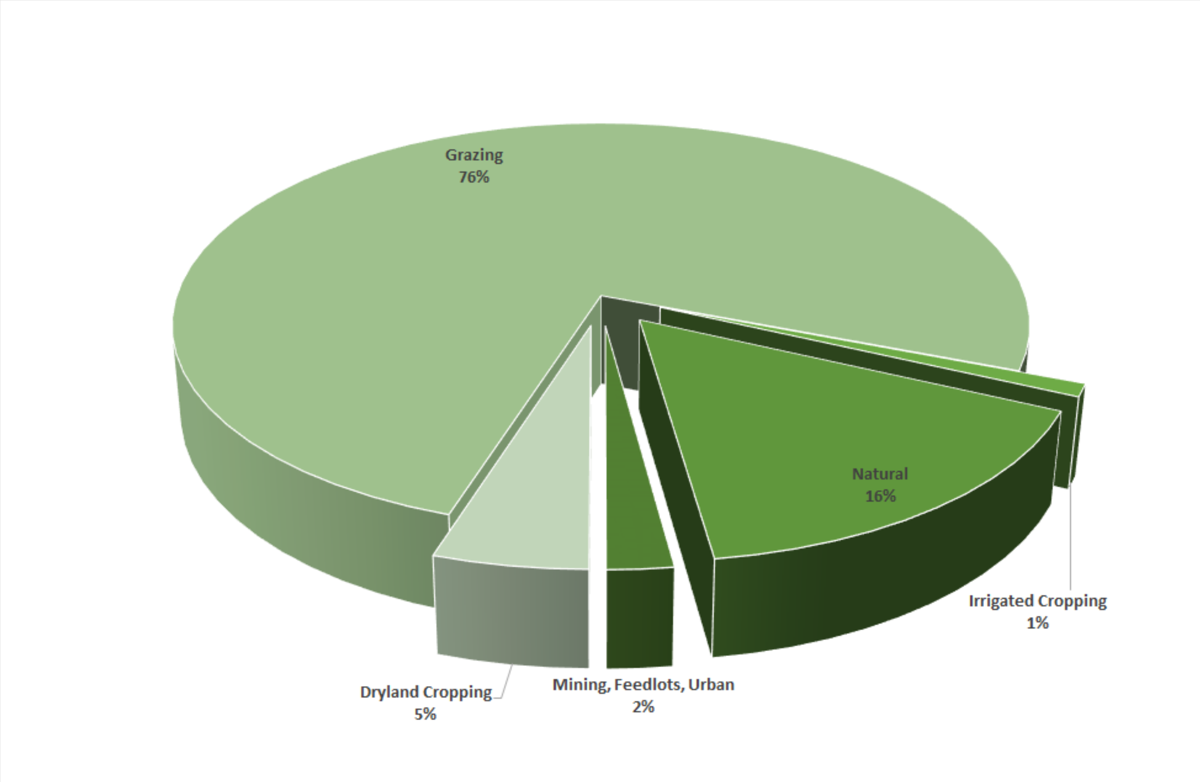


Figure 9.9: Land use in the Boyne catchment (Data source QSpatial, Land use mapping – Fitzroy NRM region 2009, Catchment boundaries, Queensland Wetland*Info*).

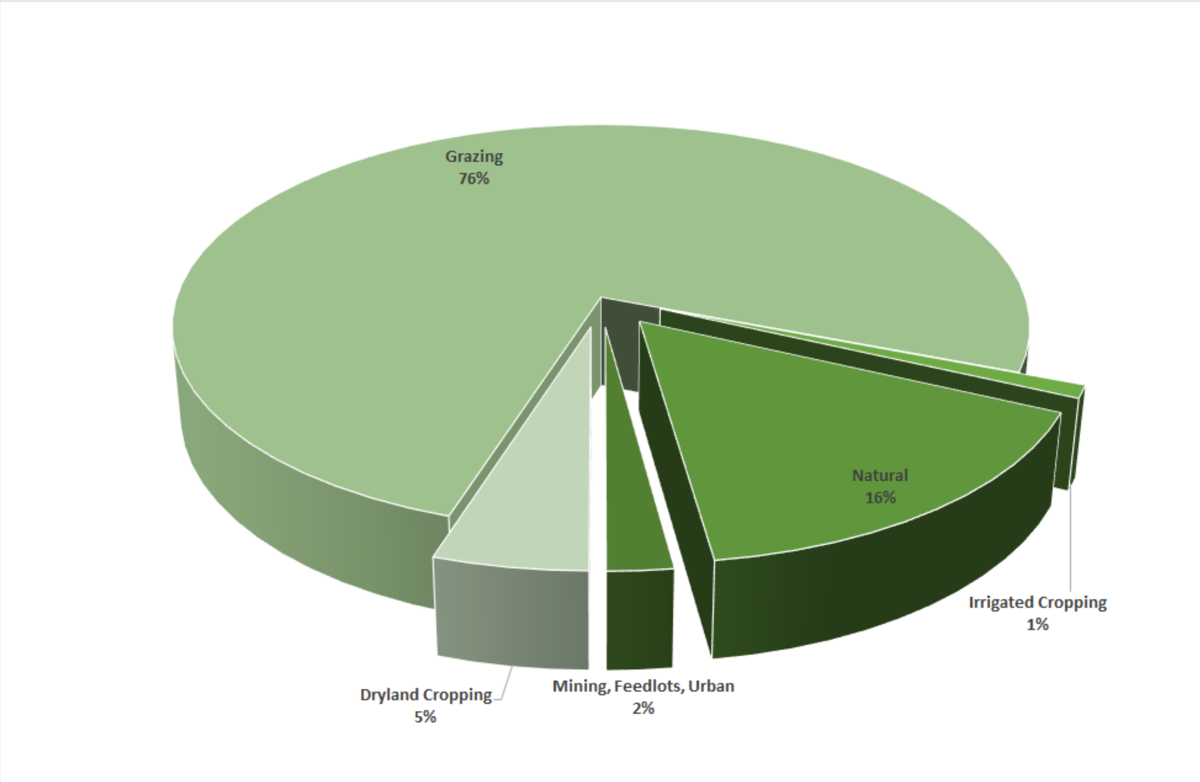


Figure 9.10: Land use in the Calliope catchment (Data source QSpatial, Land use mapping – Fitzroy NRM region 2009, Catchment boundaries, Queensland Wetland*Info*).

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.

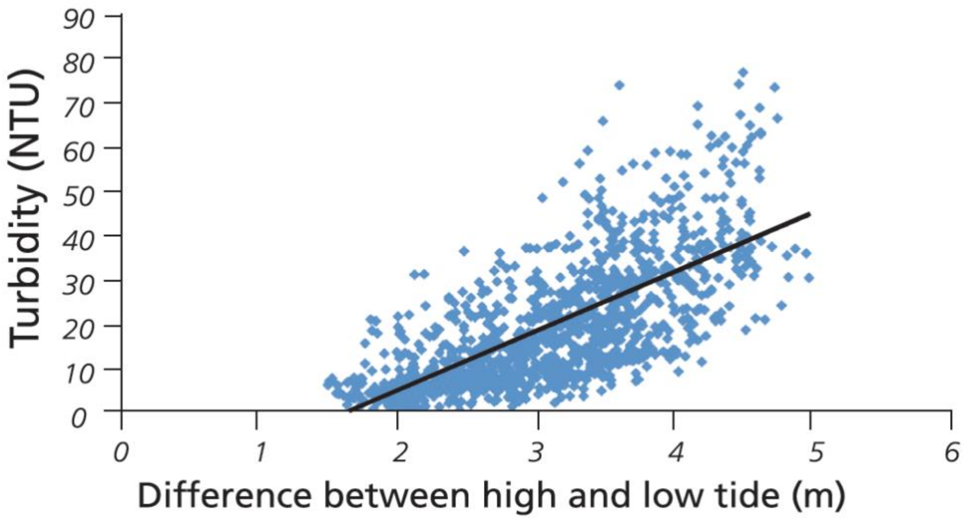


Figure 9.11: The relationship between tidal movement and turbidity in Gladstone Harbour (DEHP 2014 personal communication). NTU: nephelometric turbidity unit.

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 continue 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 monitoring period (until May), the value of the residential buildings in Gladstone remained at $40 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 continued to decline from 2012 (ABS, 2017). The data is 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).

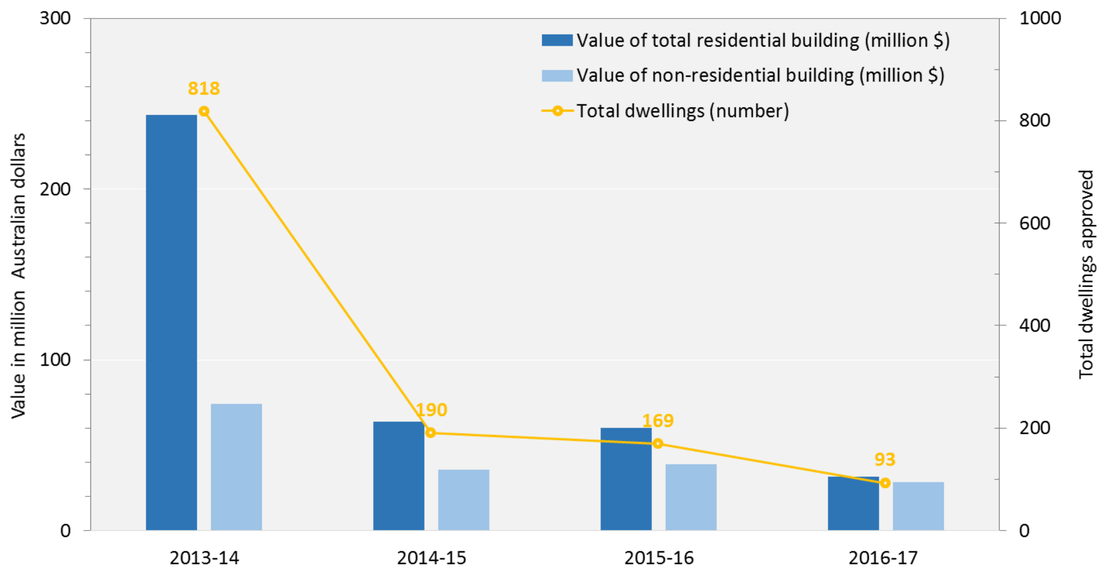


Figure 9.12: The value of residential and non-residential building approvals and approved new dwellings in Gladstone LGA from 2012 to May 2017 (Data has been collected monthly and averaged to obtain an annual value).

The number of businesses actively trading in Gladstone also steadily declined from June 2014 (4081) to June 2015 (3915) and then to 3842 in 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.

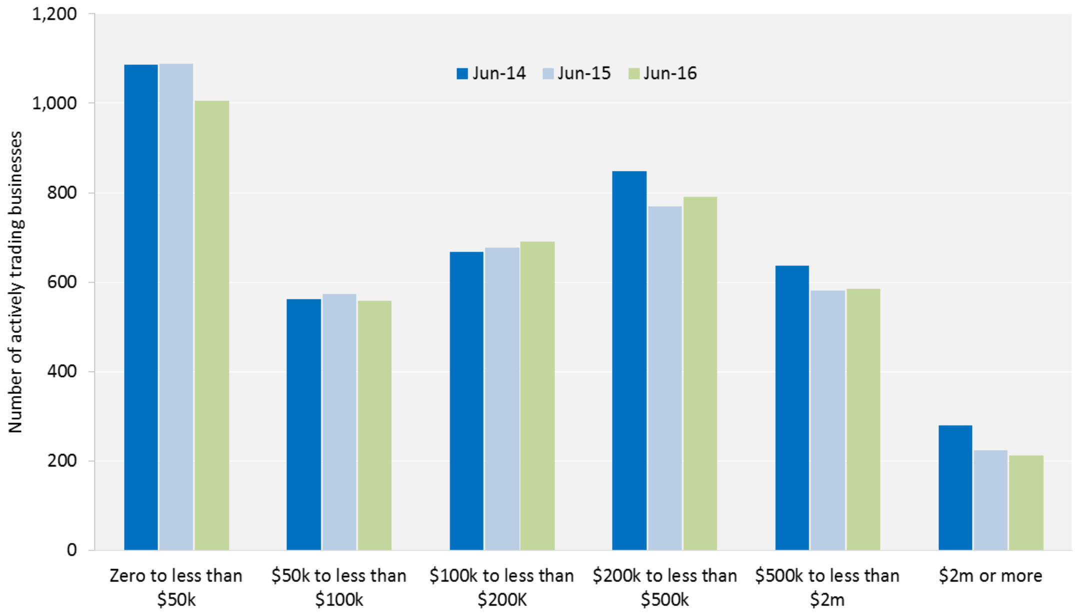


Figure 9.13: The number of actively trading businesses in Gladstone in 2014, 2015 and 2016 financial years. Categories related to the annual turnover value of the business in Australian dollars reported to the Australian Taxation Office.

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, the Pacific Dawn at Gladstone's Auckland Point Terminal with 2,000 passengers in March 2016 (ABC Capricornia, 2016). For the 2017–18 financial year, there were six cruise ships docked at Gladstone Port (Windle et al., 2018). Between 1 July 2017 and 30 June 2018, four large cruise ships are expected to bring more Australian and international visitors to Gladstone. Construction work for a new cruise ship terminal at East Shore Precinct was also initiated during the first half of 2018 supporting the local leisure and tourism activities.

Reference: http://crew-center.com/gladstone-australia-cruise-ship-schedule-2018

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.

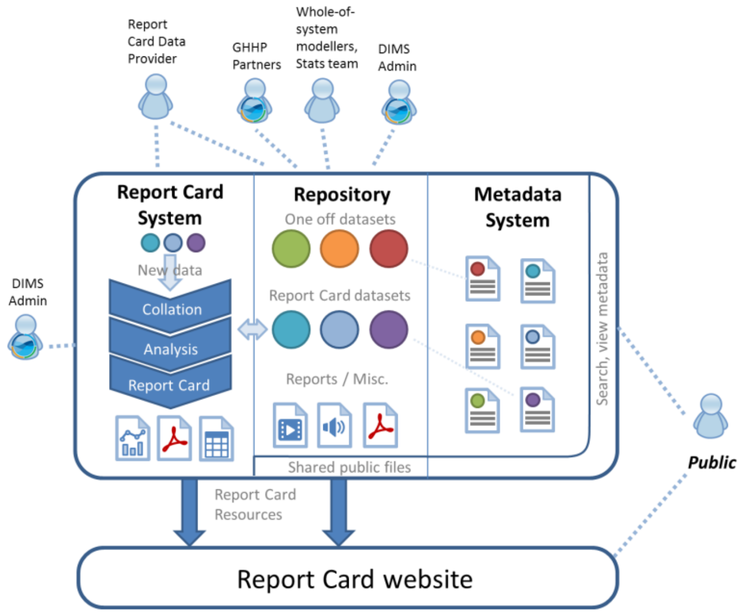


Figure 10.1: Schematic diagram of the links between the report card website and the Data Information Management System (DIMS) to illustrate major components and primary inputs and outputs (Diagram courtesy Australian Institute of Marine Science).

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. The 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.

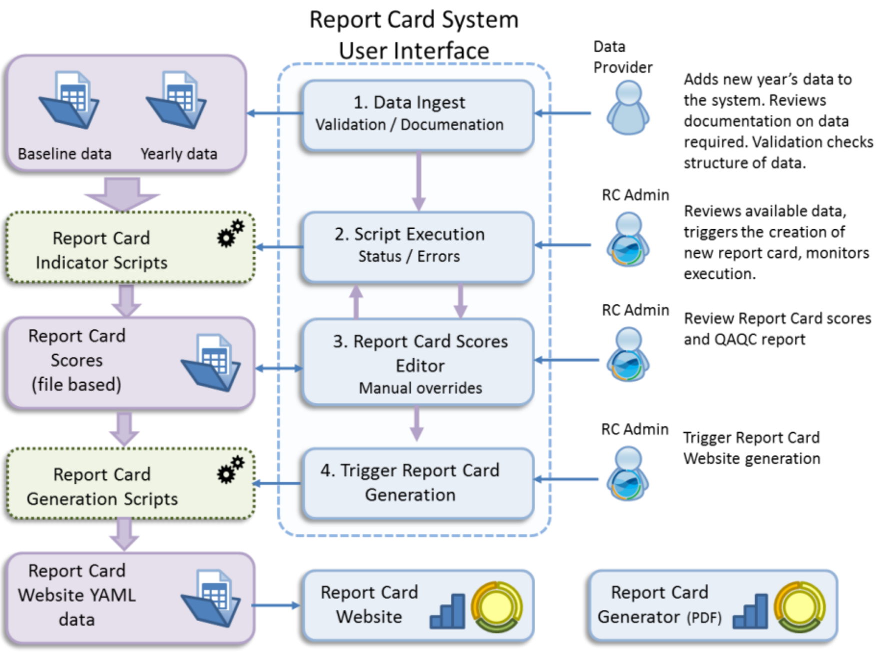


Figure 10.2: Schematic diagram of the report card system showing all data ingestion, script execution and report cards results generation modules (Diagram courtesy Australian Institute of Marine Science).

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.

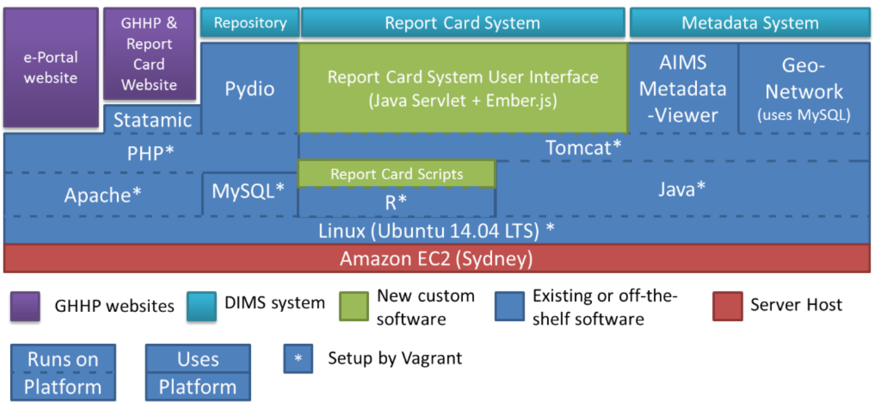


Figure 10.3: Software infrastructure underlying the Data Information Management System (DIMS) operations (Diagram courtesy Australian Institute of Marine Science).

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 influence 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 (socioeconomic 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 the local 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.

Gladstone Harbour Model Domain

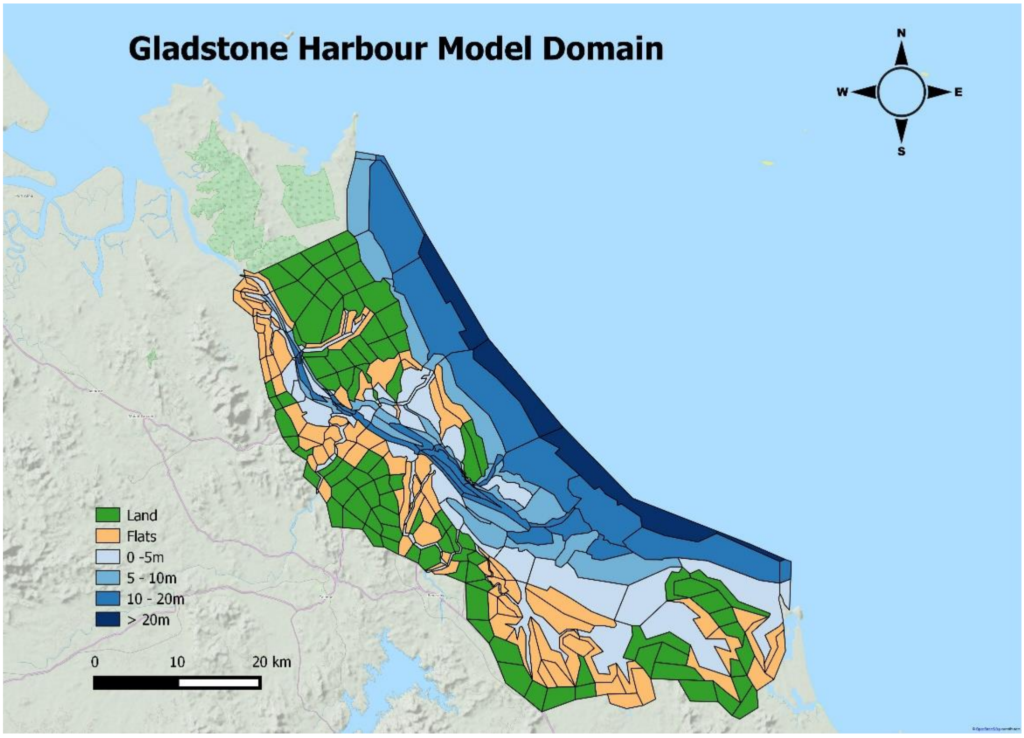


Figure 10.4: The area modelled in the GHHP Atlantis model includes the harbour and surrounding area.

The area modelled 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 (Figure 10.4).

To link the model to the surrounding region (via the hydrodynamic model) there are seven oceanic boundary boxes, three estuarine boundaries from which simulated river flows enter the model and another boundary box at the head of The Narrows. Simple land use and its influence on run-off and river flows are applied to each of the 'land-cells' within the grid.

Physical (Hydrodynamic) and Biogeochemical Model

Hydrodynamic model

The hydrodynamic model drives water circulation within the modelled harbour (Figure 10.5). Outputs from the model include three-dimensional distributions of water velocity, temperature, salinity, density, passive tracer movements, mixing coefficients and sea-level. The inputs required by the model include forcing due to wind, atmospheric pressure gradients, surface heat and water fluxes and open-boundary conditions such as tides. Initial and open boundary conditions were provided by CSIRO's eReefs model. Freshwater flows are introduced to the model corresponding to the Calliope and Boyne river flows.

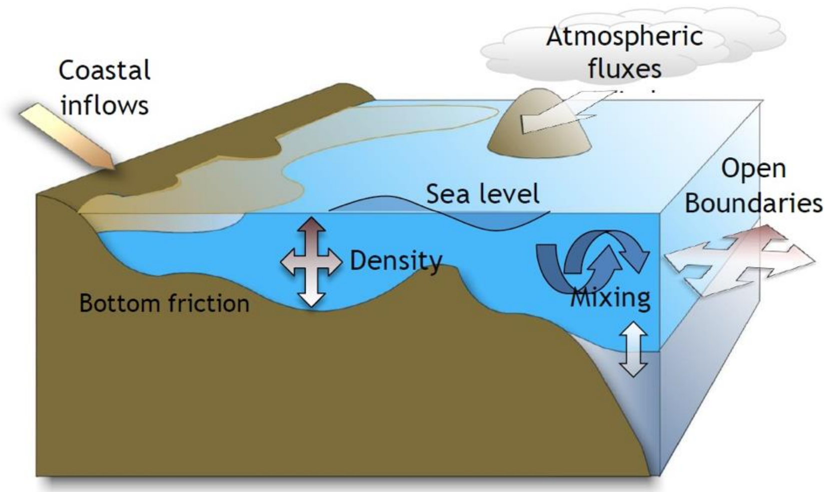


Figure 10.5: Physical processes represented in the hydrodynamic model.

Biogeochemical model

This component of the model captures the water quality dynamics of Gladstone Harbour. It provides a direct link between the hydrodynamic models and the system models. It models water-column processes which integrate hydrodynamic, sediment transport and biogeochemical modules (Figure 10.6).

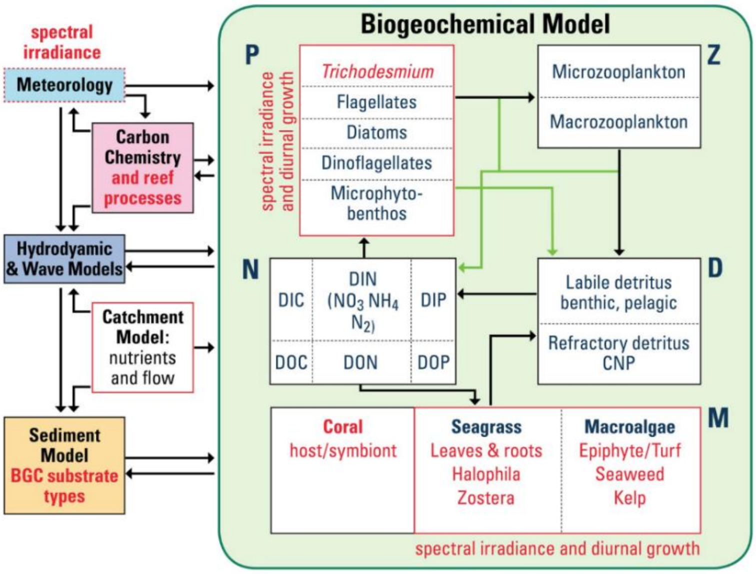


Figure 10.6: Components and processes within the Biogeochemical model.

Ecosystem Elements and Marine Food Webs

Gladstone Harbour supports a variety of habitat types (e.g. coral reefs, seagrass beds, mangroves and mudflats) and large communities of molluscs, crustaceans, finfishes, sharks, marine mammals, and birds. To capture the dynamics of life within the harbour, the Gladstone Harbour Model includes the major biophysical processes present in marine, coastal and estuarine ecosystems and a range of biota from plankton and invertebrates through to megafauna such as dolphins.

The biophysical component includes physical processes such as hydrodynamics (transport, tides and river inputs), light scattering and absorption and physicochemical processes such as nutrient fluxes and salinity levels. Environmental processes represented by the model include those that directly influence life in the harbour such as photosynthetic primary production. These processes can be limited by light, nutrients, oxygen and space, habitat dependency and competition. In addition to these ongoing processes the model also has the capacity to add the effects of climate change.

Within the modelled environment a wide range of changes to the harbour's ecosystem can be simulated. These include natural events such as floods or the effects of potential management actions such as dredging, changes to catchment loads and one-off events such as spills.

The Gladstone Harbour Model also has the capacity to assess the effects of fisheries within the models domain. In addition to the broader ecosystem the model goes into finer details around the finfish, sharks and rays that interact with local fisheries. The model also includes three invertebrate species that are targeted by fisheries; mud crabs, prawns and saucer scallops. This allows the effects of both natural events and human actions on commercial fisheries to be assessed within the modelled environment.

The Human Elements, Social and Economic, of Gladstone Harbour

The Gladstone Harbour Model has the capacity to resolve human impacts on the harbour environment and the effects of changes on the economic and social make up of Gladstone. Model runs have shown how changing one aspect of the human elements will affect other areas.

Scenarios run to date include looking at changes to shipping activity, the effects of industry closure and major storms and flooding on the local economy and changes to the levels of commercial fishing.

The human sectors component of the model is made up of 16 sub-models which include fisheries, land use, industry and employment models, shipping and boating, human demographics and components for spills and economic growth rates.

These models synthesise the cause-and-effect relationships between human pressures and the environmental and ecological components of the Gladstone Harbour region. The formulation and content of these models are based on workshops with key social, economic and cultural experts and consultation with the Gladstone community. This included people with expertise/interest in areas such as agriculture, commercial fishing, recreational fishing, retail, real estate, tourism, media and communications, shipping and ports, mining, heavy industry, the environment and education.

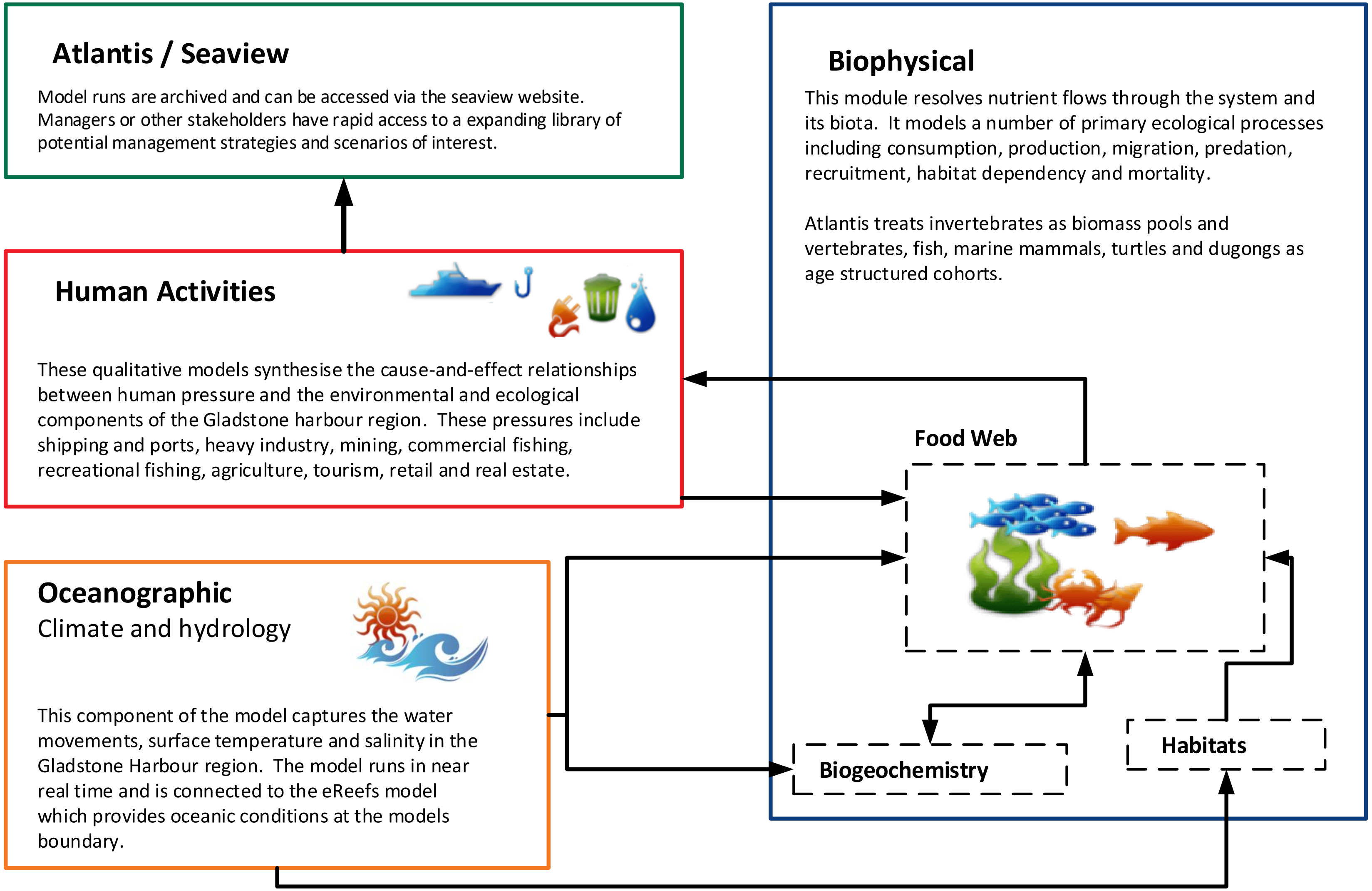
Discussions at these workshops let the researchers draw qualitative models of how the system is linked together and how it responds to change. These qualitative models where then converted into quantitative model components for use in the systems model.

Putting it all together the full systems model for the Gladstone Harbour and immediate surrounds.

The final model - the whole of system model - brings all the other models and outputs together. This model is used to improve our understanding of the potential outcomes and interactions between the many factors, human and natural that can affect the health of Gladstone Harbour (Figure 10.7).

The construction of the full system model has involved collating and adding large volumes of data for all aspects of the system including biological, physical, social, cultural and economic data. This information has come from a wide range of sources, drawing on information from the entire Healthy Harbour program, as well as a broader set of available information including 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 was conducted in order to compile an inventory of the key drivers of change in and around Gladstone Harbour. Close collaboration with stakeholders during model development has ensured that the Gladstone Harbour Model is fit-for-purpose and that it is flexible enough to handle future modifications required as new information becomes available.

Figure 10.7: Putting it all together the full system model.



Initial results

Initial model runs suggest that both the environmental and human elements of Gladstone Harbour are heavily influenced by external pressures, either storms or flooding, and climate change or external economic conditions. Flooding can have a much bigger impact on water quality than industry activity that is operating within regulatory guidelines. Similarly, nutrient loading from watershed and catchment practices also has the potential to impact water quality more than industrial activity around the harbour.

While it is the larger scale national and global economy that determine much of the economic health of the region (rapid growth, or export decline, or industry closure), local conditions do influence the social health of the harbour on indicators such as access to the harbour, local reliance on services, crime rates and 'sense of place'. These can all be influenced by the state of the environment, the levels of the non-resident workforce, whether shipping prevents local water-based recreation and access to housing and services.

Further information

Model runs are archived and can be accessed via the seaview website. Hence GHHP Partners have rapid access to a library of potential management strategies and scenarios of interest. This library can be augmented with new model runs to cover potential policy gaps and future issues as they arise.

Reports on the model's development can be found on the GHHP publications webpage http://ghhp.org.au/publications

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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 highest level of aggregation employed to determine the grades and scores in the Gladstone Harbour Report Card. The Gladstone Harbour Report Card reports on the condition of 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, its biodiversity and the people within (e.g. temperature, salinity, pH)
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 projects

Project name and institution	Reports and publications
ISP001 Mapping and synthesis of data and monitoring in Gladstone Harbour Australian Institute of Marine Science	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	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 CSIRO Wealth from Oceans Flagship	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 Central Queensland University	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 CSIRO	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. Windle, J., De Valck, J., Flint, N. & Star, M. (2016). Final report on the status of the social, cultural (Sense of place) and economic components for the Gladstone Harbour 2016 Report Card. CQU. Download the final report for this project. Windle, J., De Valck, J., Flint, N. & Star, M. (2017). Final report on the status of the social, cultural (Sense of place) and economic components for the Gladstone Harbour 2016 Report Card. CQU. Download the final report for this project. Jill Windle, Jeremy De Valck, Megan Star and Nicole Flint, 2018. Final report on the status of the social, cultural (Sense of place) and economic components for the Gladstone Harbour 2018 Report Card. CQUniversity. Final report to the Gladstone Healthy Harbour Partnership, August 2018. Download the final report for this project.
ISP006 Development of a Gladstone Harbour Model to support the Gladstone Healthy Harbour Report Card CSIRO Wealth from Oceans Flagship	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. Fulton EA, Hutton T, van Putten IE, Lozano-Montes H and Gorton R (2017) Gladstone Atlantis Model – Implementation and Initial Results. Report to the Gladstone Healthy Harbour Partnership. CSIRO, Australia. Download the final report for this project. FultonEA, HuttonT, van Putten IE, Lozano-Montes Hand GortonR(2017) Gladstone Atlantis Model–Implementation and Initial Results. Report to the Gladstone Healthy Harbour Partnership. CSIRO, Australia. Download the final report for this project.
ISP007	Condie, S., Herzfeld, M., Andrewartha, J., Gorton, B., & Hock, K. (2015). *Project ISP007: Development of connectivity indicators*

Development of connectivity indicators for the Gladstone Healthy Harbour Report Card CSIRO Wealth from Oceans Flagship, University of Queensland	*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). Connectivity Indicators for the 2015 GHHP 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. (2017). Connectivity Indicators for the 2016 GHHP Gladstone Harbour Report Card. CSIRO Wealth from Oceans Flagship, Hobart, University of Queensland. Download the final report for this project Gorton, R., Condie, S. & Andrewartha, J. (2017) 2016-17 Connectivity Indicators for the GHHP Gladstone Harbour Report Card. CSIRO Oceans and Atmosphere, Hobart. Download the final report for this project.
ISP008 Provision of statistical support during the development of the Gladstone Harbour Report Card Queensland University of Technology	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.
ISP008-2015 Provision of statistical support during the development of the Gladstone Harbour Report Card Australian Institute of Marine Science	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	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 Bill Venables, CSIRO Research Fellow	Venables, W.N. (2015). *GHHP Barramundi Recruitment Index Project Final Report*. Gladstone Healthy Harbour Partnership, Gladstone. Download the final report for this project.

ISP011 Seagrass indicators for the Gladstone Harbour Report Card Centre for Tropical Water & Aquatic Ecosystem Research	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. (2015a). *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. Carter AB, Wells JN & Rasheed MA (2017). 'Gladstone Healthy Harbour Partnership 2017 Report Card, ISP011: Seagrass'. Centre for Tropical Water & Aquatic Ecosystem Research Publication 17/29, James Cook University, Cairns. Download the final report for this project. Bryant CV, Carter AB, Chartrand KM, Wells JN & Rasheed MA (2018) *Gladstone Healthy Harbour Partnership 2018 Report Card, ISP011: Seagrass.* Centre for Tropical Water & Aquatic Ecosystem Research Publication 18/22, James Cook University, Cairns. Download the final report for this project.
ISP012 Cultural indicators pilot project Terra Rosa Consulting	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.

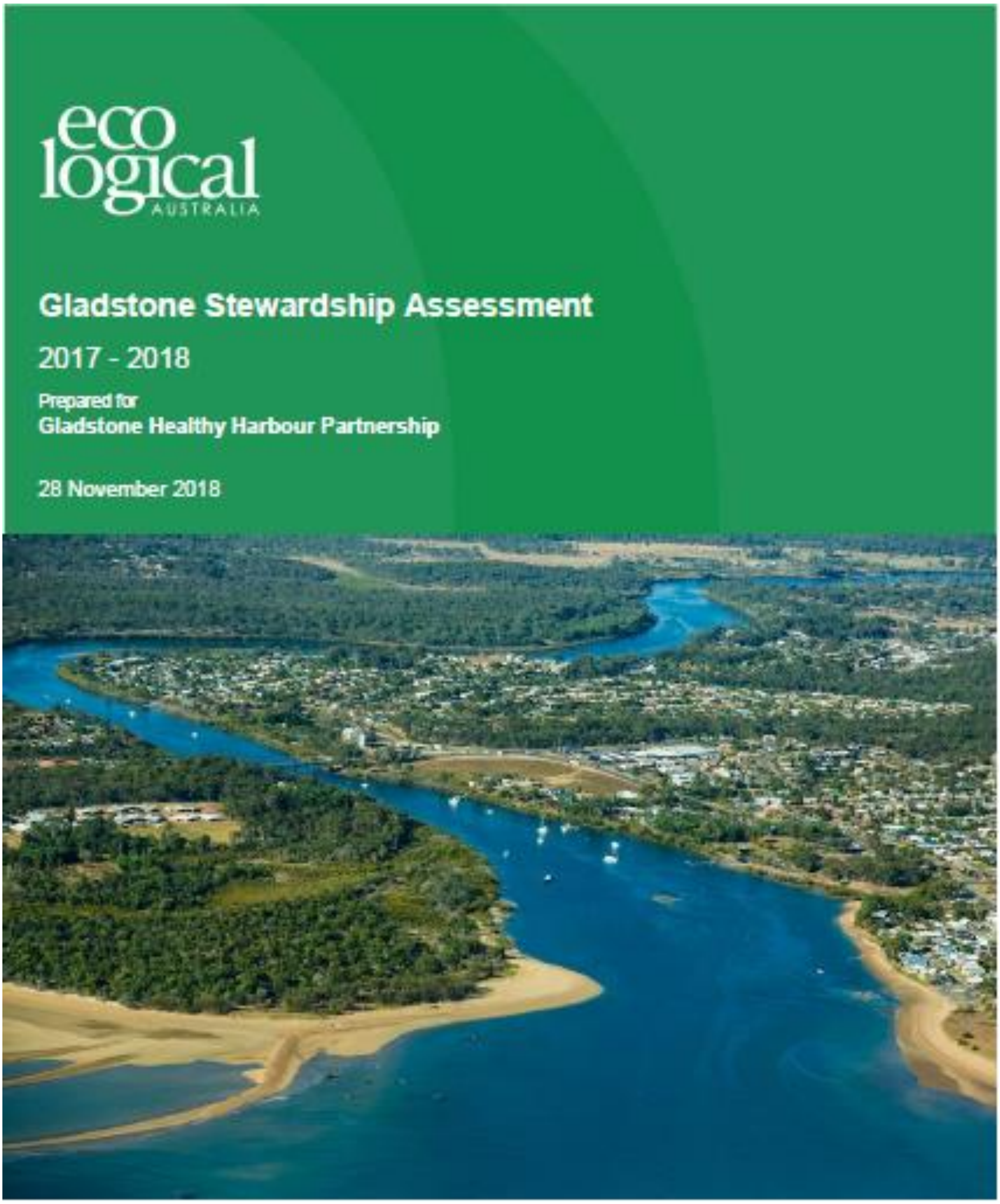
	Download the final report for this project. Indigenous Cultural Heritage Indicators for the Gladstone Healthy Harbour Partnership (GHHP) Report Card. Terra Rossa Consulting, Perth. Download the final report for this project. Terra Rosa Consulting (2018) *Final Report: ISP012-2018: Indigenous Cultural Heritage Indicators for the Gladstone Harbour Report Card.* Terra Rosa Consulting, Western Australia. Download the final report for this project.
ISP013-2015 Fish recruitment study Infofish Australia and Dr Bill Venables	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. Sawynok, B. & Venables, B. (2016a) *Developing a fish recruitment indicator for the Gladstone Harbour Report Card using data derived from castnet sampling*. Report for the Gladstone Healthy Harbour Partnership, Gladstone. Download the final report for this project. Sawynok, B. & Venables, B. (2017) *Fish recruitment indicators for the Gladstone Harbour Report Card using data derived from castnet sampling 2017.* Report for the Gladstone Healthy Harbour Partnership, Gladstone. Download the final report for this project. Sawynok, B. & Venables, B. (2018) *Fish recruitment indicators for the Gladstone Harbour Report Card using data derived from castnet sampling 2018.* Report for the Gladstone Healthy Harbour Partnership, Gladstone. Download the final report for this project.
ISP014 Coral indicator pilot project Australian Institute of Marine Science	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. Costello P., Thompson A., Davidson J. (2017) *Coral Indicators for the 2017 Gladstone Harbour Report Card 2017: ISP014.* Report prepared for Gladstone Healthy Harbour Partnership. Australian Institute of Marine Science, Townsville. For this project for this project. Costello P, Thompson A, Davidson J (2018) *Coral Indicators for the 2018 Gladstone Harbour Report Card 2018: ISP014.* Report prepared for Gladstone Healthy Harbour Partnership. 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	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.
ISP015-2017 Developing Mud Crab Indicators for the Gladstone Harbour Report Card	Flint, N., Anastasi, A., De Valck, J., Chua, E., Rose, A., and Jackson, E.L. (2017). Developing mud crab indicators for the Gladstone Harbour Report Card. Report to the Gladstone Healthy Harbour Partnership. CQU Australia, Queensland. Download the final report for this project. Flint, N., Anastasi, A., De Valck, J., and Jackson, E.L. (2018) *Mud Crab Indicators for the Gladstone Harbour Report Card.* Report to the Gladstone Healthy Harbour Partnership. CQUniversity Australia, Queensland. Download the final report for this project.
ISP016 **GHHP Gladstone fish health research program (a)** Gladstone Harbour Healthy Partnership, Fisheries Research and Development Canberra, AusVet Animal Health Services.	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
ISP016	Kroon, F.J., Streten, C., & Harries, S.J. (2016) *The Use of Biomarkers in Fish Health Assessment Worldwide and Their*

GHHP Gladstone fish health research program (b) Australian Institute of Marine Sciences	*Potential Use in Gladstone Harbour.* Australian Institute of Marine Science, Townsville. Download the final report for this project.
ISP016 **GHHP Gladstone fish health research program (c)** Infofish Australia Pty Ltd, Rockhampton.	Sawynok W, Sawynok S and Dunlop A (2018) *New Tools to Assess Visual Fish Health.* FRDC report, Infofish Australia Pty Ltd, Rockhampton. Download the final report for this project.
ISP017 Additional PAH monitoring 2015 Port Curtis Integrated Monitoring Program	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** JCU/TropWATER	Duke N.C., and Mackenzie J. (2018) Project ISP018: Development of mangrove indicators for the Gladstone Harbour Report Card. Report to Gladstone Healthy Harbour Partnership by TropWATER Centre. Publication 18/38, James Cook University, Townsville, 42 pp. Download the final report for this project.
ISP019 Coral coring in Gladstone Harbour to enable a comparison of pre- and post-industrial eras in Gladstone Harbour Australian Institute of Marine Science	Cantin, N.E., Fallon, S., Wu, Y. & Lough, J.M. (2018) Project ISP019: Calcification and geochemical signatures of industrial development of the Gladstone Harbour from century old coral skeletons. Report prepared for Gladstone Healthy Harbour Partnership. Australian Institute of Marine Science, Townsville, Qld.
ISP020 Development of R scripts to calculate, aggregate and integrate cultural heritage indicators with Bayesian model and Data Information Management System	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: Stewardship

The 2017–18 Stewardship report can downloaded here



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 (24µg/L, 95% species protection) is now applicable to all harbour zones.

[c] A single manganese guideline (140µg/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).

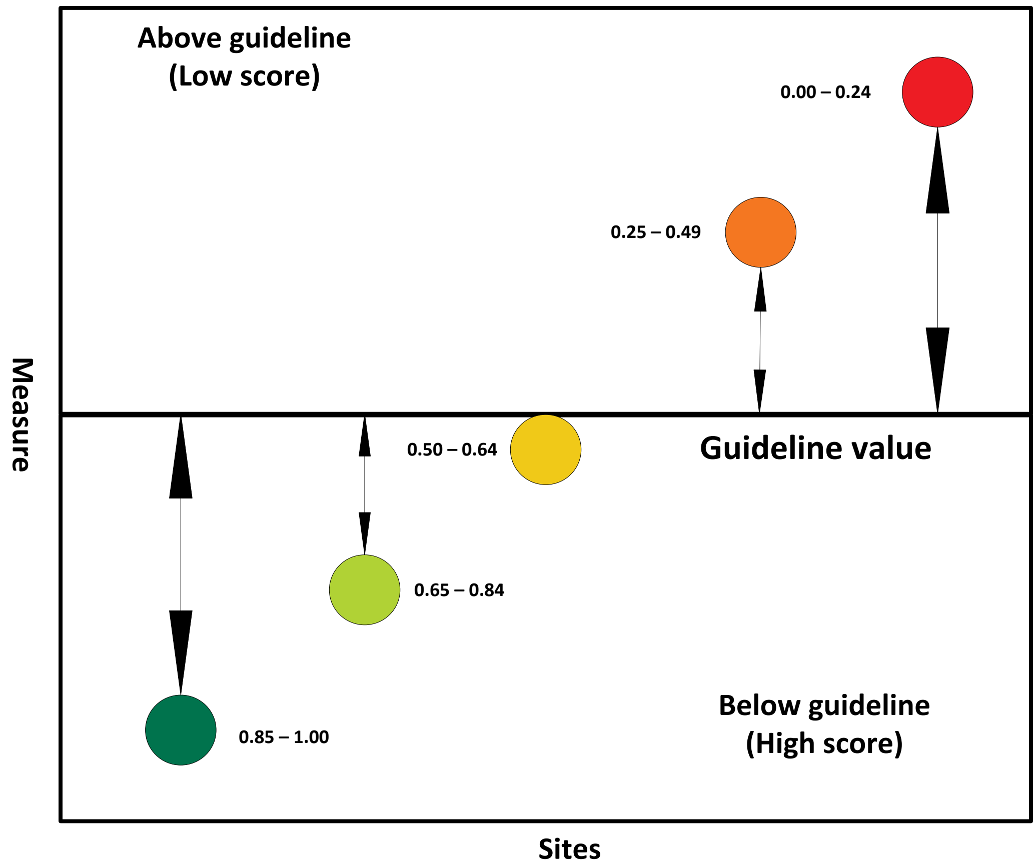


Figure A1: Water and sediment quality measures are scored relative to zone and measure specific guideline values.

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 (0.0 – 0.24). Similarly, in Zone 2 in Figure A2 the zone-specific guideline 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.

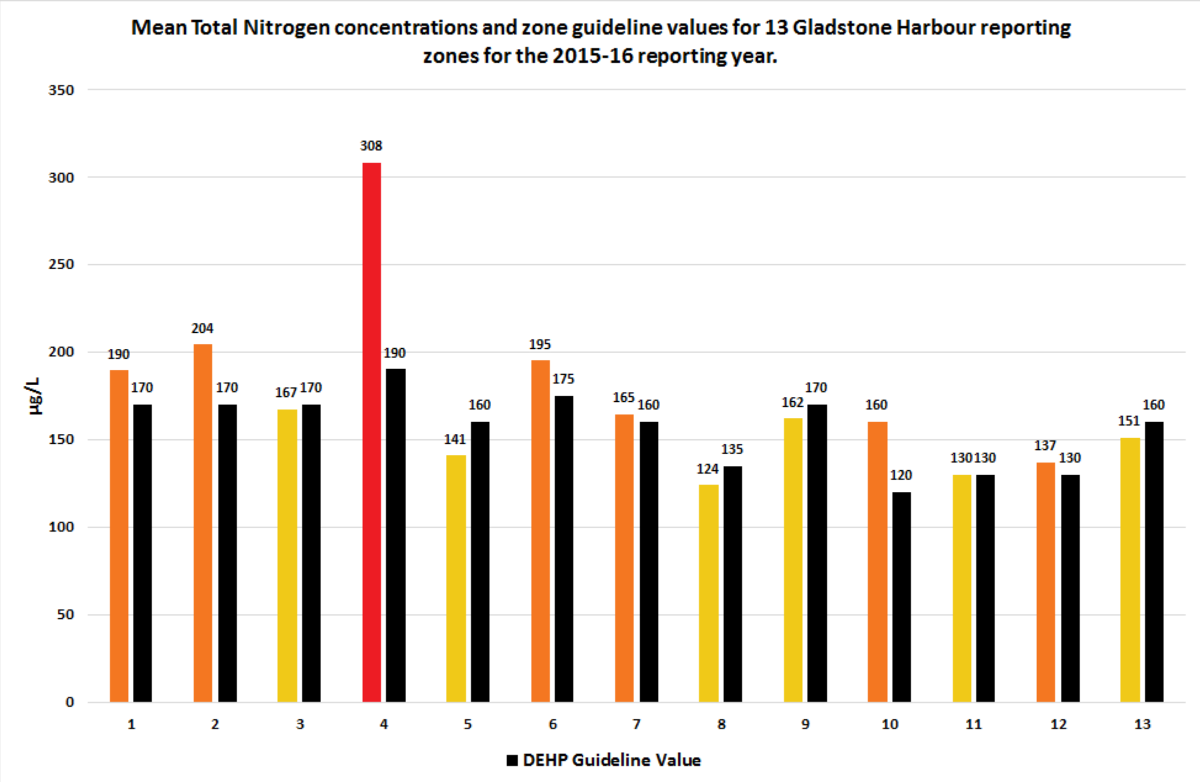


Figure A2: Mean values for total nitrogen concentrations (coloured bars) compared to the DEHP (2014a) guideline values (black bars) for the 13 GHHP reporting zones in the 2015-16 reporting year.

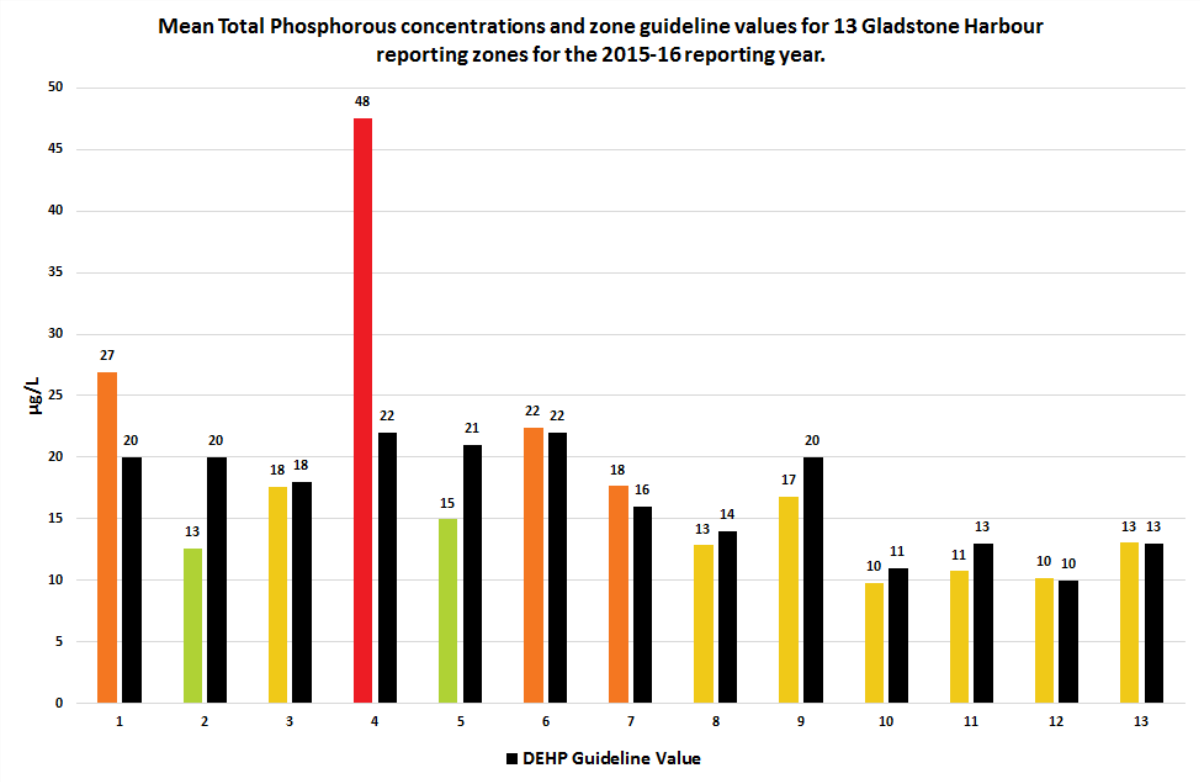


Figure A3: Mean values for total phosphorous concentrations (coloured bars) compared to the DEHP (2014a) guideline values (black bars) for the 13 GHHP reporting zones in the 2015-16 reporting year.

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