Gladstone
Healthy Harbour
Partnership

ISBN 978-0-646-87351-0

2022 TECHNICAL REPORT

2022 GLADSTONE HARBOUR REPORT CARD

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.

Oversight and additional material

Dr Mark Schultz, Science Team, Gladstone Healthy Harbour Partnership
Mr Mac Hansler, Science Team, Gladstone Healthy Harbour Partnership

Water and sediment quality (statistical analysis)

Dr Murray Logan, Australian Institute of Marine Science

Seagrass

Dr Tim Smith, Tropical Water & Aquatic Ecosystem Research, James Cook University
Dr Alex Carter, Tropical Water & Aquatic Ecosystem Research, James Cook University
Dr Michael Rasheed, Tropical Water & Aquatic Ecosystem Research, James Cook University

Corals

Mr Angus Thompson, Australian Institute of Marine Science
Ms Cassandra Thompson, Australian Institute of Marine Science
Mr Johnston Davidson, Australian Institute of Marine Science

Mangroves

Dr Norman Duke, Tropical Water & Aquatic Ecosystem Research, James Cook University
Dr Jock Mackenzie, Tropical Water & Aquatic Ecosystem Research, James Cook University

Fish health (CQU)

Dr Nicole Flint, CQUniversity
Assoc. Prof. Andrew Irving, CQUniversity
Dr Amie Anastasi, CQUniversity
Dr Jeremy De Valck, CQUniversity

Fish health (Infofish)

Mr Stefan Sawynok, Infofish Australia
Mr Bill Sawynok, Infofish Australia
Mr James Reid, Infofish Australia
Mr Phoenix Sawynok, Infofish Australia

Fish recruitment

Mr Bill Sawynok, Infofish Australia
Mr Stefan Sawynok, Infofish Australia

Mud crabs

Dr Nicole Flint, CQUniversity
Dr Jeremy De Valck, CQUniversity
Dr Amie Anastasi, CQUniversity

Social, Cultural and Economic components

Dr Jeremy De Valck, CQUniversity

Acknowledgements

The authors would like to thank the members of the Gladstone Healthy Harbour Partnership Independent Science Panel (ISP) for their considered input into the development of this document.

The current members of the ISP are:

Prof. John Rolfe (Chair)	Professor of Regional Economic Development, School of Business and Law, CQUniversity
Assoc. Prof. Eva Abal	Chief Executive Officer – International River Foundation; Associate Professor, University of Queensland
Dr Rob Coles	Principal Research Scientist – Seagrass Ecology, Centre for Tropical Water and Ecosystem Research, James Cook University
Dr Jenny Stauber	Chief Research Scientist – CSIRO Land and Water
Dr Melissa Dobbie	Independent Statistical Consultant
Ms Jane Waterhouse	Senior Partner, C_2O Consulting; Casual Senior Research Scientist – Catchment to Reef Processes, Centre for Tropical Water and Ecosystem Research, James Cook University
Dr Erin Bohensky	Senior Research Scientist – CSIRO Livelihoods and Adaptive Development
Dr Roger Chong	Veterinary Aquatic Pathologist – CSIRO Aquaculture Research
Dr Barbara Robson	Principal Research Scientist – Biogeochemical Modeller, Australian Institute of Marine Science

Particular thanks also go to:

- the Port Curtis Integrated Monitoring Program for providing water and sediment quality data;
- Gladstone Ports Corporation for providing seagrass data to generate GHHP scores and information from the annual Gladstone Ports Corporation Seagrass report for GHHP products;
- the ISP009 Data Information Management System project team – Dr Lyndon Llewellyn, Dr Eric Lawrey, Dr Murray Logan, Mr Gael Lafond, Mr Aaron Smith and Mr Marc Hammerton for data management;
- Tangaroa Blue Foundation and Jordan Gacutan from University of New South Wales for contributions to the litter metric;
- Natalia Muszkat Photography for all photographs in Section 7;
- CQUniversity for all photographs in Section 3.3.1;
- Infofish Australia for all photos in Section 3.3.2 & 3.3.6;
- Partners in the Gladstone Healthy Harbour Partnership (listed below); and
- Members of the Gladstone Healthy Harbour Partnership Management Committee (listed below).

Gladstone Healthy Harbour Partnership partners

Australian Government, Australian Institute of Marine Science, Australian Pacific LNG, Boyne Smelters, CQG Consulting, CQUniversity, CSIRO, Fitzroy Basin Association, Gidarjil Development Centre, Gladstone Ports Corporation, Gladstone Area Water Board, Gladstone Regional Council, NRG, Orica, QGC, Queensland Government, Queensland Alumina Limited, Queensland Energy Resources, Rio Tinto, Santos GLNG Project, Sealink, Smit Lamnalco, Wiggins Island Coal Export Terminal.

Management Committee representatives

Chair

Prof. Iain Gordon (Australian National University)

Community

Ms Elyse Riethmuller (Fitzroy Basin Association)
Mr Codey Stowe (Gidarjil Development Centre)

Government

Councillor Darryl Branthwaite (Gladstone Regional Council)
Ms Rachel D'Arcy (Queensland Department of Environment and Heritage Protection)

Industry

Dr Megan Ellis (Gladstone Ports Corporation)
Mr Alan Hayter (Conoco Phillips)
Ms Chantale Lane (Gladstone Industry Leadership Group)

Research

Prof. Emma Jackson (CQUniversity, Gladstone)

Disclaimer

Suggested citation

Gladstone Healthy Harbour Partnership (2022) *Technical Report, Gladstone Harbour Report Card 2022*, GHHP Technical Report No. 9. Gladstone Healthy Harbour Partnership, Gladstone.

Table of contents

Executive summary

Context

The 2022 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 social, cultural, economic and environmental monitoring undertaken in the period 1 July 2021 to 30 June 2022 and Indigenous cultural monitoring undertaken in 2018, mangrove monitoring undertaken in 2019 and fish Health Assessment Index (HAI) monitoring undertaken in 2021. Indicator scores range between 0.00 and 1.00 and are converted into grades (Figure 1).

A	**Very good** (0.85 – 1.00)
B	**Good** (0.65 – 0.84)
C	**Satisfactory** (0.50 – 0.64)
D	**Poor** (0.25 – 0.49)
E	**Very poor** (0.00 – 0.24)

Figure 1: Grading scheme used to convert scores to grades in the 2022 Gladstone Harbour Report Card for each component of harbour health.

Overall component grades

The overall component scores and grades for the 2022 report card were: Environmental 0.64 (C), Social 0.68 (B), Cultural 0.61 (C) and Economic 0.76 (B). Except for mangroves, all Environmental indicators were assessed in the 2022 report card year hence the environmental score is based on new data and the 2019 mangrove data. New monitoring was conducted for the Social and Economic components and these scores are based on data collected in the 2022 report card year. No new monitoring was conducted for the Indigenous cultural heritage indicator group, hence scores for the Cultural component are based on Indigenous cultural heritage data collected in 2018 and data collected for the 'sense of place' indicator group collected in the 2022 report card year. New monitoring for the Indigenous cultural heritage indicator is scheduled for 2023–24.

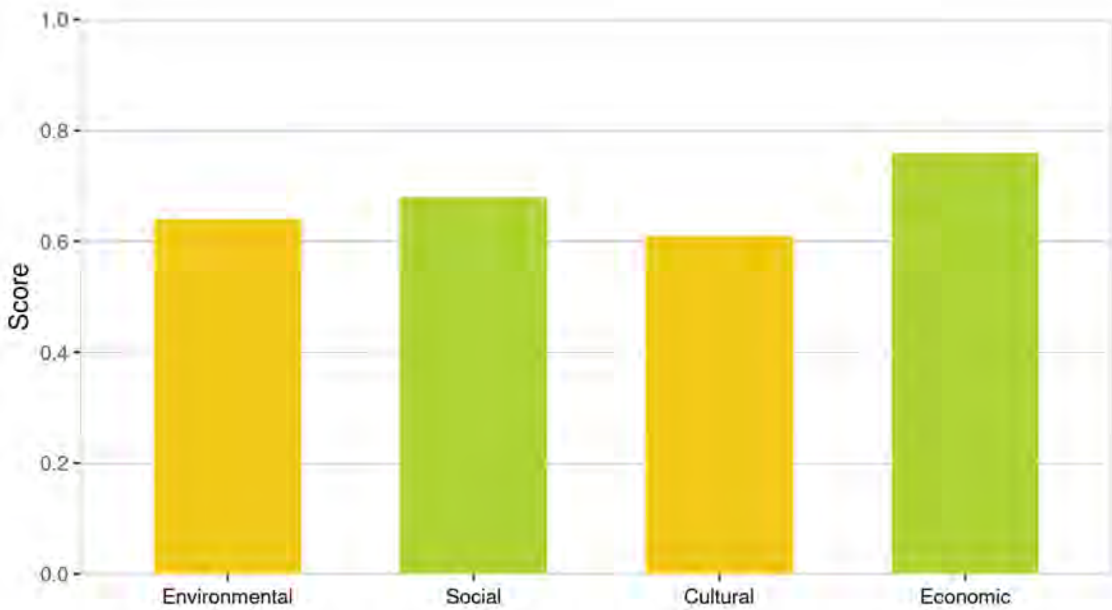


Figure 2: Overall scores for each of the four components of Gladstone Harbour Health in 2022.

Environmental health

The overall grade for the Environmental component was a C (0.64), a lower grade than received in 2021 (B, 0.68).

- In comparison with 2021 scores, the water and sediment quality score was slightly lower (0.89, A) than the previous year (0.93, A), but received the highest score of the three indicator groups. This is due to good water quality (B, 0.81), and very good sediment quality (A, 0.96).

- Habitats received an identical score to 2021 (D, 0.48), owing to a very poor score for corals (E, 0.15) offsetting a good score for seagrass (B, 0.70). Mangroves retained the 2019 score of C (0.57).

- Fish and crabs received a lower score in 2022 (C, 0.55) than 2021 (C, 0.62) due to reduced scores for mud crabs and fish recruitment. Overall, this resulted in a lower reporting score for the Environmental component in the current reporting year.

Table 1: Environmental indicator group scores for the 13 harbour zones and the overall harbour scores in 2022.

Zone	Indicator groups		
	Water and sediment quality	Habitats (seagrass, corals and mangroves)	Fish and crabs
1. The Narrows	0.85	0.79	0.67
2. Graham Creek	0.91	0.64	0.64
3. Western Basin	0.88	0.66	0.89
4. Boat Creek	0.84	0.46	0.57
5. Inner Harbour	0.89	0.47	0.48
6. Calliope Estuary	0.89	0.58	0.57
7. Auckland Inlet	0.86	0.65	0.47
8. Mid Harbour	0.91	0.45	0.69
9. South Trees Inlet	0.88	0.80	0.66
10. Boyne Estuary	0.93	0.26	0.71
11. Outer Harbour	0.94	0.42	0.80
12. Colosseum Inlet	0.89	0.72	0.54
13. Rodds Bay	0.88	0.53	0.42
Harbour score	**0.89**	**0.48**	**0.55**

Water and sediment quality

In 2022, water quality received a good score (0.81, B) while the sediment quality indicator received a very good score (0.96, A). While the sediment quality score was identical to the previous year, the water quality score was lower compared the 2021 score (0.91, A) which was the highest within the monitoring program. Since the first report card in 2015, water quality has been rated as good or very good and sediment quality has been rated as very good.

Water quality

Water quality was relatively uniform across the harbour. Ten of the thirteen zones received a good score, with the remaining three zones receiving a very good score (Table 2). Compared to the previous year, scores for the physicochemical and nutrient groups were lower at all thirteen zones. At the zone level in 2022, the physicochemical group scored mostly good (B) while the nutrient group scored mostly satisfactory (C). In contrast, dissolved metal scores were uniformly very good for the eighth consecutive year.

Table 2: Water quality indicator scores for the 2022 Gladstone Harbour Report Card. Scores from 2021 and 2020 are shown for comparison.

Water quality	Physico-chemical score	Nutrients score	Dissolved metals score	Zone score 2022	*Zone score 2021*	*Zone score 2020*
1. The Narrows	0.79	0.51	1.00	0.77	*0.84*	*0.85*
2. Graham Creek	0.94	0.62	1.00	0.85	*0.92*	*0.91*
3. Western Basin	0.77	0.56	0.99	0.77	*0.95*	*0.89*
4. Boat Creek	0.82	0.54	0.98	0.78	*0.84*	*0.85*
5. Inner Harbour	0.84	0.68	1.00	0.84	*0.94*	*0.85*
6. Calliope Estuary	0.76	0.68	1.00	0.81	*0.94*	*0.94*
7. Auckland Inlet	0.74	0.64	0.95	0.78	*0.85*	*0.82*
8. Mid Harbour	0.81	0.69	1.00	0.84	*0.91*	*0.87*
9. South Trees Inlet	0.81	0.57	1.00	0.79	*0.91*	*0.87*
10. Boyne Estuary	0.92	0.67	1.00	0.86	*0.87*	*0.90*
11. Outer Harbour	0.95	0.70	1.00	0.88	*0.97*	*0.96*
12. Colosseum Inlet	0.91	0.51	1.00	0.81	*0.93*	*0.89*
13. Rodds Bay	0.77	0.51	1.00	0.76	*0.96*	*0.89*
Harbour score	**0.83**	**0.61**	**0.99**	**0.81**	***0.91***	***0.89***

Sediment quality

Sediment quality was very good in all harbour zones (Table 3). This was a result of low concentrations of all measures (arsenic, cadmium, copper, lead, mercury, nickel and zinc).

Table 3: Sediment quality indicator scores for the 2022 Gladstone Harbour Report Card. Scores from 2021 and 2020 are shown for comparison.

Zone	Metals and metalloid score	Zone score 2022	*Zone score 2021*	*Zone score 2020*
1. The Narrows	0.94	0.94	*0.92*	*0.91*
2. Graham Creek	0.97	0.97	*0.95*	*0.90*
3. Western Basin	0.98	0.98	*0.99*	*0.98*
4. Boat Creek	0.89	0.89	*0.92*	*0.89*
5. Inner Harbour	0.94	0.94	*0.94*	*0.93*
6. Calliope Estuary	0.97	0.97	*0.95*	*0.95*
7. Auckland Inlet	0.95	0.95	*0.93*	*0.95*
8. Mid Harbour	0.98	0.98	*0.96*	*0.97*
9. South Trees Inlet	0.97	0.97	*0.97*	*0.96*
10. Boyne Estuary	0.99	0.99	*0.99*	*1.00*
11. Outer Harbour	1.00	1.00	*0.98*	*0.99*
12. Colosseum Inlet	0.96	0.96	*1.00*	*0.97*
13. Rodds Bay	1.00	1.00	*0.98*	*0.96*
Harbour score	**0.96**	**0.96**	***0.96***	***0.95***

Habitats

The overall score for habitats was poor (0.48, D) and was an identical score to that recorded in 2021.

Seagrass

Gladstone Harbour seagrass condition was assessed for fourteen representative meadows in six monitoring zones. Three sub-indicators were used: biomass (above-ground biomass of a meadow), area (total area of a meadow) and species composition (relative proportions of different species within a meadow).

The overall seagrass score in 2022 was 0.70 (B) indicating a good overall condition (Table 4). This is the third consecutive year of good condition, a marked improvement from 2015–2018 when the overall condition was poor. Although the overall seagrass condition was good, changes from the previous year varied meadow to meadow. Nine of the fourteen meadows showed an improved score—five of which showed a marked increase—when compared to the previous year. However, exceptions to recovery were seen in the Inner Harbour meadow due to very poor species composition and in Rodds Bay where there were large declines in all three measures of one meadow (Meadow 94).

Table 4: Seagrass scores for the 2022 Gladstone Harbour Report Card. Scores from 2021 and 2020 are shown for comparison. Note, 2022 scores may differ slightly to those reported by Smith et al. (2022b) due to bootstrapping used to calculate GHHP report card scores (see Logan et al., 2016).

Zone	Meadow	Biomass	Area	Species composition	Overall meadow	2022	*2021*	*2020**
1. The Narrows	21	0.94	0.98	0.98	0.94	0.94	*0.84*	*0.80*
3. Western Basin	4	1.00	1.00	0.93	0.98	0.82	*0.75*	*0.81*
	5	0.93	1.00	0.86	0.89			
	6	0.89	0.93	0.74	0.81			
	7	0.61	0.77	1.00	0.61			
	8	0.92	0.73	0.77	0.73			
	52–57	0.87	0.99	1.00	0.87			
5. Inner Harbour	58	0.77	0.89	0.00	0.39	0.39	*0.59*	*0.70*
8. Mid Harbour	43	0.54	0.81	0.78	0.54	0.67	*0.48*	*0.44*
	48	0.85	0.80	0.89	0.80			
9. South Trees Inlet	60	1.00	1.00	0.99	1.00	1.00	*0.97*	*0.99*
13. Rodds Bay	94	0.38	0.17	0.00	0.09	0.42	*0.70*	*0.87*
	96	0.65	1.00	1.00	0.65			
	104	0.53	0.57	0.88	0.53			
Harbour score						0.70	*0.72*	*0.77*

*Note, 2020 scores shown were corrected for an error in biomass calculation and differ from the scores previously reported on. Refer to 2020 Seagrass Report or 2020 Technical Report for further detail.

Corals

Coral health was assessed at six representative reefs located in the Mid Harbour and the Outer Harbour. Four sub-indicators were used to assess coral health: coral cover, macroalgal cover, juvenile density and change in hard coral cover. Coral cover and macroalgal cover measure the percent cover of living, adult corals and macroalgae respectively; juvenile density is the number of coral recruits (<5 cm); and change in hard coral cover was averaged over a three-year period to give the rate at which hard coral cover increases or decreases. Coral cover is used to assess the state of a reef while the other sub-indicators measure a reef's potential to recover.

In 2022, corals were in a very poor condition for the fifth consecutive year and received an overall score of 0.15 (E). This was a result of a low cover of living coral, high macroalgal cover, low abundance of juvenile corals, and a poor overall score for change in hard coral cover (Table 5). Score changes at the sub-indicator level were minor between 2021 and 2022—with coral cover, macroalgal cover, juvenile density and change in hard coral cover all receiving similar scores to the previous year. Ongoing pressures such as high macroalgal cover and the widespread presence of the bio-eroding sponge *Cliona orientalis* appear to be hindering the recovery of the coral communities in Gladstone Harbour.

Table 5: Coral indicator scores for the 2022 Gladstone Harbour Report Card. Scores from 2021 and 2020 are shown for comparison.

Zone	Coral cover	Macroalgal cover	Juvenile density	Change in hard coral cover	2022	*2021*	*2020**
8. Mid Harbour	0.06	0.07	0.13	0.26	0.13	*0.16*	*0.20*
11. Outer Harbour	0.12	0.00	0.11	0.48	0.18	*0.12*	*0.14*
Harbour score	**0.09**	**0.04**	**0.12**	**0.37**	**0.15**	***0.14***	***0.17***

*Note, 2020 scores shown were corrected for an error in change in hard cord cover calculation and differ from the scores previously reported on. Refer to 2020 Coral Report or 2020 Technical Report for further detail.

Mangroves

Scores for the mangrove indicator have remained stable since it was included in the report card in 2018. As a result, this indicator will only be monitored every five years and no new monitoring was conducted in 2022. The 2019 mangrove scores as presented below are used to calculate the overall scores for the habitats indicator group and the overall Environmental score.

In 2019 three sub-indicators were used to assess mangrove health: extent, canopy condition and shoreline condition. Mangrove extent, the proportion of mangroves in a tidal wetland, and canopy condition, 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 0.57 (C) marginally lower than the score of 0.60 (C) in 2018 (Table 6). This may have been a result of the drier conditions which prevailed during the 2018–19 reporting year.

Table 6: Overall mangrove zone and harbour scores for the 2019 to 2022 reporting years. Scores from 2018 are shown for comparison.

Zone	Mangrove extent	Mangrove canopy condition	Shoreline condition	2019 to 2022	*2018*
1. The Narrows	0.79	0.55	0.61	0.65	*0.56*
2. Graham Creek	0.83	0.34	0.76	0.64	*0.67*
3. Western Basin	0.76	0.39	0.37	0.51	*0.57*
4. Boat Creek	0.54	0.38	0.46	0.46	*0.63*
5. Inner Harbour	0.62	0.51	0.53	0.55	*0.43*
6. Calliope Estuary	0.80	0.48	0.47	0.58	*0.67*
7. Auckland Inlet	0.76	0.57	0.62	0.65	*0.68*
8. Mid Harbour	0.39	0.63	0.63	0.55	*0.55*
9. South Trees Inlet	0.79	0.50	0.51	0.60	*0.61*
10. Boyne Estuary	0.39	0.19	0.19	0.26	*0.41*
11. Outer Harbour	0.76	0.64	0.59	0.66	*0.65*
12. Colosseum Inlet	0.85	0.67	0.65	0.72	*0.69*
13. Rodds Bay	0.68	0.57	0.67	0.64	*0.71*
Harbour score	**0.69**	**0.49**	**0.54**	**0.57**	***0.60***

Fish and crabs

The overall score for fish and crabs was 0.55 (C). Fish recruitment received a score of 0.57 (C) in 2022, lower than the score of 0.62 (C) received in 2021. The mud crab indicator received a poor score 0.39 (D), the fourth consecutive year in which a poor score was recorded. The fish health indicator (Fish Health Assessment Index and Fish Condition) received a good (B) score of 0.80, similar to a score of 0.82 (B) in 2021.

Fish health

The harbour score for fish health was 0.80 (B) which was the average of the harbour scores for the two fish health sub-indicators:

1. **Fish Condition (FC):** An automated visual assessment of images captured by fishers using a mobile phone app. Length and weight data were also recorded at the time of capture. Scores for FC are based on two separate metrics; a visual assessment of fish health which includes skin, eyes, fins parasites and deformities (Fish Visual Condition FVC) and an analysis of weight and length measures (Fish Body Condition FBC).
2. **Fish Health Assessment Index (HAI)**: A thorough assessment of the health of individual fish based on visual condition and the condition of several internal organs and tissues.

As no new data for the Fish Health Assessment Index was collected in 2022, data from the 2021 Fish Health Assessment Index was used to calculate the overall fish health score. Both sub-indicators assessed the health of fish species commonly caught in Gladstone Harbour. However, there were some differences in the species assessed because of the different fishing methods used. The overall score for the fish health assessment index was 0.90, an improvement from the 2020 score of 0.67 (Table 7). The score for fish condition (0.72, B) was slightly lower than the previous year (0.74, B) (Table 8). The scores for fish condition are derived from two metrics: an external visual assessment of fish health, which includes the skin, eye sand fins and the incidence of parasites, deformities and fish body condition determined from the length weight relationship.

Table 7: Overall fish health assessment index (HAI) species and harbour scores from 2019 to 2022.

Fish health assessment Index (HAI)	HAI 2021 & 2022	*HAI 2020*	*HAI 2019*
Bream	0.98	*ND*	*0.78*
Barred javelin	0.90	*0.84*	*0.77*
Barramundi	0.98	*0.55*	*0.58*
Blue catfish	0.81	*0.61*	*0.60*
Mullet	0.81	*ND*	*0.73*
Harbour score	**0.90**	***0.67***	***0.69***

ND – No data or insufficient data to determine a score.

Table 8: Overall fish condition species and harbour scores from 2020 to 2022.

Fish condition	FVC	FBC	FC 2022	*FC 2021*	*FC 2020*
Yellow-finned bream	0.90	0.43	0.72	*0.71*	*0.71*
Pikey bream	0.98	0.46	0.73	*0.73*	*0.74*
Barred javelin	0.94	0.44	0.72	*0.74*	*ND*
Dusky flathead	0.97	0.43	0.70	*0.76*	*ND*
Mangrove jack	0.96	0.50	0.72	*0.75*	*ND*
Harbour score			**0.72**	***0.74***	***0.72***

FVC– Fish visual condition; FBC – Fish body condition; ND – No Data, FC – Fish condition

Fish recruitment

Fish recruitment was assessed for two species: yellow-finned bream *Acanthopagrus australis* and pikey bream *Acanthopagrus pacificus*. The overall score for 2022 was 0.57 (C), which was lower than the score of 0.62 recorded in 2021. The final scores (Table 9) were measured against a 2012 to 2021 baseline. The 2022 score for fish recruitment indicates a season with higher recruitment rate (increased catch rate) relative to the mean reference level determined over the baseline period. The total number of bream caught in the 2022 reporting year was 764, which was composed of 316 yellow-finned bream and 448 pikey bream. Between 2016 and 2022 the catch rate for yellow-finned bream varied between 0.15 to 0.20 yellow-finned bream per cast while the catch rate for pikey bream rose from 0.10 to 0.25 pikey bream per cast.

Table 9: Fish recruitment scores zone and harbour scores from 2018 to 2022.

Zone	2022	*2021*	*2020*	*2019*	*2018*
1. The Narrows	0.64	*0.54*	*0.63*	*0.18*	*0.58*
2. Graham Creek	0.80	*0.84*	*0.92*	*0.17*	*0.77*
3. Western Basin	0.98	*0.94*	*0.98*	*0.13*	*0.79*
4. Boat Creek	0.33	*0.35*	*0.38*	*0.32*	*0.61*
5. Inner Harbour	0.51	*0.61*	*0.63*	*0.16*	*0.67*
6. Calliope Estuary	0.47	*0.68*	*0.66*	*0.28*	*0.70*
7. Auckland Inlet	0.60	*0.63*	*0.80*	*0.53*	*0.87*
8. Mid Harbour	0.57	*0.78*	*0.62*	*0.12*	*0.58*
9. South Trees Inlet	0.53	*0.47*	*0.39*	*0.25*	*0.69*
10. Boyne Estuary	0.63	*0.53*	*0.51*	*0.32*	*0.52*
11. Outer Harbour	Not surveyed				
12. Colosseum Inlet	0.29	*0.56*	*0.63*	*0.39*	*0.61*
13. Rodds Bay	0.45	*0.51*	*0.52*	*0.33*	*0.59*
Harbour score	**0.57**	***0.62***	***0.64***	***0.27***	***0.66***

Mud crabs

Seven zones were sampled to collect data on three mud crab sub-indicators: sex ratio, abundance and prevalence of rust lesions. Sex ratio quantifies the ratio of legal-sized male crabs (>15 cm spine width) to female crabs of the same size. Abundance was used to estimate the number of crabs via catch per unit effort. The prevalence of rust lesions was calculated by comparing the number of crabs with rust lesions to the total number of mud crabs caught at each monitoring zone.

The overall mud crab score in 2022 was 0.39 (D) (Table 10). Although a decline from 2021, this score was within the range of previous years (0.39 to 0.49 (D) since 2018). This was a result of very poor scores for sex ratio and abundance while prevalence of rust lesions received mostly very good scores. Two zones received a satisfactory overall score, two zones received a poor overall score and one zone received a very poor overall score. Zone scores were not calculated in Auckland Inlet (for the fifth consecutive year) and Rodds Bay due to an insufficient catch of mud crabs.

Table 10: Mud crab indicator scores for the 2022 Gladstone Harbour Report Card. Scores from 2021 and 2020 are shown for comparison.

Zone	Sex Ratio	Abundance (CPUE)	Prevalence of rust lesions	2022	*2021*	*2020*
1. The Narrows	0.00	0.85	0.90	0.58	*0.64*	*0.60*
2. Graham Creek	0.00	0.00	1.00	0.33	*0.39*	*0.34*
4. Boat Creek	0.43	0.32	0.98	0.58	*0.60*	*0.71*
5. Inner Harbour	0.00	0.11	0.32	0.14	*0.39*	*0.39*
6. Calliope Estuary	0.29	0.00	1.00	0.43	*0.47*	*0.19*
7. Auckland Inlet	NC	0.00	NC	NC	*NC*	*NC*
13. Rodds Bay	NC	0.00	NC	NC	*0.56*	*0.22*
Harbour score	**0.14**	**0.18**	**0.84**	**0.39**	***0.48***	***0.39***

CPUE - catch per unit effort, NC - Not calculated owing to inadequate sample size (n < 5)

Social health

The overall score for social health in 2022 was 0.68 (B) similar to the 2019 to 2021 score of 0.67 (B). This score was based on three indicator groups: harbour usability 0.62 (C), harbour access 0.68 (B) and liveability and wellbeing 0.71 (B) (Table 11). All indicator scores were similar to scores received since 2018 and the overall social health has remained stable since 2015—suggesting Gladstone residents continue to feel that Gladstone Harbour provides them with a positive living experience and quality of life.

Table 11: Social indicator group and indicator scores for the 2022 report card. Scores from 2018 to 2021 are shown for comparison.

Indicator groups	Social indicators	2022	2022	*2019 to 2021*	*2018*
Harbour usability	Satisfaction with harbour recreational activities	0.73	0.62	*0.64*	*0.63*
	Perceptions of air and water quality	0.59			
	Perceptions of harbour safety for human use	0.55			
Harbour access	Satisfaction with access to the harbour	0.75	0.68	*0.67*	*0.67*
	Satisfaction with boat ramps and public spaces	0.67			
	Perceptions of harbour health	0.63			
	Perceptions of barriers to access	0.69			
Liveability and wellbeing	Liveability and wellbeing	0.71	0.71	*0.70*	*0.70*
Overall score			**0.68**	***0.67***	***0.67***

Cultural health

The overall score for the Cultural health of Gladstone was 0.61 (C). Two indicator groups for Cultural health were assessed: 'sense of place' 0.68 (B) (Table 12) and Indigenous cultural heritage 0.54 (C) (Table 13).

The overall 'sense of place' score was similar to 2019 when it was last assessed suggesting that the community expectations of the Gladstone Harbour area are being met.

The scores for the Indigenous cultural heritage indicator group have been stable since it was included in the report card in 2016. As a result, this component will only be monitored every five years. As no new monitoring for Indigenous cultural heritage was conducted in 2022 the results from the 2018 monitoring were used to calculate the overall score for the Cultural health and the Indigenous cultural heritage indicator scores (Table 13).

Table 12: Scores for the 'sense of place' indicator group for the 2022 report card. Scores from 2021 to 2018 are shown for comparison.

Indicator group	Indicators	2022	2022	*2019 to 2021*	*2018*
'Sense of place'	Place attachment	0.61	0.68	*0.66*	*0.65*
	Continuity	0.65			
	Pride in the region	0.76			
	Wellbeing	0.62			
	Appreciation of the harbour	0.84			
	Values	0.68			

Table 13: Scores for Indigenous cultural heritage indicators and overall harbour score for the 2018 to 2022 report cards.

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

In 2022, the overall score for the Economic component was 0.76 (B). This score was estimated by the scores from three indicator groups: economic performance 0.90 (A), economic stimulus 0.64 (C) and economic value 0.77 (B) (Table 14). While the overall economic health of Gladstone was similar to 2019 when it was last assessed, the score was influenced by poor scores for commercial fishing and employment indicators. All other indicators received good or very good scores.

Table 14: Scores for the economic indicator groups from 2018 to 2022. The 2021 to 2018 scores are shown for comparison.

Indicator group	Indicators	2022	2022	*2019 to 2021*	*2018*
Economic performance	Shipping activity	0.90	0.90	*0.90*	*0.90*
	Tourism	0.90			
	Commercial fishing	0.41			
Economic stimulus	Employment	0.45	0.64	*0.58*	*0.58*
	Socio-economic status	0.74			
Economic value (recreation)	Land-based recreation	0.79	0.77	*0.76*	*0.74*
	Recreational fishing	0.73			
	Beach recreation	0.77			
	Water-based recreation	0.77			
Overall score		**0.76**	**0.76**	*0.72*	*0.74*

1. Introduction

1.1 The Gladstone Healthy Harbour Partnership

The Gladstone Healthy Harbour Partnership (GHHP) is a forum that brings together numerous parties to monitor 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 and annual reporting of the health of Gladstone Harbour. Actions are based on rigorous science and strong stakeholder engagement to ensure the ongoing and continuous improvement of the health of Gladstone Harbour.

The GHHP partnership currently has 23 partners comprising 15 industry representatives; 3 research and monitoring agencies; local, state and federal government representatives and 2 community groups including Traditional Owners. The GHHP was formally launched in 2013.

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.

The Gladstone Harbour Report Card reports on the Environmental, Social, Cultural and Economic health of the harbour (Figure 1.1). Stakeholder and community consultation identified these four components as important to the community during workshops conducted by GHHP in 2013.

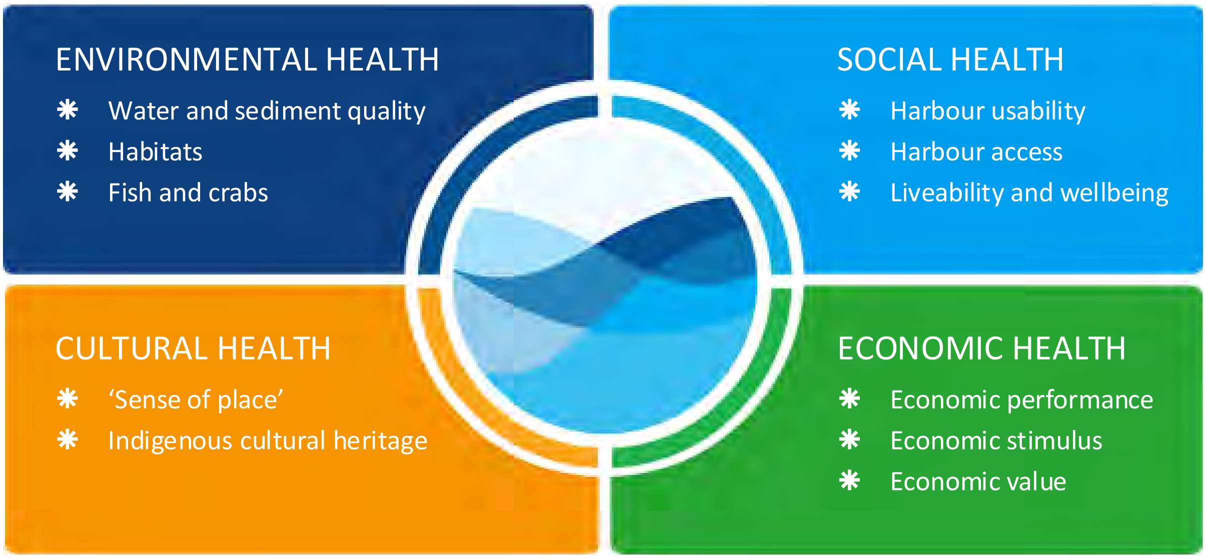


Figure 1.1: The four components of harbour health.

1.2. Reporting periods

The reporting period for the 2022 Gladstone Harbour Report Card was 1 July 2021 to 30 June 2022. However, mangrove data collected in the 2018–19 reporting year and fish Health Assessment Index (HAI) data collected in the 2020–21 reporting year was used to complete the Environmental component. No new data for the Indigenous cultural heritage were collected during the 2021–22 report card year. All grades and scores for this indicator group are those used in the 2018 report card.

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 the final 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 2022 Gladstone Harbour Report Card.

Name	Explanation
Level 1: Component	The 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 commercial 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 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, total phosphorus and chlorophyll-*a*.
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 are used to calculate the grade for each measurement type. The methods used to determine baselines for each indicator are described in detail in the relevant sections of this report. Each threshold is a decimal value between 0.00 and 1.00 (Figure 2.1). Scores are assigned to measurements that are then aggregated upwards to the component level.

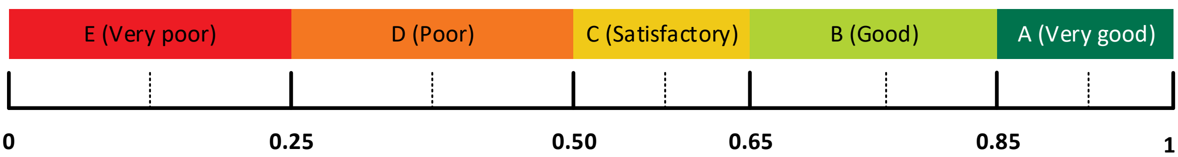


Figure 2.1: Grade ranges used in the 2022 Gladstone Harbour Report Card.

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) in the 2021–22 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 2021–22 reporting year. The annual site means were used to develop indexed scores between 0.00 and 1.00 compared with relevant guidelines (Figure 2.2; Department of Environment and Heritage Protection (DEHP) water quality objectives or Australia and New Zealand Guidelines (ANZG) default guideline values as appropriate). This yielded final indexed scores at site level which could be aggregated to higher levels of reporting (Figures 2.3–2.6). References have been provided on the methods used to calculate the indexed values for coral, seagrass, mangroves 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 2.7).

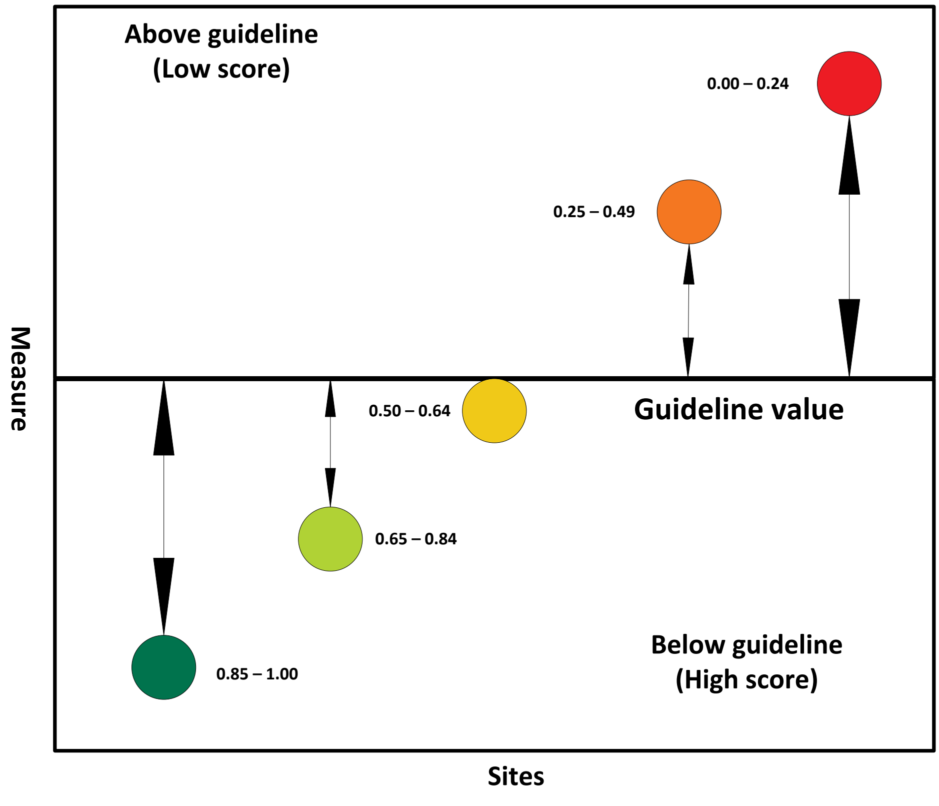


Figure 2.2: Water and sediment quality measures are scored relative to zone and measure specific guideline values.

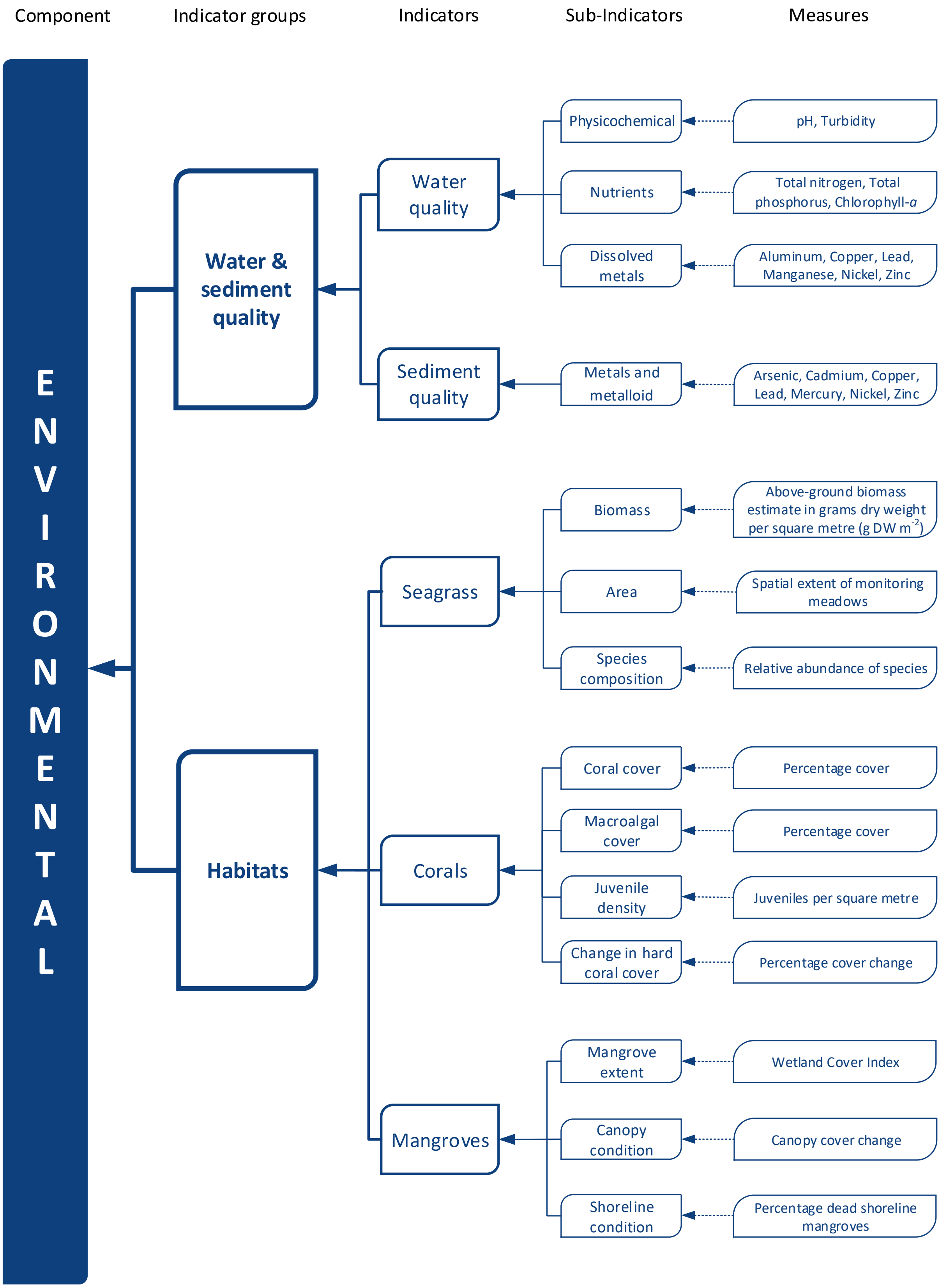


Figure 2.3a: The levels of aggregation used to determine the environmental scores and grades in the 2022 Gladstone Harbour Report Card. There are three environmental indicator groups, eight indicators, 19 sub-indicators and 47 measures.

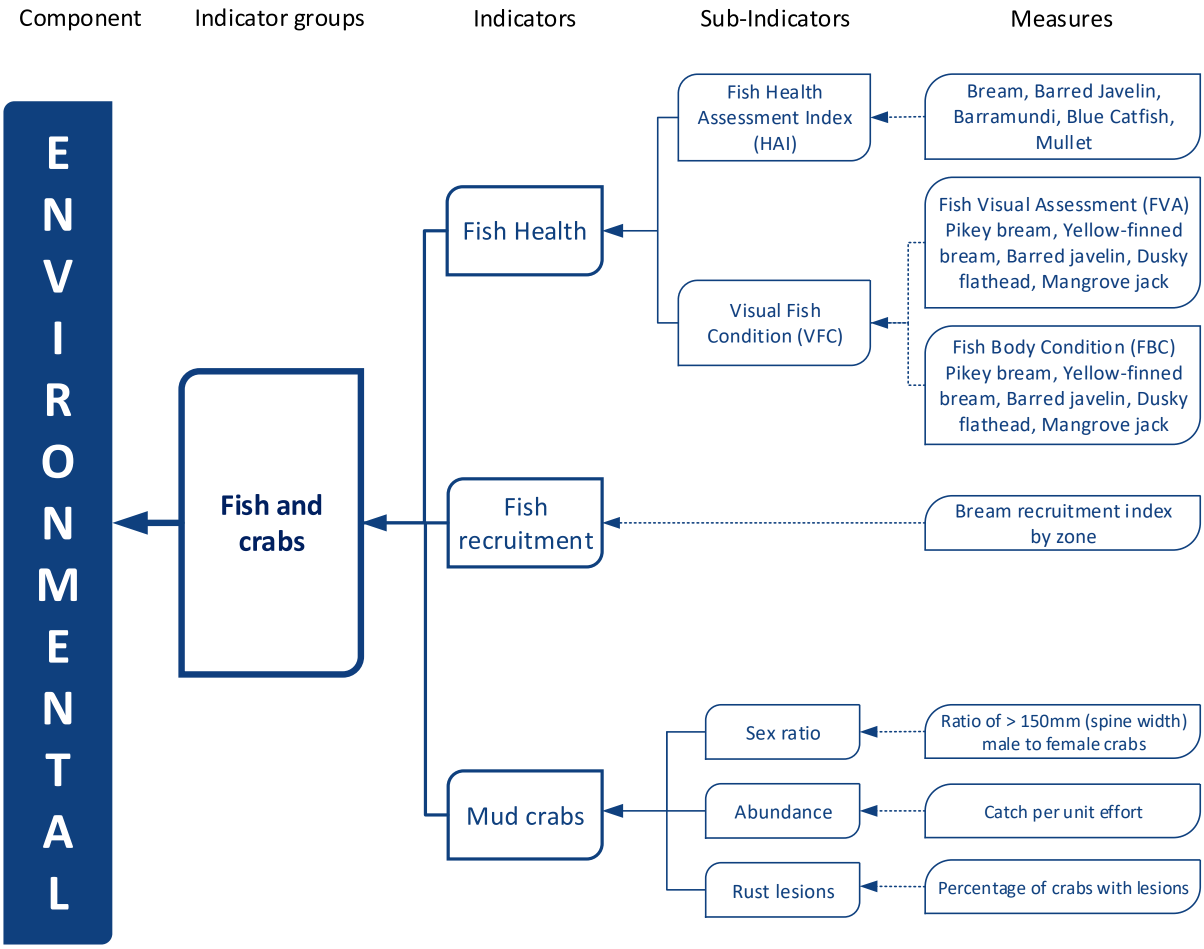


Figure 2.3b: The levels of aggregation used to determine the environmental scores and grades in the 2022 Gladstone Harbour Report Card. There are three environmental indicator groups, eight indicators, 19 sub-indicators and 47 measures.

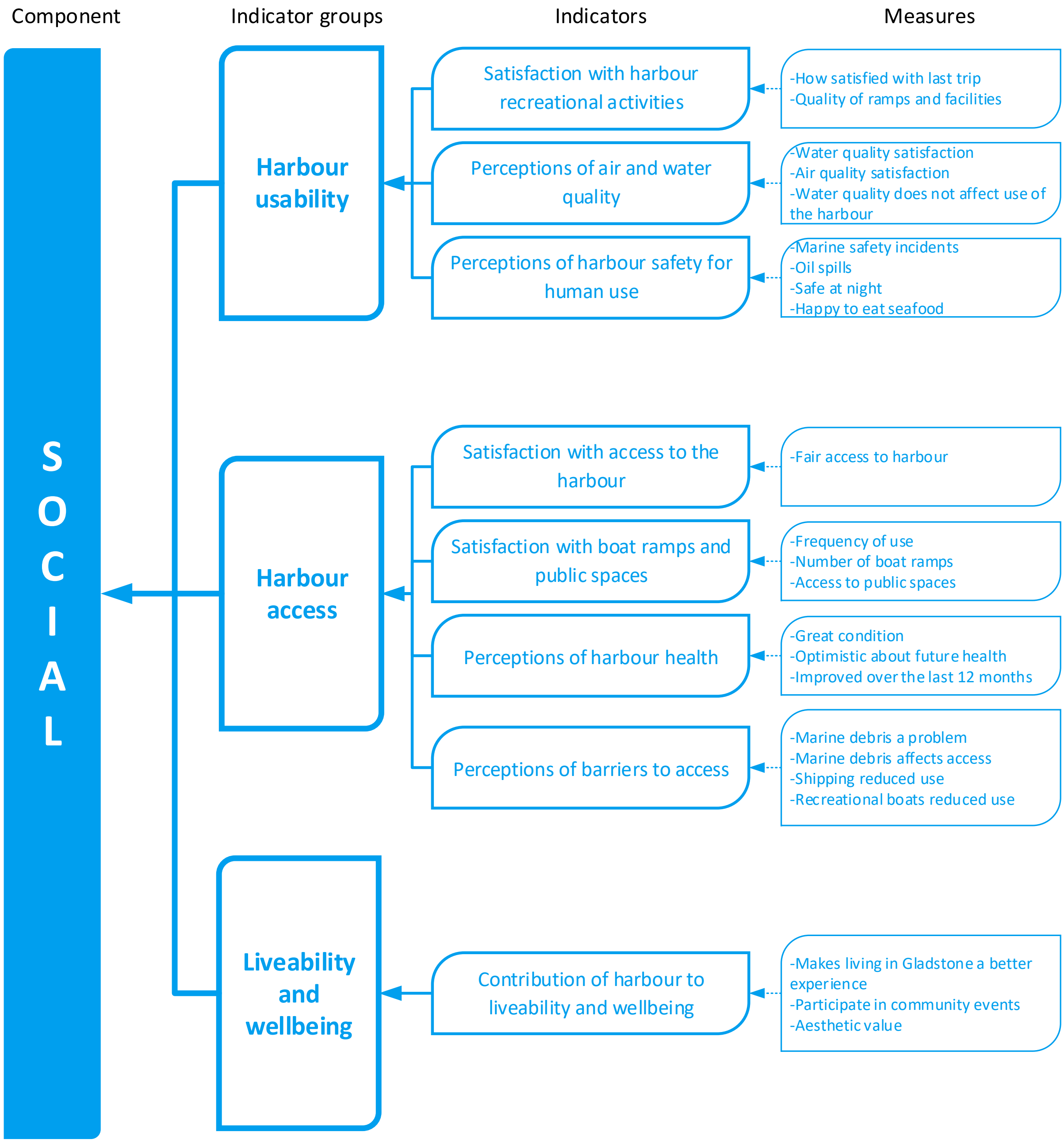


Figure 2.4: The levels of aggregation used to determine the social scores and grades in the 2022 Gladstone Harbour Report Card. There are three social indicator groups, eight indicators and 23 measures.

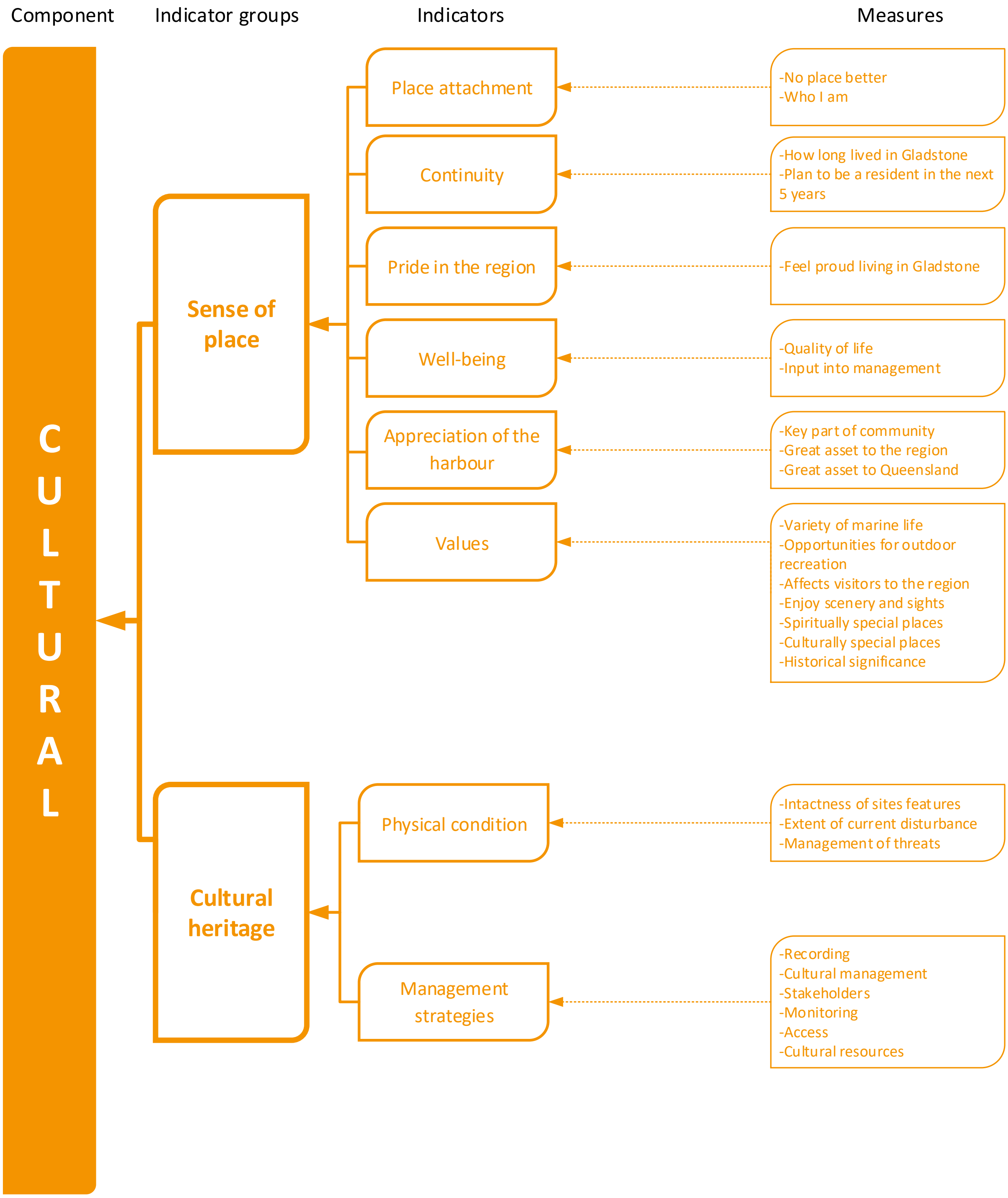


Figure 2.5: The levels of aggregation used to determine the cultural grades and scores in the 2022 Gladstone Harbour Report Card. There are two cultural indicator groups, eight indicators and 26 measures.

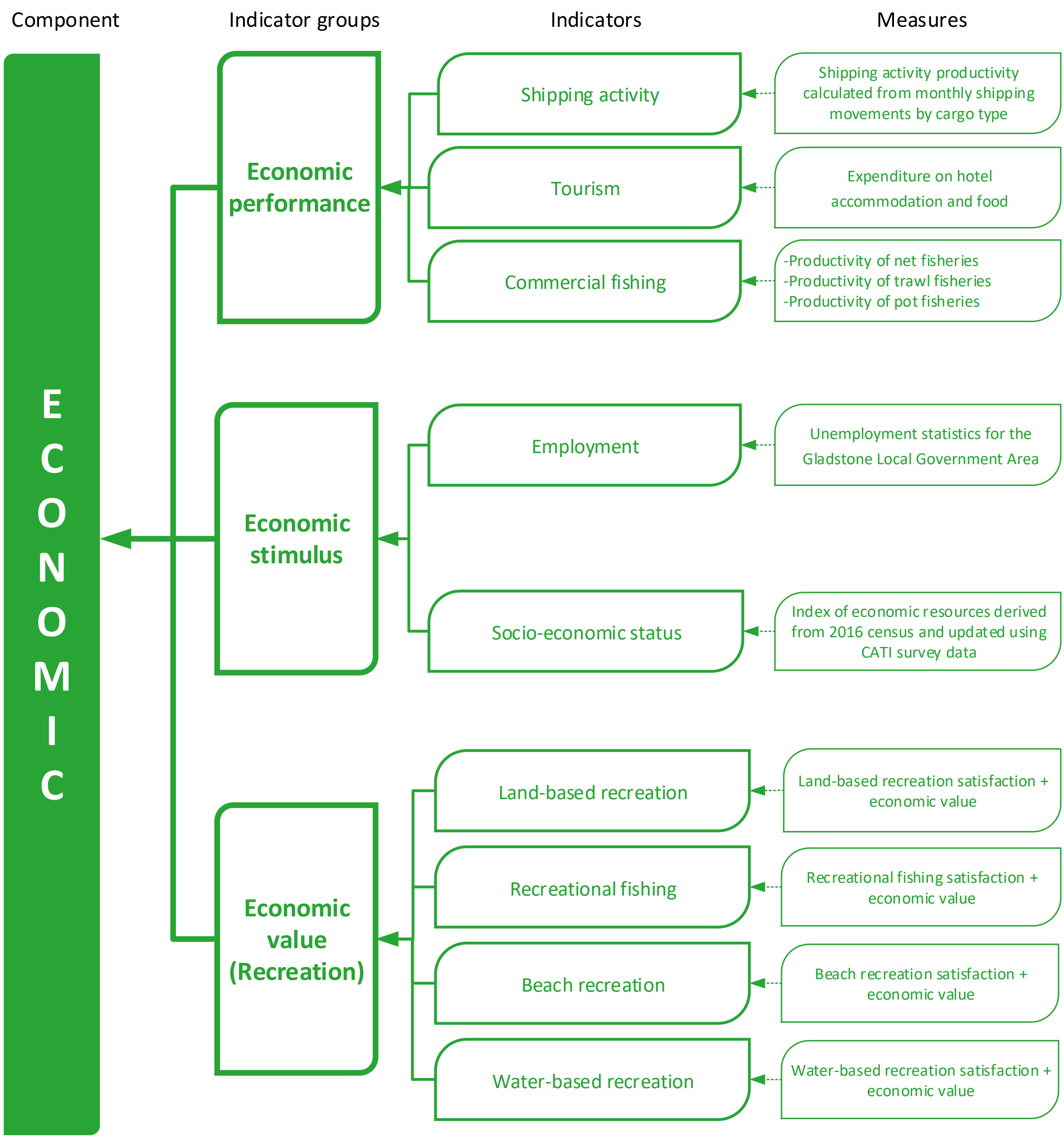


Figure 2.6: The levels of aggregation used to determine the economic scores and grades in the 2022 Gladstone Harbour Report Card. CATI = Computer-Assisted Telephone Interviewing. There are three economic indicator groups, nine indicators and 11 measures.

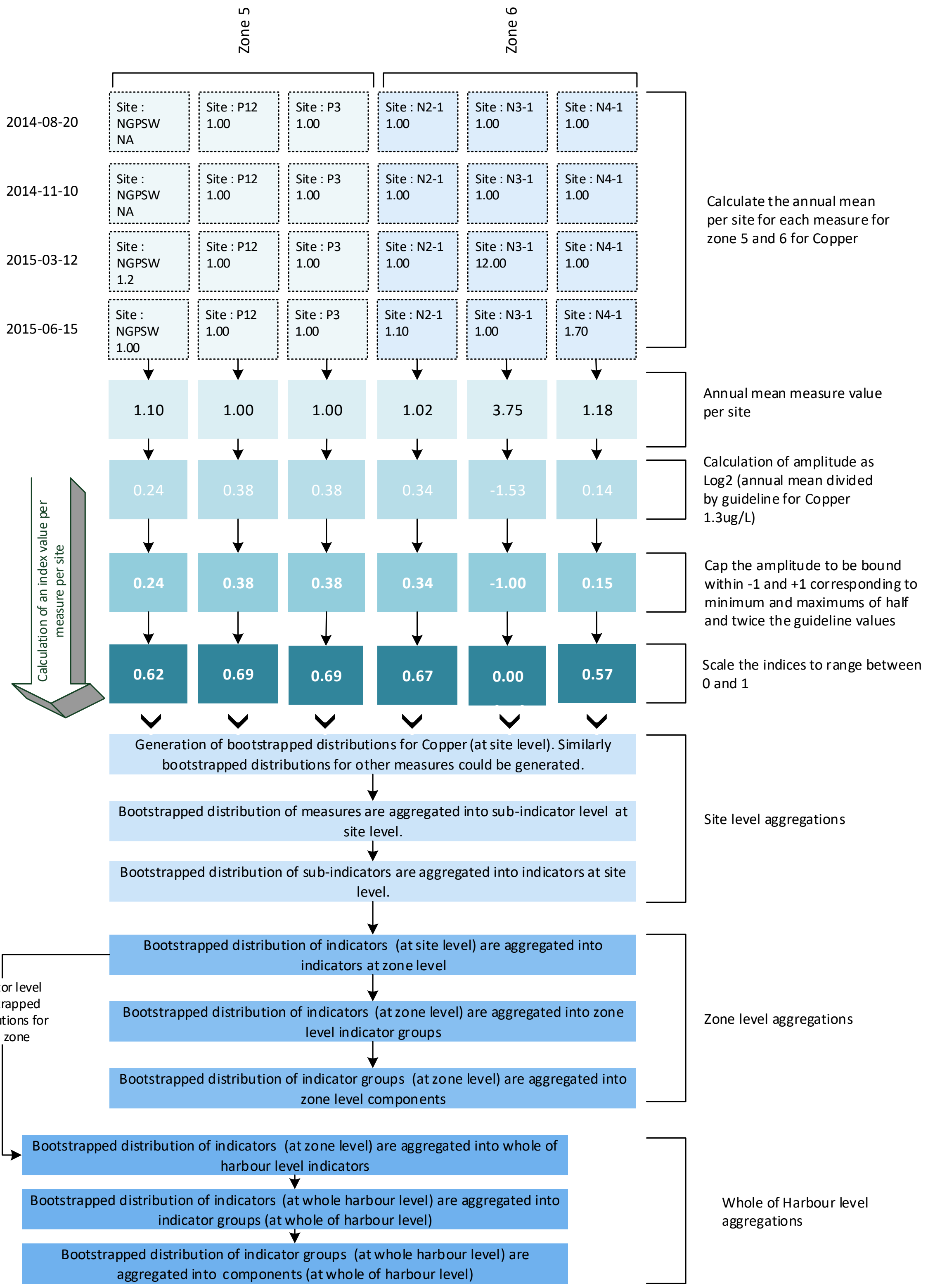


Figure 2.7: Aggregation of report card scores—a worked example using the water quality measure for copper in zones 5 and 6.

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 high confidence rating in 2022. The Social and Economic components received high confidence ratings in 2022 while the Cultural component rating was rated at moderate.

The Environmental component received a high confidence rating for the first time in 2019 and has retained that rating for the 2021 and 2022 report cards. The high confidence rating was achieved as the Environmental component has been complete (all indicators included) and additional years of data indicate the robustness of the methods used to determine the grades. Six of the eight indicators received high confidence ratings, while water and quality and fish health received moderate ratings (Table 2.2).

Table 2.2: Confidence ratings for individual environmental indicators in 2022.

Indicator	Confidence	Reason
Water quality	Moderate	Exclusively, 'far-field' sites were reported on, and these were specifically sampled four times per year.
Sediment quality	High	Appropriate methodology and sampling frequency, minimal laboratory issues since the pilot report card in 2014.
Seagrass	High	Consistent methods used over eight years of monitoring. Minor changes to scoring methods in 2018.
Corals	High	Consistent methods used over eight years of monitoring. Minor changes to scoring methods in 2018.
Mangroves*	High (2019)	Two years of monitoring, high quality data and consistent with other mangrove monitoring programs in Queensland. The 2019 results were used in the 2020, 2021 and 2022 report cards.
Fish health	Moderate	Four years of monitoring (2018–2022) and the program is based on previous fish health studies. The two fish health projects had similar results. HAI 2021 was used to calculate 2022 scores.
Fish recruitment	High	Seven years of monitoring with consistent methods and data analysis. Minor change to sampling frequency in 2021.
Mud crabs	High	Six years of monitoring with an appropriate methodology. The benchmarks are based on local populations. Minor changes to scoring methods in 2020.

* The mangrove data used to calculate the overall 2022 Environmental score were collected in 2019.

The confidence ratings for the Social, Cultural and Economic components remain unchanged from 2019.

The Social component received a high confidence rating. The methodology was developed specifically for Gladstone Harbour and has been stable since the Pilot Report Card in 2014. The computer-assisted telephone interview (CATI) survey that contributed most of the data was regarded as reliable and repeatable. Data collection was improved with the inclusion of mobile phones in 2017. The 18 to 24-year-old age group were still under-represented while older age participants were over-represented in the survey. The Maritime Safety Queensland data was for the Gladstone Maritime Region which included areas beyond the harbour. Despite these minor issues 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', which was derived from data collected from the CATI survey received a moderate confidence rating. There were improvements in the Indigenous cultural heritage indicator including weighting the scores based on inputs from Traditional Owners and Elders in 2018. However, no survey work has been conducted between 2019 and 2022 and the 2018 scores and grades have been used. The methodology to assess Indigenous cultural heritage in a report card framework is still relatively new and further refinements may be required. 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. The Environmental component

The Environmental component for the 2022 report card consists of three indicator groups: water and sediment quality, habitats, and fish and crabs. Monitoring for all environmental indicators except mangroves occurred between 1 July 2021 and 30 June 2022. As no new mangrove monitoring was conducted in the 2022 report card year, the 2019 mangrove results were used for the 2022 report card. This data was collected between 1 July 2018 and 30 June 2019. Data for fish HAI was collected in the 2020–21 report card year.

3.1. 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, climatic and other environmental factors play a major role in determining the water and sediment quality recorded in the harbour. The Independent Science Panel (ISP) recommended the measures for water and sediment quality that are used in the report card, all of which have local or national guidelines.

For the Gladstone Harbour Report Card, water quality objectives (WQOs) and guideline values were provided by:

- Department of Environment and Heritage Protection Water Quality Objectives for the Capricorn Curtis Coast (DEHP, 2014) for pH, turbidity and nutrients;
- ANZG (2018) for metals in water and sediments (except aluminium); and
- Golding et al. (2014) for aluminium in marine waters.

The WQOs used to calculate report card scores differed among geographic zones within Gladstone Harbour for all physicochemical and nutrient measures but the guideline values were consistent for all metals.

The aluminium guidelines developed by Golding et al. (2014) ranged from 2.1 µg/L in high ecological value zones in Gladstone Harbour (The Narrows, Colosseum Inlet, Rodds Bay) to 24 µg/L in moderately disturbed zones (all other zones). This led to similar actual concentrations of aluminium being scored as very poor in high ecological value zones and very good in moderately disturbed zones. This created the misleading impression that the aluminium concentrations were far worse in high ecological value zones than in moderately disturbed zones. For this reason, the ISP applied the moderately disturbed guideline of 24 µg/L across all zones for aluminium.

For the same reason, GHHP applied a draft manganese guideline value for marine waters of 140 µg/L for the water quality assessment in all zones from 2014–2019, which was the appropriate guideline for moderately disturbed systems with corals present (COAG Standing Council on Environment and Water, 2013). The draft guideline value of 140 µg/L was recommended by the ISP as it was derived using the species sensitivity distribution method and was based on the most relevant information available at the time. However, the draft manganese guideline value has yet to be finalised and additional chronic studies with corals are to occur in 2022. Given that there is no longer a strong rationale to maintain the original draft guideline value (140 µg/L), the ISP recommended to change the GHHP manganese guideline value to the ANZG (2018) value of 80 µg/L, consistent with

ANZECC/ARMCANZ (2000) Since 2020, the ISP has applied the guideline of 80 µg/L across all zones for manganese in marine waters, and will consider future revisions as more reviews and guidelines are published

The 95% species protection value from the ANZG (2018) water quality guidelines was applied to copper (Cu), lead (Pb), and zinc (Zn), while the 99% species protection value was applied to nickel (Ni). Water quality guideline values were selected for moderately disturbed systems.

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, 5667.12:1998)
- *American Public Health Association (APHA) Standard Methods for the Examination of Water and Wastewater* (APHA, 2005)
- *Australian and New Zealand Water Quality Guidelines* (ANZECC, 1992, 1998; ANZECC/ARMCANZ, 2000; ANZG, 2018)
- *Queensland Water Quality Guidelines* (DEHP, 2009)
- *Department of Environment and Science Monitoring and Sampling Manual* (DES, 2018)
- *Revision of the ANZECC/ARMCANZ Sediment Quality Guidelines* (Simpson et al., 2013)

3.1.1. Water and sediment quality data collection

Water quality

Under a data-sharing agreement, Port Curtis Integrated Monitoring Program (PCIMP) provided GHHP with water quality data for calculating scores for the 2022 report card. Those data were based on samples collected from 51 sites across the 13 harbour zones in August and November 2021 and March and June 2022 (Figures 10.1–10.27). Methods in this section were provided by PCIMP (PCIMP, 2019).

Eleven water quality parameters were assessed: two physicochemical measures, three nutrient measures and six dissolved metals (Table 3.1). Physicochemical parameters were measured using a multi-parameter water quality sonde (YSI ProDSS), which was calibrated and checked prior to sampling. Measurements were taken at 0.5 m depth intervals through the water column until the seabed was reached. Triplicate sub-surface readings (0.5 m) were recorded at each site.

Water samples for nutrient and dissolved metal analyses were collected from a depth of about 0.5 m using a Perspex pole sampler and a pre-acid washed Nalgene bottle (triple rinsed in Milli-Q and site water). Powder free gloves were worn to avoid contamination. Sample water was added directly to laboratory-provided sample bottles for total nitrogen, total phosphorous and chlorophyll-*a*. A sub-sample of water was filtered through a 0.45 µm membrane filter in the field for dissolved metals and dissolved nutrients. All samples were placed immediately on ice and dispatched to arrive at the nominated analysing laboratories within their recommended holding times. Field blanks, travel blanks and duplicate samples (at 20% of sites) were also collected and analysed in accordance with the standard protocols described above for laboratory and field quality assurance and quality control (QA/QC) purposes.

All analysing laboratories 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.

Dissolved metal samples were sent to the National Measurement Institute and nutrient samples were sent to the Queensland Health laboratories apart from chlorophyll-*a* samples, which were sent to Australian Laboratory Services. Field blanks, travel blanks and duplicate samples were dispatched to the same respective laboratories based on sample type.

Table 3.1: Water quality sub-indicators and measures in the 2022 Gladstone Harbour Report Card.

Indicator	Sub-indicator	Measure	Guideline source
Water quality	Physicochemical	pH	DEHP, 2014
		Turbidity	DEHP, 2014
	Nutrients	Total nitrogen (TN)	DEHP, 2014
		Total phosphorus (TP)	DEHP, 2014
		Chlorophyll-*a*	DEHP, 2014
	Dissolved metals	Aluminium (Al)	Golding et al., 2014
		Copper (Cu)	ANZG, 2018
		Lead (Pb)	ANZG, 2018
		Manganese (Mn)	ANZG, 2018
		Nickel (Ni)	ANZG, 2018
		Zinc (Zn)	ANZG, 2018

See Appendix 2 for a full list of WQOs and water quality guidelines.

Sediment quality

Six sediment metals and one metalloid (arsenic) were assessed (Table 3.2). Methods in this section were provided by PCIMP (PCIMP, 2019).

Sediment samples were collected from the same 51 harbour monitoring sites used for water quality sampling in May 2022. Grab samples were collected for sediment quality measures using a stainless steel Ponar grab sampler (0.008 m^3 volume). 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 100 mm of the sample, which were deposited into laboratory-provided sample containers using pre acid-washed polypropylene trowels.

All sample containers were bagged and stored at 4° C and transported to the analysing laboratory, National Measurement Institute, within their recommended holding times. For field QA/QC, separate grabs were made for duplicate samples at 20% of sites.

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. Polycyclic aromatic hydrocarbons have not been included since the first report card owing to the extremely low concentrations recorded in 2015.

Table 3.2: Sediment quality measures in the 2022 Gladstone Harbour Report Card.

Indicator	Sub-indicator	Measure	Guideline source
Sediment quality	Metals and metalloid	Arsenic (As)	ANZG, 2018
		Cadmium (Cd)	ANZG, 2018
		Copper (Cu)	ANZG, 2018
		Lead (Pb)	ANZG, 2018
		Mercury (Hg)	ANZG, 2018
		Nickel (Ni)	ANZG, 2018
		Zinc (Zn)	ANZG, 2018

See Appendix 3 for a full list of sediment quality guidelines.

What water and sediment quality measures were not included?

In October 2022, the ISP discussed QA/QC issues with the raw dataset for 2022 for the water and sediment quality data collected.

Based on discussions, the ISP recommended not to include NOx and orthophosphate measures in the report card analysis owing to the following issues:

1. Most of the data were below the limit of reporting (LOR), meaning that the bulk of the observations were not measured accurately.
2. Scores below the LOR could only be calculated by making an assumption about what the measure might be (e.g., 50% of LOR). This becomes difficult to justify when it involves most of the observations.
3. As WQOs differ between zones, the application of the scoring created potentially perverse results (e.g., zones with the lowest WQOs tended to have the lowest scores).
4. There would be an element of double counting if NOx and orthophosphate were included, as these are already measured under total nitrogen and total phosphorous respectively.

In 2022, the limit of reporting (LOR) value for sediment mercury was at an acceptable level (0.01 mg/kg) compared to the guideline value (0.15 mg/kg). As such, the ISP recommended to include sediment mercury in the report card analysis. Sediment mercury was included in previous years when the LOR was at an acceptable level (e.g., 0.01 mg/kg in 2017, 2019 and 2021) and excluded in previous years when the LOR was not at an acceptable level (e.g., 0.2 mg/kg in 2018 and 2020).

3.1.2. Water and sediment quality measures

A total of 18 water and sediment quality measures were assessed and reported in the 2022 Gladstone Harbour Report Card. These measures were recommended by the GHHP ISP as indicative of the factors relevant to the harbour and its condition. The importance of each measure to overall harbour health is described in the sections below.

Physicochemical indicators

pH

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

Turbidity

Turbidity is a measure of water clarity and is affected by the levels of suspended sediment (sand, silt and clay), organic matter and plankton in the water. Coloured substances such as pigments and tannins from decaying plant matter may also reduce water clarity, but to a lesser extent. High turbidity decreases the light levels reaching the seabed which reduces photosynthesis and the production of dissolved oxygen. This can lead to supressed growth and reproduction and if exposed to low light for prolonged periods, eventually to mortality of algae, seagrasses and corals. Suspended material in water with very high turbidity levels may also clog fish gills and smother benthic invertebrates.

Nutrients

Nitrogen and phosphorus 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 in enclosed or poorly flushed waters.

Total nitrogen

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

Total phosphorus

In aquatic systems, phosphorus (P) exists in different forms such as dissolved orthophosphate, organically bound phosphorus and particulate phosphorus. The total phosphorus 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 levels it can lead to algal blooms and increased growth of macroalgae, both of which may 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 phytoplankton, seagrasses and seaweeds. High levels of chlorophyll-*a* may indicate blooms of algae which can occur when nutrient concentrations are elevated. In enclosed or poorly flushed waters, this can lead to depleted levels of oxygen in the water and potentially, to fish kills. Algal blooms may also contribute to reduced light reaching the seabed which may influence coral and seagrass ecosystems.

Dissolved metals and metalloid

A suite of metals and one metalloid (arsenic) have been selected as indicators of harbour health. General information on the descriptions of metals, factors affecting toxicity and toxicology were retrieved from ANZG (2018).

Aluminium

The element aluminium (Al) is a silvery white metal and the most abundant metal in the Earth's crust (Zumdahl and 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) or anthropogenic (e.g., mining waste, industrial discharges, urban run-off). 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, inorganic forms of which may be toxic to aquatic species. Most biota convert inorganic arsenic to less toxic organic forms (e.g., arsenosugars, arsenobetaine).

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., released 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. Natural waters generally have very low concentrations of lead. In water, lead is mostly adsorbed onto sediment and suspended particles. This metal has no known benefits to aquatic plants or animals. In marine environments, increased lead can disrupt invertebrate growth and therefore affect populations (Botte., et al. 2022).

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 (except corals) is low. Two manganese deposits near Gladstone Harbour have previously been mined and produced over 1,000 tonnes of manganese ore. Those deposits were at Auckland Inlet (mined 1882–1900) and Boat Creek (mined 1901–1902) (Wilson & Anastasi, 2010).

Mercury

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

Nickel

Nickel (Ni) is the 24th most abundant metal in the Earth's crust and is essential for all organisms (Cempel & Nikel, 2006). Nickel in waterways can come from sources that are industrial 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 is toxic to organisms.

3.1.3. Water and sediment quality results

3.1.3.1 Water quality

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

The overall score for water quality in the 2022 report card was 0.81 (B). This was the sixth time since monitoring began in 2015 that the water quality indicator received a good score, and the third highest overall score. However, the overall score decreased from the previous two years, when water quality received a very good score. Ten zones received good scores (0.76 – 0.84, B) and three zones received very good scores (0.85 – 0.88, A) (Table 3.3).

Table 3.3: Water quality indicator scores for the 2022 Gladstone Harbour Report Card. Scores from 2021 and 2020 are shown for comparison.

Water quality	Physico-chemical score	Nutrients score	Dissolved metals score	Zone score 2022	*Zone score 2021*	*Zone score 2020*
1. The Narrows	0.79	0.51	1.00	0.77	*0.84*	*0.85*
2. Graham Creek	0.94	0.62	1.00	0.85	*0.92*	*0.91*
3. Western Basin	0.77	0.56	0.99	0.77	*0.95*	*0.89*
4. Boat Creek	0.82	0.54	0.98	0.78	*0.84*	*0.85*
5. Inner Harbour	0.84	0.68	1.00	0.84	*0.94*	*0.85*
6. Calliope Estuary	0.76	0.68	1.00	0.81	*0.94*	*0.94*
7. Auckland Inlet	0.74	0.64	0.95	0.78	*0.85*	*0.82*
8. Mid Harbour	0.81	0.69	1.00	0.84	*0.91*	*0.87*
9. South Trees Inlet	0.81	0.57	1.00	0.79	*0.91*	*0.87*
10. Boyne Estuary	0.92	0.67	1.00	0.86	*0.87*	*0.90*
11. Outer Harbour	0.95	0.70	1.00	0.88	*0.97*	*0.96*
12. Colosseum Inlet	0.91	0.51	1.00	0.81	*0.93*	*0.89*
13. Rodds Bay	0.77	0.51	1.00	0.76	*0.96*	*0.89*
Harbour score	**0.83**	**0.61**	**0.99**	**0.81**	***0.91***	***0.89***

The physico-chemical scores for pH were very good (1.00) in all zones (Table 3.4). In contrast, the scores for turbidity ranged from poor to very good, with the majority of zones being ranked satisfactory or above. Only Auckland Inlet had a poor score. The harbour score for the physico-chemical sub-indicator was 0.83 (B).

Like all preceding report cards, nutrients received the lowest score of 0.61 (C) amongst the water quality sub-indicators. Nutrient scores were lower at the majority of zones for all three sub-indicators. However, all 13 zones had a satisfactory or above overall nutrient score (Table 3.3). The Outer Harbour had the highest nutrient score (0.70, B) while The Narrows, Colosseum Inlet and Rodds Bay had the lowest nutrient scores (0.51, C). At the measure level, total phosphorous received the highest scores, total nitrogen received the lowest scores, and chlorophyll-a scores were more variable ranging from 0.32 (D) to 0.72 (B) (Table 3.4).

All zones had consistently very good scores (0.95–1.00, A) for dissolved metals (Table 3.3). The same was true at the measure level as all six metals received very good scores (0.85–1.00, A) across the 13 zones (Table 3.4).

Table 3.4: Scores for water quality measures for each of the 13 zones in the 2022 Gladstone Harbour Report Card.

Zone	Physicochemical		Nutrients			Dissolved metals					
	pH	Turbidity	TN	TP	Chl-*a*	Al	Cu	Pb	Mn	Ni	Zn
1. The Narrows	1.00	0.58	0.52	0.63	0.37	1.00	1.00	1.00	1.00	1.00	1.00
2. Graham Creek	1.00	0.88	0.58	0.94	0.35	1.00	0.97	1.00	1.00	1.00	1.00
3. Western Basin	1.00	0.53	0.50	0.68	0.50	1.00	0.94	1.00	1.00	1.00	1.00
4. Boat Creek	1.00	0.65	0.41	0.55	0.66	1.00	0.90	1.00	1.00	1.00	1.00
5. Inner Harbour	1.00	0.69	0.56	0.95	0.51	1.00	0.98	1.00	1.00	1.00	1.00
6. Calliope Estuary	1.00	0.51	0.53	0.79	0.72	1.00	0.99	1.00	1.00	1.00	1.00
7. Auckland Inlet	1.00	0.49	0.50	0.70	0.72	1.00	0.85	1.00	0.87	1.00	0.99
8. Mid Harbour	1.00	0.62	0.56	0.89	0.64	1.00	1.00	1.00	1.00	1.00	1.00
9. South Trees Inlet	1.00	0.61	0.53	0.77	0.41	1.00	0.98	1.00	1.00	1.00	1.00
10. Boyne Estuary	1.00	0.83	0.46	1.00	0.56	1.00	1.00	1.00	1.00	1.00	1.00
11. Outer Harbour	1.00	0.91	0.55	0.98	0.56	1.00	1.00	1.00	1.00	1.00	1.00
12. Colosseum Inlet	1.00	0.82	0.35	0.74	0.43	1.00	1.00	1.00	1.00	1.00	1.00
13. Rodds Bay	1.00	0.54	0.45	0.77	0.32	1.00	1.00	1.00	1.00	1.00	1.00
Harbour score	**1.00**	**0.67**	**0.50**	**0.80**	**0.52**	**1.00**	**0.97**	**1.00**	**0.99**	**1.00**	**1.00**

TN – total nitrogen; TP – total phosphorous; Chl-*a* – chlorophyll-*a*; Al – aluminium; Cu – copper; Pb – lead; Mn – manganese; Ni – nickel; Zn - zinc

3.1.3.2. Sediment quality

The overall sediment quality scores were derived from one sub-indicator—metals and metalloid. Six metals (cadmium, copper, lead, mercury, nickel and zinc) and the metalloid arsenic were assessed. The harbour score for sediment quality was 0.96 (A)—identical to the previous year and similar to preceding years (0.95–0.99, A).

Zone scores for sediment quality were all very good, ranging from 0.89 (A) in Boat Creek to 1.00 (A) in Outer Harbour and Rodds Bay (Table 3.5). This was a result of low concentrations of all measures (arsenic, cadmium, copper, lead, mercury, nickel and zinc) (Table 3.6). While zone scores were uniformly very good for most measures, there were a number of good or satisfactory scores for sediment arsenic and nickel.

Table 3.5: Sediment quality indicator scores for the 2022 Gladstone Harbour Report Card. Scores for 2021 and 2020 are shown for comparison.

Zone	Metals and metalloid score	Zone score 2022	*Zone score 2021*	*Zone score 2020*
1. The Narrows	0.94	0.94	*0.92*	*0.91*
2. Graham Creek	0.97	0.97	*0.95*	*0.90*
3. Western Basin	0.98	0.98	*0.99*	*0.98*
4. Boat Creek	0.89	0.89	*0.92*	*0.89*
5. Inner Harbour	0.94	0.94	*0.94*	*0.93*
6. Calliope Estuary	0.97	0.97	*0.95*	*0.95*
7. Auckland Inlet	0.95	0.95	*0.93*	*0.95*
8. Mid Harbour	0.98	0.98	*0.96*	*0.97*
9. South Trees Inlet	0.97	0.97	*0.97*	*0.96*
10. Boyne Estuary	0.99	0.99	*0.99*	*1.00*
11. Outer Harbour	1.00	1.00	*0.98*	*0.99*
12. Colosseum Inlet	0.96	0.96	*1.00*	*0.97*
13. Rodds Bay	1.00	1.00	*0.98*	*0.96*
Harbour score	**0.96**	**0.96**	***0.96***	***0.95***

Table 3.6: Scores for sediment quality measures for each of the 13 zones in the 2022 Gladstone Harbour Report Card.

Zone	Metals and metalloid						
	Arsenic	Cadmium	Copper	Mercury	Lead	Nickel	Zinc
1. The Narrows	0.88	1.00	1.00	1.00	1.00	0.70	1.00
2. Graham Creek	0.93	1.00	1.00	1.00	1.00	0.85	1.00
3. Western Basin	0.94	1.00	1.00	1.00	1.00	0.95	1.00
4. Boat Creek	0.73	1.00	0.94	1.00	1.00	0.58	1.00
5. Inner Harbour	0.59	1.00	1.00	1.00	1.00	0.99	1.00
6. Calliope Estuary	0.94	1.00	1.00	1.00	1.00	0.85	1.00
7. Auckland Inlet	0.86	1.00	0.94	1.00	1.00	0.83	1.00
8. Mid Harbour	0.85	1.00	1.00	1.00	1.00	1.00	1.00
9. South Trees Inlet	0.87	1.00	1.00	1.00	1.00	0.93	1.00
10. Boyne Estuary	0.93	1.00	1.00	1.00	1.00	1.00	1.00
11. Outer Harbour	0.97	1.00	1.00	1.00	1.00	1.00	1.00
12. Colosseum Inlet	0.75	1.00	1.00	1.00	1.00	1.00	1.00
13. Rodds Bay	0.98	1.00	1.00	1.00	1.00	1.00	1.00
Harbour score	**0.86**	**1.00**	**0.99**	**1.00**	**1.00**	**0.90**	**1.00**

3.1.4. Water and sediment quality conclusions

Scores for the water quality indicator have remained high since the first full report card in 2015—receiving a good grade (B) from 2015 to 2019, a very good grade (A) from 2020 to 2021 and a good grade (B) in the current report card year (Figure 3.1). In 2022, water quality was relatively consistent across the harbour, with most zones receiving good scores and three receiving very good scores overall. Compared to the previous year, scores for the physicochemical and nutrient group were lower at all 13 zones. Dissolved metals scores were very good for the eighth consecutive year. Despite lower scores for both turbidity and nutrients, the overall water quality score (0.81, B) was the third highest observed since GHHP reporting began.

The nutrient sub-indicator maintained the lowest score of the three sub-indicators for the eighth consecutive year. Although nutrient sources are difficult to define, catchment run-off is a major source of nutrients in estuarine waters such as Gladstone Harbour (Hale & Box, 2014). The level of nutrients entering the harbour can also be influenced by land use (agricultural, industrial, urban, etc.), discharge from portside industries 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 within Gladstone Harbour.

Lower nutrient and turbidity scores as compared to 2021 may have resulted from the slightly higher-than-average rainfall and discharge from the Boyne and Calliope rivers, particularly at the end of 2021 and in May 2022 (Figures 8.3, 8.5 & 8.7).

As in previous years, the Outer Harbour received the highest nutrient, physico-chemical (turbidity) and overall zone score for the sixth consecutive year. These results indicate that the more ocean-influenced zones (such as Outer Harbour) have lower nutrient concentrations relevant to respective WQOs and improved water clarity compared to other zones. The small and shallow nature of several of the estuarine zones, which are more prone to the resuspension of sediments owing to wind and tidal movement, likely influences the higher nutrient concentrations and turbidity values exhibited at more freshwater-influenced zones.

For additional information on the water and sediment quality indicators of Gladstone Harbour, can be found the 2018 and 2019 reports (Schultz et al., 2019; Hansler et al., 2020). These technical reports provide greater detail on potential factors affecting water quality, data quality assurance and quality control and other comparison techniques used to elucidate trends in the water and sediment quality of Gladstone Harbour.

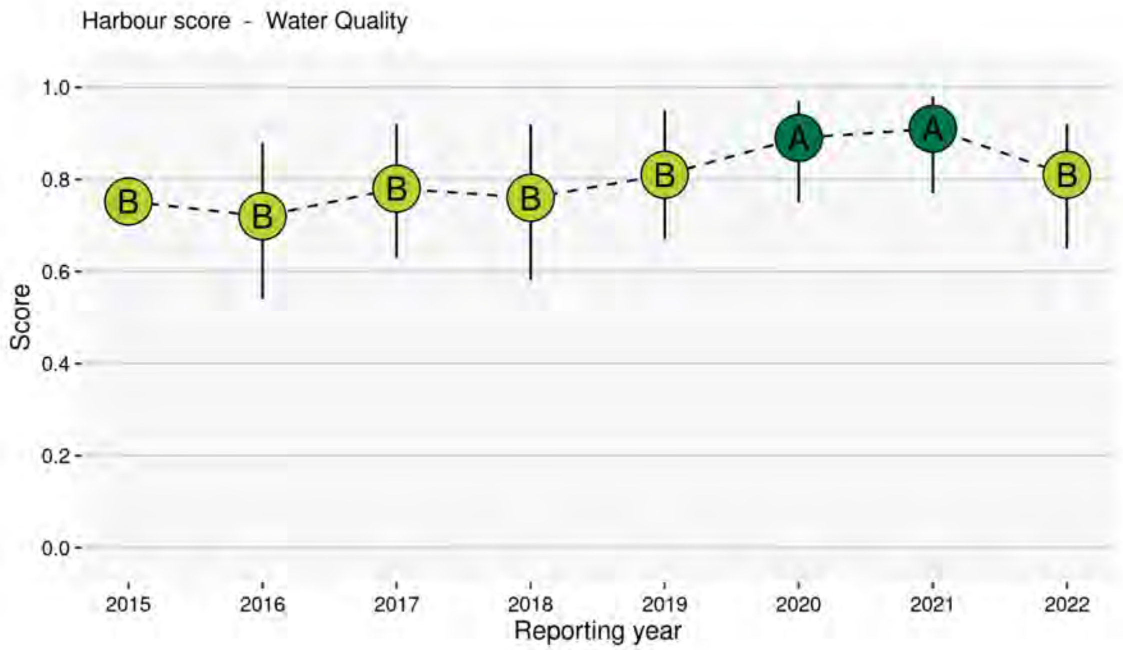


Figure 3.1: Trends in the harbour score for water quality, 2015–2022 (Error bars show 95% bootstrap confidence intervals).

Sediment quality scores were uniformly very good across all Gladstone Harbour reporting zones as they have been in all previous report cards (Figure 3.2). This is a result of low concentrations of all measures (arsenic, cadmium, copper, lead, nickel and zinc).

As in previous years, zone scores for arsenic and nickel were occasionally good or satisfactory. The lowest score for an individual measure was for arsenic, which received the only good score. Angel et al. (2012) showed that particulate arsenic concentrations exceeded the ANZECC/ARMCANZ ISQG[1]-low trigger value in two samples from The Narrows and one sample near Quoin Island. They noted that the source of this arsenic was natural (geological formation on the area) and not associated with anthropogenic inputs. Similarly, it has been suggested that The Narrows is a source of dissolved nickel, as dissolved nickel concentrations in water increase with proximity to the Narrows (Angel et al., 2010; Angel et al., 2012). The same general pattern was evidenced in sediment nickel scores in the current and previous Gladstone Harbour report cards, further implying a natural source of nickel.

[1] ISQG refers to the Interim Sediment Quality Guideline. For sediment arsenic and cadmium this guideline is used in the report card.

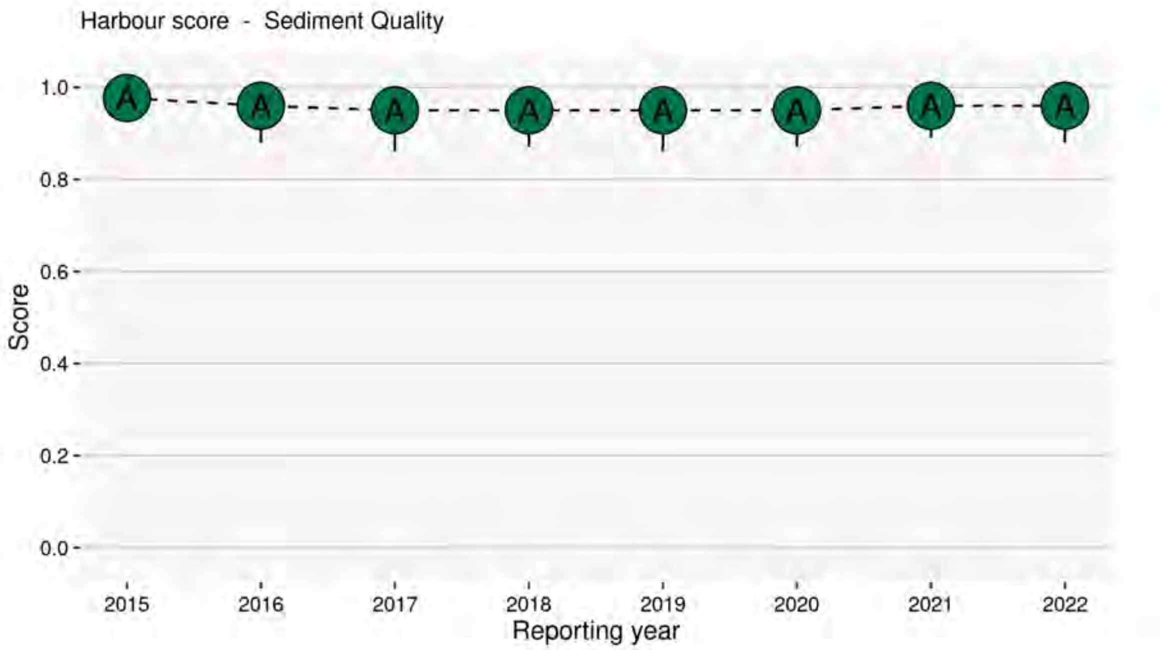


Figure 3.2: Trends in the harbour score for sediment quality, 2015–2022 (Error bars show 95% bootstrap confidence intervals).

3.2. Habitats

3.2.1. *Seagrass*

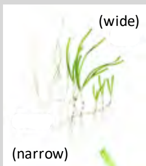
> **What is seagrass?**
>
> Seagrasses are the only flowering plants that can live entirely submerged in seawater. These unique, aquatic plants grow in sediment on the seafloor with erect elongate or oval leaves and a buried rhizome and root structure. Seagrasses are widely distributed along the coastlines of the world and provide a range of important functions within the marine ecosystem. There are four families of seagrass worldwide, three of which are commonly found in Gladstone Harbour. The seagrass indicators in the report card are based on five species of seagrass:
>
> *Zostera muelleri* ssp. *capricorni*
> *Halophila ovalis*
> *Halophila decipiens*
> *Halophila spinulosa*
> *Halodule uninervis* (wide and narrow leaf)

Zostera muelleri ssp. *capricorni*

Halophila ovalis

Halophila decipiens

Halophila spinulosa



Halodule uninervis

Seagrass meadows are one of the most important habitat types in 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 12,000 ha (Davies et al., 2016). This area includes intertidal, shallow subtidal and deep-water habitats. Seagrasses 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, including sediment stabilisation, nutrient cycling and carbon sequestration (Figure 3.3). They also provide nursery areas for juvenile fishes and foraging areas for dugongs, turtles and large fish such as 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 seagrass growth and the size and extent of 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 may be associated with flooding, large tidal movements or dredging. 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). While a number of factors can negatively impact seagrass growth, McCormack et al. (2013) indicated environmental conditions are key influences on seagrass meadow condition in Gladstone Harbour.

Information in the following sections is drawn from a seagrass monitoring project that commenced in 2002 (Smith et al., 2022a; Smith et al., 2022b), and funded by the Gladstone Ports Corporation Ltd. Nearly two decades of monitoring and research has provided insight into potential causes and trends with regard to changes in the seagrass meadows of Gladstone Harbour.

3.2.2. 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 estimate the seagrass scores. In 2002, Gladstone Ports Corporation 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 10.2, 10.6, 10.10, 10.16, 10.18 and 10.26). 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.

Three sub-indicators of seagrass health were measured to calculate the seagrass scores for the Gladstone Harbour 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 within a monitoring meadow

Why species composition is important

Figure 3.3: Seagrasses at low tide.

Fisheries habitat: Fish display a distinct preference for particular species of seagrass. A shift in species composition can lead to a change in the abundance and diversity of fishes.

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 can recover more rapidly following disturbances.

Biomass and species composition

Above-ground biomass was estimated using visual estimates. At each site, 0.25 m^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 ($gDWm^{-2}$) for each of the replicate quadrats at a site.

Area

The area of the monitored seagrass meadows was determined with ArcGIS 10.8®. For each meadow a mapping precision estimate ranging from ≤5 m to 50-200m was developed based on the mapping methodology (Table 3.7). Spatial data from the survey were entered into the Gladstone Harbour GIS as seagrass meadow layers.

Table 3.7: Mapping precision and mapping methodology for seagrass meadows for seagrass surveys conducted in November 2021 (Source: Smith et al., 2022b).

Mapping precision	Mapping method
<5 m	Meadow boundaries mapped 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.
10-20 m	Meadow boundaries determined from helicopter and boat surveys, Intertidal boundaries interpreted from helicopter mapping and survey sites, Recent aerial photography aided in mapping, Subtidal boundaries interpreted from survey sites, Moderately high density of mapping and survey sites.
20-50 m	Meadow boundaries determined from helicopter and boat surveys, Intertidal boundaries interpreted from helicopter mapping and survey sites, Subtidal boundaries interpreted from boat survey sites, Lower density of survey sites for some sections of boundary.
50-200 m	Meadow boundaries determined from boat surveys, Subtidal meadows interpreted from survey sites, Lower density of survey sites for meadow boundary.

3.2.3. Development of seagrass indicators and scoring

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

To estimate 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.

Threshold ranges were developed for the meadow types for the sub-indicator's biomass, area and species composition (Table 3.8). Scores for each sub-indicator were based on these thresholds and a score between 0.00 and 1.00 was calculated to fit the GHHP grade range (Carter et al., 2015).

Between 2015 and 2017, the overall score for each monitoring meadow was defined as the lowest score received for each of the three indicators. The lowest score, rather than the mean of the three indicator scores, was applied because a poor score for any one of the three indicators described a seagrass meadow in poor condition. A review in 2018 of how meadow scores were calculated led to a change in 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 species composition score of zero despite having very good and good biomass and area scores, respectively. 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 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.

Note, 2022 scores may differ slightly to those reported by Smith et al. (2022b) due to bootstrapping used to calculate GHHP report card scores. 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.

Table 3.8: Threshold values between grades A to E varied for the seagrass meadow types for each of the three seagrass sub-indicators (biomass, area and species composition). Each grade was determined by the percentage difference from a baseline of the 10-year mean (Source: Smith et al., 2022b).

Seagrass condition indicators/ Meadow class		Seagrass grade				
		A Very Good	B Good	C Satisfactory	D Poor	E Very Poor
Biomass	Stable	>20% above	20% above–20% below	20–50% below	50–80% below	>80% below
	Variable	>40% above	40% above–40% below	40–70% below	70–90% below	>90% below
Area	Highly stable	>5% above	5% above–10% below	10–20% below	20–40% below	>40% below
	Stable	>10% above	10% above–10% below	10–30% below	30–50% below	>50% below
	Variable	>20% above	20% above–20% below	20–50% below	50–80% below	>80% below
	Highly variable	>40% above	40% above–40% below	40–70% below	70–90% below	>90% below
Species composition	Stable and variable; Single species dominated	>0% above	0–20% below	20–50% below	50–80% below	>80% below
	Stable; Mixed species	>20% above	20% above–20% below	20–50% below	50–80% below	>80% below
	Variable; Mixed species	>20% above	20% above–40% below	40–70% below	70–90% below	>90% below

3.2.4. Seagrass results

The overall score in the 2022 reporting year was 0.70 (B), indicating a good overall condition for seagrass. This is the third year of good condition, a marked improvement from the overall poor condition observed from 2015 to 2018. At the zone level, condition scores were good or above at four of the six zones. While Inner Harbour and Rodds Bay were in poor condition, both zone level scores were the result of poor scores from a single meadow. Overall, 12 of the 14 monitored meadows were in satisfactory, good or very good condition (Table 3.9).

Table 3.9: Seagrass scores for the 2022 Gladstone Harbour Report Card. Scores from 2021 and 2020 are shown for comparison. Note, 2022 scores may differ slightly to those reported by Smith et al. (2022b) due to bootstrapping used to calculate GHHP report card scores (see Logan, 2016).

Zone	Meadow	Biomass	Area	Species composition	Overall meadow	2022	*2021*	*2020**
1. The Narrows	21	0.94	0.98	0.98	0.94	0.94	*0.84*	*0.80*
3. Western Basin	4	1.00	1.00	0.93	0.98	0.82	*0.75*	*0.81*
	5	0.93	1.00	0.86	0.89			
	6	0.89	0.93	0.74	0.81			
	7	0.61	0.77	1.00	0.61			
	8	0.92	0.73	0.77	0.73			
	52–57	0.87	0.99	1.00	0.87			
5. Inner Harbour	58	0.77	0.89	0.00	0.39	0.39	*0.59*	*0.70*
8. Mid Harbour	43	0.54	0.81	0.78	0.54	0.67	*0.48*	*0.44*
	48	0.85	0.80	0.89	0.80			
9. South Trees Inlet	60	1.00	1.00	0.99	1.00	1.00	*0.97*	*0.99*
13. Rodds Bay	94	0.38	0.17	0.00	0.09	0.42	*0.70*	*0.87*
	96	0.65	1.00	1.00	0.65			
	104	0.53	0.57	0.88	0.53			
Harbour score						0.70	*0.72*	*0.77*

*Note, 2020 scores shown were corrected for an error in biomass calculation and differ from the scores previously reported on. Refer to 2020 Seagrass Report or 2020 Technical Report for further detail.

Zone 1 – The Narrows

The Narrows has one monitored meadow at Black Swan Island, an intertidal meadow with variable biomass. The overall score for this meadow was very good (0.94, B), receiving the highest score since GHHP monitoring began. All three sub-indicators showed very good scores: demonstrating the highest meadow biomass since 2010 (~17.5 $gDWm^{-2}$), a very good meadow area (for the fourth consecutive year) and a high presence of the historically dominant species, *Zostera muelleri*.

Zone 3 – Western Basin

Western Basin contains six monitored seagrass meadows, five of which are intertidal and one subtidal (Meadow 7). In 2022, this zone was in good condition (0.82, B) for the fourth consecutive year. All seagrass meadows were in satisfactory or better condition—with one meadow scored as satisfactory, two meadows scored as good, and three meadows scored as very good. This resulted in the highest overall zone score since GHHP monitoring began.

Sub-indicator scores at the six meadows were mostly very good. Biomass scores were very good (0.87–1.00, A) at five of the meadows, with Meadow 7 receiving a satisfactory score (0.61, C). Area and species composition sub-indicators also received good or better scores. For the area sub-indicator, four meadows received very good scores (0.93–1.00, A) and two meadows received good scores

(0.73–0.77, B). Similarly for the species composition sub-indicator, four meadows received very good scores (0.86–1.00, A) and two meadows received good scores (0.74–0.77, B).

Zone 5 – Inner Harbour

Inner Harbour has one monitored meadow in the south-east corner of the zone near South Trees Inlet. In 2022 the Inner Harbour was in poor condition (0.39, C)—a continued decline since the Meadow 58 score peaked at 0.70 (B) in 2020. The continued decrease in zone/meadow score was the result of changes in the meadow species composition with no persistent *Z. muelleri* recorded in the meadow in 2022. Conversely, meadow area was very good (0.89, A) and meadow biomass was good (0.77, B).

Zone 8 – Mid Harbour

Mid Harbour has two monitored meadows adjacent to the south-east corner of Curtis Island. Meadow 43, known locally as Pelican Banks, is the largest (baseline = 632 ha) and most productive (baseline = 19 $gDWm^{-2}$) seagrass meadow assessed for the report card. It is also the only meadow where all three indicators are classed as stable or highly stable. Pelican Banks is an intertidal meadow while Meadow 48 is a subtidal meadow neighbouring the eastern side of Quoin Island.

Overall condition of the Mid Harbour seagrass was good (0.67, B) for the first time since GHHP began utilising Gladstone Ports Corporation monitoring data in 2015. This was driven by improvements in both meadows. Meadow 48 received good score (0.80, B) for the first time since 2008. The change was driven by a marked improvement in biomass from the previous year, with area showing a slight improvement and species composition remaining very good. Pelican Banks also showed an improved condition compared to previous years, receiving an overall satisfactory score (0.54, C) after six years of poor or very poor condition. Notable improvements in biomass and species composition was responsible for this positive result compared to the previous year.

Zone 9 – South Trees Inlet

This zone has one monitored meadow which sits off the northern tip of South Trees Island. Meadow 60 is an intertidal meadow and the second smallest of the monitored meadows. The overall condition of this meadow was very good (1.00, A), with all three sub-indicators in very good condition for the fifth consecutive year. This marks the sixth year of improved seagrass condition from the poor condition (0.48, D) in 2016. Both meadow biomass and area received the highest possible scores (1.00, A) with species composition also receiving a very good score (0.99, A).

Zone 13 – Rodds Bay

There are three intertidal monitoring meadows in Rodds Bay—Meadows 94, 96 and 104. The overall condition of this zone was poor (0.42, D) in 2022. This was a continued decrease from the peak score in 2020 (0.87, A) when Rodds Bay received the best overall condition score of the past decade. Results were caused by a marked decline in scores at Meadow 94. In 2022, there was a large decline in seagrass area, biomass and species composition resulting in a very poor score at Meadow 94. The remaining two meadows within Rodds Bay received the same grade as the previous year. However, the overall score at Meadow 96 also decreased (0.65 in 2022, 0.75 in 2021) which further contributed to the overall poor score (0.42, D) at Rodds Bay.

3.2.5. Seagrass conclusions

The overall condition of monitored seagrass meadows in Gladstone Harbour was good in 2022 for the third consecutive year. This is the first time that seagrass has maintained good condition over three consecutive years since widespread losses due to flooding in 2009 and 2010. Overall, 12 of the 14 monitored meadows were in satisfactory, good or very good condition.

Environmental conditions such as rainfall and Calliope River discharge are key influences on the seagrass meadow condition of Gladstone Harbour (McCormack et al., 2013). For the past four reporting years there has been below average rainfall and river flow (Figures 5.3 to 5.8; GHHP, 2019; GHHP, 2020; GHHP, 2021). Flow from the Calliope River over the past four years has been below average, and outflow was very low again during the 2021 wet season. Note, seagrass sampling occurs in November (i.e., before higher-than-average rainfall starting in November 2021 would have had a strong influence on seagrass condition). Dry, benign weather conditions cause an increase in benthic light, which has created ideal conditions for seagrass growth in Gladstone Harbour. Reduced daytime tidal exposure this reporting year likely provided further protection from desiccation and thermal stress for the region’s intertidal seagrasses (e.g., Unsworth et al. 2012 as cited in Smith et al., 2022b). There has been a general trend in improvement in seagrass meadows along Queensland’s east cost between Cairns and Port Curtis since widespread losses in 2009 and 2010 (Smith et al., 2022b). However, recovery has varied by location, local climate events and the severity of the initial seagrass losses. In context with the state, Gladstone Harbour zones had one of the better outcomes for seagrass condition in the 2022 reporting year (Smith et al., 2022b).

There was a general improvement in meadow condition with nine of the 14 meadows showing an improved score compared to the previous year. Five meadows showed a marked improvement in score, which included Meadow 21 (The Narrows), Meadows 8 and 52-57 (Western Basin) and Meadows 43 and 48 (Mid Harbour). These improvements were mostly the result of increases in biomass and improved species composition. This was particularly evident at the largest seagrass meadow in Port Curtis, Pelican Banks located in the Mid Harbour, which improved to be in satisfactory condition after six years in poor or very poor condition.

The exceptions to recovery in Gladstone Harbour were seen in the Inner Harbour’s single meadow as a result of poor species composition and in Rodds Bay where there were large declines in area and biomass of a single meadow (Meadow 94). Meadow 94 declined from a good condition in the previous year to a very poor condition for the 2022 reporting year. Ongoing monitoring is required to determine if low biomass and area of Meadow 98 is permanent, or it recovers rapidly as in previous years.

Seagrass meadows in Gladstone Harbour started 2022 with a high level of resilience to external pressures, both natural and anthropogenic. Meadows in the harbour are likely to have preserved and replenished their seedbanks, further strengthening their resilience and recovery capacities. Continuing high levels of resilience mean seagrasses should be well placed to cope with large rainfall events recorded in March and May of 2022 that may cause low light conditions detrimental to seagrass health.

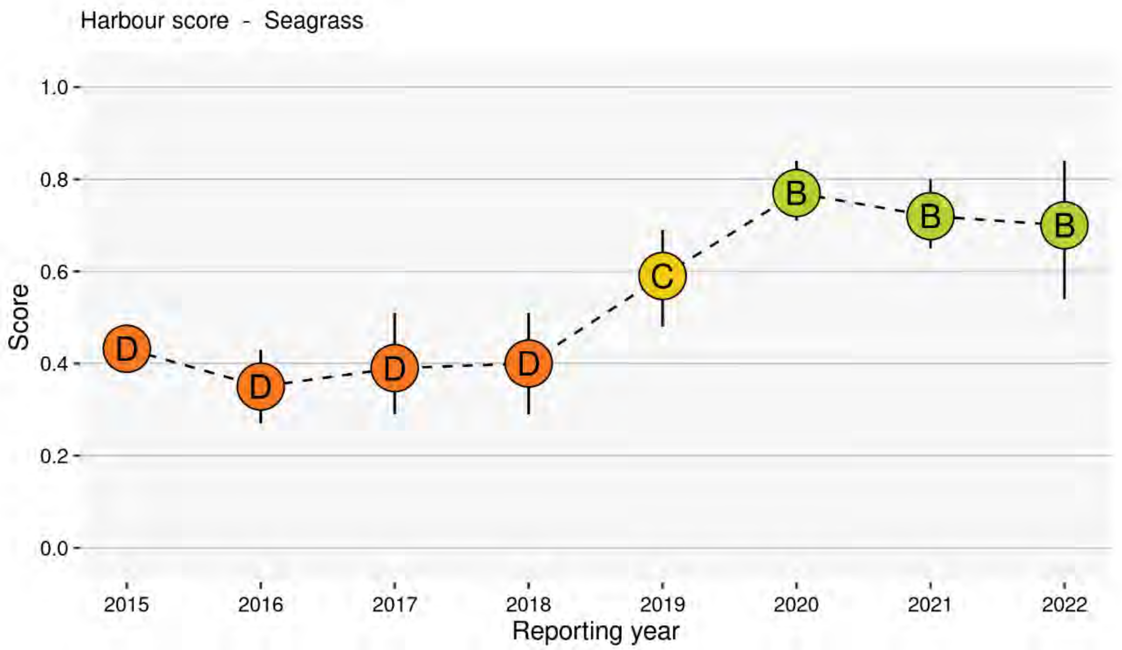


Figure 3.4: Trends in the harbour score for seagrass, 2015 – 2022 (Error bars show 95% bootstrap confidence intervals). Note, the 2020 score was corrected for an error in biomass calculation and differs from the score previously reported on. Refer to 2020 Seagrass Report or 2020 Technical Report for further detail.

Table 3.10: Grades for individual seagrass monitoring meadows from annual (November) surveys, 2002–2022 (Source: Carter et al., 2023). Note, report card and monitoring years differ (e.g., 2022 Report Card = Nov. 2021 monitoring). Grades from monitoring in 2019–2021 were added separately for comparison.

Zone	Meadow	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
1. The Narrows	21								A	B	B	C	E	D	D	C	D	B	B	B	A
3. Western Basin	4	B		C	D	B	A	B	A	E	D	B	D	D	C	B	D	C	A	A	A
	5	C		D	C	B	B	A	C	D	D	C	E	D	D	C	C	C	A	B	A
	6	B		D	C	B	A	B	A	E	D	D	D	B	B	B	D	C	B	B	B
	7	B		B	E	A	D	B	D	E	E	E	D	B	B	D	E	A	B	C	C
	8	A		D	E	B	B	B	B	C	E	D	E	D	D	E	D	D	B	C	B
	52-57*								C	E	E	B	B	C	D	B	B	A	B	B	A
5. Inner Harbour	58	B		D	B	D	B	B	B	E	D	C	E	D	D	D	E	E	B	C	D
8. Mid Harbour	43	B		B	B	C	C	A	B	B	C	C	C	C	D	E	D	D	D	D	C
	48	B		C	B	B	A	B	E	D	D	D	C	D	D	C	C	C	C	C	B
9. South Trees	60	A		E	E	B	A	A	C	E	E	C	E	C	D	B	A	A	A	A	A
13. Rodds Bay	94	A		D	A	B	A	A	E	E	E	E	E	D	E	E	E	C	A	B	E
	96	B		D	C	B	A	A	B	D	E	D	E	D	D	D	E	B	A	B	B
	104	B		D	B	B	B	A	C	E	E	E	E	C	D	E	E	D	A	C	C

3.2.6. 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, 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 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 (>5 m) 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 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 2022 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}): the density of juvenile corals observed at the monitored reefs
4. Change in hard coral cover (%): averaged over a three-year period to give the rate at which hard coral cover increases or decreases.

3.2.7. Coral data collection

Establishment of long-term monitoring sites

Coral surveys in 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 Island, Farmers Reef, Facing Island and Manning Reef and two permanent sites were established in the Outer Harbour at Seal Rocks North and Seal Rocks South (Figures 10.16 and 10.22).

Coral monitoring

Coral monitoring was conducted on 5–6 May 2022 and included the following three methodologies:

1. Photo point intercept transects

The methodology outlined below closely follows that outlined in the Australian Institute of Marine Science Long-term Monitoring Program (Jonker et al., 2008). At each 20 m transect, digital photographs were taken at 50 cm 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.

2. Juvenile corals

Juvenile coral colonies, up to 5 cm in diameter were counted within a 34 cm band along each permanently marked transect. Each colony was identified to genus and assigned to a size class of 0–2 cm or 2–5 cm. 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.

3. 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 two-metre belt centred on the transect tape. These data are not used in the calculation of report card scores. In the long term, however, they may be valuable for explaining changes in coral condition.

3.2.8. Development of coral sub-indicators and scoring

Each of the four coral sub-indicators was scored against a baseline based on expert opinion and data from the Marine Monitoring Program (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 3.11 and Figure 3.5). The lowest score of 0.00 was set to represent the worst condition that could be expected in the local environment (Table 3.11 and Figure 3.5). 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, which increases the potential of other reefs in the vicinity to recover from disturbance. High coral cover also contributes to the structural complexity of a reef and increases its biodiversity by providing habitat for fishes 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 3.11). This figure is 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 3.7 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 subsequent changes to the thresholds and bounds for coral cover in the MMP (Thompson et al., 2016) mean that these thresholds are no longer consistent with the Gladstone Harbour Report Card.

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 D/C threshold (the point where the grade changes from passing to failing) for coral communities in Gladstone Harbour (Table 3.11).

Owing to changes in the calculation of macroalgae scores in the MMP, including the use of reef-specific water quality conditions (Thompson et al., 2016), 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 & Steneck, 2008) will also negatively impact the number of juvenile colonies observed. Hence juvenile coral density can provide an indication of a reef's potential for recovery from disturbance given the current conditions.

Prior to 2018, coral in three size classes (0–2 cm, >2–5 cm and >5–10 cm) were identified to the genus level and recorded. In 2018, the >5–10 cm class was discontinued to realign the methodology with that used in the MMP (Thompson et al., 2016). This method was adopted by the MMP because limiting observations to the 0–5 cm 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 2 m 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 3.11).

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., 2016).

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 MMP 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 twice the upper 95% confidence interval of the change predicted. Observations falling within the upper and lower confidence intervals of the change in predicted cover were scored as neutral (sub-indicator score 0.5) and those below twice the lower confidence interval of the predicted change received a 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., 2016).

Table 3.11: 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%†	0%
Macroalgal cover	14%	5%	20%
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

†Reduced from 100% as coral cover rarely attains 100% coverage due to areas of colonisable substrate and variable population dynamics.

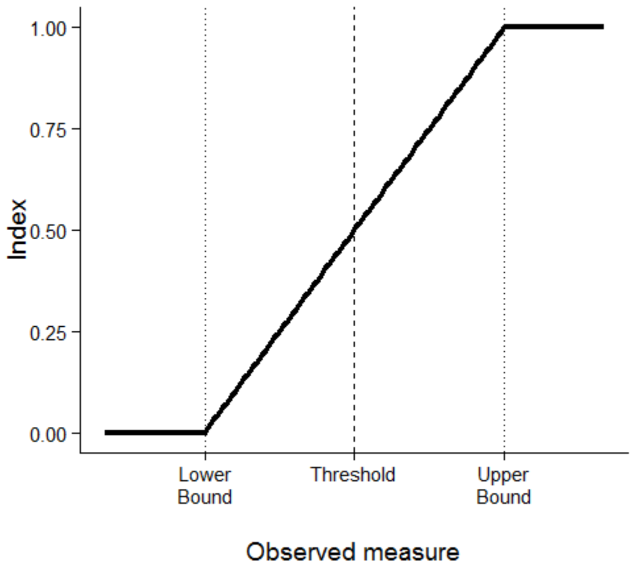


Figure 3.5: Generic scoring of the coral sub-indicators based on the threshold and bounds outlined in Table 3.11.

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 overall harbour indicator score was calculated as the mean of the harbour sub-indicator scores.

3.2.9. Coral results

The overall grade for the 2022 report card was an E (0.15) for the fifth consecutive year. This was a result of a low cover of living coral, high macroalgal cover, low abundance of juvenile corals, and a poor score for change in hard coral cover at most of the surveyed reefs. Score changes at the sub-indicator level were minor between 2021 and 2022, with all four sub-indicators scores within ±0.04 of the previous year. There have been no grade changes in at the sub-indicator level since 2019. Both the Mid Harbour and the Outer Harbour demonstrated very poor coral condition for the fourth consecutive year, receiving scores of 0.13 and 0.18 (E) respectively (Table 3.12). In comparison with 2021 scores, the overall score of the Mid Harbour was marginally lower while the Outer Harbour improved.

Coral cover (%) was very low at all reefs and substantially lower than the 40% threshold required to receive a grade of C (Table 3.13). Scuba surveys indicated that the bio-eroding sponge *Cliona orientalis* continues to impact the coral community across the Harbour and in particular colonies of *Turbinaria* at Seal Rocks South and *Porites* at Facing Island. Although minor fluctuations in scores have occurred since GHHP monitoring began in 2015, both zones had very poor coral cover scores for the eighth consecutive year (Table 3.14). The general exception to this was demonstrated at Seal Rocks South, where coral cover has steadily increased since 2018. However, the present cover in both the Mid and Outer Harbour remains considerably lower than those reported in previous surveys. In 2009, a mean cover of 39% was recorded for hard corals in the Mid Harbour (BMT WBM, 2013). Although this figure accounted for 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).

Despite a very poor macroalgal cover condition (0.00, E) at five of the surveyed reefs and poor condition (0.29, D) at Farmers Reef (Table 3.13), the mean cover of macroalgae decreased slightly relative to 2021 levels. As with coral cover, this sub-indicator was graded E for the eighth consecutive year. Macroalgae communities are more variable at reefs in the Mid Harbour zone, where cover and composition vary both from year to year within individual reefs but also between reefs. In 2022, communities at the four reefs were dominated by the red macroalgae *Asparagopsis* or the brown macroalgae *Sargassum*. In contrast, community composition at the two Outer Harbour reefs was stable, with communities consistently dominated by the two brown macroalgae genera, *Sargassum* and *Lobophora*.

The size for juvenile corals can indicate their age as corals spawn annually. Juvenile coral colonies in the 0–2 cm range can broadly be considered a result of the previous spawning event. Juvenile coral colonies in the 2–5 cm range are estimated to be between one and two years old. The harbour-wide mean density of juvenile corals has continued to decline, receiving a very poor score (0.12, E) for the fourth consecutive year (Table 3.12). Scores for juvenile coral density were predominantly very poor at the reef level, with only Farmers Reef receiving a poor score (0.27, D)—an identical result to 2019 and 2020. Of note was the continued and overall lack of the fast-growing, branching corals of the family Acroporidae across the harbour. Though the limited presence of *Acropora* juveniles within the harbour, particularly at the two Seal Rocks reefs, remains a promising sign.

The overall change in hard coral cover score remained poor (0.37, D) and increased marginally from the 2021 score (0.34, D). This result was due to improvements in coral cover in the Outer Harbour. In contrast, reef scores in the Mid Harbour declined. In general, the ongoing 'poor' score demonstrates that recovery of coral communities continues to fall short of modelled expectations. Note, the presence of bleached corals at Outer Harbour reefs in 2020 meant that changes in hard coral cover between 2019 and 2020 did not inform on the sub-indicator scores at those reefs. This also impacted the 2022 change in hard coral cover sub-indicator as the score is calculated over a three-year period. It is equally important to note that acute pressures have not been observed (e.g., flood, cyclone) over the past three years and thus, coral cover should be in a state of recovery.

Table 3.12: Coral indicator scores for the 2022 Gladstone Harbour Report Card. Scores from 2021 and 2020 are shown for comparison.

Zone	Coral cover	Macroalgal cover	Juvenile density	Change in hard coral cover	2022	*2021*	*2020**
8. Mid Harbour	0.06	0.07	0.13	0.26	0.13	*0.16*	*0.20*
11. Outer Harbour	0.12	0.00	0.11	0.48	0.18	*0.12*	*0.14*
Harbour score	**0.09**	**0.04**	**0.12**	**0.37**	**0.15**	***0.14***	***0.17***

*Note, 2020 scores shown were corrected for an error in change in hard cord cover calculation and differ from the scores previously reported on. Refer to 2020 Coral Report or 2020 Technical Report for further detail.

Table 3.13: Individual coral sub-indicator values and scores by reef.

Zone/Reef	Coral cover		Macroalgal cover		Juvenile density		Change in hard coral cover	
	Value (%)	Score	Value (%)	Score	Value (m^{-2})	Score	Value (%)	Score
8. Mid Harbour								
Facing Island	5.28	0.07	65.97	0.00	0.56	0.06	-2.97	0.00
Farmers Reef	3.63	0.05	16.53	0.29	2.53	0.27	1.12	0.55
Manning Reef	1.50	0.02	44.75	0.00	0.94	0.10	0.13	0.24
Rat Island	10.38	0.13	28.75	0.00	0.67	0.07	-1.75	0.24
11. Outer Harbour								
Seal Rocks North	3.50	0.04	54.44	0.00	0.93	0.10	2.36	0.50
Seal Rocks South	16.13	0.20	41.88	0.00	1.08	0.12	2.12	0.47

3.2.10. Coral conclusions

The overall score for corals was very poor (0.15, E) in 2022 (Figure 3.6; Table 3.12). Recent results demonstrate a further decline in the condition of coral communities since the poor condition (0.27, D) evidenced in 2017. Ongoing monitoring since 2015 further reinforces a lack of recovery since the severe loss of coral evidenced pre-GHHP monitoring.

Initial GHHP coral monitoring in 2015 noted very low coral cover which reflected the severe flood impacts of 2013. Reduced salinity levels from freshwater run-off in flood plumes is a recognised cause of coral mortality. Major flooding of the Boyne and Calliope rivers, a result of heavy rainfalls associated with TC Oswald in January 2013, temporarily lowered salinity levels within Gladstone Harbour. Converting temperature and conductivity data to practical salinity units (psu) for the Mid Harbour revealed a period of approximately three days (27–29 January 2013) where salinity levels remained below 20 psu at a depth of 0 m (Vision Environment Queensland 2013a,b). A minimum level of 5 psu 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 22 psu for three days; beyond this level mortality can be expected. Recovery since the severe impacts of flooding in 2013 has been limited thus far in Gladstone Harbour coral communities.

Although coral cover has remained low since monitoring began in 2015, it is the recovery potential of these reefs that best describes overall condition. Scores for macroalgal cover, juvenile density and change in hard coral cover are all formulated to assess the recovery process. Collectively, poor to very poor scores for these three sub-indicators highlight the limited recovery potential of corals in Gladstone Harbour.

Results strongly suggest a continued shift from coral to macroalgal dominance within Gladstone Harbour. In combination, the continued poor or very poor scores for each sub-indicator corroborate studies that demonstrate density-dependant feedback mechanisms which promote macroalgal dominance where conditions maintain the proliferation of macroalgae (e.g., Mumby et al., 2007, Mumby et al., 2013, cited in Thompson et al., 2022). The persistent high cover of macroalgae may be affecting coral recruitment processes by occupying available space for juvenile settlement. Results from the MMP have recorded a general pattern of high macroalgal cover and low juvenile coral densities on several reefs. The poor to very poor scores for change in hard coral cover are also likely to be influenced by coral-macroalgae interactions. Macroalgae genera such as *Sargassum* and *Asparagopsis* and in particular *Lobophora* and *Dictyota* have direct negative impacts on living corals (e.g., Lirman, 2001; Vega Thurber et al., 2012, Morrow et al., 2017, cited in Thompson et al., 2022). In addition to macroalgae, the widespread presence of the bio-eroding sponge *Cliona orientalis* continues to be the most significant contributor to coral mortality within the harbour (Table 3.15). Similarly coral bleaching, in response to high water temperature in early 2020, is likely to have contributed to the current very poor condition. Ongoing monitoring since 2015 demonstrates a clear lack of recovery since the severe loss of coral noted in 2015.

In the broader context of inshore reefs on the Great Barrier Reef, the coral communities in Gladstone Harbour score poorly compared with other reefs monitored by the MMP. As might be expected, the Gladstone Harbour reefs are regionally most similar to those in the Fitzroy Region, in particular Pelican Island. Pelican Island is proximal to the mouth of the Fitzroy River and was severely impacted by flooding in 2011. Like reefs in Gladstone Harbour, recovery of coral communities at Pelican Island has been negligible with high cover of red and brown macroalgae persisting to 2021. Reefs monitored by GHHP also group closely with Daydream and Double Cone islands from the Whitsundays region, which were severely impacted by cyclone Debbie in 2017. Communities at Pelican, Daydream and Double Cone islands and Gladstone Harbour reefs shared characteristics such as low coral cover, high macroalgae cover or a combination of the two.

Corals in Gladstone Harbour were in very poor condition and demonstrated limited recovery potential in 2022. Recovery will be largely dependent on connectivity with populations of living corals beyond the harbour.

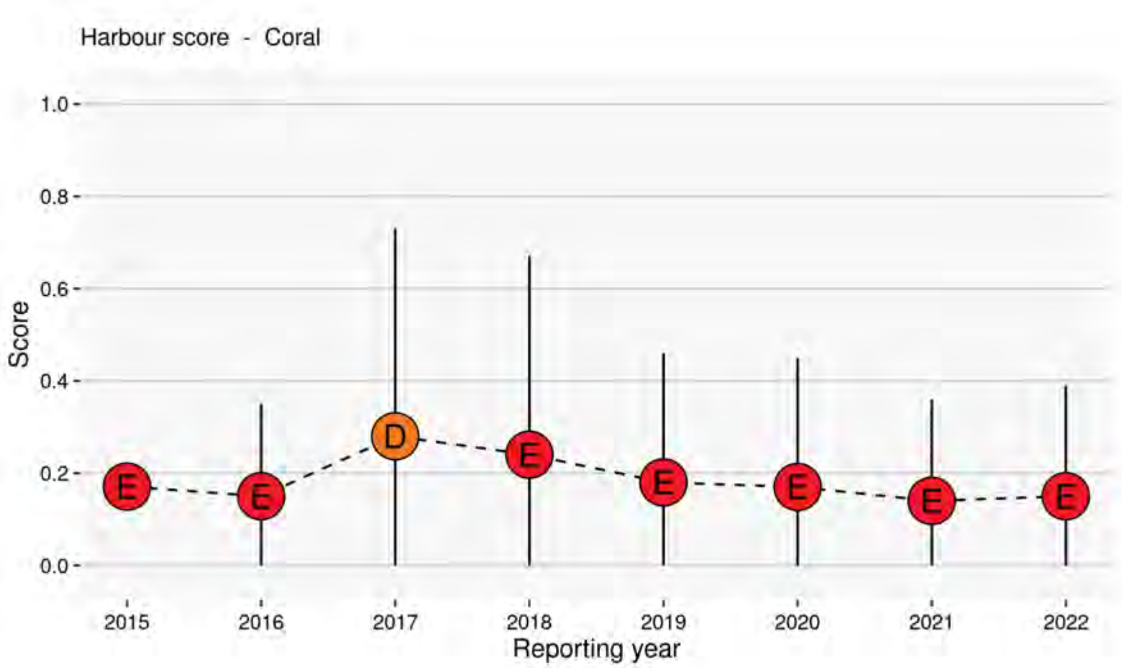


Figure 3.6: Trends in the harbour score for coral, 2015 – 2022 (Error bars show 95% bootstrap confidence intervals). Note, the 2020 score was corrected for an error in change in hard cord cover calculation and differs from the score previously reported on. Refer to 2020 Coral Report or 2020 Technical Report for further detail.

Table 3.14: A comparison of coral sub-indicator scores for the Mid Harbour and Outer Harbour for surveys conducted from 2015 to 2022.

Zone	Year	Coral cover	Macroalgae cover	Juvenile density	Change in hard coral cover	Zone Score
Mid Harbour	2015	0.08	0.37	0.23	-	0.23
	2016	0.05	0.10	0.33	-	0.16
	2017	0.08	0.50	0.33	0.44	0.33
	2018	0.06	0.41	0.34	0.30	0.27
	2019	0.09	0.02	0.24	0.42	0.19
	2020*	0.09	0.15	0.15	0.44	0.20
	2021	0.07	0.00	0.15	0.43	0.16
	2022	0.06	0.07	0.13	0.26	0.13
Outer Harbour	2015	0.05	0.00	0.33	-	0.13
	2016	0.09	0.00	0.33	-	0.14
	2017	0.06	0.00	0.44	0.37	0.21
	2018	0.05	0.00	0.45	0.33	0.20
	2019	0.07	0.00	0.22	0.40	0.17
	2020*	0.08	0.00	0.08	0.39	0.14
	2021	0.07	0.00	0.15	0.26	0.12
	2022	0.12	0.00	0.11	0.48	0.18

*Note, 2020 scores shown were corrected for an error in change in hard cord cover calculation and differ from the scores previously reported on. Refer to 2020 Coral Report or 2020 Technical Report for further detail.

Table 3.15: Causes of coral mortality at time of survey in 2022. Survey area of 200 m^2 at each reef. Data from 2019–2021 included for comparison. No data are included for Manning Reef as no ongoing mortality was recorded. Bio-eroding sponge is primarily *Cliona orientalis*.

Reef	Damage	Genus	Colonies affected			
			2019	2020	2021	2022
Facing Island	Bio-eroding sponge	*Porites*	17	22	8	10
		Turbinaria			1	
	Bleaching			0-5%		
Farmers Reef	Atramentous necrosis	*Cyphastrea*			2	
	Bio-eroding sponge	*Cyphastrea*	5	7	4	7
		Turbinaria	1			1
	Bleaching			0-1%		
	Unknown					1
Rat Island	Atramentous necrosis	*Cyphastrea*			1	7
	Bio-eroding sponge	*Cyphastrea*	6	8	9	5
		Plesiastrea	2	1		
		Porites				1
		Turbinaria	2	4	3	2
		Favites		1	1	
	Black band disease	*Turbinaria*		1		
	Bleaching			0-10%		
Seal Rocks North	Bleaching			1-50%		
Seal Rocks South	Atramentous necrosis	*Turbinaria*			1	
	Bio-eroding sponge	*Turbinaria*	8	9	7	6
		Favites			1	1
	Bleaching		0-1%	20-40%		
	Physical			0-1%		
	Unkown	*Acropora*				1

3.3. Fish and crabs

3.3.1 Fish health

Figure 3.7: Pikey bream caught during Gladstone Harbour fish monitoring 2018 (Photo courtesy of CQUniversity).

Fish are one of the most important social, economic and ecological resources in Gladstone Harbour. As a result, they were identified as a major concern at community workshops conducted by GHHP in 2013 to develop a community-based vision for the Gladstone Harbour Report Card.

Commercial and recreational fishing in Gladstone occurs throughout the harbour and Gladstone hosts annual fishing competitions.

Fish play a multitude of roles in aquatic ecosystems including nutrient cycling, ecosystem regulation and bioturbations. They are important in nutrient cycling as they store a large proportion of ecosystem nutrients like phosphorus and nitrogen in their tissue, transport nutrients further than other aquatic animals and the nutrients they excrete are readily available to primary producers such as algae or seagrass. Fish can also play a vital role in ecosystem regulation such as herbivorous fish keeping algae in check on coral reefs.

Fish health was assessed by two separate fish monitoring projects:

1. Fish condition (Automated visual assessment using mobile phones and length weight data)
2. Health assessment index (Gross pathological analysis)

Relying on a citizen science approach for data collection fish condition provides a less detailed assessment of fish health when compared to the Health Assessment IndexHAI. However, this approach incurs significantly lower costs and by using data collected during fishing competitions like the Australian Bass Tournaments (ABT) and by recreational fishers (e.g., Gladstone Sportfishing Club), a large portion of the harbour can be assessed at a lower cost than more traditional methods.

The fish condition (FC) scores are based on two separate metrics. The first is an external assessment of fish health fish visual condition (FVC). This includes skin, eyes, fins, parasites and deformities. The second metric is a fish body condition (FBC) index. This is calculated from length and weight data recorded at the time of capture. Measures of body condition are widely used to assess the health of individual or groups of fish. Generally, fish that are heavier than average for their length are considered healthier with more energy reserves for normal activities including reproduction.

The HAI is a more detailed assessment of fish health which requires a gross pathological assessment during dissection and produces a score based on the condition of several organs and tissues. The index scores add together to reflect the acute and chronic stressors that are present in the fish's environment. A fish with a high HAI score is less healthy than a fish with a low score. Although providing a more rigorous assessment of fish health—owing to the time and expense involved in transporting fish for laboratory analysis—fewer fish are assessed compared to the VFC method. This sub-indicator was not assessed in 2022 and the 2021 data has been used in the calculation of the overall fish health and Environmental score.

3.3.2 Fish health data collection

Fish mobility

Ideally, the fish health monitoring program should reflect the prevailing conditions within Gladstone Harbour. Hence fish that remain resident within the harbour provide a more relevant localised measure of conditions than species that have large movements and may be affected by conditions outside of the harbour. The movements of potential target species for the two fish health monitoring programs were assessed in two previous fish health studies which conducted mobility assessments using Suntag fish tag and recapture data provided by Infofish Australia.

Flint et al. (2018), examined the movements of inshore and estuarine fish, that had available tagging data, for six species, including four species assessed for fish health in the 2019 report card (barramundi, dusky flathead, yellow-finned bream and pikey bream). The majority of recorded movements were less than 20 km. Barramundi had the longest movements (mean 8.42 km, maximum 704 km) and the recorded movements of pikey bream were entirely within Gladstone Harbour.

Sawynock et al. (2018) analysed the movements of four target species; yellow-finned bream, pikey bream, dusky flathead and barred javelin, and found that in these species only 5% of the recorded movements were greater than 5 km.

While the analysis of fish movements demonstrated these species would generally be restricted to the harbour, the recorded movements were still larger than the spatial scale of the 13 environmental monitoring zones. Hence fish health is scored at the harbour level with a single overall score generated for both projects being applied to all 13 environmental monitoring zones. This single score is because the health of each of the target species can not necessarily be attributed to the conditions within individual environmental monitoring zones. The survey methods for both projects reflect this approach and fish sampling has not been conducted in all 13 zones. However, data for both projects has been collected from north, south and central harbour areas and provides a good spatial coverage that included developed and undeveloped areas. As the location of each fish captured will be recorded it will be possible to identify any fish health 'hot spots' that may occur using this approach.

Fish condition

Data was collected for six fish species. These are fish that are most likely to be caught during fishing competitions and represent fishes found in a range of environments. They include fish that are bottom dwellers such as dusky flathead and those that feed higher in the water column. As these species occupy a variety of trophic level and habitats, they may be differentially affected by any fish health issues. For example, demersal or benthic species are in closer contact with pollutants accumulated in sediments and as a result are more likely than pelagic species to present with abnormalities (Cowled, 2016). The target species are:

- Yellow-finned bream *Acanthopagrus australis*
- Pikey bream *Acanthopagrus berda*
- Barred javelin *Pomadasys kaakan*

- Dusky flathead *Platycephalus fuscus*
- Mangrove jack *Lutjanus argentimaculatus*
- Barramundi *Lates calcarifer*

Data for fish condition was collected using the Trackmyfish app (Figure 3.8). The data recorded on the Trackmyfish app included:

- Photos of one side of the fish, preferable on a measuring ruler
- Photos collected by Infofish, both sides of the fish were recorded and assessed
- Total fish length ± 0.05cm
- Tag number from any tagged fish
- GPS location at point of capture, GHHP monitoring zone
- Weight of fish (g) caught for calculation of fish body condition

Data was collected over the course of the 2021–22 reporting year with the aim of collecting a minimum of 325 photographs of the six target species in the GHHP environmental reporting area, spread evenly across the 13 environmental monitoring zones. Four methods of data collection were used:

- Data collected at the ABT Bream Tournament
- Data collected at the Boyne Tannum HookUp
- Data collected by members of the Gladstone Sports Fishing Club during normal fishing trips
- Data collected by the public when reporting the recapture of tagged fish
- Data collected by Infofish

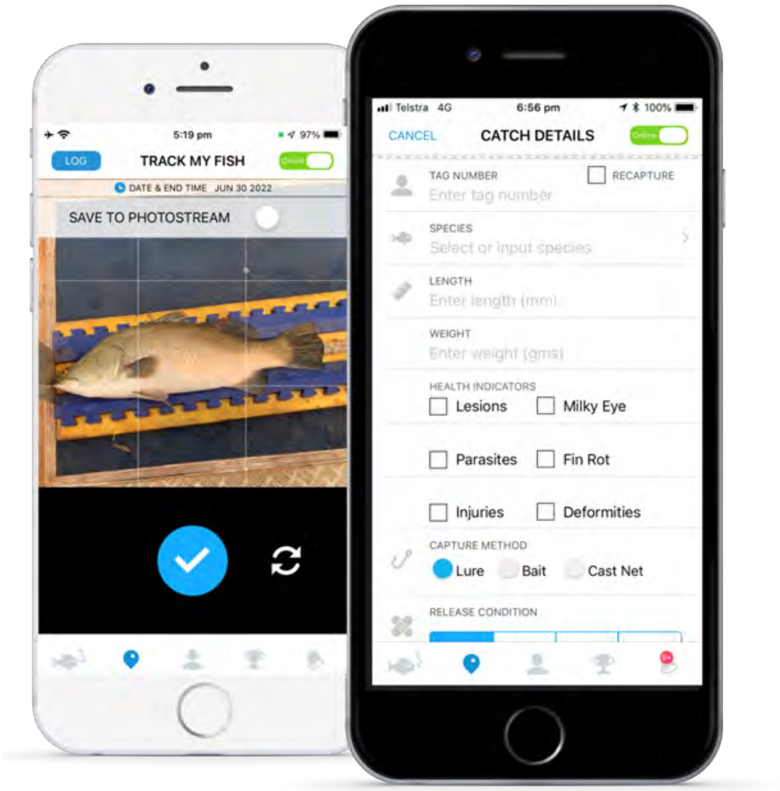


Figure 3.8: Data for the visual fish condition index was collected by fishers using the Trackmyfish app.

Over the course of the study period, 1 July 2021 to 30 June 2022, a total of 896 images of the six target species were captured using the app (Figure 3.9). These images were used to calculate the score for visual fish condition. Human and visual assessments were made for each condition with close to 100% agreement between the two.

Data for fish body condition were collected in Gladstone Harbour at the Boyne Tanum Hook-up between 29 April and 1 May 2022. Length weight data from 462 fish were used to calculate the report card scores. These data were used to calculate the scores for fish body condition.

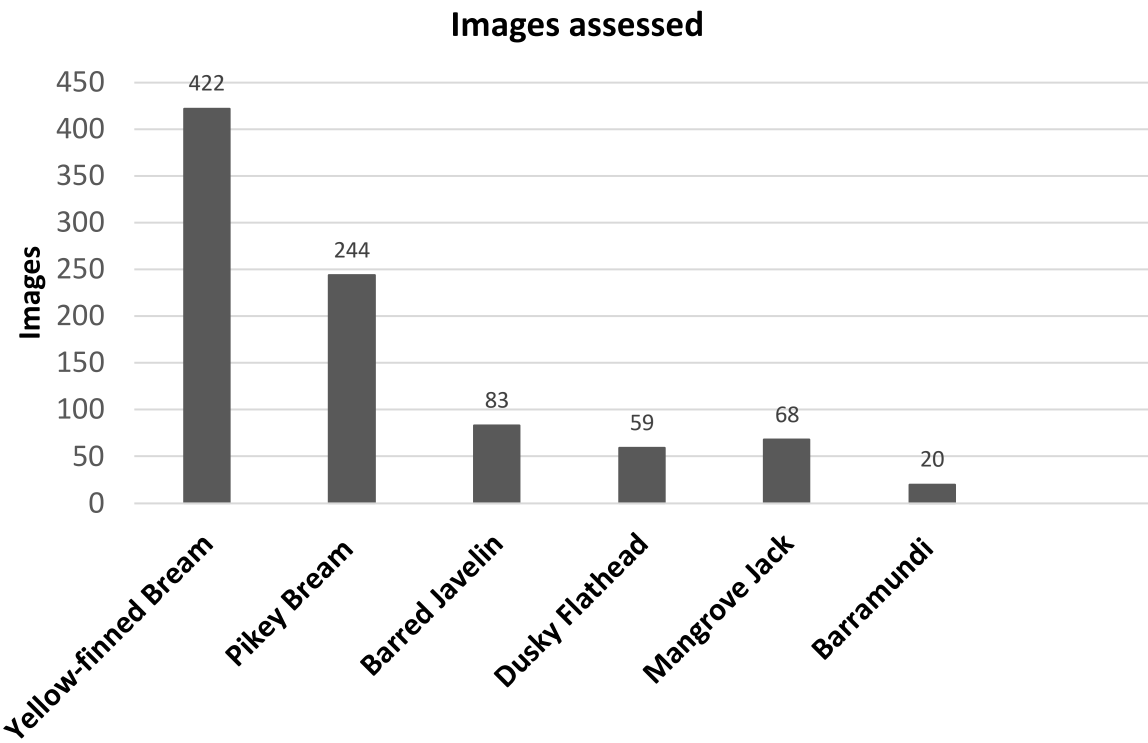


Figure 3.9: Number of images of each of the six target species captured using the Trackmyfish App over the 2022 reporting year.

Health assessment index

Based on recommendations from previous fish health studies (Flint et al., 2018, Cowled, 2016 & Kroon et al., 2016) and the GHHP Independent Science Panel the following fish species / taxa were identified as target species.

- Barramundi *Lates calcarifer*
- Bream: Pikey bream *Acanthopagrus berda* and yellow-finned bream *Acanthopagrus australis*
- Mullet: Diamond scale mullet *Liza vaigiensis* and sea mullet *Mugil cephalus*
- Barred javelin *Pomadasys kaakan*
- Dusky flathead *Platycephalus fuscus*

These species have been identified as being suitable for biomonitoring on the basis that they are present and abundant, commercially or recreationally fished and spend time low in the water column. Demersal or benthic species are in closer contact with pollutants in sediments and as a result are more likely than pelagic species to present with abnormalities (Cowled, 2016). These species were also caught in sufficient numbers in previous surveys to provide adequate sample sizes for the calculation of report card scores.

No new sampling for this sub-indicator was conducted in the 2021–22 reporting year. The results presented in this year's report card are based on sampling conducted in the previous reporting year. This sampling was conducted in Spring 2020 and Autumn 2021. The surveys in Gladstone Harbour were designed to produce an even catch effort across the northern, central and southern areas of the harbour with a focus on inshore and estuarine sites, this included 11 environmental monitoring zones.

At each survey site three 50 m long gill nets with stretched mesh sizes of 4.5 inches, 6 inches and 8 inches were deployed for an average soak time of 30 minutes. At some sites an additional 110 m long gill/ring net with a 2.13 inch stretched mesh size was also deployed to supplement the catch. Gear was deployed at times and locations designed to maximise the catch of the identified target species.

Captured fish were given a unique identification code and were either processed immediately or kept alive in an aerated swim tank. Bony fish were photographed, measured including length and weight, and the skin, fins and eyes were examined for abnormalities, parasites, lesions or erosion. Sharks and rays were recorded and photographed but were not handled other than to ensure their live release. Non-target fishes were released alive and target species were euthanised for laboratory analysis. All euthanised fish were individually bagged in an ice slurry and returned to the laboratory on the same day.

A total of 126 fishes from 17 species were caught across Gladstone Harbour and the Baffle Creek reference site. Barred javelin (n = 31) and blue catfish (n = 32) were caught in the highest numbers and barred javelin were caught in the most zones. A total of 80 fishes from four of the five target species were caught, no bream were caught and only four diamond scale mullet were caught in the harbour. With the absence of bream and the low mullet numbers the report card scores were calculated based on three species: barred javelin, blue catfish and barramundi.

3.3.3. Development of fish health indicators and scoring

Fish condition

The fish visual condition is based on the HAI developed by Adams et al. (1993). However, unlike the HAI in which the fish is euthanised and both external and internal health parameters are assessed. The fish visual condition is based on external indicators of health only and fish are released alive after processing. The five variable conditions assessed are fins, skin, eyes, parasites, and deformities. All parameters are scored between 0 and 30 depending on the severity of the condition with the most severe conditions receiving the highest score (Table 3.16).

To calculate the fish visual condition score for each species, the variable condition scores for each fish were summed and the mean calculated for each species. The harbour wide score was generated by summing the individual species scores, then calculating the average score. All scores were converted to a report card score by standardising the scores to have a range of 0 to 1.

Table 3.16: Scoring for five variable conditions used in fish visual condition in 2022.

Measure	Variable condition	Score
Fins	No active erosion	0
	Light active erosion	10
	Moderate active erosion with some haemorrhage	20
	Severe active erosion with some haemorrhage	30
Skin	Normal no aberrations	0
	Mild skin aberrations	10
	Moderate skin aberrations	20
	Severe skin aberrations	30
Eyes	No aberrations	0
	Opaque / Milky eye	10
	Swollen eye	20
	Haemorrhaging or bleeding eye	30
	Missing eye	30
Parasites	No parasites	0
	Observed parasites	10
Deformities	No deformity	0
	Observed deformity	10

Fish body condition was calculated using a relative condition factor. This length-weight relationship is a key measure of fish condition used by fisheries agencies across Australia and internationally (Schneider, 2000, King, 2007). The relationship is calculated from the length–weight curve of best fit (Le Cren, 1951) for each of the key species using data recorded in the years from 2003–2019 during the Boyne-Tannum Hook-Up described by the following formula:

$$W = a \times L^b$$

where W is the calculated weight and L is the total length of the fish. Values of W have been calculated from the logarithmic (base 10) equivalent:

$$\log W = \log \mathrm{a} + \mathrm{b} \cdot \log \mathrm{L}$$

The relative condition factor (Kn) (Le Cren, 1951, Koushlesh et al., 2018) is calculated as the proportion of the observed weight (w) to the calculated weight from the length-weight relationship (W) where a condition factor Kn = 1 is consistent with a fish of average condition, Kn >1 being above average and $Kn < 1$ below average.

$$Kn = \frac{w}{W}$$

The minimum (Kn_{min}) and maximum (Kn_{max}) condition factors for the species were determined from the historical minimum and maximum conditions. Each fish is scored (S_{FISH}) by normalising the condition factor, relative to the historical minimum and maximum.

$$S_{FISH} = \frac{Kn - Kn_{min}}{Kn_{max} - Kn_{min}}$$

The final score for the species in the current year is calculated as the average score for the species (where n is the number of fish being assessed) in the current year.

$$S_{FINAL} = \frac{\sum_{i=1}^{n} S_{FISH}}{n} \frac{\sum_{i=1}^{n} S_{FISH}}{n} \frac{\sum_{i=1}^{n} S_{FISH}}{n}$$

Final grades are calculated using the standard GHHP scores (Figure 2.1).

Health assessment index

The health assessment index was developed by Adams et al. (1993) and included 14 measures of fish health. This study has employed a modified HAI which has nine measures of fish health and was used in previous studies in Gladstone Harbour by Wesche et al. (2013). The nine measures include three external measures, four internal organs, and assesses gill condition and parasite load (Table 3.16). The total HAI score was calculated for each individual fish as the sum of the nine measures and the average of the scores was calculated for each species/species group for the harbour. Barramundi, blue catfish and barred javelin are reported as individual species. Bream and mullet were analysed as species groups owing to their similar ecological characteristics and to increase sample size. The bream species group includes pikey and yellow-finned bream and the mullet species group includes diamond scale and sea mullet.

A distance to benchmark method has been employed to calculate report card scores from the average HAI scores. This method involves using a benchmark, best possible condition, and a worst-case scenario. Benchmarks and worse-case scenarios were selected based on existing studies and the data collected during monitoring in 2018–19.

The possible HAI score for an individual fish range from 0 to 270. However, even in pristine environments a HAI average of 0 is unlikely as fish may have skin abrasions, parasites or slight fin erosion. Conversely, studies employing the HAI (even in polluted environments) have shown that an average score of 270 is equally unlikely (Watson et al., 2012). Watson et al. (2012) used the full HAI on fish populations in the polluted Loskop Dam and Mamba River in South Africa and calculated average HAI scores of 113.8 and 108.0. Adjusting these scores to the nine HAI measures used in this study gives maximum scores of 73.2 and 69.4.

Benchmark: In this study a score of 0 was recorded by 70 of the 223 fish assessed from Gladstone Harbour and five fish from 23 assessed at reference sites also received scores of 0. The occurrence of scores greater than 0 (88%) at the reference sites indicated that even in pristine environments a population score of 0 is unlikely. Hence a pilot benchmark of an average HAI of 10 was used.

Worst Case Scenario: While studies in Gladstone have assessed fish populations in the harbour (Wesche et al., 2013) it is not clear if the HAI values represent a worst-case scenario. Watson et al. (2012) used the full health assessment index on fish populations in the polluted Loskop Dam and Mamba River in South Africa and calculated average HAI scores of 113.8 and 108.0. Adjusting these scores to the nine HAI measures used in this study gives maximum scores of 73.2 and 69.4. Based on these results a pilot worst-case scenario was set at an average HAI score of 70.

Scores for the 2021 report card were calculated using data from Spring 2020 as follows:

Calculated score = 1-((x-B)/(WCS-B))

Where:
x = recorded value
B = benchmark
WCS = worst case scenario

The GHHP grade range equates to the following average HAI values:
A, average HAI of 0-19
B, average HAI of 20-31
C, average HAI of 32-40
D, average HAI of 41-55
E, average HAI of 56+

Table 3.17: Scoring for nine variable conditions used in the health assessment index in 2021 (Source: Wesche et al., 2013).

Measure	Variable condition	Score
Fins	No active erosion	0
	Light active erosion	10
	Severe active erosion	20
Skin	Normal no aberration	0
	Mild skin aberration	10
	Moderate skin aberration	20
	Severe skin aberration	30
	Extensive redness as a rash. Scales intact	40
Eyes	No aberration, good clear eyes	0
	Fresh haemorrhage (eg net damage)	0
	Opaque eyes (one or both)	30
	Cloudy and swollen, red or haemorrhaging	30
	Ruptured (one or both)	30
Parasites	No observed parasites	0
	Few observed parasites	10
	Moderate parasite infestation	20
	Numerous parasites	30
Spleen	Normal, black, very dark red or red	0
	Normal, granular rough appearance	0
	Nodular, containing fistulas or nodules	30
	Enlarged	30
	Other, aberrations not fitting any above	30
Hindgut	Normal, no inflammation or reddening	0
	Slight inflammation or reddening	10
	Moderate inflammation or reddening	20
	Severe inflammation or reddening	30
Kidney	Normal, firm, dark, flat	0
	Swollen, enlarged or swollen	30
	Mottled, grey discolouration	30
	Granular in appearance and texture	30
	Urolithiasis or nephrocalcinosis	30
	Other, aberrations not fitting any above	30
Liver	Normal, solid red or light red colour	0
	Fatty liver, coffee with cream colouring	30
	Nodules or cysts in liver	30
	Focal discolouration	30
	General discolouration	30
	Other, deviation not fitting any above	30
Gills	Normal no apparent aberration	0
	Frayed, ragged appearance	30
	Clubbed, swelling of tips	30
	Marginate, light discoloured margin	30
	Pale very light colour	30
	Other	30

3.3.4. Fish health results

The overall score for fish health in 2022 was 0.80 (B), comprised of a score of 0.72 for fish condition and a score of 0.90 for the health assessment index. For both studies the overall harbour score is applied to each of the 13 environmental monitoring zones and indicates good fish health across the harbour.

Fish condition

The overall score for fish condition was 0.72 (B) comprised of an overall harbour score for fish visual condition of 0.97 (A) and a score of 0.47 for fish body condition. All species assessed for fish visual condition received a very good score ranging from 0.94 to 0.98. Fish body condition was calculated for all target species except for barramundi, these scores ranged from 0.43 for yellow-finned bream and dusky flathead to 0.50 for mangrove jack (Table 3.18).

Table 3.18: The fish condition score calculated from the mean of the fish visual condition and fish body condition for five species of fish caught in Gladstone Harbour in the 2021–22 reporting year.

Fish Species	Visual fish condition	Fish body condition	Fish condition
Yellow-finned bream	0.90	0.43	0.72
Pikey bream	0.98	0.46	0.73
Barred javelin	0.94	0.44	0.72
Dusky flathead	0.97	0.43	0.70
Mangrove jack	0.96	0.50	0.72
Harbour score			**0.72**

From the total sample (all fishes) the detection of visible pathologies was low: eye health issues were detected in three fish (0.3% of total fish), skin issues were detected in six fish (0.7% of total fish) and no detections of external parasites or deformities were recorded (Table 3.19). For all species, the most detected condition was fins (54% of the total sample) ranging from 30% detection in barred javelin to 76% in pikey bream. However, the severity of this condition was low with 99% of all fishes in which this condition was detected recording a low or moderate score (Table 3.20). Skin was the next most recorded condition, although the detection rate (1% of all fish) and the severity were both low (Table 3.21).

Table 3.19: Number of visual fish health incidences detected and species scores for six species of fish in the 2021–22 reporting year.

Species	N	Fins	Skin	Eyes	Parasites	Deformities
Yellow-finned bream	422	224 (53%)	2 (0.47%)	1 (0.2%)	0	0
Pikey bream	244	186 (76%)	0	0	0	0
Barred javelin	83	25 (30%)	2 (2.4%)	1 (1.2%)	0	0
Dusky flathead	58	25 (43%)	2 (3.45%)	0	0	0
Mangrove jack	68	34 (50%)	0	1 (1.5%)	0	0
Barramundi*	20	11 (55%)	0	0	0	0
Total	895	480 (54%)	6 (0.67%)	3 (0.3%)	0	0

*Not included in the calculation of report card scores for fish condition owing to the absence of fish body condition data.

Table 3.20: Fin condition recorded for six species of fish in in the 2021–22 reporting year.

Condition (Score) / Species	No active erosion (0)	Light active erosion (10)	Moderate active erosion with some haemorrhage (20)	Severe active erosion with some haemorrhage (30)	N
Yellow-finned bream	198 (47%)	222 (52.5%%)	2 (0.5%)	0	422
Pikey bream	58 (24%)	179 (73%)	7 (3%)	0	244
Barred javelin	58 (70%)	25 (30%)	0	0	83
Dusky flathead	55 (93%)	4 (7%)	0	0	59
Mangrove jack	34 (50%)	34 (50%)	0	0	68
Barramundi*	(45%)	11 (55%)	0	0	20
Total	412 (46%)	475 (53%)	9 (1%)	0	896

*Not included in the calculation of report card scores for fish condition owing to the absence of fish body condition data.

Table 3.21: Skin condition recorded for six species of fish in in the 2021–22 reporting year.

Condition (Score) / Species	Normal no aberrations (0)	Mild skin aberrations (10)	Moderate skin aberrations (20)	Severe skin aberrations (30)	N
Yellow-finned bream	420 (95.5%)	2 (0.5%)	0	0	422
Pikey bream	244 (100%)	0	0	0	244
Barred javelin	81 (97%)	2 (3%)	0	0	83
Dusky flathead	57 (97%)	2 (3%)	0	0	59
Mangrove jack	68 (100%)	0	0		68
Barramundi*	20 (100%)	0	0	0	20
Total	890 (99%)	6 (1%)	0	0	896

*Not included in the calculation of report card scores for fish condition owing to the absence of fish body condition data.

Fish body condition

Fish body condition (FBC) was calculated for five species of fishes caught in Gladstone Harbour at the Boyne Tannum Hook-up in April 2022 (Table 3.22). Weight (g) and length (mm) was recorded for 462 fishes from five species (Table 3.22) and the relative condition factors was calculated for each species by comparing this data to the historic mean. This mean was derived from historic data recorded during the Boyne Tannum Hook-up from 2003 to 2022; data was available for all years except 2009, 2011 and 2020.

The overall score for fish body condition was 0.47 (D), one species of fish mangrove jack (0.50, C) was in satisfactory condition and yellow-finned (0.43, D) and pikey bream (0.46, D), barred javelin (0.44, D) and dusky flathead (0.43, D) were in poor condition.

Fish body condition was not calculated for barramundi. Images were only assessed for VFC, and as no weights were obtained for Barramundi, it was not possible to calculate FBC.

Figure 3.10: Length weight relationship for five fish species from the Boyne-Tannum Hook-Up from 2003 – 2022 (Source Sawynok et al., 2022).

Table 3.22: Relative condition factor calculated for five fish species in 2022.

Species	(N)	Relative condition factor		
		Min	Max	Mean
Yellow-finned bream	277	0.710	1.995	0.998
Pikey bream	28	0.848	1.170	0.993
Barred javelin	75	0.501	1.900	0.998
Dusky flathead	41	0.721	1.128	0.990
Mangrove jack	41	0.696	1.991	1.004

Health assessment index

As no new HAI monitoring was conducted in the 2022 reporting year, the 2021 results have been used to calculate the HAI scores for the 2022 report card. The overall health assessment index score for the 2021 reporting year was 0.90 (A). Three of the five monitored fish species received a very good score and the two remaining species, blue catfish (0.81, B) and mullet (0.81, B), received good scores (Table 3.23).

The overall HAI score was the average scores for nine measures (Table 3.24). Overall scores for external pathologies; skin, eyes and fins were low. For example, the highest average score for skin was 2.14 for mullet. The highest scores (poorest health) in all species were for liver ranging from 5.63 in bream to 15.00 in mullet.

Table 3.23: Overall health assessment index scores for five fish species and the overall score for Gladstone Harbour in 2022.

Species	Bream	Barred javelin	Barramundi	Blue catfish	Mullet
Species score	0.98	0.90	0.98	0.81	0.81
Harbour Score	**0.90**				

Table 3.24: Average measures and health assessment index (HAI) total scores for fish caught in Gladstone Harbour in the 2020–21 reporting year. Organ scores ranged from 0 to 30 and HAI scores ranged from 0 to a possible maximum of 270.

Taxa / Measure	Barramundi (n = 9)	Bream (n = 16)	Barred javelin (n = 17)	Blue catfish (n = 39)	Mullet (n = 14)
Skin	0.00	0.00	0.00	0.77	2.14
Eyes	0.00	0.00	0.00	0.00	0.00
Fins	0.00	0.63	1.18	0.26	0.71
Gills	0.00	0.00	0.00	0.77	0.00
Spleen	0.00	0.00	0.00	0.00	0.00
Kidney	0.00	3.75	0.00	3.85	0.00
Hindgut	0.00	0.00	0.00	0.26	1.43
Liver	6.67	5.63	14.12	13.85	15.00
Parasites	4.44	1.25	0.59	1.54	2.14
HAI score	**11.11**	**11.25**	**15.88**	**21.28**	**21.43**

Overall

The overall score for fish health in 2022 was the aggregation of the two fish health projects (Table 3.24). As no individual zone scores are calculated for fish health, this score also constitutes the fish health score for all 13 environmental monitoring zones.

Table 3.24: Overall fish health scores for Gladstone Harbour in 2022.

Fish condition	Fish health assessment index (2021)	Overall fish health 2022
0.70	0.90	**0.80**

3.3.5. Fish health conclusions

Fish condition

In 2022, the overall score for fish condition was 0.70 (B) based on sampling from the same five species. This score was similar to the 2021 score of 0.74 (B).

All species of fish received very good scores for fish visual condition (0.94 for barred javelin to 0.98 for pikey bream). The scores for fish body condition were satisfactory (0.55, C) for mangrove jack (0.55, C) and poor for yellow-finned (0.43, D) and pikey bream (0.46, D), barred javelin (0.44, D) and dusky flathead (0.43, D) which indicated condition below the long-term average.

Health assessment index

In 2021, calculated scores for the health assessment index ranged from good (0.81 for mullet and blue catfish) to very good (0.90 to 0.98 for barred javelin, bream and barramundi). This produced an overall harbour grade of very good 0.90 (A). The 2021 score is an improvement on the good scores of 0.67 (B) recorded in 2020 and 0.69 (B) recorded in 2019.

The laboratory analysis methods and the method for calculating scores have remained unchanged since the pilot year of the fish health indicator in 2019. However, the sampling effort, and consequently the catches of target species groups, has varied by year. For the 2019 Gladstone Harbour Report Card, fish were sampled across two sampling events in Spring 2018 and Autumn 2019 (8 days each). For the 2020 Gladstone Harbour Report Card, fish were sampled only in a single event in October 2019 (7 days). The results for the 2021 Gladstone Harbour Report Card have been calculated using data collected across two shorter sampling events (4 days each), in November 2020 and May 2021. The 2021 sampling strategy appeared to provide a good balance between cost and data, in comparison to the previous years.

3.3.6. Fish recruitment

Fish recruitment is one of the three key dynamic functions that affects a fish population, the other two are growth rate and mortality. The fish recruitment index is based on the total catch of juveniles of two bream species and is defined as the annual production of juvenile fish entering the mature fish population in Gladstone Harbour (Sawynok &Venables, 2016). The fish recruitment index captures the reproductive vigour and the spatial extent of two bream species.

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 2021–22 reporting year and data from this survey are reported here.

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)

3.3.7. Fish recruitment data collection

Data for the two bream species were collected monthly from 26 sites across 12 harbour zones between December 2021 and February 2022 (Figure 3.11). This was the same number of surveys conducted ion 2020–21 but a reduction of one month from surveys conducted in previous years (2016 to 2020). The Outer Harbour was excluded from the surveys as there were no suitable bream habitats (Table 3.25). 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 range. 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 100 mm defined juvenile or year 0 recruits (Sawynok & Sawynok, 2022).

Each site was sampled 20 times using a standard castnet (monofilament net with a drop of 2.4 m, mesh size 20 mm and spread of 3.6 m. 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 (Sawynok & Sawynok, 2022) (Figure 3.12).

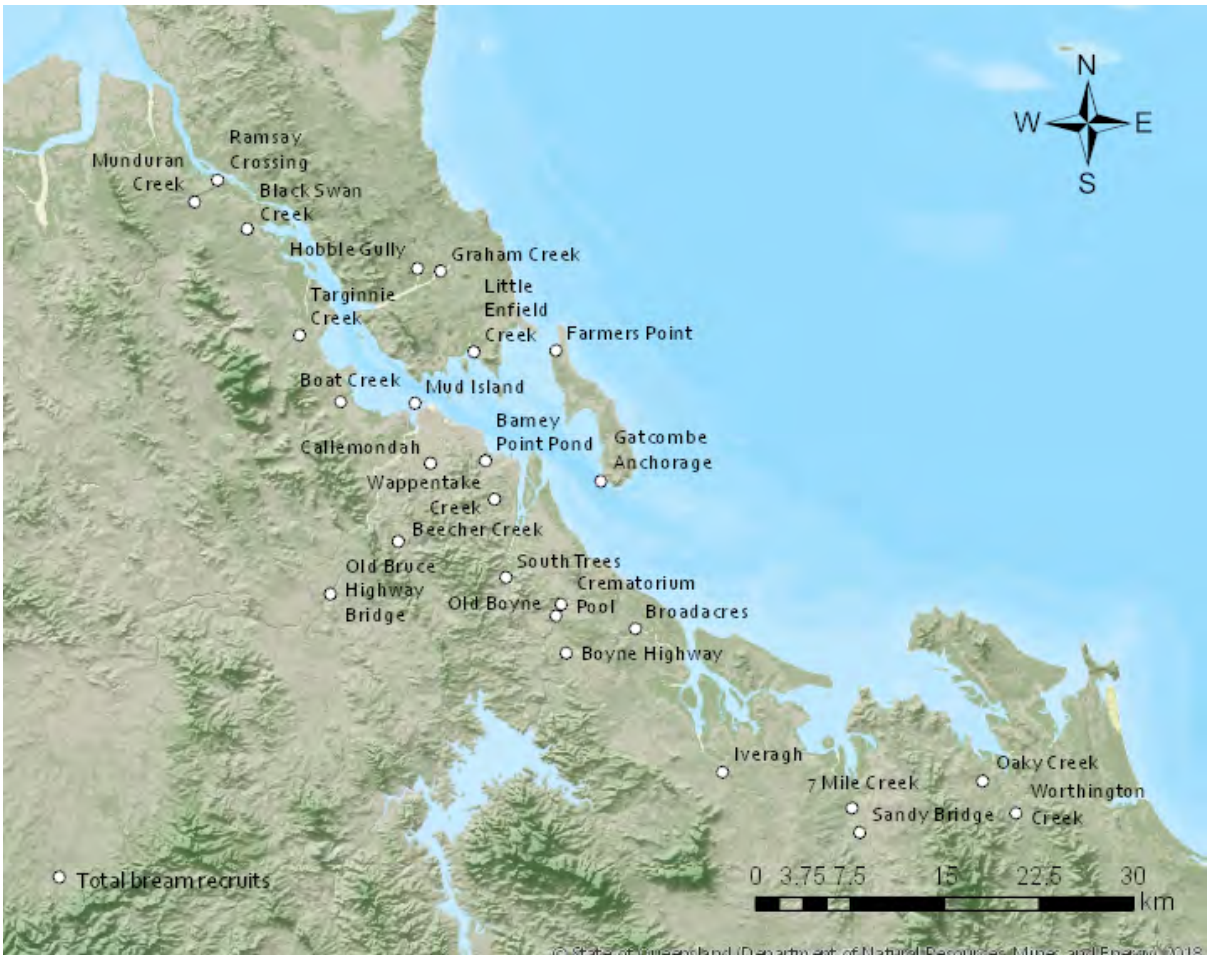


Figure 3.11: Bream nursery habitats surveyed around Gladstone Harbour between December 2021 and February 2022.

Figure 3.12: Fish recruitment surveys using in cast nets (Photos courtesy of Bill Sawynok).

Table 3.25: Number of sites surveyed and number of juvenile bream caught and released in each GHHP monitoring zone in 2021-22.

Harbour zone	Sites	Yellow-finned bream	Pikey bream
Zone 1. The Narrows	Ramsay Crossing	10	42
	Munduran Creek	12	0
	Black Swan Creek	2	25
	Targinnie Creek	26	22
Zone 2. Graham Creek	Graham Creek	2	41
	Hobble Gully	5	59
Zone 3. Western Basin	Wiggins Island	49	18
Zone 4. Boat Creek	Boat Creek	0	1
Zone 5. Inner Harbour	Little Enfield Creek	4	95
	Barney Point Pond	0	0
Zone 6. Calliope Estuary	Beecher Creek	5	5
	Old Bruce Highway Bridge	15	10
Zone 7. Auckland Inlet	Callemondah	11	27
Zone 8. Mid Harbour	Farmers Point	2	0
	Gatcombe Anchorage	5	8
Zone 9. South Trees Inlet	Wappentake Creek	0	1
	South Trees	19	27
	Crematorium Pool	27	16
Zone 10. Boyne Estuary	Old Boyne	20	12
	Boyne Highway	40	1
Zone 11. Outer Harbour	*Not surveyed*		
Zone 12. Colosseum Inlet	Broadacres	11	9
	Iveragh	5	0
Zone 13. Rodds Bay	Oaky Creek	9	7
	7 Mile Creek	12	19
	Worthington Creek	2	3
	Sandy Bridge	23	0
Total	**26 sites**	**316**	**448**

3.3.8. Development of fish recruitment indicators and scoring

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. Several 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 the bootstrapping technique) to obtain the report card results.

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), giving 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 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.

3.3.9. Fish recruitment results

Overall, the fish recruitment score for 2022 was 0.59 (C), indicating a satisfactory condition (Table 3.26). Of the 12 zones monitored one zone (Western Basin) had a very good score, three zones had good scores, four zones had satisfactory scores and four zones (Boat Creek, Calliope Estuary, Colosseum Inlet and Rodds Bay) had poor scores. The overall score was similar to that recorded in 2021 (Figure 3.13).

The total number of bream caught in 2022 from 1560 casts was 764, comprised of 316 yellow-finned bream and 448 pikey bream. There was a steady decline in the numbers of both species recorded from December to February. There were 169 Yellowfin Bream recorded in December falling to 60 in February while there were 201 Pikey Bream in December and 75 in February.

Table 3.26: Fish recruitment scores for all harbour zones and overall harbour score for fish recruitment from 2018 to 2022.

Zone	2022	*2021*	*2020*	*2019*	*2018*
1. The Narrows	0.65	*0.54*	*0.63*	*0.18*	*0.58*
2. Graham Creek	0.80	*0.84*	*0.92*	*0.17*	*0.77*
3. Western Basin	0.98	*0.94*	*0.98*	*0.13*	*0.79*
4. Boat Creek	0.35	*0.35*	*0.38*	*0.32*	*0.61*
5. Inner Harbour	0.69	*0.61*	*0.63*	*0.16*	*0.67*
6. Calliope Estuary	0.48	*0.68*	*0.66*	*0.28*	*0.70*
7. Auckland Inlet	0.61	*0.63*	*0.80*	*0.53*	*0.87*
8. Mid Harbour	0.58	*0.78*	*0.62*	*0.12*	*0.58*
9. South Trees Inlet	0.54	*0.47*	*0.39*	*0.25*	*0.69*
10. Boyne Estuary	0.64	*0.53*	*0.51*	*0.32*	*0.52*
11. Outer Harbour	*Not Surveyed*				
12. Colosseum Inlet	0.29	*0.56*	*0.63*	*0.39*	*0.61*
13. Rodds Bay	0.47	*0.51*	*0.52*	*0.33*	*0.59*
Harbour score	**0.59**	***0.62***	***0.64***	***0.27***	***0.66***

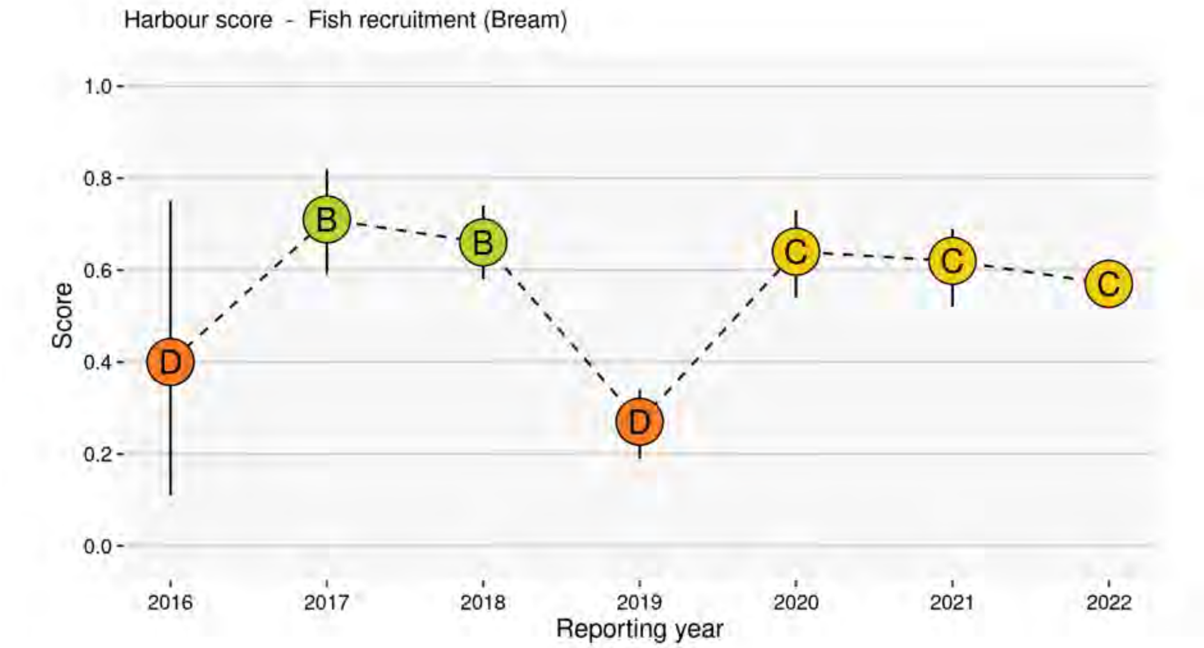


Figure 3.13: Trends in the harbour score for fish recruitment, 2016–2022 (Error bars show 95% bootstrap confidence intervals).

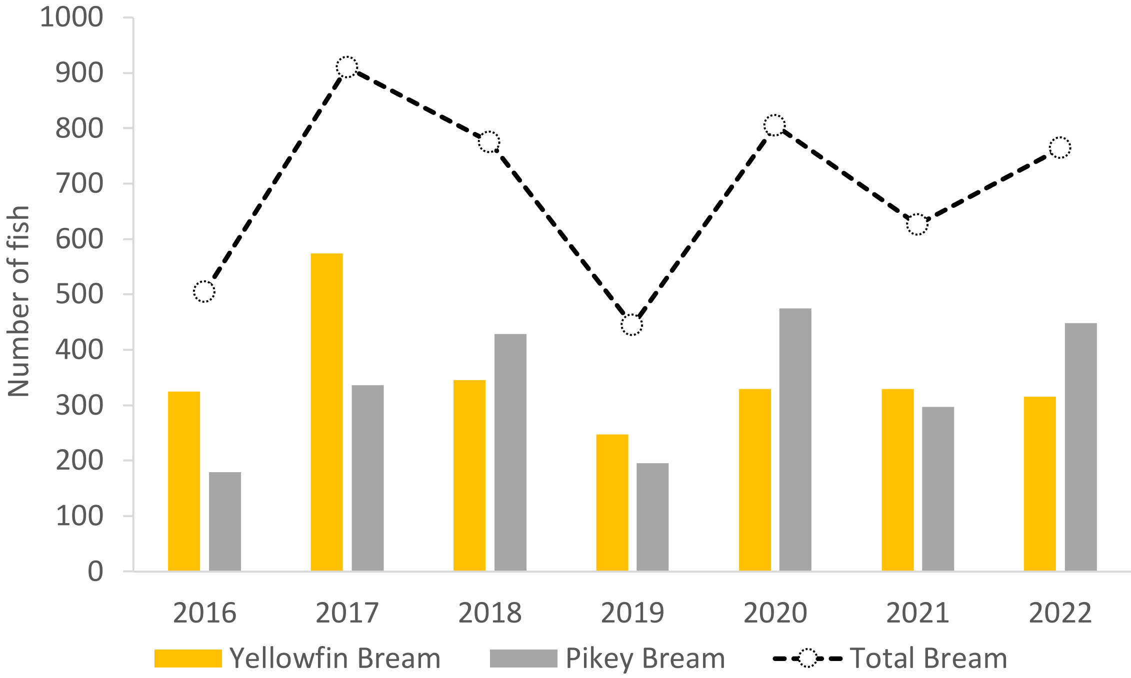


Figure 3.14: Yellow-finned and pikey bream recruits from 2016–2022 fish recruitment surveys.

3.3.10. Fish recruitment conclusions

For 2021–22 the number of surveys conducted was 78, the same number as in 2020–21. As per the previous year three surveys were conducted between December and February. No surveys conducted in March as they had been between 2015–16 and 2019–20 reporting years. However, the reduction in the number of surveys has had little effect on the overall result.

The average catch rates per cast increased overall however this does not have a direct relationship to the scores. The derived final score includes the site level effect and as such is more sensitive to individual site variation than the catch rate. At the individual sites there were variations that showed several sites underperformed relative to last year, and this is the likely explanation for the higher catch rate but lower scores.

The number of prawns this year was the lowest recorded in any year, even considering the reduced number of surveys, resulting in the lowest catch rate of 0.32 prawns per cast. The previous lowest catch rate for prawns was 0.42 prawns per cast in 2018–19. The low catch rate was surprising as the rainfall of 367 mm for November and December would normally be associated with an increase in prawn numbers.

Between 2016 and 2022 the catch rate for yellow-finned bream has varied between 0.15 to 0.20 yellow-finned bream per cast while the catch rate for pikey bream has risen steadily from 0.10 to 0.25 pikey bream per cast (see also Figure 3.14). This suggests that there may be a general increase in the abundance of pikey bream over this period.

3.3.11. 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. 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 3.15: Mud crab feeding at a Baited Retrievable Underwater Video during the pilot study in 2017 (Photo courtesy of CQUniversity).

The mud crab indicator was developed specifically for GHHP 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 suitable indicators of mud crab health and a methodology for determining report card scores (Figure 3.15).

3.3.12. 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 from 5–6 June 2017. A survey of Gladstone Harbour conducted between 19–23 June 2017 assessed the suitability of sites for permanent mud crab monitoring in eight of GHHP's environmental monitoring zones. A second round of mud crab surveys between 3–5 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 3.27). 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 3.27: 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

Mud crab monitoring

Two rounds of mud crab monitoring were conducted in 2022—a summer (warm, wet season) survey from 24–27 February and a winter (cool, dry season) survey from 21–24 June.

Twenty heavy-duty, four-entry collapsible crab pots were set at a minimum of 100 m apart at each site. The exception was Boat Creek where fewer pots could be placed within the confines of this small zone. Sampling dates and times were determined by tidal cycles. The baited crab pots were set at least three 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. Pots were placed as close as possible to mangrove habitats within this limit.

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

- Species;
- Sex;
- Carapace width (notch to notch) (mm); and
- Abnormalities: type, body location, dimensions of rust spot lesions, grade of rust spot lesion (Source: Andersen et al., 2003).

For all bycatch (crabs and fish), the species was recorded. Blue swimmer crabs were also weighed, measured and checked for abnormalities. All mud crabs and bycatch were released alive at the site of capture. Used baits were kept on board the vessel and not discarded at the sampling site. This was to reduce interference with commercial and recreational mud crabbers in the area.

3.3.13. Development of mud crab indicators and scoring

A literature search for potential mud crab indicators identified nine classes of potential mud crab indicators (Table 3.28). This included the three sub-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 3.28: Potential mud crab indicators were identified and ranked based on their suitability for calculating report card scores.

Potential mud crab indicators	Total score (30 = highest possible score)
Size: Sex ratio 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 three indicators were selected for the report card:

1. Sex ratio: based on legal size limit

   (number of male mud crabs >150 mm carapace width)
   (number of female mud crabs >150 mm carapace width)

2. Abundance: catch per unit effort (CPUE)

   (total number of mud crabs caught)
   (number of pots set)

3. Visual health: prevalence of rust lesions

   (number of mud crabs with lesions)
   (number of mud crabs assessed for lesions)

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 3.29). 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. Benchmarks and worse-case scenarios were selected based on existing data and data collected during the 2017 report card monitoring.

A potential fourth sub-indicator (biomass) was previously considered. Owing to a lack of baseline data, biomass was not included in the 2017 or 2018 report cards. In 2019, the ISP discussed the potential inclusion of biomass as there was three years of baseline data; however, recommended that biomass not be included due to complications in assessment.

Table 3.29: Calculation of mud crab scores for the 2022 report card.

Measure	Benchmark	Worst-case scenario	Method
Sex ratio	Male to female sex ratio of 2:1 from an unfished Central Queensland population at Eurimbula Creek (Flint et al., 2019) **(2)**	25th percentile of Long-Term Monitoring Program data **(0.25)**	1–((x-B)/(WCS-B)) Where: x=recorded ratio B=benchmark (2) WCS=worst-case scenario (0.25)
Abundance (CPUE)	Moving average of 75th percentile of the combined 2017–2022 scores **(1.6)**	Catch rate of < 1 crab per allowable 4 pots **(0.25)**	1–((x-B)/(WCS-B)) Where: x=recorded CPUE B=benchmark (1.6) WCS=worst-case scenario (0.25)
Prevalence of rust lesions	25th percentile of the 2017 data (4%) **(0.04)**	Prevalence recorded by Dennis et al. (2016) in Gladstone Harbour of 37%, rounded down to 35% **(0.35)**	1–((x–B)/(WCS–B)) Where: x=recorded prevalence B=benchmark (0.04) WCS=worst-case scenario (0.35)

The sex ratio measure assessed fishing pressure, as only male crabs can be retained. A minimally disturbed benchmark requires data from an unfished population, where an undisturbed male to female crab ratio can be determined. The 2017 benchmark was set at 3:1 based on unfished populations in Micronesia (Alberts-Hubatsch et al., 2016). In 2018, the sex ratio benchmark was updated to 2:1 using data from unfished populations in northern NSW and an unfished section of Moreton Bay (Butcher, 2004, Pillans et al., 2005). In 2018–19, a GHHP-funded CQU study investigated the sex ratio from a more local population in Eurimbula Creek (an un-crabbed estuary in Central Queensland). Findings from this study corroborate the previously reported sex ratio benchmark of 2:1 (Flint et al., 2019). 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).

Abundance was indirectly measured as catch per unit effort (CPUE)—total catch divided by the number of pots within each of the seven monitoring zones. The benchmark for abundance (measured as CPUE) was set as the 75th percentile of the past three years. An accumulating average of the 75th percentile will be used for up to 10 years to account for natural variability. Using the accumulating average from 2017–2022, the benchmark for 2022 was 1.6 crabs/pot. 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 less than one mud crab from four pots is undesirable.

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.

In 2020, the ISP recommended a change in mud crab scoring methodology which was approved by the GHHP Management Committee. Boot-strapping processes described in Section 2.1 aside, calculation of the harbour score for mud crabs is as follows:

(a) Calculate the scores for each sub-indicator in each zone
(b) Average the scores of the sub-indicators to get a harbour score for each sub-indicator
(c) Average the sub-indicator harbour scores to get the overall harbour score.

Previously the harbour score was derived by averaging the zone scores. This had the effect of omitting zones in which an insufficient catch (n < 5) occurred. Under the new method, the zero for abundance is captured for zones with an insufficient catch in the abundance sub-indicator score, which is then averaged with the prevalence of rust lesions and sex ratio sub-indicator scores to calculate the overall harbour score.

3.3.14. Mud crab results

The overall mud crab score for the 2022 report card was 0.39 (D). This was a result of very poor to poor scores for sex ratio (0.00–0.43), variable but mostly very poor abundance scores (0.00–1.00) and poor to very good scores for prevalence of rust lesions (0.32–1.00) (Table 3.30). The condition of mud crab populations in the harbour was graded poor for the fifth consecutive year. The 2022 score was the lowest received (as with 2020) since monitoring began in 2017.

For the third consecutive year, the zones with the highest overall scores were The Narrows and Boat Creek (0.58, C). The Narrows has been the highest scoring zone for five of the six years of monitoring and has consistently received a very good score for abundance (0.85, A). Boat Creek had the highest sex ratio score (0.43, D) and second highest abundance score (0.32, D) in 2022.

Two zones—Calliope Estuary (0.43, D) and Graham Creek (0.33, D)—received poor scores while the Inner Harbour received a very poor score (0.14, E) (Table 3.30). An overall score for Auckland Creek was not calculated for the fifth consecutive year, as fewer than five crabs were caught in this zone over the two sampling periods. An overall score for Rodds Bay could also not be calculated due to an insufficient number of crabs sampled.

Table 3.30: Mud crab indicator scores for the 2022 Gladstone Harbour Report Card. Scores from 2021 and 2020 are shown for comparison.

Zone	Sex Ratio	Abundance (CPUE)	Prevalence of rust lesions	2022	*2021*	*2020*
1. The Narrows	0.00	0.85	0.90	0.58	*0.64*	*0.60*
2. Graham Creek	0.00	0.00	1.00	0.33	*0.39*	*0.34*
4. Boat Creek	0.43	0.32	0.98	0.58	*0.60*	*0.71*
5. Inner Harbour	0.00	0.11	0.32	0.14	*0.39*	*0.39*
6. Calliope Estuary	0.29	0.00	1.00	0.43	*0.47*	*0.19*
7. Auckland Inlet	NC	0.00	NC	NC	*NC*	*NC*
13. Rodds Bay	NC	0.00	NC	NC	*0.56*	*0.22*
Harbour score	**0.14**	**0.18**	**0.84**	**0.39**	***0.48***	***0.39***

CPUE - catch per unit effort, NC - Not calculated owing to inadequate sample size (n < 5)

Sex ratio (based on legal size limit)

In 2022, three zones received the lowest possible score (0.00, E) while Boat Creek and Calliope Estuary received poor scores (Table 3.30). It is important to note scores for all zones except The Narrows were based on a relatively small number of crabs (n ≤ 22). Moreover, a score for Auckland Creek and Rodds Bay could not be calculated due to an insufficient catch (n < 5); see Table 3.31.

In 2022, a total of 89 legal-sized mud crabs (carapace width >150 mm) were caught, of which 21 were male—about four females for every one male crab. This was a similar general overall sex ratio as in 2021, however, nearly triple the number of crabs were sampled in the previous year (n = 229). Overall, the harbour score for sex ratio (0.14, E) was identical to 2021 and higher than preceding years.

Table 3.31: Sex ratio of legal-sized mud crabs (carapace width >150 mm) in February and June 2022 by zone. Note, figures for sex ratio represent actual male-to-female crab ratios and not GHHP scores.

Zone name	**February 2022**			**June 2022**		
	Males	Females	Sex ratio	Males	Females	Sex ratio
1. The Narrows	0	7	0.00	4	34	0.12
2. Graham Creek	/	4	/	1	3	0.33
4. Boat Creek	2	4	0.50	6	4	1.50
5. Inner Harbour	0	2	/	1	6	0.17
6. Calliope Estuary	1	1	1.00	2	3	0.67
7. Auckland Inlet	1	/	/	/	/	/
13. Rodds Bay	1	/	/	2	0	inf
Harbour average			**0.50**			**0.56**

/ - not calculable as no crabs caught, inf - infinity

Abundance: catch per unit effort (CPUE)

For the fifth consecutive year, the highest catch rate was recorded in The Narrows where there was an average of 1.4 mud crabs per pot (Table 3.32). However, this was considerably lower than in 2021 where there was an average of 3.9 mud crabs per pot. Abundance at Boat Creek received a poor score (0.32, D) while the remaining five zones received a very poor score; see Table 3.30. Abundance scores at four zones—Graham Creek, Calliope Estuary, Auckland Creek and Rodds Bay—were the lower possible score (0.00, E). Overall, the harbour score for abundance showed a marked decline from 0.45 (D) in 2021 to 0.18 (E) in 2022.

Table 3.32: Catch per unit effort (CPUE) for pots set in seven harbour zones during the February and June 2022 mud crab surveys.

Zone name	February 2022			June 2022		
	Pots	Crabs caught	CPUE	Pots	Crabs caught	CPUE
1. The Narrows	20	10	0.50	20	46	2.30
2. Graham Creek	20	4	0.20	20	4	0.20
4. Boat Creek	16	7	0.44	16	15	0.94
5. Inner Harbour	20	6	0.30	20	10	0.50
6. Calliope Estuary	20	4	0.20	20	6	0.30
7. Auckland Inlet	20	1	0.05	20	0	0.00
13. Rodds Bay	20	1	0.05	20	3	0.15
Harbour average			**0.25**			**0.63**

Visual health: prevalence of rust lesions

A very low incidence of rust lesions was recorded at four of the five zones where it could be calculated. Very good scores (0.90–1.00, A) were shown at The Narrows, Graham Creek, Boat Creek and Calliope Estuary (Table 3.30). In contrast and as in the previous year, the Inner Harbour received a poor score (0.32, D). The score for prevalence of rust lesions was not calculated in Auckland Inlet and Rodds Bay due to an insufficient catch (n < 5). Overall, the 2022 score for this sub-indicator was similar to the previous year (0.86, A). When comparing sampling events, fewer crabs with rust lesions were encountered in the June sample (Table 3.33).

Table 3.33: Number and percentage of mud crabs with external lesions (rust spot) in February and June 2022 by zone.

Zone name	February 2022		June 2022	
	# with lesions	% with lesions	# with lesions	% with lesions
1. The Narrows	0	0%	4	9%
2. Graham Creek	0	0%	0	0%
4. Boat Creek	0	0%	1	7%
5. Inner Harbour	3	50%	1	10%
6. Calliope Estuary	0	0%	0	0%
7. Auckland Inlet	0	0%	/	/
13. Rodds Bay	0	0%	0	0%
Harbour average		**7%**		**4%**

/ - not calculable as no crabs caught

3.3.15. Mud crab conclusions

The mud crab sub-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. The mud crab sub-indicators were designed to reveal change over time and elucidate trends in mud crab health. Confidence in the mud crab indicator will improve as the dataset grows annually. The overall score 0.39 (D) was similar to the previous four years (which ranged from 0.39 to 0.49, D), however, showed a decline from the preceding year (0.48, D) (Figure 3.16). This result was due to an overall very poor sex ratio, very poor abundance, and good prevalence of rust lesions scores (Table 3.30).

In Queensland, it is illegal to take female crabs, hence changes in the ratio of male to female crabs can indicate changes in fishing pressures. In 2022, the majority of zones where sex ratio could be calculated scored very poorly—a similar pattern to previous years. When the two sampling periods were combined, there were more than two females to every one male crab within all five of the measured zones. This pattern suggests that fishers are observing regulations for the release of female crabs, which may be skewing the sex ratio towards a female-dominated population. 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. In addition to changes in population dynamics, sex ratio may impact 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. Research is required to understand how a changed sex ratio impacts the health of mud crab populations.

In the current year, abundance received a very poor overall score. This is the first year since monitoring began in 2017 in which this has occurred. Caution is required in interpreting the abundance scores as CPUE data can be highly variable. As in previous years the abundance scores ranged from very good to very poor at the zone level. Mud crab populations can be influenced by a range of anthropogenic and natural impacts. Natural factors include differences in crab distribution, growth or survival related to habitat, reproductive cycles, and environmental conditions such as temperature and water motion (Knuckey, 1999; Alberts-Hubatsch et al., 2016). Sampling factors including capture technique, sampling area and time may also influence mud crab catches. When these factors are controlled, abundance can indicate changes to external pressures such as extraction (fishing), habitat availability and recruitment limitation. The reliability of the abundance sub-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 year. Four of the five zones where this measure could be calculated received very good scores (Table 3.30). 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 7% in February and 4% in June, considerably lower than the 37% incidence recorded in 2012 (Dennis et al., 2016) or less than half of the 22% recorded in the late 1990s by Andersen et al. (2000).

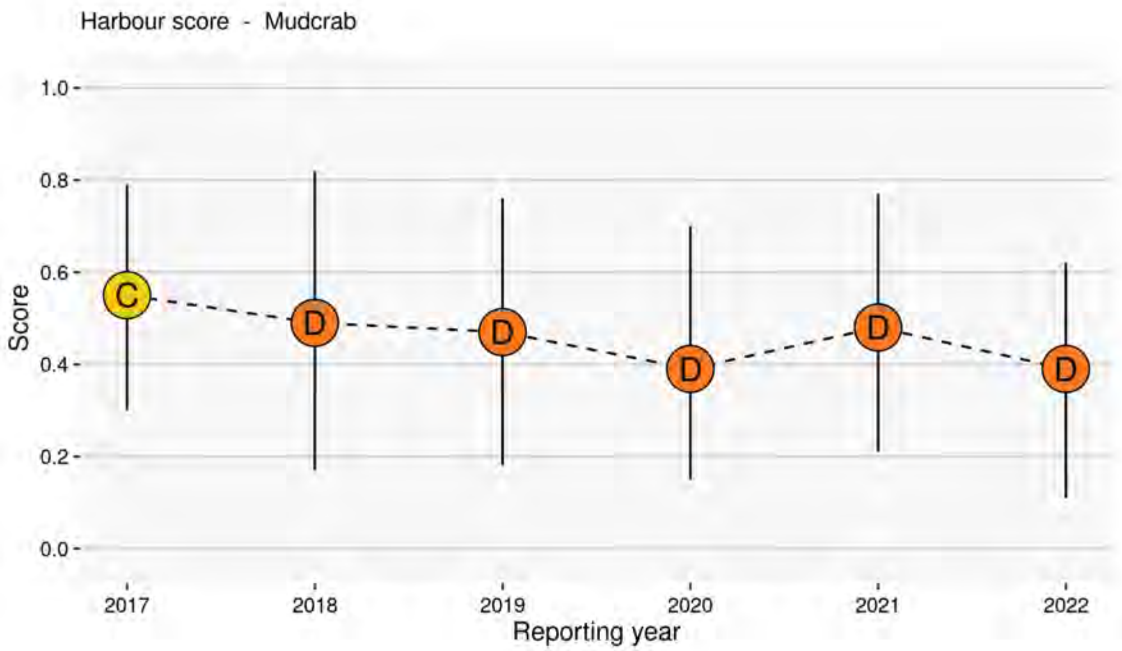


Figure 3.16: Trends in the harbour score for mud crabs, 2017 – 2022 (Error bars show 95% bootstrap confidence intervals).

3.4. Other data used in the Calculation of 2022 Environmental component scores

Report card monitoring between 2014 and 2022 has revealed that while some environmental indicators are sensitive to short-term environmental changes in response to climate variables such as rainfall (e.g. seagrass and fish recruitment) other environmental indicators such as mangroves are more stable owing to the greater buffering capacity of these long-lived species.

From 2020, there was a move to less frequent monitoring where indicators or components show little annual variation but will show long-term trends. From 2020, monitoring of the social, cultural, economic components and the mangroves indicator will move to a frequency of between two and five years. Where an indicator has shown little variation e.g., water quality and coral, but there is strong public interest, annual monitoring will be retained.

Report card scores for indicators monitored at a frequency of greater than one-year will be calculated with the data collected in previous years. In the 2022 report card, the full results for the mangrove indicator are those presented in the 2019 and 2020 report card Technical Report. A summary of these results is presented below.

The move to less frequent monitoring of less variable indicators is an approach consistent with other regional report cards (e.g. Wet Tropics, Dry Tropics and Mackay-Whitsunday) which monitor indicators such as invasive weeds, fish, riparian condition, mangrove salt march, impoundment, fish barriers, fresh water wetlands, and agricultural stewardship at greater than one-year frequency (Wet Tropics Healthy Waterways Partnership, 2018; Mackay-Whitsunday Healthy Rivers to Reef Partnership, 2018; Whitehead, 2020).

3.4.1 Mangroves 2019

Mangroves were last monitored in 2019 (Duke & Mackenzie, 2019) and had an overall score of 0.57, a small change from 2018 when the score was 0.60 (Figure 3.17). As variation in mangrove scores is likely to be small from year to year in response to changes to climatic conditions such as wet or dry years and/or changes in sea level, mangrove monitoring will move to a five-year cycle with the next scheduled monitoring to occur in 2024. While it is acknowledged that mangrove condition could change rapidly in response to unpredictable catastrophic events such as cyclones or major marine spills the probability of such events is small. Hence, the results from monitoring conducted in 2019 will be used to calculate the overall Environmental score in 2022 and in subsequent report cards until the next round of mangrove monitoring is conducted. A full description of the mangrove indicator including all methods and results can be found in the 2019 Technical Report and 2019 Mangrove project report.

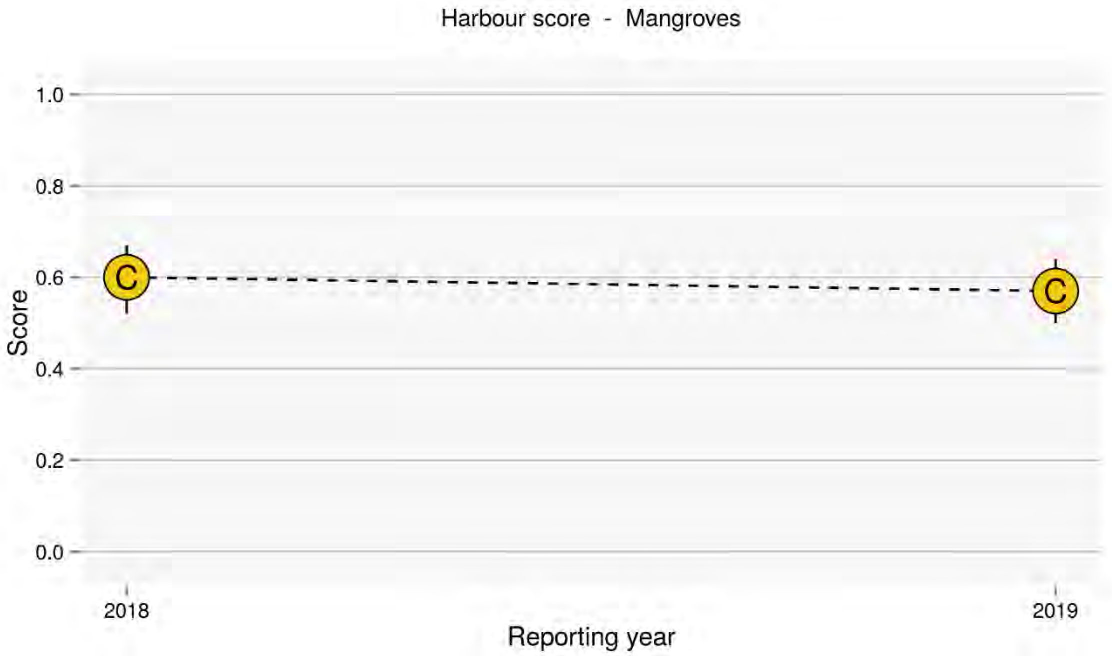


Figure 3.17: Change in overall mangrove score between 2018 and 2019 (Error bars show 95% bootstrap confidence intervals).

3.4.2 Overall mangrove results 2019

The overall score for mangroves in Gladstone Harbour in 2019 was 0.57 (C). Three zones were in good condition and eight zones were considered satisfactory (Table 3.34). Two zones Boat Creek (0.46, D) and Boyne Estuary (0.26, D) received poor overall scores—a result of poor scores for canopy condition (0.38, D) and shoreline condition (0.46, D) in Boat Creek and very poor scores for canopy condition (0.19, E) and shoreline condition (0.19, E) in Boyne Estuary.

Table 3.34: Overall mangrove zone and harbour scores for the 2019 reporting year. The 2018 scores are shown for comparison.

Zone	Mangrove extent	Mangrove canopy condition	Shoreline condition	Zone score 2019	*Zone score 2018*
1. The Narrows	0.79	0.55	0.61	0.65	*0.56*
2. Graham Creek	0.83	0.34	0.76	0.64	*0.67*
3. Western Basin	0.76	0.39	0.37	0.51	*0.57*
4. Boat Creek	0.54	0.38	0.46	0.46	*0.63*
5. Inner Harbour	0.62	0.51	0.53	0.55	*0.43*
6. Calliope Estuary	0.80	0.48	0.47	0.58	*0.67*
7. Auckland Inlet	0.76	0.57	0.62	0.65	*0.68*
8. Mid Harbour	0.39	0.63	0.63	0.55	*0.55*
9. South Trees Inlet	0.79	0.50	0.51	0.60	*0.61*
10. Boyne Estuary	0.39	0.19	0.19	0.26	*0.41*
11. Outer Harbour	0.76	0.64	0.59	0.66	*0.65*
12. Colosseum Inlet	0.85	0.67	0.65	0.72	*0.69*
13. Rodds Bay	0.68	0.57	0.67	0.64	*0.71*
Harbour score	**0.69**	**0.49**	**0.54**	**0.57**	***0.60***

3.5. Environmental component and indicator groups results

The overall Environmental component score for the 2022 report card was 0.64 (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 scores were derived by aggregating the water and sediment quality indicator scores for water and sediment quality, aggregating the seagrass, corals and mangrove indicators for habitats and aggregating the two fish health indicators, fish recruitment and mud crabs for fish and crabs. The overall scores for the three indicator groups were: water and sediment quality 0.89 (A), habitats 0.48 (D), and fish and crabs 0.55 (C) (Table 3.35).

The zone scores for the habitat indicator group only include the habitat indicators present in each zone. While mangroves are present in all zones, coral is 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. Sampling for fish health was conducted in the north, central and southern areas of the harbour and a single fish health score was applied to all zones. Fish recruitment surveys were conducted in all zones except the Outer Harbour. Mud crab monitoring was conducted in six zones. Water and sediment quality sampling was conducted in all zones. No new mangrove monitoring was conducted in 2022 and the mangroves scores are based on the survey work conducted in 2019.

Table 3.35: Environmental indicator group scores and overall environmental scores for the 13 harbour zones and the overall harbour scores in 2022.

Zone	Indicator groups		
	Water and sediment quality	Habitats (seagrass, corals and mangroves)	Fish and crabs
1. The Narrows	0.85	0.79*	0.67~
2. Graham Creek	0.91	0.64	0.64~
3. Western Basin	0.88	0.66*	0.89
4. Boat Creek	0.84	0.46	0.57~
5. Inner Harbour	0.89	0.47*	0.48
6. Calliope Estuary	0.89	0.58	0.57~
7. Auckland Inlet	0.86	0.65	0.47
8. Mid Harbour	0.91	0.45*#	0.69
9. South Trees Inlet	0.88	0.80*	0.66
10. Boyne Estuary	0.93	0.26	0.71
11. Outer Harbour	0.94	0.42#	0.80
12. Colosseum Inlet	0.89	0.72	0.54
13. Rodds Bay	0.88	0.53*	0.42~
Harbour score	**0.89**	**0.48**	**0.55**

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

The first full report card was released in 2015 and contained four environmental indicators; water quality, sediment quality, seagrass and coral. Since then, four additional environmental indicators have been added to the program. These are fish recruitment in 2016, mud crabs in 2017, mangroves in 2018 and fish health in 2019. From 2020, owing to budget constraints, several environmental indicators will only be monitored every three or five years. Hence mangroves were not assessed in the 2020 to 2022 report cards and the 2019 results were used to calculate the habitat score.

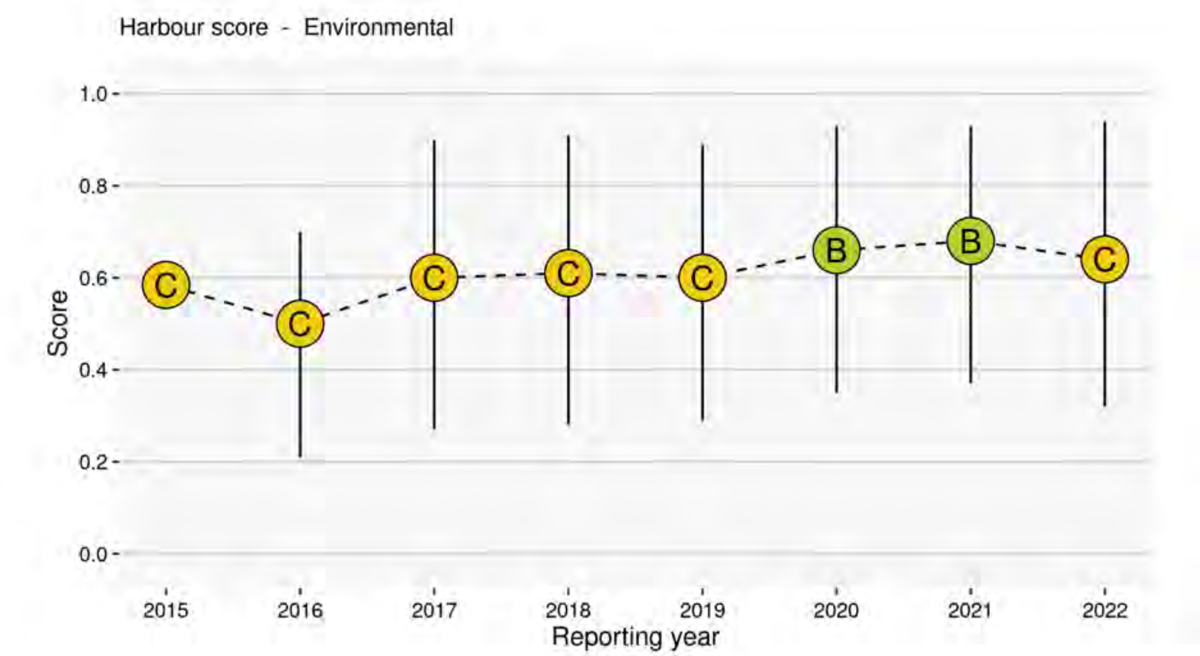


Figure 3.18: Trends in the overall Environmental score, 2015 – 2022 (Error bars show 95% bootstrap confidence intervals).

4. The Social component

Report cards have become an increasingly popular way to document environmental condition. The 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 4.1). These indicators were developed from the GHHP vision and piloted in 2014 (Pascoe et al., 2015).

4.1. 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 residents from the Gladstone 4680 postcode area was conducted in June 2022. Participants were contacted using a random dialling technique to mobile phone numbers. Note that the CATI survey was administered via different avenues across years; with 2014 to 2016 via landline only, 2017 to 2018 via landline and mobile numbers, and 2019 via landline, mobile numbers, and internet survey. 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, each participant was asked a specific question to suggest the first three words that come to their mind when thinking about Gladstone Harbour.

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).

Table 4.1: The indicator groups, indicators and measures used to determine social scores for the 2022 report card (Source: De Valck, 2022).

Indicator Groups	Indicators	Measures	Data Source	Baseline data
Harbour usability	Satisfaction with harbour recreational activities	How satisfied with last trip	CATI Survey (avg: Questions: Q11b, Q12b1, Q15b, Q25)	10-point scale
		Quality of ramps and facilities	CATI Survey (avg: Q28, Q28a)	10-point scale
	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
	Harbour safety	Marine safety incidents	*Marine incidents in Queensland 2020* Department of Transport and Main Roads, Maritime Safety Queensland	Data 2011-2020 (calendar year). Rate of incidents in Gladstone maritime region compared to other Qld regions
		Oil spills	Queensland Department Transport and Main Roads, *Maritime Safety Queensland Branch, 2019-2020 and 2020-2021*	Data 2011-2020 (calendar year). Rate of incidents in Gladstone maritime region compared to other Qld regions
		Safe at night	CATI Survey (Q44)	10-point scale
		Happy to eat seafood	CATI Survey (Q43)	10-point scale
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
	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, Q45b))	10-point scale

4.2. Development of indicators and scoring

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.

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 scientists). 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).

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.

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 perceptions of harbour safety for human use. The harbour usability survey questions related to participants' satisfaction with their last trip to the harbour, quality of boat ramps and facilities, satisfaction with air and water quality, safety at night, and whether people were happy to eat seafood from the harbour. There were 11 harbour usability-related survey questions in total. 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 have been 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 oil 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 2022 so that scores from 2016 continue to be 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 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 whether Gladstone Harbour makes living in Gladstone a better experience, the level of participation in community events, and the aesthetic value of Gladstone Harbour to residents.

The aesthetic value measure was added to the liveability and wellbeing indicator group in 2018. Previous word cloud analysis highlighted the importance of the 'aesthetic aspect' of the harbour to Gladstone residents although there was no related measure in the indicator framework until that point. The addition of the aesthetic value measure complemented the liveability and wellbeing indicator group. By adding this measure, it was expected that the score of the indicator group would slightly improve compared to previous years, as aesthetic value is likely to attract a relatively high score. This means the score for the indicator group is not fully comparable with previous years.

4.3. Results

A total of 200 respondents participated in the 2022 CATI survey. A 'snapshot' impression of the harbour was captured from the community survey respondents when they were asked to provide three words to describe the harbour. As in previous years 'Beautiful' and 'Fishing' were the two most used words, followed by words evoking the industrial nature of the harbour ('Busy', 'Industry', 'Industrial').

The overall score for the Social component in the 2022 Gladstone Harbour Report Card was 0.68 (B), which was comparable with the 2019 score (0.67, B). Although scores have been similar since 2016, the overall Social health of Gladstone Harbour has shown a strong improvement since the 2014 Pilot Report Card when it was 0.58 (C).

Of the three indicator groups, harbour usability received a score of 0.62 (C), harbour access a score of 0.68 (B) and liveability and wellbeing a score of 0.71 (B) (Figure 4.1). All three indicator group scores were comparable (+/- 0.02) with the scores received in 2019.

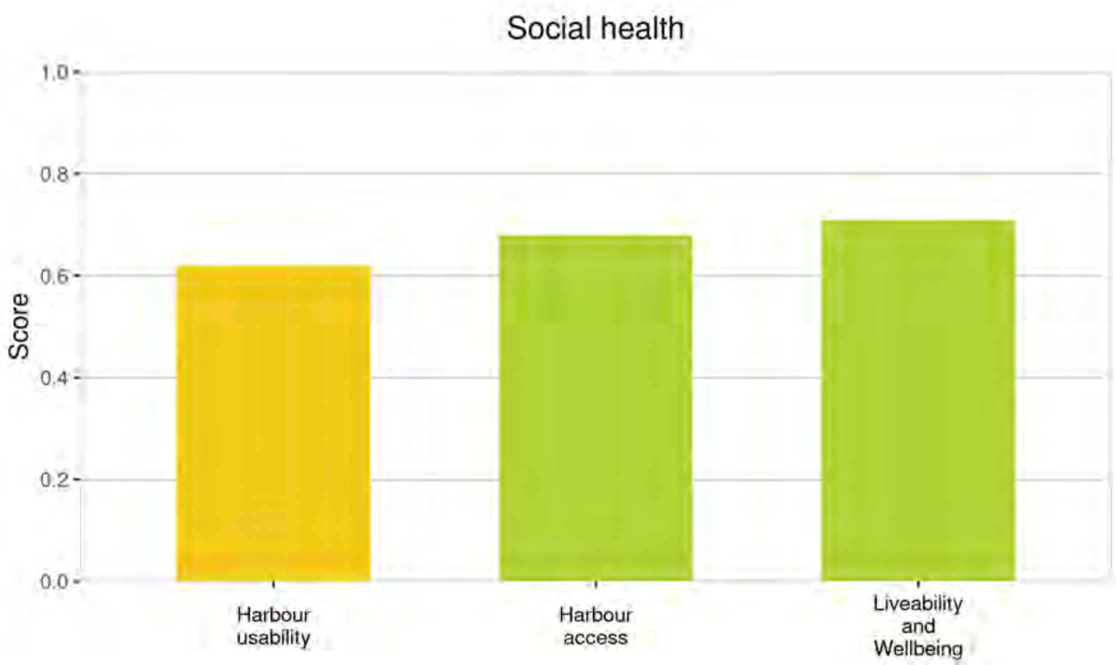


Figure 4.1: Indicator group scores within the Social component of the 2022 Gladstone Harbour Report Card.

Harbour usability

The scores for the three indicators of harbour usability ranged from 0.55 (C) for *perceptions of harbour safety for human use*, up to 0.59 (C) and 0.73 (B) for *perceptions of air and water quality* and *satisfaction with harbour recreational activities* respectively (Figure 4.2). The overall score for the harbour usability has been relatively stable since monitoring began in 2014, particularly since 2017 (Figure 4.3).

Scores from two measures, *how satisfied with the last recreational trip* (0.76) and *quality of boat ramps and facilities* (0.66) determined the final scores for *satisfaction with harbour recreational activities* indicator. The scores were averaged from the satisfaction ratings received for four CATI questions for the former measure and two CATI questions for the latter. Overall, the *satisfaction with harbour recreational activities* indicator score 0.73 (B) was slightly higher than in previous years.

The score for the *perceptions of air and water quality* indicator has steadily increased since monitoring began in 2014 0.46 (D) to 0.59 (C) in 2022. All three measure scores for this indicator remained broadly consistent to the 2019 scores: *water quality satisfaction* was 0.60 (C), *air quality satisfaction* was 0.47 (D) and *water quality does not affect use of the harbour* was 0.69 (B).

The score for the *perceptions of harbour safety for human use* indicator declined, receiving a satisfactory score (0.55, C). This indicator has two measures based purely on the secondary data and another two based on satisfaction ratings from the CATI survey. Both *marine safety incidents* (0.46, D) and *oil spills* (0.38, D) received poor scores. The other two measures in this indicator, *safety at night* and *happy to eat seafood*, received a good score of 0.69 (B).

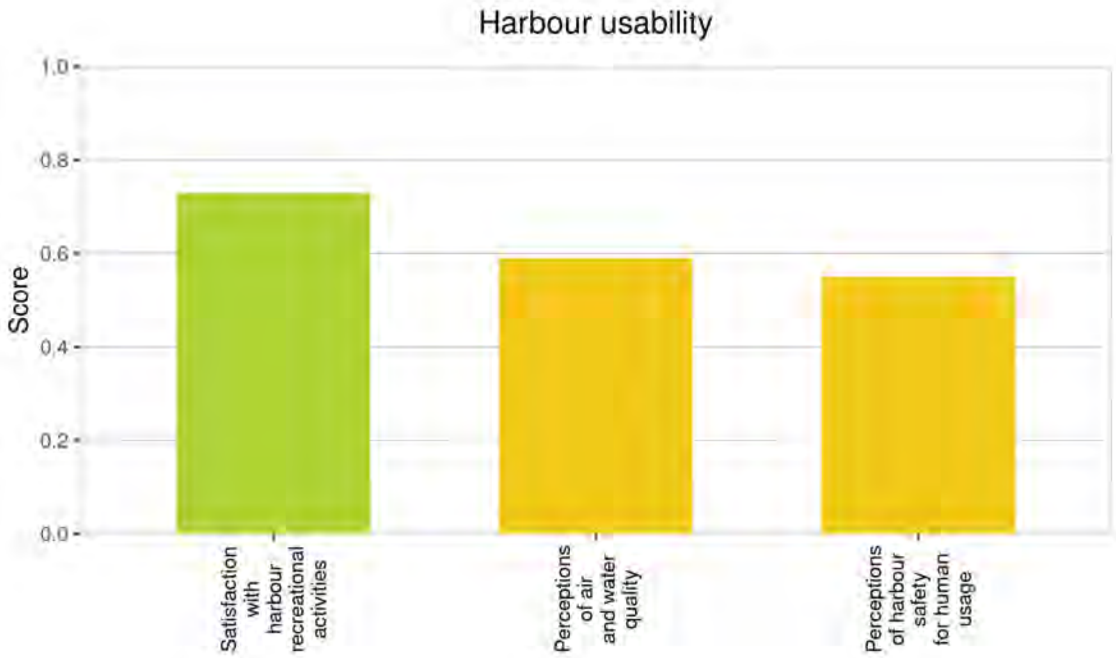


Figure 4.2: Scores for the three indicators of harbour usability in the 2022 Gladstone Harbour Report Card.

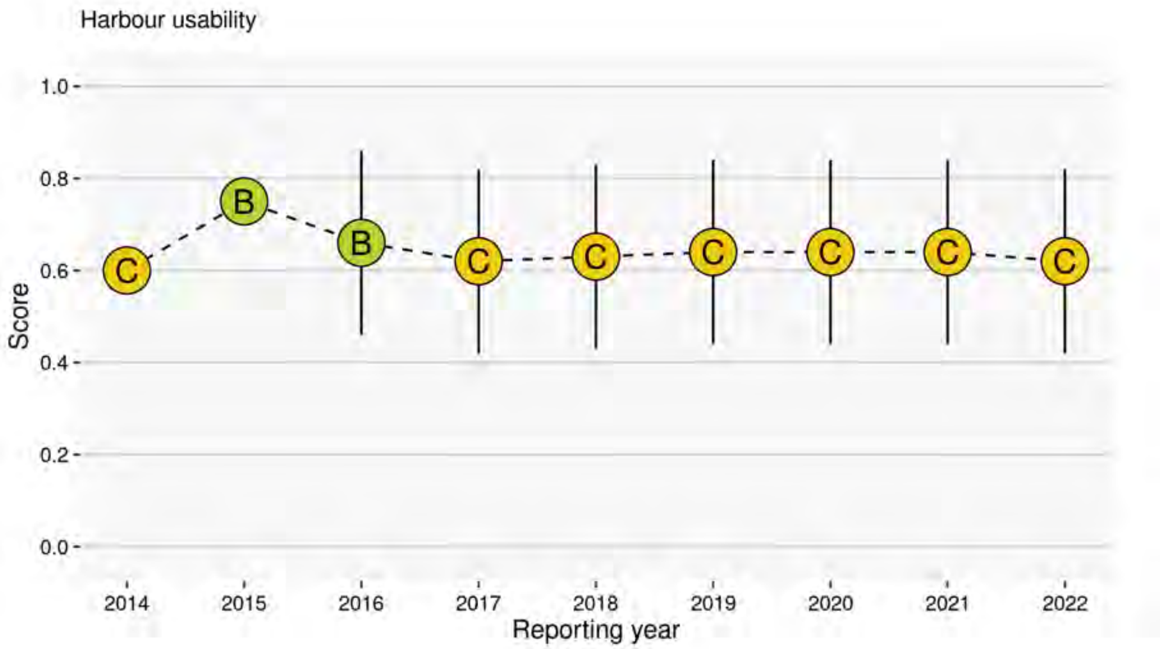


Figure 4.3: The trend of scores received for the harbour usability indicator group since year 2014. Please note an error in the 2014-2015 score which was reported at 0.75 instead of 0.65, hence there has been little real change from 2014-2015 to 2015-2016.

Harbour access

The scores for the four indicators of harbour access ranged from 0.63 (C) for *perceptions of harbour health* to 0.75 (B) for *satisfaction with harbour access* (Figure 4.5). *Satisfaction with boat ramps and public spaces* and *perceptions of barriers to access* both had good scores at 0.67 (B) and 0.69 (B) respectively. All four indicator scores were consistent with the previous year. Specifically, scores for *satisfaction with boat ramps and public spaces*, *satisfaction with access to harbour* and *perceptions of harbour health* showed a slight increase while *perceptions of barriers to access* remained unchanged to 2019 scores. Of the eleven measures used to report on the *harbour access* indicator group there were seven good scores (B) and four satisfactory scores (C).

All four harbour access indicator scores have been steadily increasing since the pilot report card in 2014 (Figure 4.6).

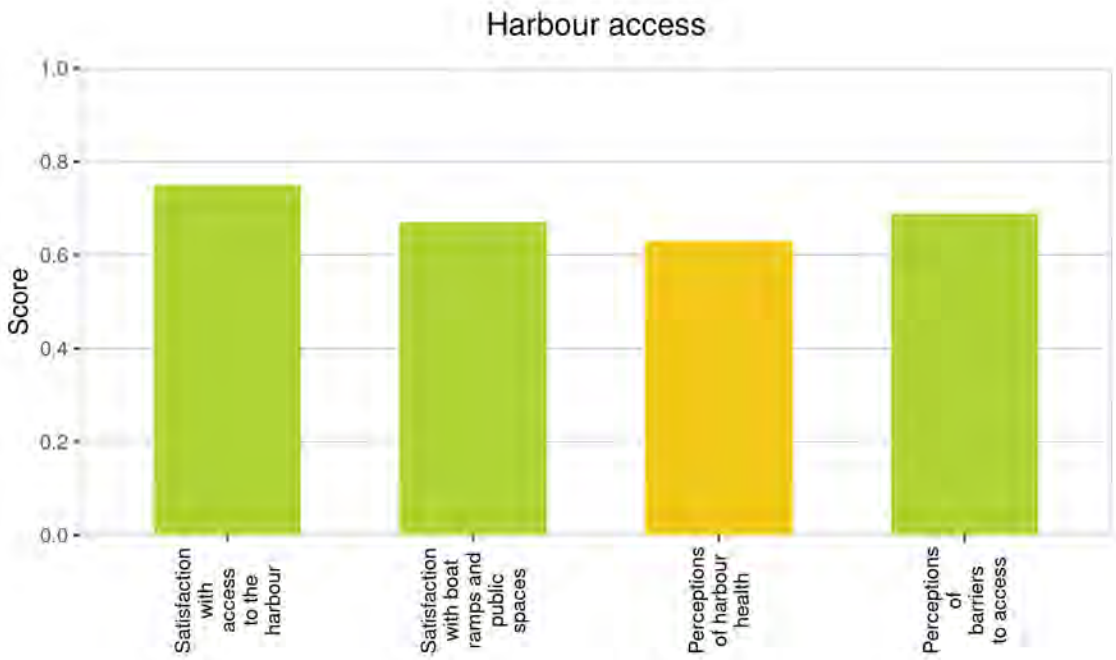


Figure 4.4: Scores for the four indicators of harbour access in the 2022 Gladstone Harbour Report Card.

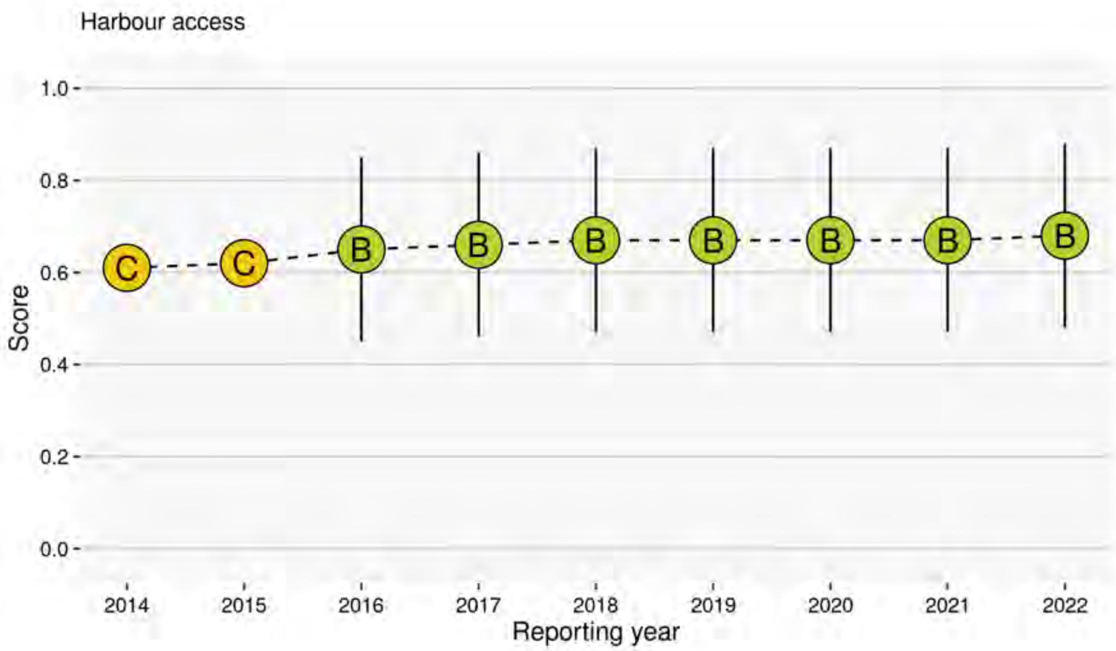


Figure 4.5: The trend of scores received for the harbour access indicator group since year 2014.

Liveability and wellbeing

Liveability refers to the elements in a region that affect how individuals feel about living there. These elements include the 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). The *contribution of the harbour to liveability and wellbeing* indicator was 0.71 (B), which was one point higher than the 2019 score (0.70, B) and seven points higher than the 2014 baseline (0.64, D).

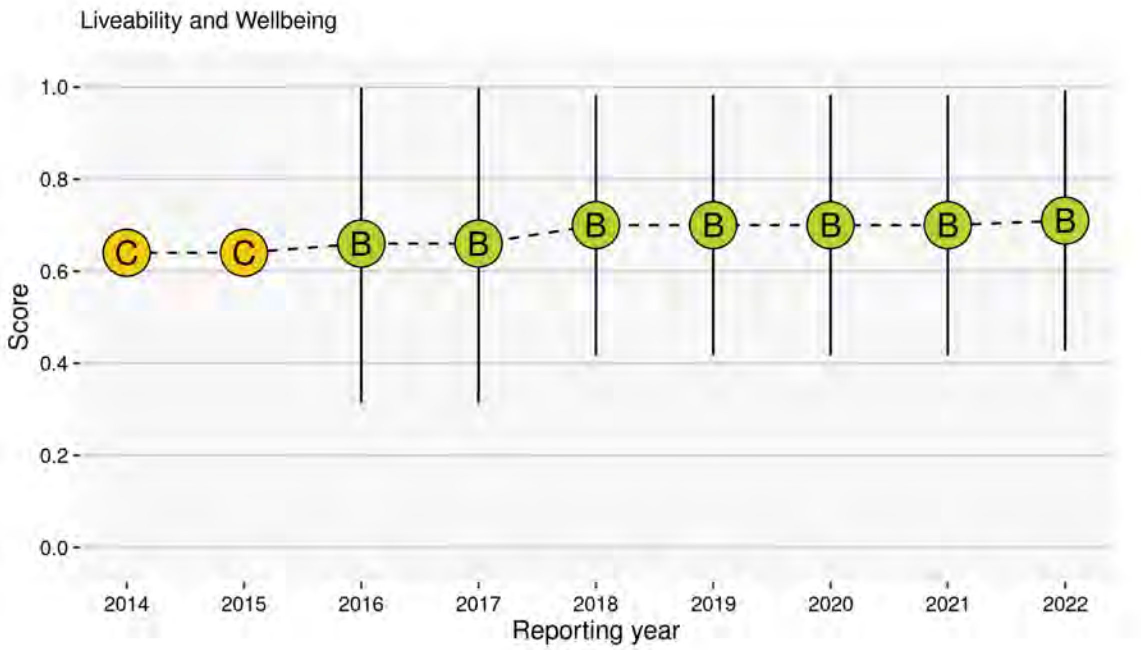


Figure 4.6: The trend of scores received for the liveability and wellbeing indicator group since year 2014. Scores prior to 2018 were based on two measures. The third measure *aesthetic value* was added to the indicator group in 2018.

4.4. 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 (Table 4.2). The overall score was one-point higher than in 2019 and was similar to that in 2016, 2017 and 2018. The Social component has received a good score (B) for the fifth consecutive year in which it was actively monitored (Figure 4.7). Note active monitoring was not completed in 2020 and 2021.

Harbour usability

Overall, the harbour usability score improved from the 2014 baseline.

The harbour usability scores have fluctuated between satisfactory and good scores since monitoring began in 2014. This year, the indicator declined slightly compared to 2018 and maintained its score as satisfactory. This decline comes from the 8-point decline in people's *perception of harbour safety for human use*. The *oil spills* and *marine safety incidents* figures have worsened compared to 2019—from 0.66 (B) to 0.38 (D) and from 0.54 (C) to 0.46 (D), respectively. Over the 2018-2020 period 1,360 new vessels were registered in Gladstone, with a new total of 49,115 vessels. The increased traffic may have contributed to the higher number of maritime incidents. It is also worth noting that many oil spill incidents reported in 2020 represent small amounts (in litres) whereas more pollution events in past years were reported in surface terms. As such, the significant reduction in *oil spills* score may be a data-entry artefact. Beyond these two measures, other measures scored similar to the previous year.

As in previous years, the survey indicated 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 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 harbour area.

Harbour access

The harbour access score has been stable over the last five years when monitoring occurred.

The 2022 harbour access results indicate that residents continue to enjoy 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 increases in the recreational use of the harbour, boat ownership and use of boat ramps compared to 2018. Residents' perceptions around barriers to access has increased slightly since 2018. However, respondents continue to perceive that marine debris and litter is a problem in the harbour, although they did not see the levels 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 Gladstone Harbour.

There seems to be a steady trend in people's perception of Gladstone Harbour as an essential part of the experience of living in Gladstone. Respondents are also generally happy with the aesthetics of the harbour. However, many respondents state that they rarely participate in community events in the Gladstone Harbour area, indicating that improvements in community participation can still be made. Overall, respondents enjoyed going to the harbour because of its natural beauty.

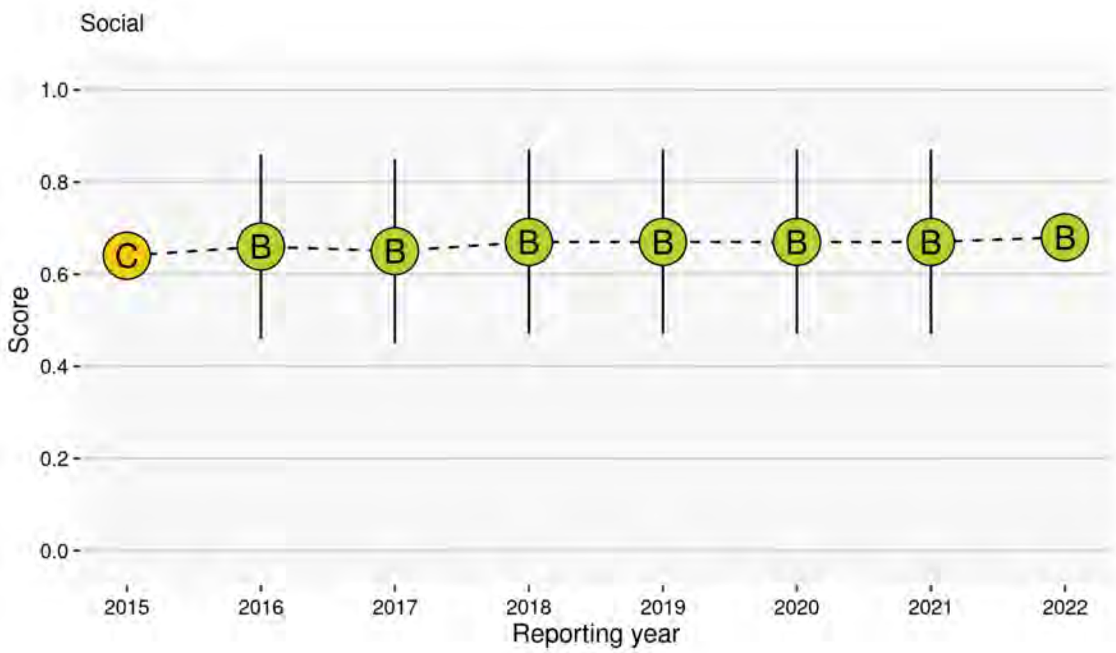


Figure 4.7: Report card scores for the Social component from 2015 to 2022.

Table 4.2: Social health scores compared between report cards, 2014–2022 (De Valck, 2022).

Social component: 2022 = 0.68 (B) 2019 = 0.67 (B); 2014 = 0.58 (C)									
Indicator Group	**Score**	**Indicators**	**Score**			**Measures**	**Score**		
			2022	**2019**	**2014**		**2022**	2019	2014
Harbour usability	**0.62 (C)** *2019: 0.64* *2014: 0.60*	Satisfaction with harbour recreational activities	**0.73**	0.71	0.70	How satisfied last recreational trip	**0.76**	0.74	0.74
						Quality of ramps and facilities	**0.66**	0.67	0.63
		Perceptions of air and water quality	**0.59**	0.58	0.46	Water quality satisfaction	**0.60**	0.58	0.39
						Air quality satisfaction	**0.47**	0.48	0.40
						Water quality does not affect harbour use	**0.69**	0.67	0.58
		Perceptions of harbour safety for human use	**0.55**	0.63	0.38	Marine safety incidents	**0.46**	0.54	0.24
						Oil spills	**0.38**	0.66	0.15
						Safety at night	**0.69**	0.62	0.58
						Happy to eat seafood	**0.69**	0.68	0.55
Harbour access	**0.68 (B)** *2019: 0.67* *2014: 0.61*	Satisfaction with access to the harbour	**0.75**	0.73	0.67	Fair access to harbour	**0.75**	0.73	0.67
		Satisfaction with boat ramps + public spaces	**0.67**	0.65	0.60	Frequency of use	**0.51**	0.51	0.46
						Number of boat ramps	**0.70**	0.69	0.65
						Access to public spaces	**0.77**	0.74	0.68
		Perceptions of harbour health	**0.63**	0.63	0.53	Great condition	**0.68**	0.68	0.54
						Optimistic about future health	**0.62**	0.63	0.56
						Improved over the last 12 months	**0.60**	0.59	0.50
		Perceptions of barriers to access *(Note: scores are reversed. A higher score denotes a decrease in the barrier)*	**0.69**	0.66	0.64	Marine debris a problem	**0.51**	0.48	0.51
						Marine debris affects access	**0.74**	0.72	0.70
						Shipping reduced my use	**0.74**	0.69	0.63
						Recreation boats reduced my use	**0.74**	0.72	0.69
Liveability wellbeing	**0.71 (B)** *2019: 0.70* *2014: 0.64*	Liveability and wellbeing	**0.71**	0.70	0.64	Makes living in Gladstone a better experience	**0.78**	0.76	0.71
						Participate in community events	**0.55**	0.56	0.53
						Aesthetic value	**0.76**	0.73	na

5. The Cultural component

To assess the Cultural health of the harbour six 'sense of place' indicators and two Indigenous cultural heritage indicators are used. The Indigenous cultural heritage indicators have been developed and piloted during 2016, with further refinement to the indicator framework in 2018. As no new Indigenous cultural heritage surveys were conducted in 2022, the Indigenous cultural heritage scores are those used in the 2018 report card and the overall Cultural component score is aggregated from the 2022 'sense of place' scores and the 2018 Indigenous cultural heritage scores.

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'.

5.1. Data collection

Sense of place

The CATI survey of 439 people conducted in June 2019 to assess Social health also collected data for the 'sense of place' indicator. That survey included 17 questions dedicated to gathering community views on six Cultural indicators (Table 5.1. '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 2018 (Table 5.2). 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 Consulting, 2018). Overall, 11 sites were revisited in 2017–18 (Table 5.2).

Table 5.1: Indicator groups, indicators and measures used to determine cultural scores for the 2022 Gladstone Harbour Report Card (Source for 'sense of place': De Valck, 2022). Note, Indigenous cultural heritage was last assessed in 2018.

Indicator Group	Indicators	Measures	Data source	Baseline data
Sense of place	Place attachment	No place better	CATI survey (Q30)	10-point scale
		Who I am	CATI survey (Q51)	10-point scale
	Continuity	How long lived in the area	CATI survey (Q3)	10-point scale
		Stay in area five years?	CATI survey (Q53)	10-point scale
	Pride in the region	Proud living in the area	CATI survey (Q50)	10-point scale
	Well-being	Quality of life	CATI survey (Q52)	10-point scale
		Input into management	CATI survey (Q47)	10-point scale
	Appreciation of the 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	Variety of marine life	CATI survey (Q55)	10-point scale
		Opportunities for outdoor recreation	CATI survey (Q56)	10-point scale
		Affects 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

Data collection involved recording the health of various heritage aspects relevant to Cultural health (e.g. knapping floor, chopper tools, signage, gravestones and monuments) in relation to pre-defined criteria (Terra Rosa Consulting, 2018). A series of 360° panoramic imagery were 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 2019 report card (Terra Rosa Consulting, 2016, 2017 & 2018).

Traditional Owners and Elders from Gooreng Gooreng and Byellee groups assisted the field studies.

Table 5.2: Sites within each zone surveyed during 2016, 2017 and 2018.

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**

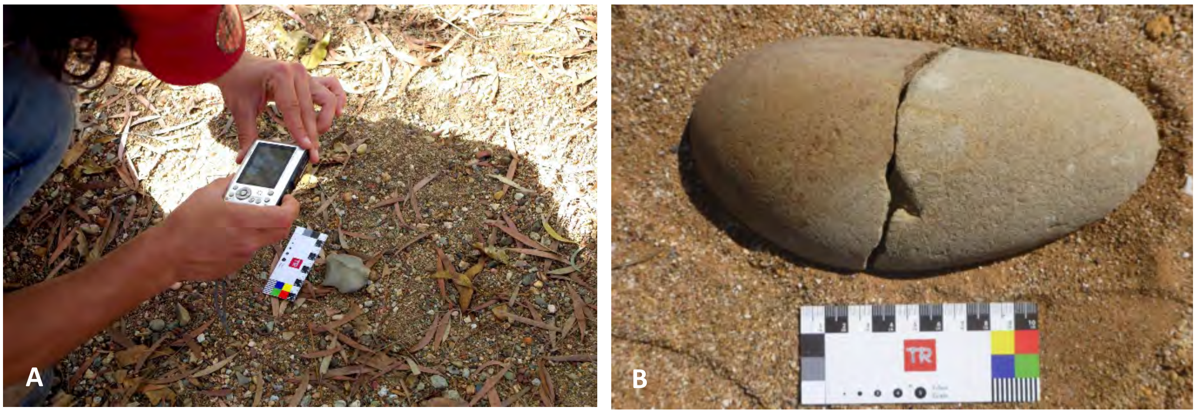


Figure 5.1: A – Photographing site features, B – Grinding stone at Facing Island (Source: Terra Rosa, 2018)

Definition of indicators 'sense of place'

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

- Place attachment 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.

- Pride in the region 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.

- Well-being 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.

- Appreciation of the 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 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 heritage scores for the report card are based on three physical condition measures assessed at site level and six management strategies measures assessed at zone level (Figure 5.2). The new framework simplifies the assessment and calculation of the Indigenous cultural heritage indicators, although the scores calculated through the new framework may not be fully comparable to 2016 and 2017 scores.

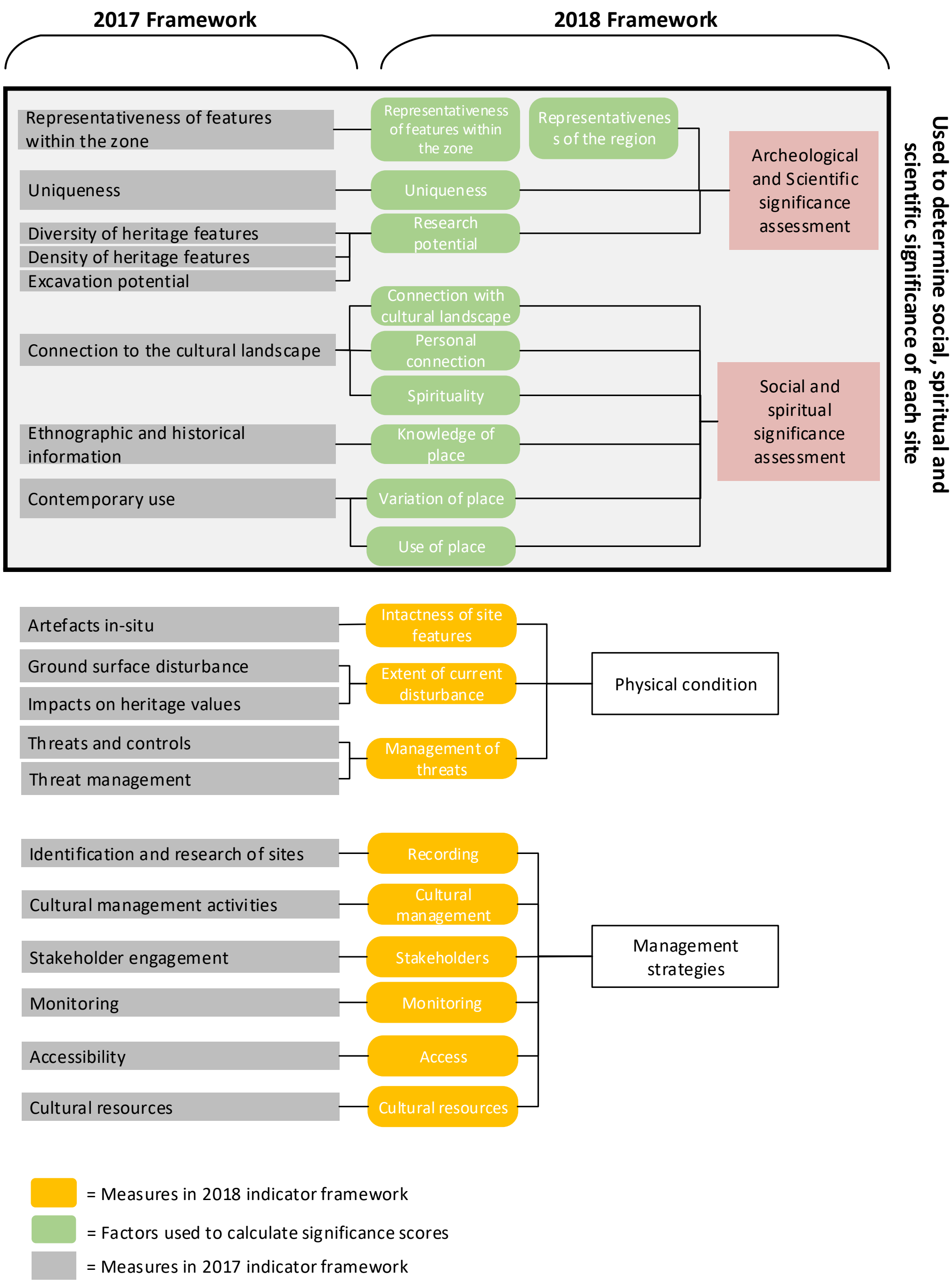


Figure 5.2: 2017 Indigenous cultural health indicators are mapped to the 2018 indicator framework. Two measures which were in the 2017 framework—site registration and developmental pressure measures—are no longer assessed in the 2018 framework.

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 the degree to which sites have been 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.

- 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.

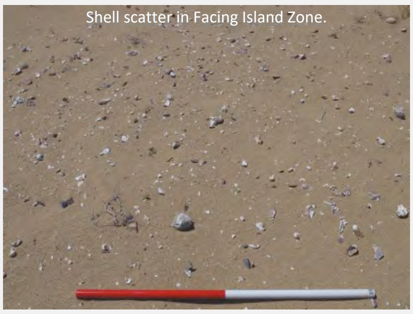
What are heritage elements and heritage features?

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)

- 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.

5.2. Development of indicators and scoring

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.

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.

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 Consulting, 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 5.2). 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 Consulting, 2018).

A cultural locus site is considered to be the most important for ongoing monitoring and management of that zone (Terra Rosa Consulting, 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 5.3). The management strategies indicators were given fixed weightings at sub-indicator level.

Data aggregation was done using simple averages.

Figure 5.3: Weightings derived from ethnographic consultation for cultural locus and other sites within each zone for Cultural health indicators.

5.3. Results

The overall score for the Cultural component of the Gladstone Harbour Report Card for 2022 was 0.61 (C). This comprised two indicator groups, 'sense of place' assessed on new data for 2022 and Indigenous cultural heritage (Figure 5.4) which uses the 2018 report card scores. 'Sense of place' received a score of 0.68 (B) and Indigenous cultural heritage received a score of 0.54 (C).

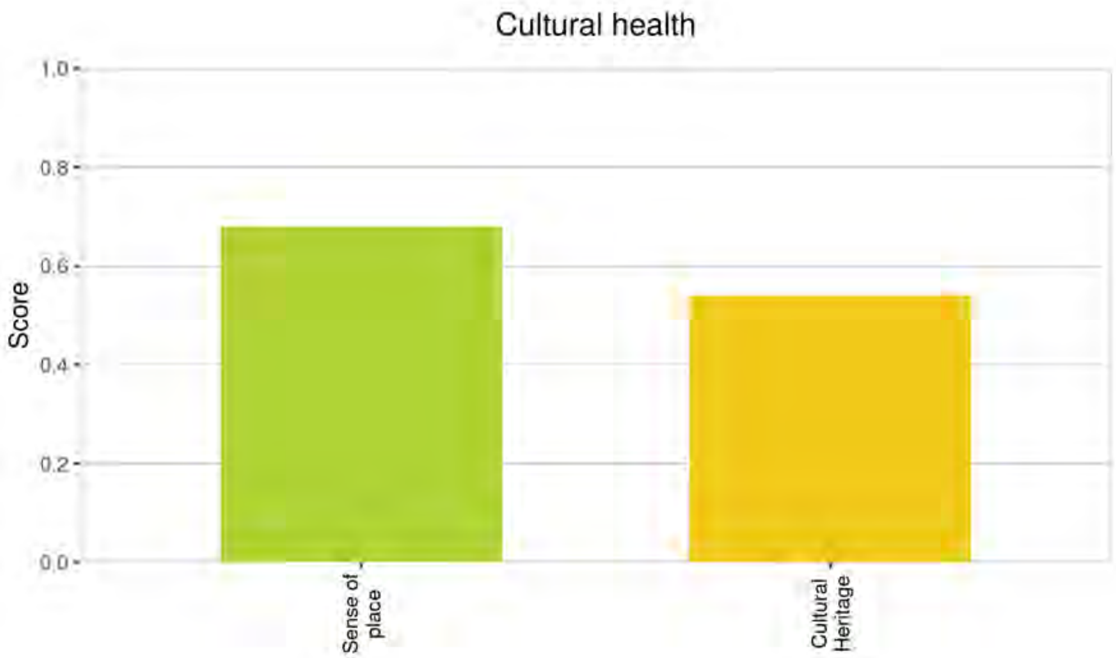


Figure 5.4: Indicator group scores within the Cultural component of the 2022 Gladstone Harbour Report Card.

Sense of place

The 'sense of place' indicator scores ranged from 0.61 (C) for place attachment to 0.84 (B) for appreciation of the harbour (Figure 5.5). All scores were similar to those recorded in 2019.

The highest score of 0.84 (B) received for appreciation of the harbour was driven by three measures which received equally high scores (*key part of community* – 0.82 (B), *great asset to region* – 0.83 (B) and *great asset to Queensland* – 0.83 (B)). The lowest score of 0.61 (C) was for place attachment which received scores of 0.56 (C) for no better place and 0.65 (C) for who I am.

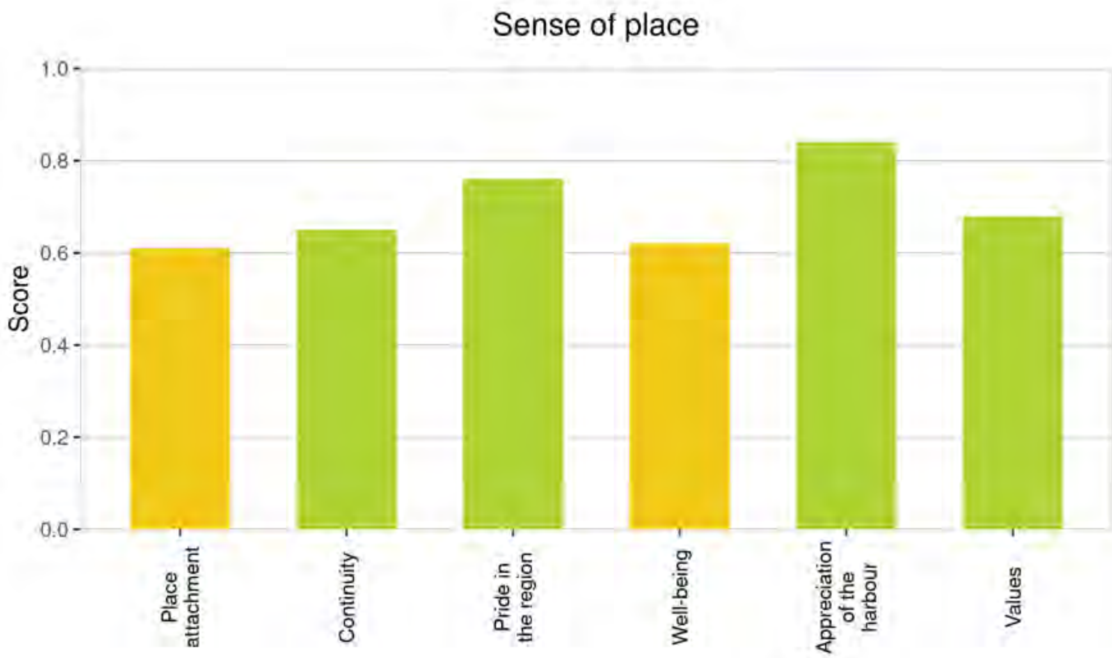


Figure 5.5: Indicator scores for 'sense of place' indicator group used for Cultural health in the 2022 Gladstone Harbour Report Card.

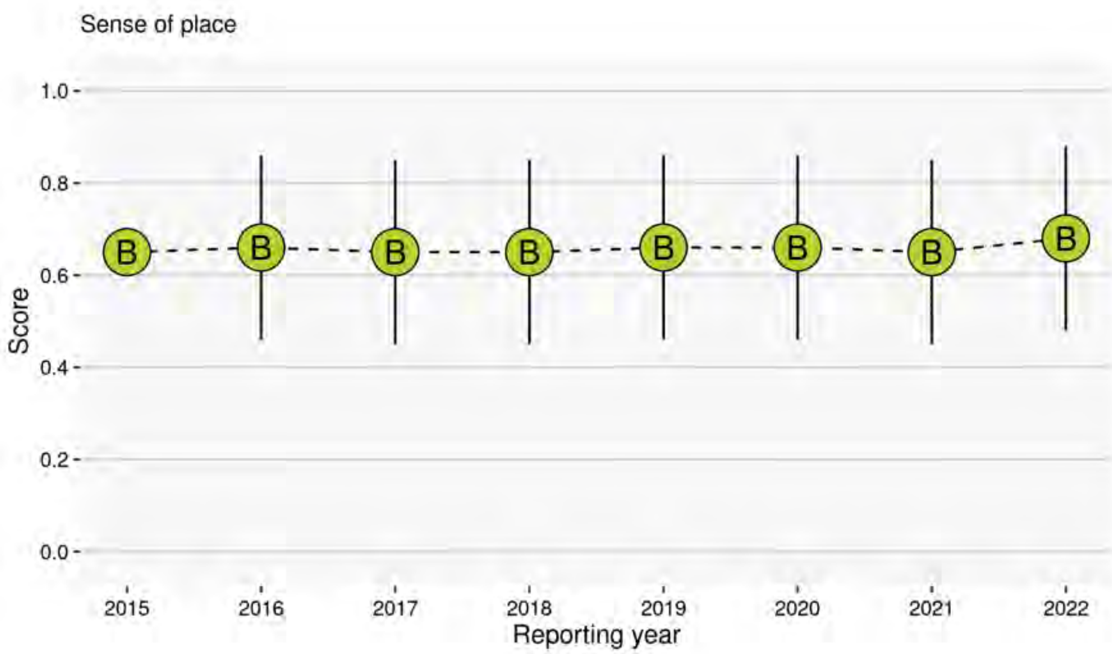


Figure 5.6: Report card scores for the 'sense of place' indicator group from 2015 to 2022.

Indigenous cultural heritage

The overall score for Indigenous cultural heritage in 2018 was 0.54 (C), similar to the 2017 score of 0.55 (C). This score is based on the satisfactory scores received for physical condition (0.56, C) and management strategies (0.52, C) 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 5.7).

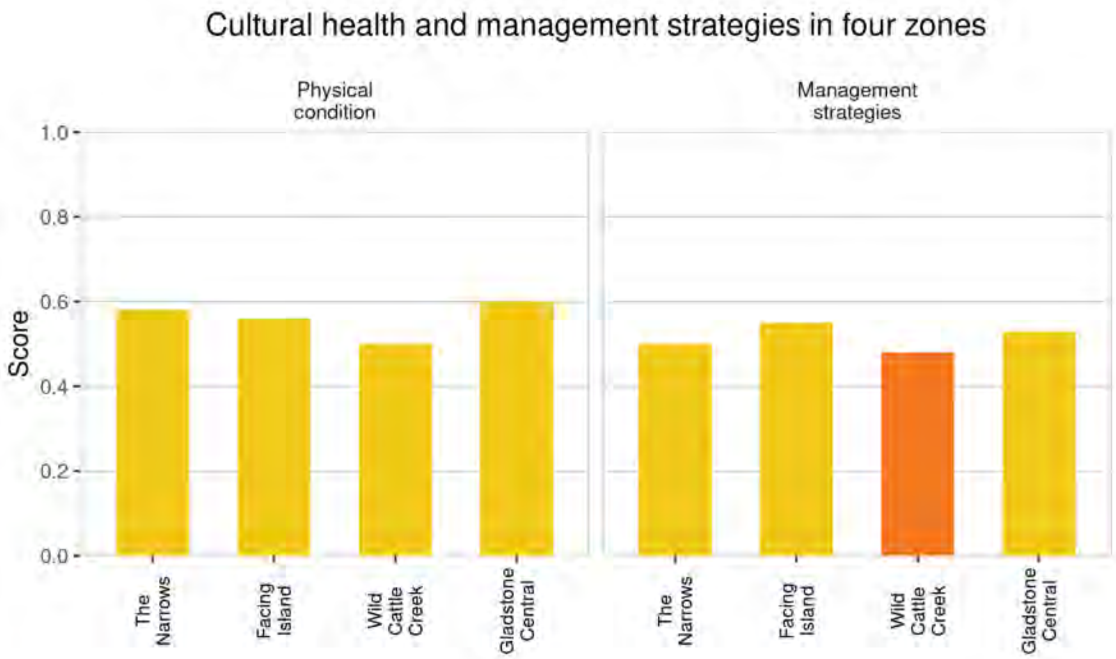


Figure 5.7: Indicator scores for physical condition and management strategies across four reporting zones in the 2022 Gladstone Harbour Report Card (based on data collected in 2018).

The physical condition is based on three measures—*intactness of site features, extent of current disturbance* and *management of threats* (Table 5.3).

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 5.8) (Terra Rosa Consulting, 2018).

Table 5.3: Overall scores for physical condition scores across four zones.

	Intactness of sites 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 5.8: 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 5.4). 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 Consulting, 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 5.4: 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

5.4. Cultural indicator conclusions

Sense of place

Overall, the score for 'sense of place' was 0.68 (C). This score has showed little variation over the five years it has been assessed (0.65 in 2015, 0.66 in 2016, 0.65 in 2017,0.65 in 2018 and 0.68 in 2019) (Table 5.5). This result suggests that the community's expectations of Gladstone Harbour area are mostly being met.

The 2022 score for place attachment was slightly higher than the scores from 2016 to 2018 scores, suggesting an increased engagement with and appreciation of the harbour.

The continuity score also improved compared to the previous years receiving a B grade for the first time. This indicator measures the length of time people have lived in the area and whether they planned to stay for the next five years. These results suggest that the community is becoming less transient and more stable.

The score for appreciation of the harbour remains the highest scoring indicator (0.84) and this has remained relatively stable since 2014. This shows that residents continue to have a positive outlook for the harbour area and what it provides to the community.

The pride in the region score has also remained stable indicating that residents continue to feel proud living in the Gladstone community.

The values indicator scores have also been stable between 2015 and 2019. The scores and stability suggest that residents of 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 values indicator keeps rising, thanks to the good scores received for the scenery and outdoor recreation measures. By contrast, the three measures related to cultural, spiritual and historical significance of the area still receive low scores (0.55, 0.54 and 0.57, respectively, as per Table 5.5).

Table 5.5: 'Sense of place' scores compared between report cards, 2014–2022 (De Valck, 2022).

Indicator group Score/grade	Indicators	Score			Measures	Score		
		2022	2019	2014		**2022**	2019	2014
Cultural component ('Sense of place') **0.68 (B)** *2019: 0.66* *2014: 0.64*	Place attachment	**0.61**	0.58	0.55	No place better	**0.56**	0.51	0.49
					Who I am	**0.65**	0.64	0.61
	Continuity	**0.65**	0.58	0.57	How long lived in area	**0.55**	0.44	0.46
					Plan to stay the next 5 years	**0.76**	0.71	0.68
	Pride in the region	**0.76**	0.74	0.69	Feel proud living in Gladstone	**0.76**	0.74	0.69
	Well-being	**0.62**	0.61	0.55	Quality of life	**0.69**	0.69	0.64
					Input into management	**0.55**	0.54	0.46
	Appreciation of the harbour	**0.84**	0.83	0.80	Key part of community	**0.82**	0.82	0.79
					Great asset to region	**0.83**	0.82	0.79
					Great asset to Queensland	**0.83**	0.81	0.81
	Values	**0.68**	0.66	0.64	Variety of marine life	**0.72**	0.73	0.64
					Opportunities for outdoor recreation	**0.79**	0.78	0.76
					Affects visitors to the region	**0.74**	0.73	0.67
					Enjoy scenery and sights	**0.79**	0.76	0.75
					Spiritually special places	**0.54**	0.50	0.52
					Culturally special places	**0.55**	0.51	0.50
					Historical significance	**0.57**	0.52	0.58

Indigenous cultural heritage

The Indigenous cultural heritage indicator framework was revised for the 2018 report card. The overall score for Indigenous cultural heritage is a result of nine 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 scores.

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 5.6).

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. 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 5.6: Overall scores for Indigenous cultural heritage indicator.

Zone	Overall			
	2022 (2018)	*2018[a]*	*2017*	*2016*
The Narrows	0.54	*0.54*	*0.56*	*0.53*
Facing Island	0.56	*0.56*	*0.55*	*0.57*
Wild Cattle Creek	0.49	*0.49*	*0.50*	*0.44*
Gladstone Central	0.57	*0.57*	*0.60*	*0.59*
Overall score	**0.54**	***0.54***	***0.55***	***0.53***

[a] Indigenous cultural heritage indicator framework was simplified in 2018. As such, scores are not directly comparable to previous years.

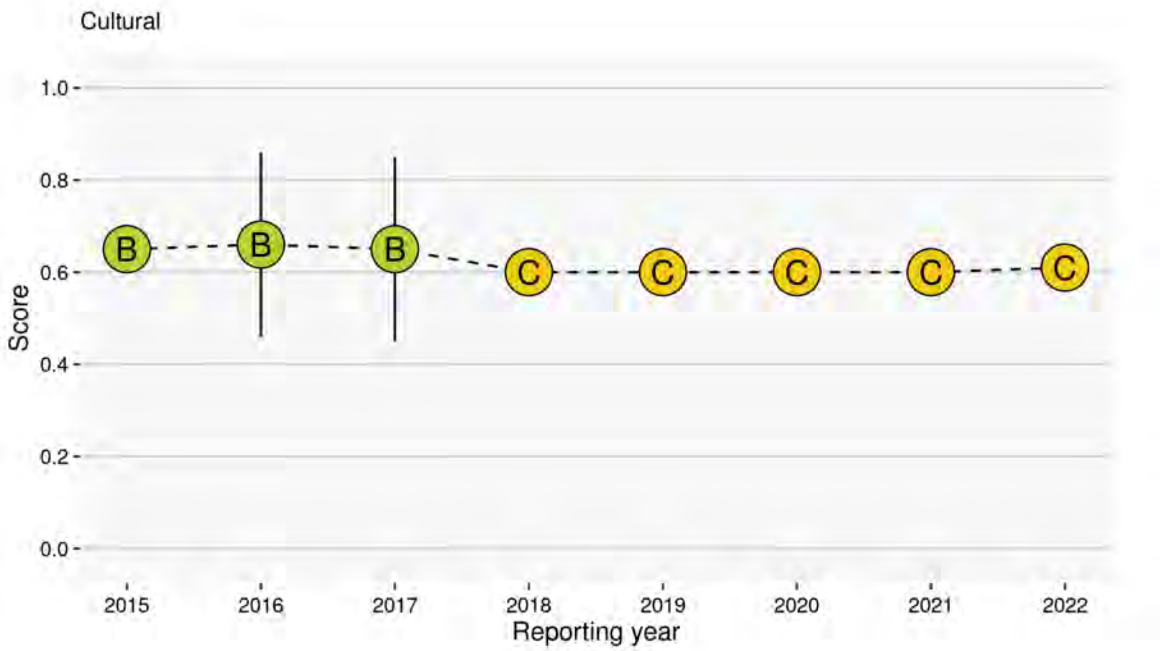


Figure 5.9: Report card scores for the Cultural component from 2015 to 2022.

6. 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.

6.1. Data collection

The Gladstone Local Government Area (LGA)was used as the broader geographic area for collecting economic data (Figure 10.28). 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 10.28).
- 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 10.29).

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 6.1). 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 6.1).

Overall, the data collection and analytical techniques in 2022 remained the same as the 2019 reporting year for all economic indicators. To improve the quality of the indicator framework, minor modifications have been made since the pilot report card in 2014:

- 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 in 2018.

Figure 6.1: Left – A ship being loaded with coal at Wiggins Island Coal Terminal. Right – A ship docked at Curtis Island prior to being loaded with liquefied natural gas (LNG) (Photo courtesy Uthpala Pinto).

Table 6.1: Data sources and baselines employed to derive the economic scores for the 2022 Gladstone Harbour Report Card (Source: De Valck, 2022).

Indicator group	Indicator	Measure	Data source	Baseline data
Economic Performance	Shipping activity	Shipping activity productivity calculated from monthly shipping movements by cargo type (2021-22 financial year)	Gladstone Ports Corporation (GPC) https://www.gpcl.com.au/wp-content/uploads/2022/09/DOCSCQPA-1820065-v1A-2021-22_Annual_Report_-_attached_to_Letter_to_shareholding_Ministers_on_15Sep22_pdf.pdf	Time series data from 2012-13 to 2021-2022
	Tourism expenditure	Gladstone region's total tourism expenditure output (2018-19 financial year)	Tourism Research Australia's information at the LGA level (Gladstone): https://www.tra.gov.au/Regional/local-government-area-profiles	10-year average 2009-10 to 2018-19
	Commercial fishing	Productivity of net fisheries	**Production (fishing effort)** Queensland Fishing (QFish), Queensland Department of Agriculture and Fisheries **Prices (fish, prawns & crabs)** Australian Bureau of Agricultural and Resource Economics and Sciences – Australian fisheries and aquaculture statistics 2020 (published Aug 2021)	10-year average (time series data from 2012-13 to 2021-22
		Productivity of trawl (otter) fisheries		
		Productivity of pot fisheries		
Economic stimulus	Employment	Gladstone LGA unemployment data (2021 Dec quarter)	Australian Department of Employment, *Small Area Labour Markets*	Queensland 2021 distribution (Dec quarter)
	Socio-economic status	Index of economic resources derived from 2016 ABS census and updated using the community CATI survey	2022 CATI survey; Australian Bureau of Statistics, 2016 census	Australian 2016 distribution
Economic value (Recreation)	Land-based recreation	Land-based recreation satisfaction + economic value	*Satisfaction*: CATI survey + economic value (Pascoe et al., 2014)	10-point scale
	Recreational fishing	Recreational fishing satisfaction + economic value	Satisfaction: CATI survey + 2018 updated economic value (Cannard et al., 2015; Windle et al., 2018)	10-point scale
	Beach recreation	Beach recreation satisfaction + economic value	Satisfaction: CATI survey + 2019 updated economic value	10-point scale
	Water-based recreation	Water-based recreation satisfaction + economic value	Satisfaction: CATI survey + economic value (Windle et al., 2017)	10-point scale

6.2. Development of indicators and scoring

Economic performance

The economic performance indicator group consists of three indicators: 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.

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).

Time series data from 2012-13 to 2021-2022 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 score is based on the expenditure on hotel accommodation, food and other local services relative to a 10-year average from 2009 to 2019 in the Gladstone Region. This information is sourced from Tourism Research Australia's information at the LGA level (Gladstone): https://www.tra.gov.au/Regional/local-government-area-profiles.

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:

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

$$= 50\%$$

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 and '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 2019 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.

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 2012. Production figures come from the three grids, but prices are Queensland state-wide estimates (Figure 10.29).

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 10.29).

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 in 2020.

The total value of fisheries production in Mackay (Grid O25) and Yeppoon (Grid R29) was also included in the analysis 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 2021 December 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 rec`reation 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 200 people within the Gladstone Region via the 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).

6.3. Results

The scores for each of the three economic indicator groups ranged from satisfactory to very good yielding an overall score of 0.76 (B) for the Economic component of the 2022 Gladstone Harbour Report Card (Figure 6.2). Of those indicator groups, economic performance received the highest score of 0.90 (A), economic value of recreation received a score of 0.77 (B) and economic stimulus received a score of 0.64 (C).

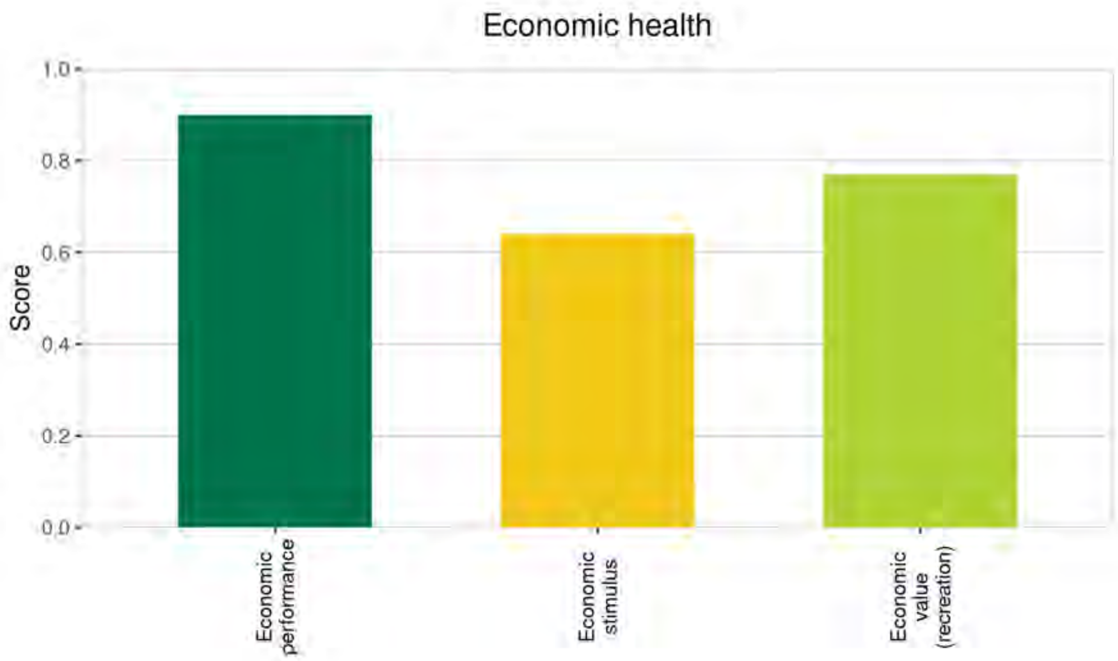


Figure 6.2: Indicator group scores within the Economic component of the 2022 Gladstone Harbour Report Card.

Economic performance

The economic performance of Gladstone Harbour remains in very good state (0.90, A) in 2022, a score that was identical to the 2019 score.

Within the economic performance indicator group, shipping activity received the highest score 0.90 (A) (0.90 in 2019) followed by tourism 0.90 (A) (0.90 in 2019). The commercial fishing received the lowest score of 0.45 (D) (0.36 in 2019) (Figure 6.3).

As with 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 6.4).

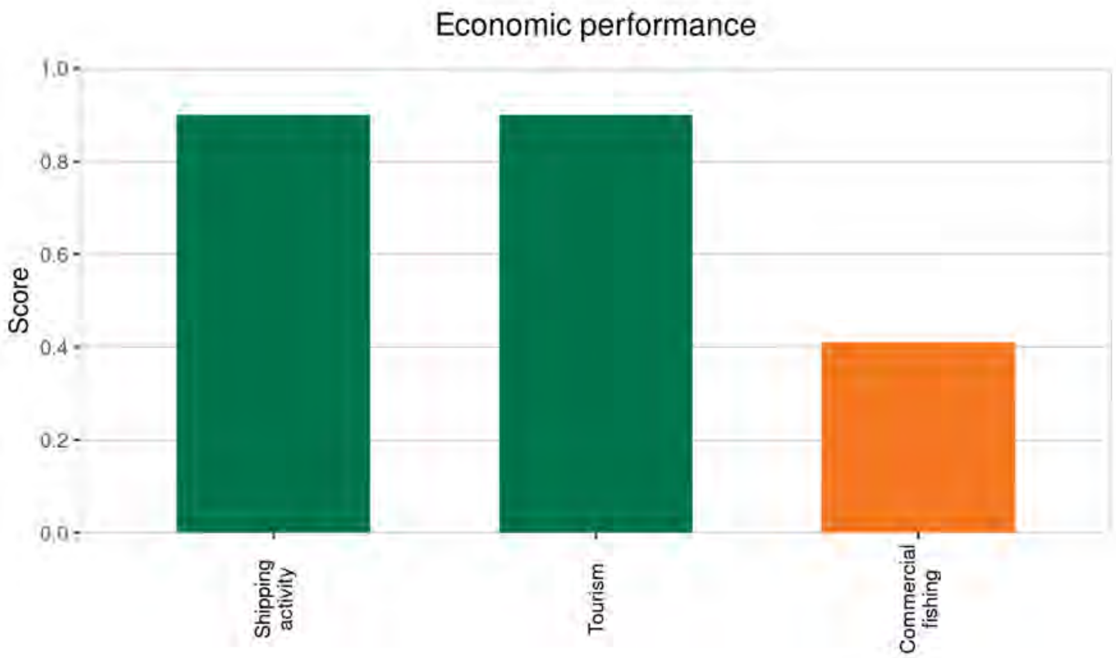


Figure 6.3: Scores for the three indicators of economic performance in the 2022 Gladstone Harbour Report Card.

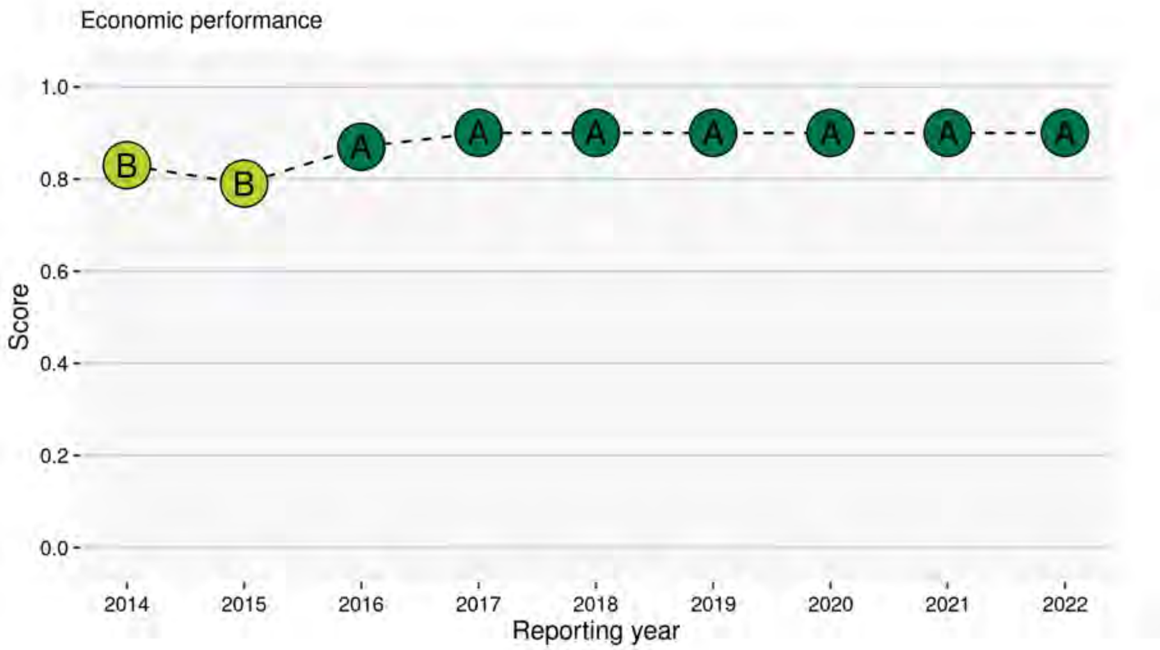


Figure 6.4: Economic performance scores from 2014 to 2022.

Shipping activity

The shipping activity indicator, based on the movement of shipping by cargo type, remained very good 0.90 (A), the same score as 2019. Overall capacity utilisation remains high even when the now completed Fisherman's Landing expansion is taken into consideration.

Tourism

The tourism indicator was 0.90 (A) in 2022, an identical score to that recorded in 2019.

Expenditure on tourism (accommodation, food and other local services) in the Gladstone Region was $308 million in 2017–18, down from $341 million in 2016–17, but up over previous years ($274.8 million in 2014–15, $266.7 million in 2013–14). Although there were some analytical differences since the 2014 pilot year, generally the score has increased over time.

Commercial fishing

The commercial fishing indicator score was poor 0.41 (D) in 2019 with a similar score to that recorded in 2018 (0.36, D). The scores in these two years represent a decline from 0.66 (B) in 2014 when this indicator was first assessed. The estimated value of recreational fishing ($61.2M in 2022) was considerably higher than commercial fishing ($0.53M in 2022) in the harbour.

Economic stimulus

The score for economic stimulus of 0.64 (C) was aggregated from the scores of two indicators: employment 0.45 (D) and socio-economic status 0.74 (C) (Figure 6.5). While the overall economic stimulus scores steadily declined since the monitoring began in 2014, this year's score was higher than the previous year's score (Figure 6.6).

The score for employment in 2022 (0.45) was similar to that reported in 2019 (0.44). The socio-economic status score for 2022 0.74 (C) was an improvement on the score recorded in 2019 (0.64). This may be explained by the fact that the Gladstone area might have been less heavily impacted by Covid-related socio-economic disruptions than larger urban areas in Australia.

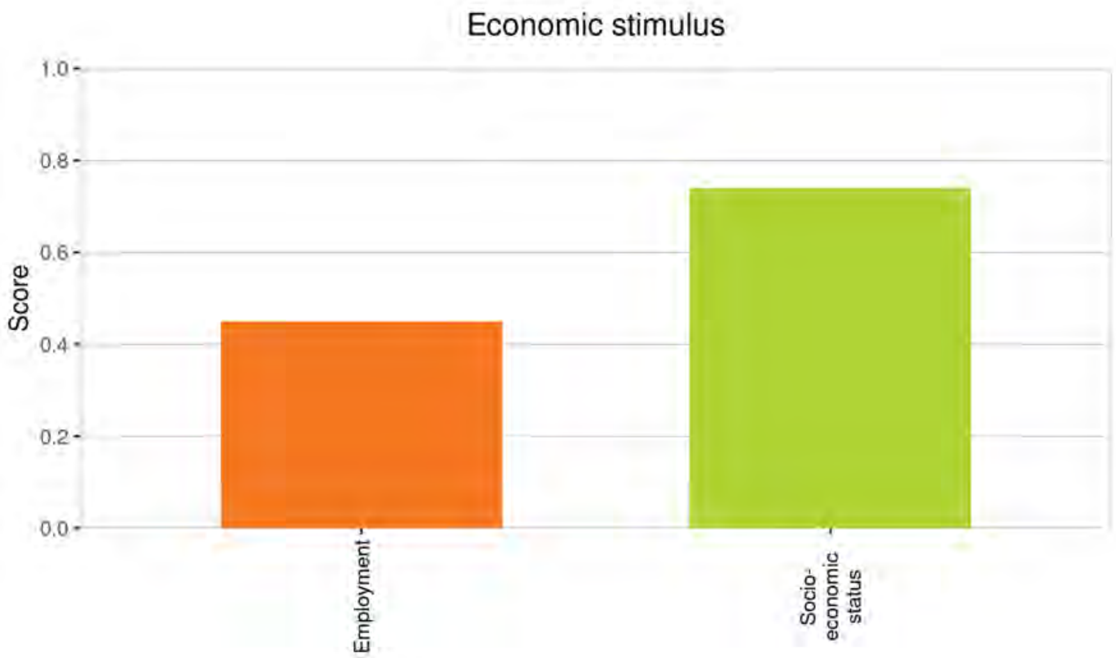


Figure 6.5: Scores for the two indicators of economic stimulus in the 2022 Gladstone Harbour Report Card.

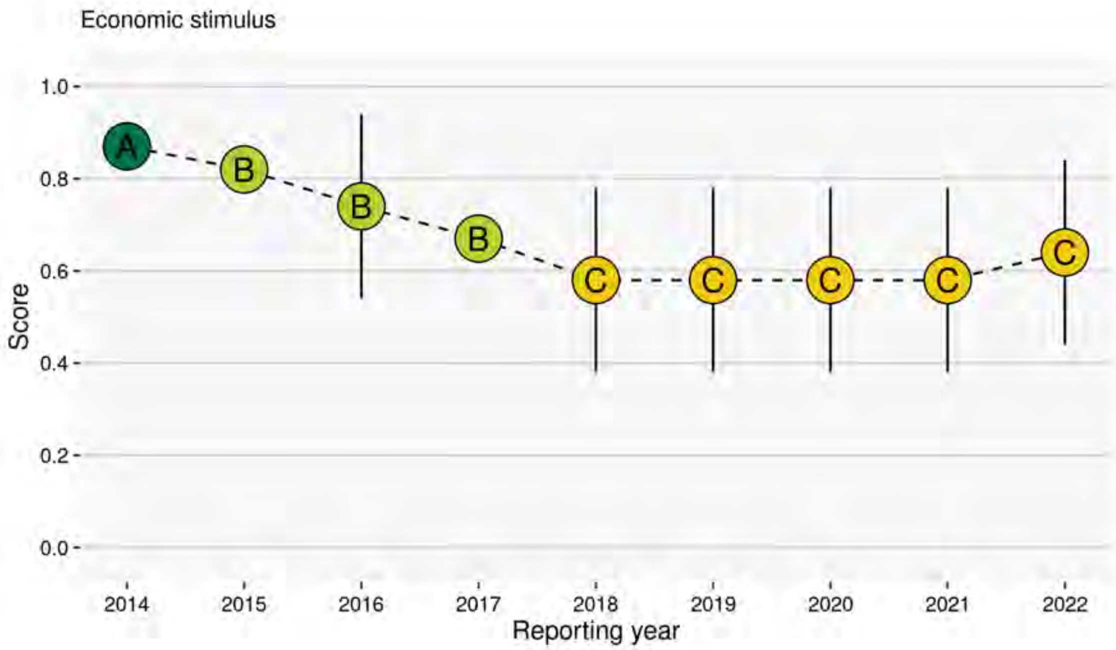


Figure 6.6: Economic stimulus scores from 2014 to 2022.

Economic value (Recreation)

Good scores were received for land-based recreation 0.79, recreational fishing 0.73, beach recreation (0.77) and water-based recreation 0.77 (Figure 6.7). Overall economic value received a score of 0.77 (B) similar to previous reporting years (Figure 6.8). The 'Economic Value (Recreation)' indicator group scored slightly better than in 2019 and has remained on a continuingly improving trend since 2014. All four types of recreation appear to be greatly valued by Gladstone residents and represent an important element of the Gladstone lifestyle.

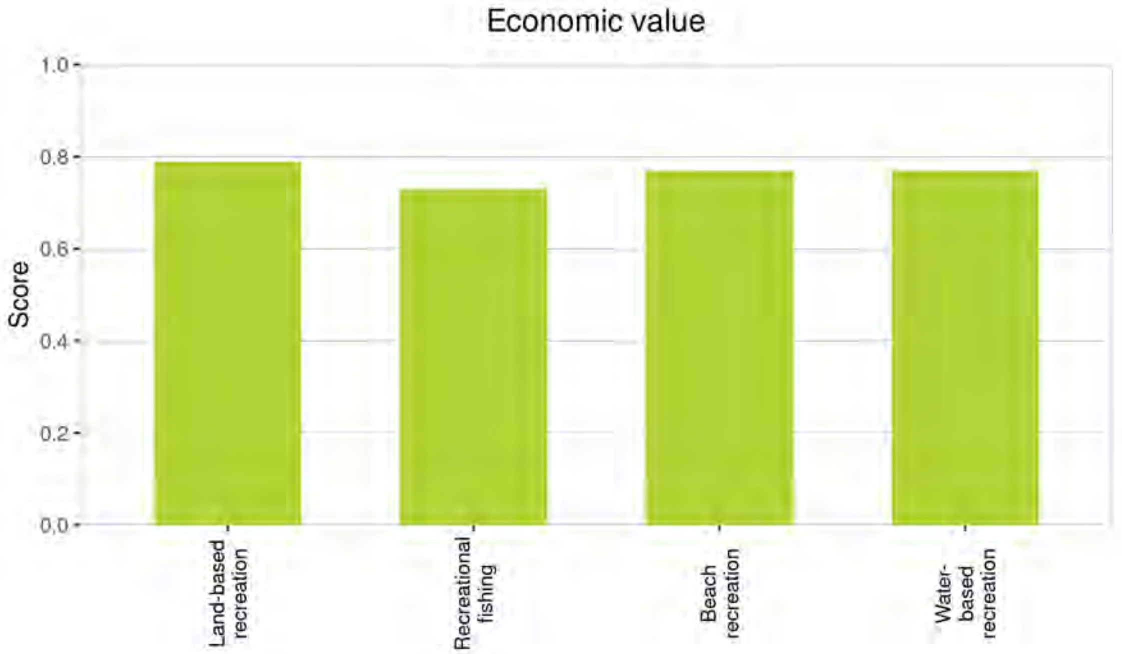


Figure 6.7: Scores for the four indicators of economic value (recreation) in the 2022 Gladstone Harbour Report Card.

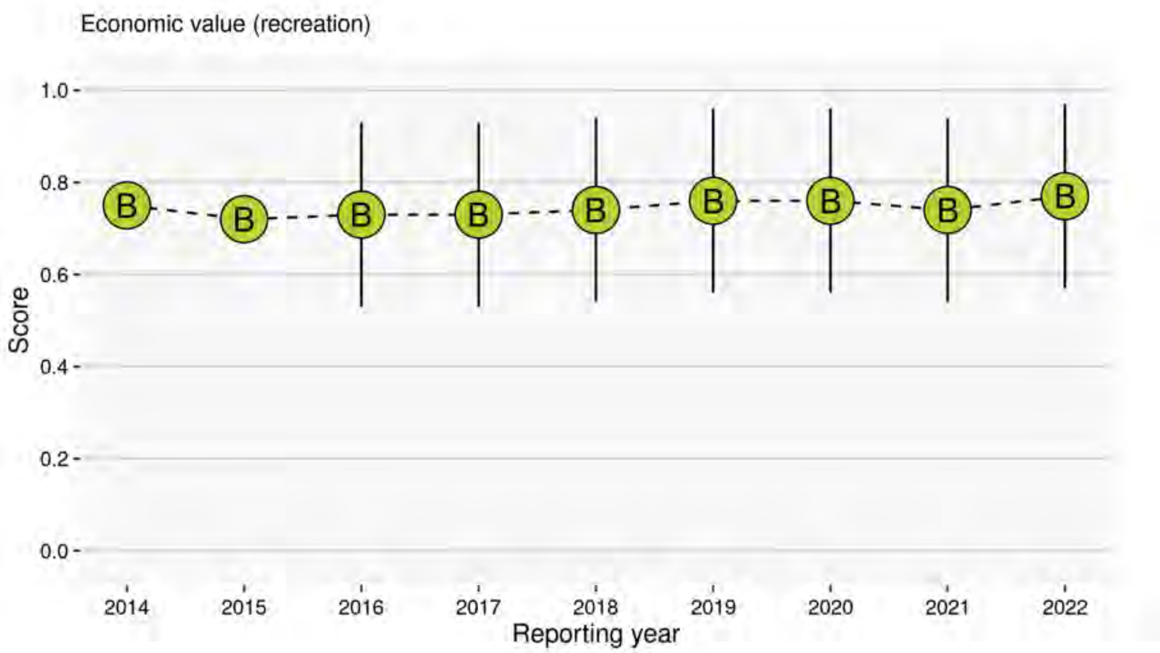


Figure 6.8: Economic value (recreation) scores from 2014 to 2022. Scores prior to 2018 were based on three indicators. The fourth indicator (water-based recreation value) was added to the indicator group in 2018.

Gladstone Healthy Harbour Partnership

6.4. Economic indicator conclusions

The overall economic health of Gladstone Harbour remains good and has been relatively stable since the first full report card in 2015 (Figure 6.9). However, the trend for the three indicator groups and the indicators they contain has been quite different. Within the economic performance indicator group there have been substantial increases in the scores for shipping and particularly tourism which has increased from a score of 0.64, (C) in 2015 to 0.90 (A) in 2019 (Table 6.2). Conversely the score for commercial fishing has declined from 0.63 (C) in 2015 to 0.36 (D) in 2019. Within the economic stimulus indicator group both employment and socio-economic status have declined since 2015 although the 2019 score for socio-economic status (0.64, C) is satisfactory while the score for employment has declined from satisfactory in 2015 to poor in both 2018 and 2019 (Table 6.2). The score for economic value (recreation) has remained relatively stable since 2015 and it has received good scores in all years.

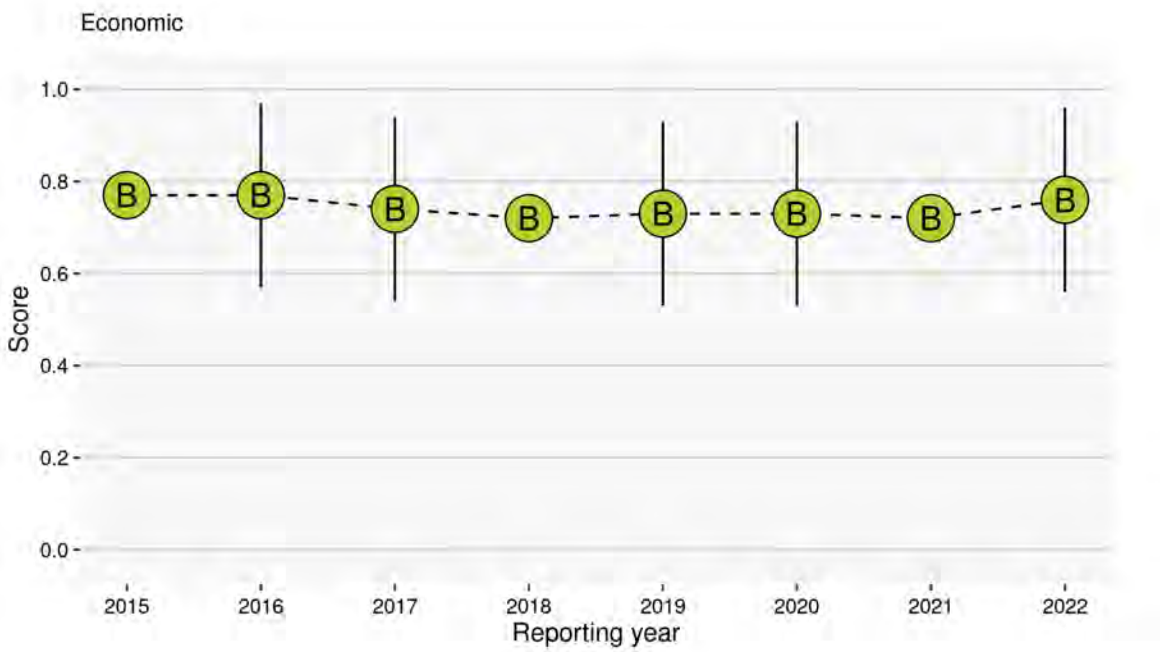


Figure 6.9: Report card scores for the Economic component from 2015 to 2022.

Table 6.2: Economic health scores compared between report cards, 2014–2022 (De Valck, 2022).

	Economic component: 2022 = 0.76 (B) 2019 = 0.73; 2014: 0.75							
Indicator group Score/grade	**Indicators**	**Score**			**Measures**	**Score**		
		2022	**2019**	**2014**		**2022**	**2019**	**2014**
Economic performance 0.90 (A) *2019: 0.90* *2014: 0.83*	Shipping activity	**0.90**	0.90	0.83	Shipping activity: productivity	0.90	0.90	0.83
	Tourism	**0.90**	0.90	0.60	Tourism expenditure	0.90	0.90	0.60
	Commercial fishing	**0.41**	0.36	0.66	Net fisheries: productivity	0.45	0.25	na
					Trawl fisheries: productivity	0.31	0.29	na
					Pot fisheries: productivity	0.55	0.64	na
Economic stimulus 0.64 (C) *2019: 0.58* *2014: 0.87*	Employment	**0.45**	0.44	0.72	Unemployment statistics for the Gladstone LGA	0.45	0.44	0.72
	Socio-economic status	**0.74**	0.64	0.90	Index of economic resources	0.74	0.64	0.90
Economic Value (Recreation) 0.77 (B) *2019: 0.76* *2014: 0.75*	Land-based recreation	**0.79**	0.77	0.76	Satisfaction rating from CATI survey + value from 2014 survey	**0.79**	0.77	0.76
	Recreational fishing	**0.73**	0.71	0.67	Satisfaction rating from CATI survey + value from 2015 survey	**0.73**	0.71	0.67
	Beach recreation	**0.77**	0.76	0.71	Satisfaction rating from CATI survey + value from 2014 survey	**0.77**	0.76	0.71
	Water-based recreation	**0.77**	0.76	na	Satisfaction rating from CATI survey + value from 2017 survey	**0.77**	0.76	na

7. Litter indicator

7.1. Litter

Litter is included as a formal indicator in the 2022 Gladstone Harbour Report Card. However, results for the litter indicator are reported separately to the four components of harbour health (Environment, Social, Cultural and Economic) in the following sections.

Currently this indicator has only one category, total litter, with the goal to divide this into three categories in the coming years. Total litter is compared against a baseline derived from four years of data from 1 July 2014 until 30 June 2018.

Data are sourced from the Australian Marine Debris Initiative (AMDI) Database as collected by volunteers from across Australia, including at Tangaroa Blue Foundation and ReefClean events. Technical expertise for the calculation of scores and grades was provided to this project by Bill Venables and Tegan Whitehead (model development), and by Jordan Gacutan from the University of New South Wales (UNSW) (data filtering and processing).

As this metric is based on a dataset collected by volunteers there is some inconsistency with sample sizes and sampling locations across zones and years. Scores and grades are therefore presented at the site level, rather than rolled up into a zone level score. This reduces biases on scores that would come with changes in sampling effort from year-to-year and will allow better representation and comparison of how the amount of litter has changed at particular sites across report cards.

The following methods are described as per that designed for the Dry Tropics Partnership for Healthy Waters Report Card (Whitehead, 2020) with filtering methods applied by UNSW as per Appendix 4. Note, different methods may have been applied to the other regional report cards.

GHHP acknowledges the Australian Marine Debris Initiative, Tangaroa Blue Foundation, the community organisations, and individuals involved in the collection and the provision of data.

7.2 Litter data collection

Forty-nine clean-ups were recorded in the AMDI Database in 2021-22 in the Gladstone region. These clean-ups were one of two types: standardised 'ReefClean' sampling or non-standardised clean-ups.

7.2.1. Standardised 'ReefClean' sampling

The ReefClean project began in early 2019 with funding from the Australian Government's Reef Trust, led by the Tangaroa Blue Foundation and several partner organisations. Volunteers collected litter along measured transects for a designated length of time. Standardised clean-ups began in mid-2018 and will continue quarterly until June 2023. This standardised method enables comparisons across years. All debris were sorted into one of 127 categories and recorded in the AMDI Database. ReefClean data are incorporated into the litter metric where available.

7.2.2. *Non-standardised clean-ups*

Non-standardised clean-ups were also conducted across the Gladstone region, varying in location and frequency across years. Generally, easy-to-access and 'volunteer friendly' sites (such as popular beaches) are cleaned more frequently than other beaches. Non-standardised clean-ups have no defined boundary and while the number of participants and the total duration of the clean-up event is recorded, individual effort is not (leading to unequal effort of individuals across the duration of the event). All debris collected was sorted into the AMDI categories and entered into the database. Due to inconsistency in how rigorous the debris sorting and recording process was among volunteers, the litter could not be divided into individual categories, so litter was totalled into a 'total litter' category.

7.3 Development of litter indicators and scoring

Development of the litter indicator was completed by Bill Venables and Tegan Whitehead (Dry Tropics Partnership) and first incorporated in the Townsville Dry Tropics Report Card 2019.

Currently this indicator has only one category, total litter, with the goal to divide this into plastic bags, single-use items, and cans/bottles in the near-future. The three categories were designed to align with current management/litter reduction campaigns:

- plastic bags (align with the plastic bag ban in Queensland);
- plastic bottles and drink containers (align with the bottle container recycling scheme); and
- single-use items (align with the single-use plastic ban in Queensland).

7.3.1. *Establishing the baseline*

Total litter collected at each site in the current reporting year is compared against a baseline derived from four years of data from 1 July 2014 until 30 June 2018. This period was used to establish a reference distribution and was designed to be used as a permanent baseline to which data will be compared against. These dates were the earliest period where four years of data were available in more than one zone. Similarly, the four-year baseline period was chosen to represent a time before the Queensland Government state-wide management restrictions were put in place (plastic bag ban from 1 July 2018 and the container refund scheme from 1 November 2018). As such, the baseline may need to be reviewed in future years with consideration of the newest Queensland government restriction—single use plastics ban from 1 September 2021.

During the baseline period between 1 July 2014 and 30 June 2018, clean-ups occurred at 65 sites across 12 GHHP monitoring zones in the Gladstone region (Appendix 5). The frequency that each site was cleaned during this four-year baseline period varied. Please refer to Appendix 5 for details related to surveys since 2014.

7.3.2. *Litter index scoring*

To calculate scores and grades for total rubbish, scores and grades for the 2020-21 reporting year were determined by relating annual data to the four-year reference distribution. Data were scaled from 0 to 1 for the report card, with close to zero equating to "near pristine" and close to 1 being a "highly littered" state.

The reference distribution was created by:

1. Calculating the number of items collected and number of hours spent cleaning.
2. Standardising catch per unit effort (CPUE) to an approximately normal distribution:
   loge(CPUE) = loge(items collected) - ½ loge(hours cleaned)
3. loge(CPUE) was considered to index the individual sites within and between years.
4. Where sites were cleaned more than once in a year, loge(CPUE) was averaged over sites within a reporting year.
5. After ordering the loge(CPUE) values from smallest to largest, an empirical survivor function (ESF) was derived for the reference distribution (i.e. the probability of survival past time y which is independent of distributional assumptions.
6. The ESF was then created by plotting p (which equals [r + ½]/n), against loge(CPUE), with r the number of values greater in the sorted list, and n the total number of values.
7. Smoothing the ESF produced the working reference distribution and algorithm, which can be easily applied to present and future data.
8. The score corresponding to any loge(CPUE) value is then obtained using the smoothed ESF constrained to between zero and one.
9. From the smoothed ESF, the cut off values ('very high pressure' to 'slight pressure') can be determined (Figure 7.1; Table 7.1).

Scoring the litter indicators was designed to show any change (increase or decrease) compared to the four-year baseline. For example, if the mean for a financial year is lower than the mean from the four-year baseline, the indicator will be graded as a 'very high pressure', 'high pressure' or 'moderate pressure', but would be 'low pressure' to 'slight pressure' if there was more rubbish than previous years (or 'the mean from the baseline period'). For more detailed methods on how the scores for the litter index was generated, refer to the 'A Proposal for Litter Scores and Grades' document (Whitehead and Venables, unpublished). The above method has been described as in Whitehead (2020).

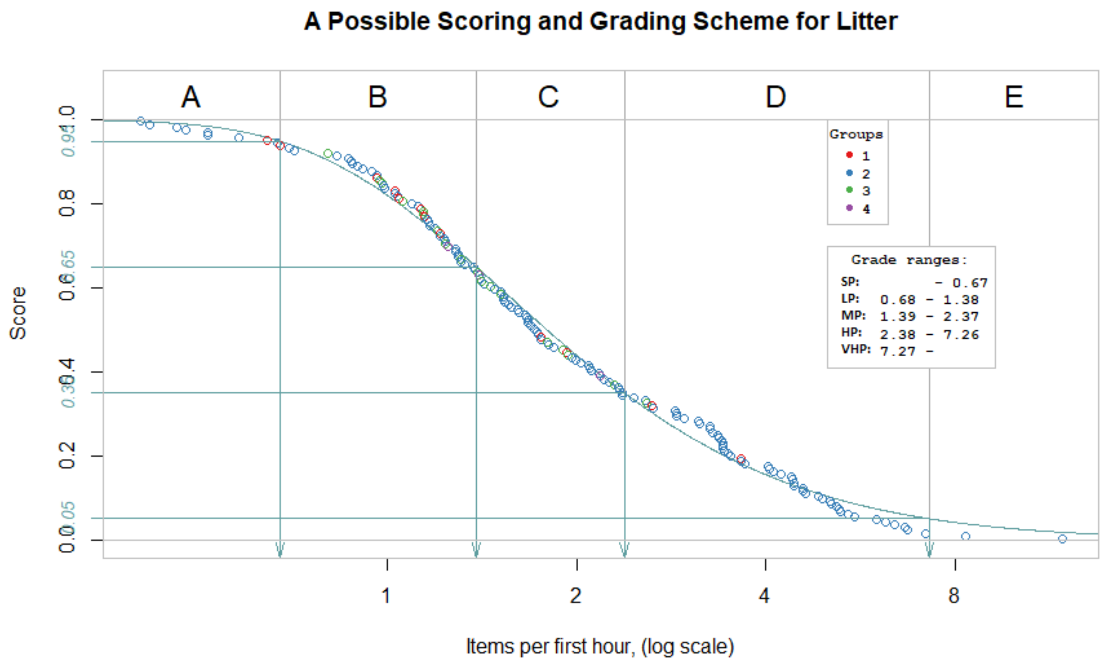


Figure 7.1: Transformation of standardised collection rates to scores and grades (CPUE vs scores).

7.3.3. Note about scoring used for litter indicator

It is important to note that scoring for the litter indicator is different to the standard scoring system used by all other GHHP indicators (see Table 8.1). This was to ensure consistency in the scoring system among other regional report cards such as Wet Tropics, Dry Tropics and Mackay-Whitsundays Isaac. Although the scoring system and thresholds are consistent between the four partnerships, it is not appropriate to directly compare grades/scores between regional report cards. This is because grades/scores for each report card are based on a four-year baseline which is unique to the dataset in their region. Thus, a 'moderate pressure' score for one partnership is not equal to a 'moderate pressure' score for another partnership. Comparability is only relevant in terms of site improvement or deterioration (e.g., the number of sites that showed less rubbish and thus had a better score than the previous year, and vice versa).

Table 7.1: Scoring range guide to colours and textual context. Note that scoring range cut-offs are dependent on annual data distribution.

Colour	Context	Score range
	Very high pressure	0 to 5
	High pressure	>5 to 35
	Moderate pressure	>35 to 65
	Low pressure	>65 to 95
	Slight pressure	>95 to 100

7.4. Litter results

For interpreting litter results, it is notable that score cut-off points are based on annual data distribution (see Figure 7.1) and refer to a scale of 'very high pressure' to 'slight pressure' (Table 7.1). Refer to Table 7.2 and Figure 7.2 for sites scores, with results summarised as:

- Scores ranged from 'high pressure' to 'slight pressure' across the Gladstone region.
- The majority of clean-up sites in 2022 (n = 9 of 13) showed a lower mean total rubbish as compared to the four-year baseline, thus receiving a 'moderate pressure' score or better.
- Six of the 8 sites where clean-ups occurred in both 2021 and 2022 showed improved scores, which may indicate a positive impact through clean-up efforts.
- East Beach (0.94) located in the Mid Harbour, Wild Cattle Creek Mouth (0.83) located in the Outer Harbour and Barney Point (0.81) located in the Inner Harbour were the highest scoring sites.
- Auckland Creek [Site ID 3402] (0.25), Lilley's Beach (0.21) and Eastern Foreshore (0.20) were the poorest scoring sites for the second consecutive year. Lilley's Beach is a popular four-wheel driving area in the region, and it may therefore be impacted by higher levels of recreation. Similarly, Auckland Creek [Site ID 3402] and Eastern Foreshore are frequented areas.
- Esplanade Beach also showed high pressure (0.27) and had the greatest reduction in score as compared to 2021 results.

Table 7.2: Litter scores by site across the Gladstone region for the 2022 Report Card. Note that scoring range cut-offs are dependent on annual data distribution. 2021 scores are shown for comparison, with change in scores between 2021 and 2022 also illustrated.

Zone	Site Name	2022 Score	*2021 Score*	Score Change
3. Western Basin	Fisherman's Landing*	-	*0.61*	-
5. Inner Harbour	Barney Point	0.81	*0.79*	↑
7. Auckland Inlet	Auckland Creek (Site ID 2799)	-	*0.50*	-
	Auckland Creek (Site ID 3402)*	0.25	*0.09*	↑
	Police Creek	-	*0.48*	-
8. Mid Harbour	Canoe Point (Site ID 796)*	0.68	*0.48*	↑
	East Beach	1.00	-	-
	Esplanade Beach*	0.27	*0.94*	↓
	Facing Island North Point*	0.53	-	-
	North East Shore*	-	*0.35*	-
	South End Back Beach*	0.67	-	-
	Tannum Sands Main Beach	0.69	*0.63*	↑
9. South Trees Inlet	Lillys Beach North End*	-	*0.21*	-
10. Boyne Estuary	Canoe Point Conservation Area*	-	*0.80*	-
	Eastern Foreshore*	0.20	*0.10*	↑
	Lilleys Beach*	0.21	*0.10*	↑
11. Outer Harbour	Wild Cattle Creek Boat Ramp	0.62	-	-
	Wild Cattle Creek Mouth	0.83	-	-
	Wild Cattle Creek Mouth, Tannum Sands	-	*0.81*	-
	Wild Cattle Island Beach NTH	0.37	*0.57*	↓
13. Rodds Bay	The Esplanade Beach	-	*0.73*	-

Scoring range: ■ Very High Pressure = 0 to 5 | ■ High Pressure = >5 to 36 | ■ Moderate Pressure = >36 to 65 ■ Low Pressure = >65 to 95 | ■ Slight Pressure = >95 to 100 | * ReefClean survey sites

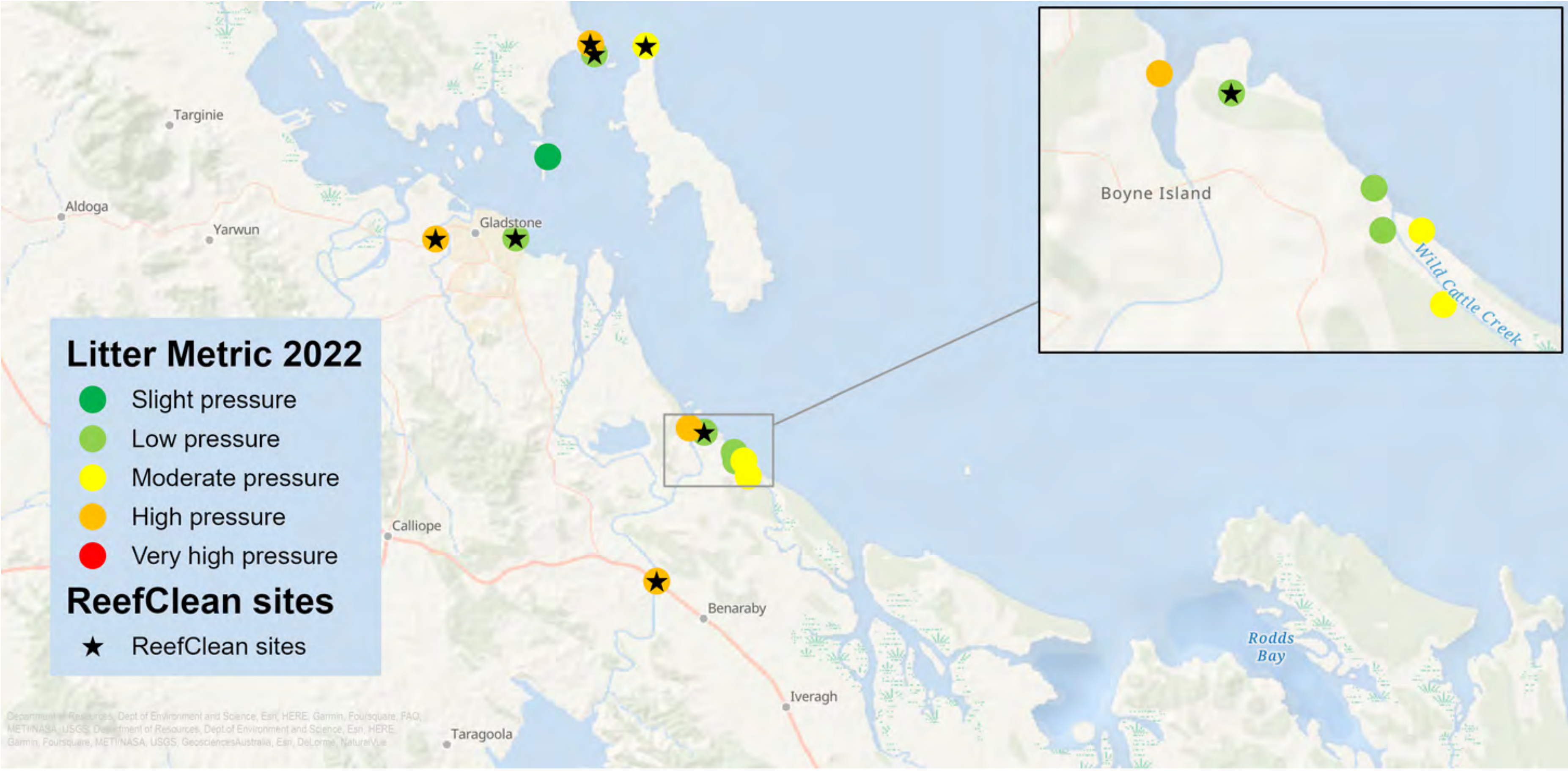


Figure 7.2: Map and grades of total litter at fourteen Gladstone Harbour sites in the 2021–22 reporting year.

8. Gladstone Harbour drivers and pressures

8.1. 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 8.1). 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 8.2).

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 2021–22 report card scores.

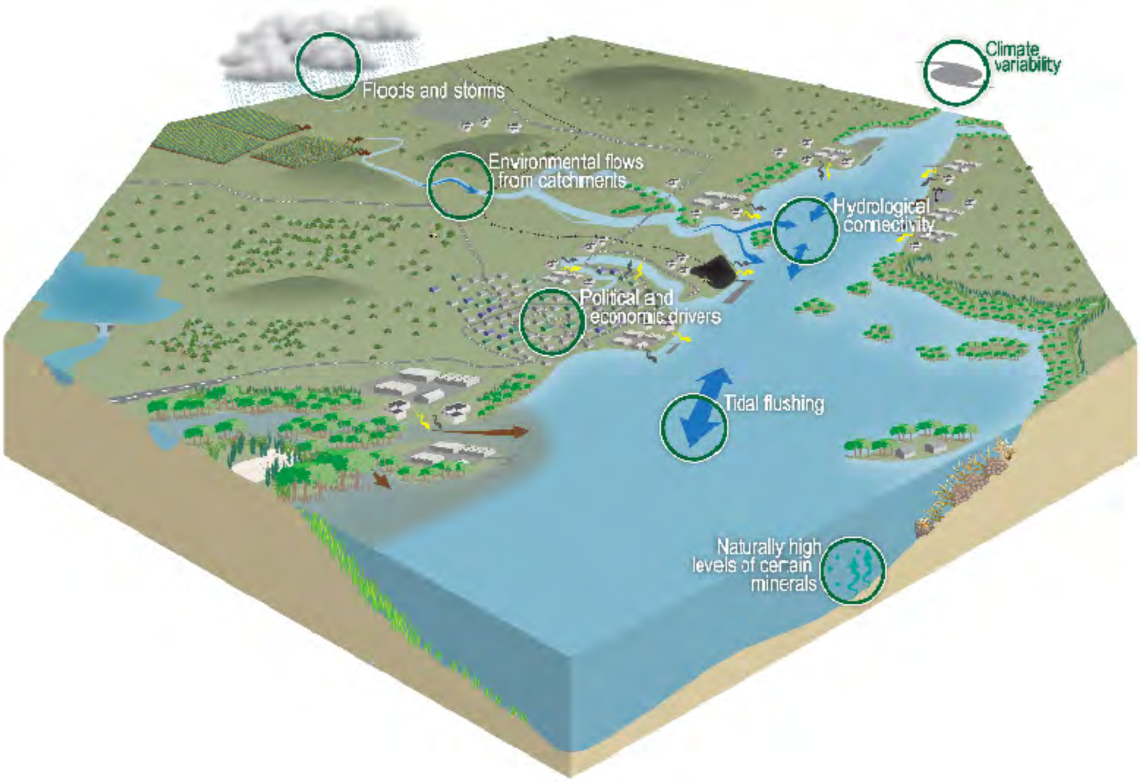


Figure 8.1: Major drivers of environmental change within Gladstone Harbour (Source: McIntosh et al., 2014).

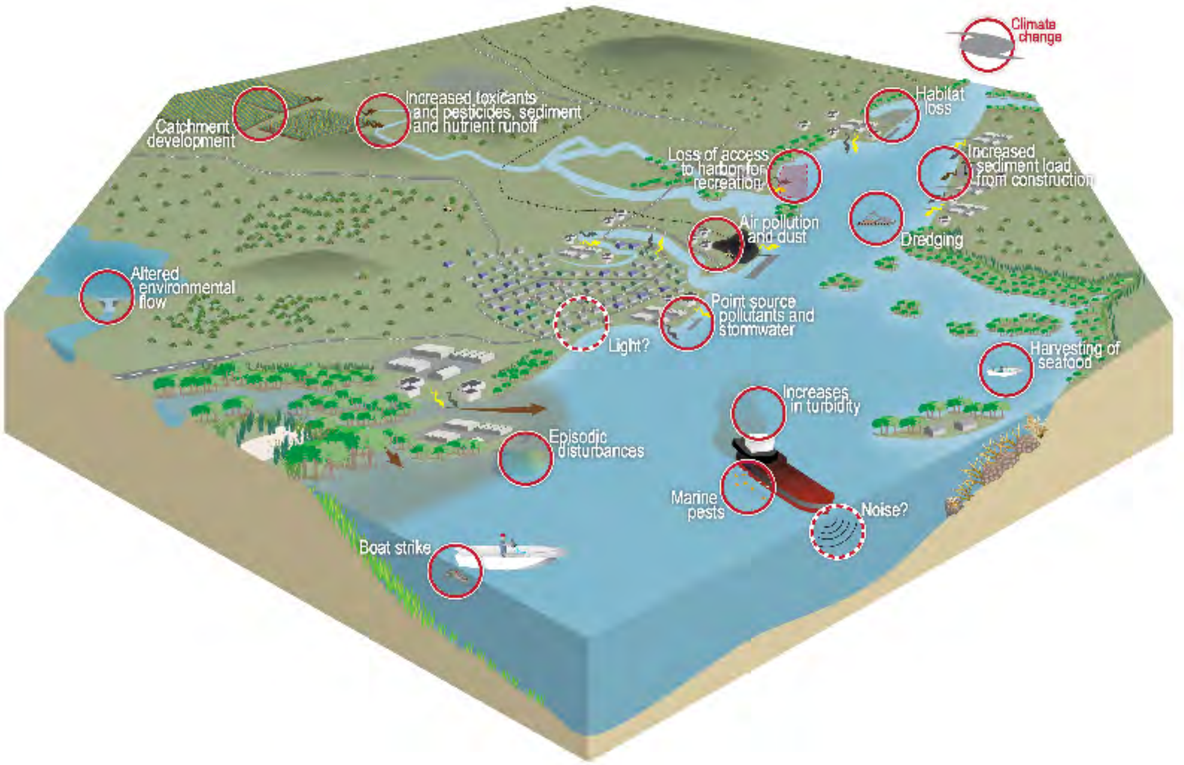


Figure 8.2: Pressures which can drive environmental change within Gladstone Harbour (Source: McIntosh et al., 2014).

8.2. Climate

Gladstone has a subtropical climate with an average maximum of 27.4°C and an average minimum of 18.1°C (Figure 8.3). Rainfall is highly variable; the average annual rainfall recorded at Gladstone (Airport) for the period 1994–2020 was 875 mm. The maximum and minimum annual rainfall totals recorded at this site were 1,542 mm in 2010 and 308 mm in 2001 respectively. Consistent with a subtropical climate, the summer months are wetter than winter months (Bureau of Meteorology [BOM] 2023).

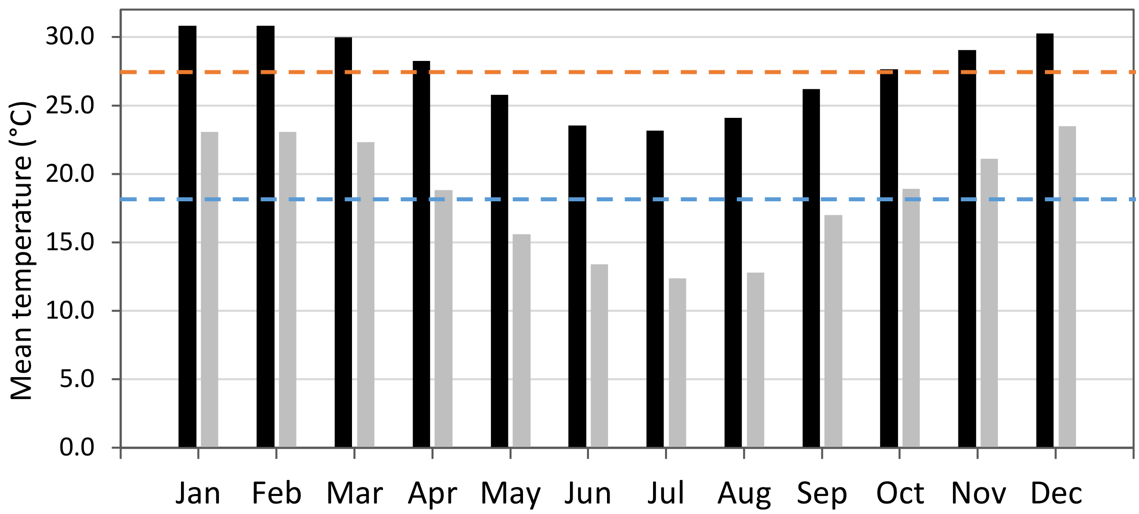


Figure 8.3: Average maximum and minimum monthly temperatures at the Gladstone Airport weather station from 1994–2022. Temperatures shown as follows: average maximum monthly for 2022 (black bars), average minimum monthly for 2020 (grey bars), annual maximum average (orange dashed line, 27.4° C), annual minimum average (blue dashed line, 18.2° C). Values were obtained from BOM (http://www.bom.gov.au/climate/data/index.shtml).

2021–22 rainfall

In the 2021–22 reporting year (July 2021 to June 2022), total rainfall recorded at Gladstone Airport was 1167.8 mm—over 300mm greater than the average for the reporting year (856.1 mm) and the first time above average rainfall has been received in four years (Figure 8.4). Total monthly rainfall was variable when compared to mean monthly rainfall of the past 27 years (Figure 8.5). Two months, November and March, had rainfall totals of greater than 270 mm both well above the monthly average—and six months recorded dryer than average conditions.

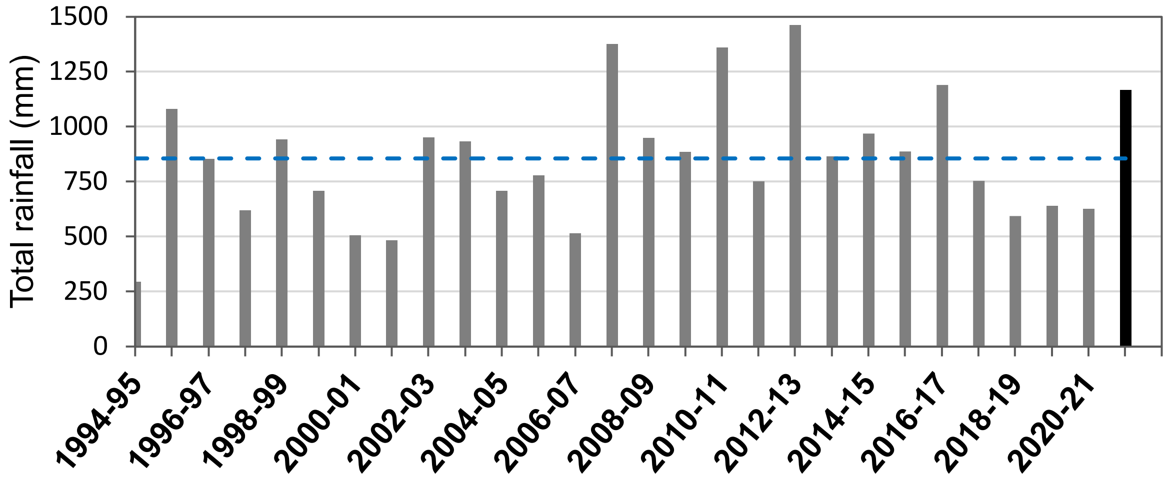


Figure 8.4: Annual rainfall (mm) by reporting year at the Gladstone Airport weather station from 1994–1995 to 2020–2021. Blue dashed line represents the annual mean of total rainfall from 1994–2021 (856 mm). Values were obtained from BOM (http://www.bom.gov.au/climate/data/index.shtml).

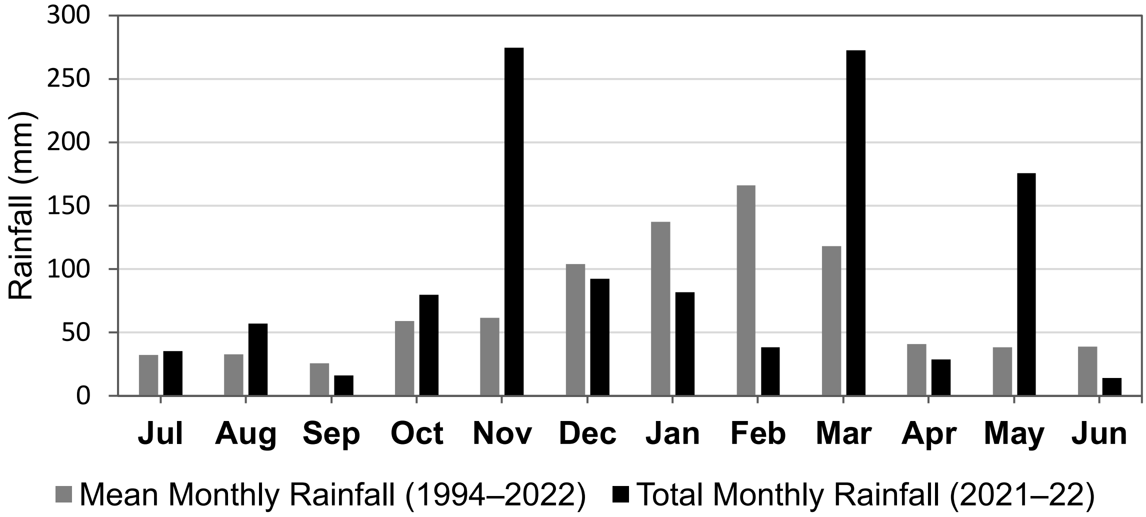


Figure 8.5: Mean monthly rainfall (mm) at the Gladstone Airport weather station (1994–2022) compared to total monthly rainfall for the 2021–22 reporting year. Values were obtained from BOM (http://www.bom.gov.au/climate/data/index.shtml).

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. Small amounts of freshwater flow 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. Average annual stream discharges for the Boyne and Calliope rivers are presented in Table 8.1. Average annual stream discharge from the Calliope River is approximately 1.7 times higher than that of the Boyne River.

Flows measured at the Calliope River between January 2014 and June 2022 show two brief but significant high flow events occurring with the passage of TC Marcia and ex TC Debbie (Figure 8.6). Rainfall associated with TC Marcia caused a peak flow of 91,666 ML/day on 21 February 2015 and rainfall associated with ex TC Debbie produced a peak flow of 105,980 ML/day on 30 March 2017. This compares to a median daily flow of 27 ML/day from October 1938 to June 2019 (DNRM Water Monitoring Information Portal).

In the 2021–22 reporting year, the mostly dry conditions resulted in below median monthly discharge from the Calliope in nine months. Whereas total monthly discharge in November, December and May were significantly above median discharge levels (Figure 8.7).

Table 8.1: Streamflow summary for the Boyne River (1984–85 to 2011–12) and the Calliope River (1938–39 to 2018–19). Values were obtained from DNRM (https://water-monitoring.information.qld.gov.au/).

Boyne River at Awoonga Dam Headwaters (1984–85 to 2011–12)			
Annual stream discharge (ML)		December stream discharge (ML)	
Mean	97,728	Mean	24,279
Median	-	Median	-
Maximum flow (2010–11)	1,194,335	Maximum flow (2010–11)	634,999
Calliope River at Castlehope (1938–39 to 2019–20)			
Annual stream discharge (ML)		December stream discharge (ML)	
Mean	163,783	Mean	20,724
Median	99,040	Median	2,727
Maximum flow (2012–13)	916,693	Maximum flow (1973–74)	401,837

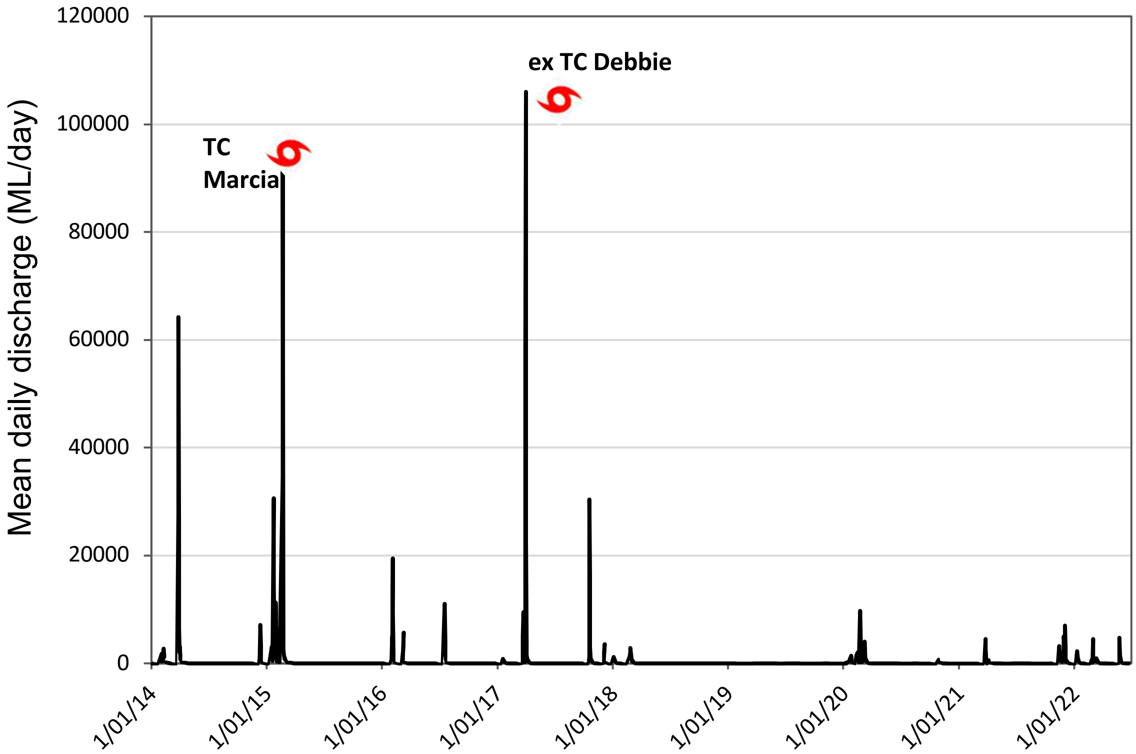


Figure 8.6: Mean daily Calliope River flows recorded at Castlehope between January 2014 and June 2022. Values were obtained from DNRM (https://water-monitoring.information.qld.gov.au/).

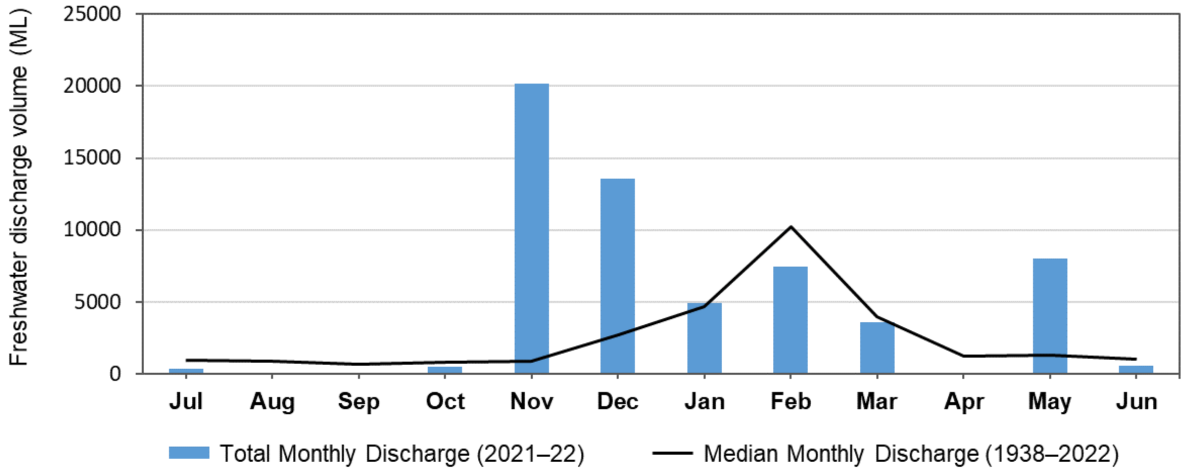


Figure 8.7: Monthly water discharge (July 2021 to June 2022) and median monthly water discharge (October 1938 to June 2022) of the Calliope River at Castlehope. Values were obtained from DNRM (https://water-monitoring.information.qld.gov.au/).

The main water storage for Gladstone is the Awoonga Dam located on the Boyne River approximately 25 km south-west of Gladstone. The dam has a storage capacity of 250,000 ML and is overtopped when the storage level exceeds 40 m Australian Height Datum (Table 8.2). Since the height of the dam wall was raised in 2002, it has overtopped eight times—in 2002, 2010, 2013, 2015, 2017 and 2018. No overtopping occurred in the 2020–21 report card year (Figure 8.8).

Table 8.2: Highest Awoonga Dam levels and last overtopping (Source: Gladstone Area Water Board).

Storage level	Date	Level (m AHD)	Volume (ML)	Capacity (%)	Surface area (ha)
Last overflow of 40m spillway	3-Jan-18	40.30	778,900	100.26	6,791
Highest level	27-Jan-13	48.3	1,498,586	192.9	10,810

AHD – Australian Height Datum

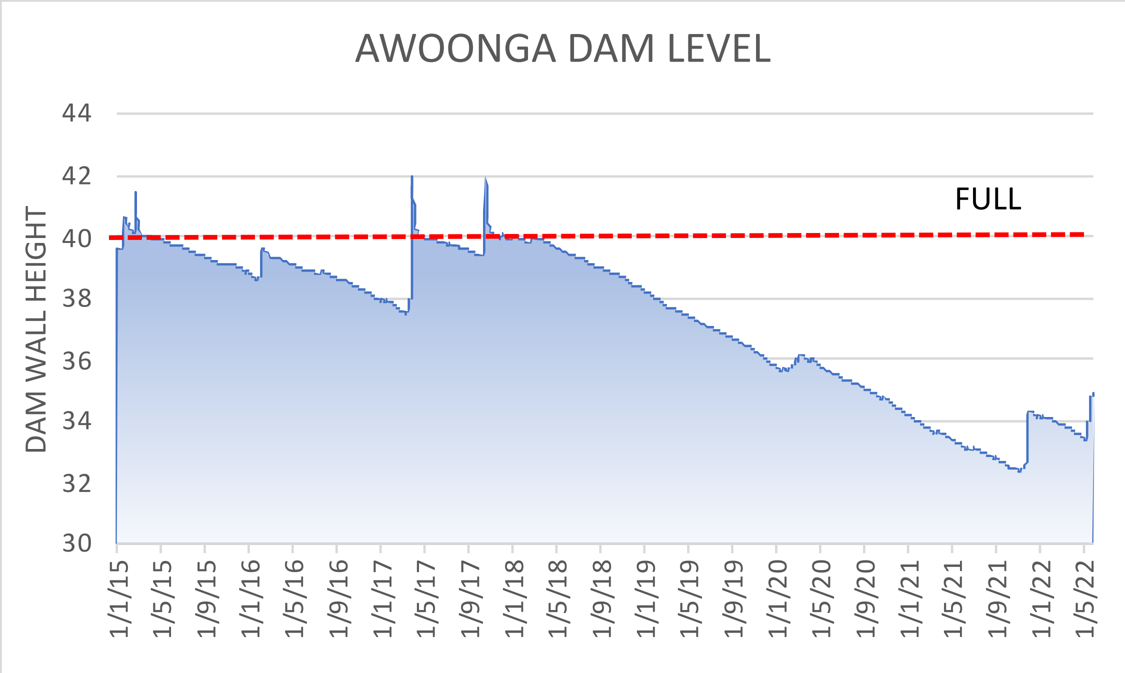


Figure 8.8: Awoonga Dam levels January 2015 to May 2022 (Source: Sawynok et al., 2022).

8.3. Catchment run-off

Gladstone Harbour is bordered by five drainage basins, the Fitzroy (142,545 km^2), the Calliope (2,241 km^2), the Boyne (2,496 km^2), Curtis Island (577 km^2) and Baffle Creek (4,085 km^2) (Queensland Government Wetland*Info* downloaded 01/06/2016) (Figure 8.9).

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 (142,665 km^2), the Calliope and Boyne are relatively small. Their catchment areas are 2,236 km^2 and 2,590 km^2 respectively. The predominant land use within these two catchments is grazing (Figures 8.10 and 8.11). 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 40 m Australian height datum 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).

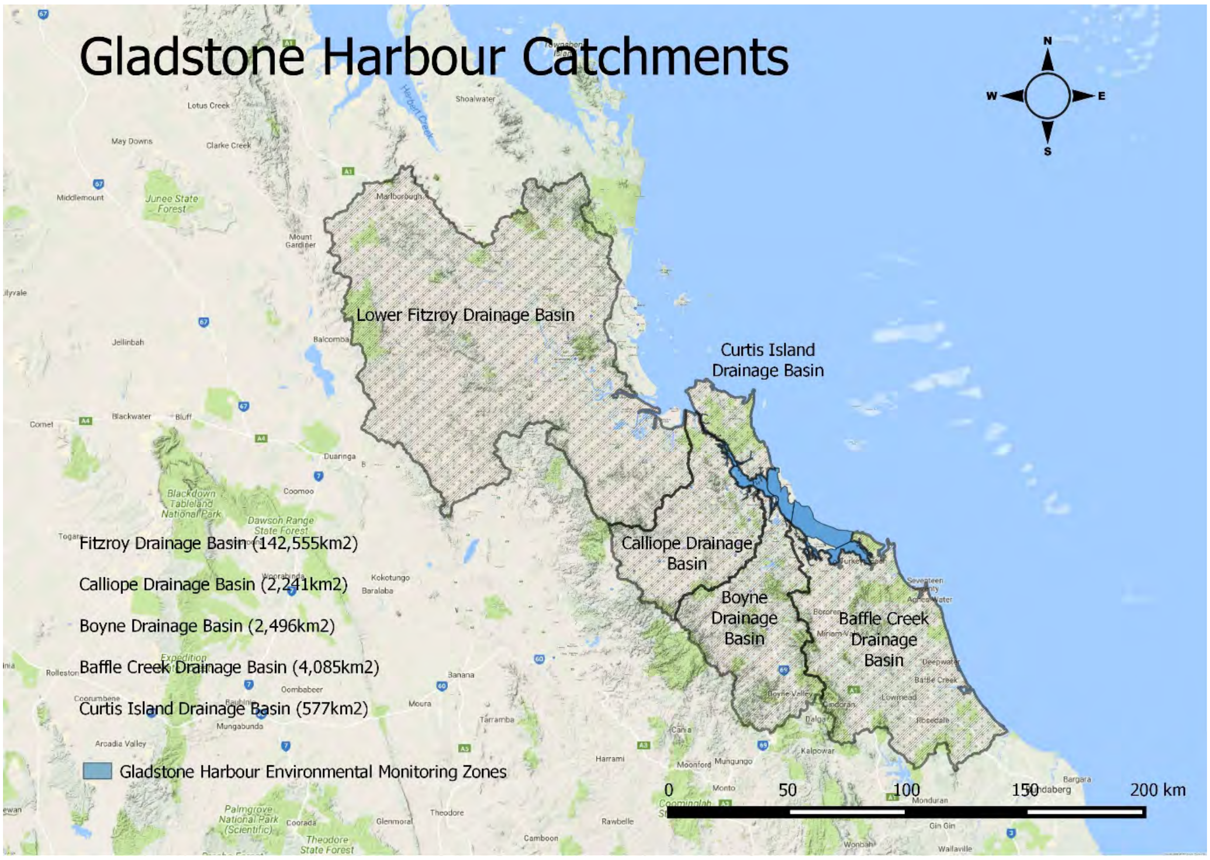


Figure 8.9: Drainage basins surrounding the Gladstone Harbour environmental monitoring zones.

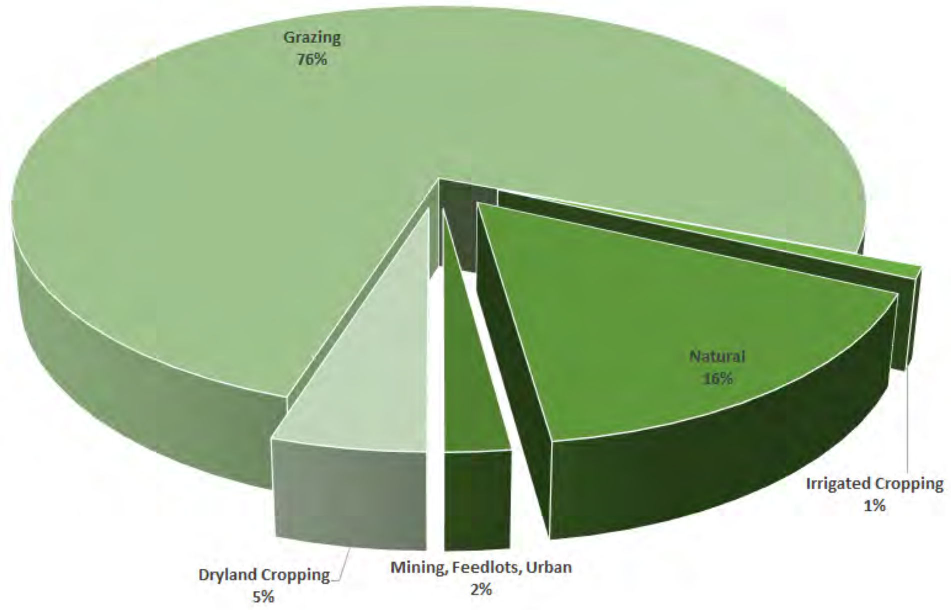


Figure 8.10: Land use in the Boyne catchment (Data source QSpatial, Land use mapping – Fitzroy NRM region 2009, Catchment boundaries, Queensland Wetland*Info*).

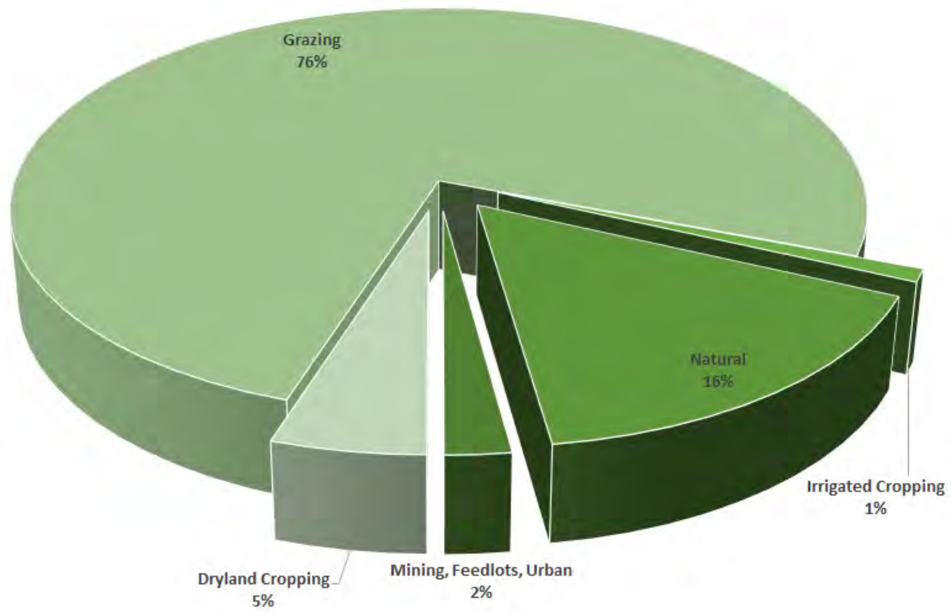


Figure 8.11: Land use in the Calliope catchment (Data source QSpatial, Land use mapping – Fitzroy NRM region 2009, Catchment boundaries, Queensland Wetland*Info*).

Tidal movement and turbidity

Turbidity in Gladstone Harbour is strongly influenced by the large tidal movements. This results in significant resuspension of fine sediments which is directly related to the tidal cycle; larger tides result in increased turbidity (Figure 8.12). 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.

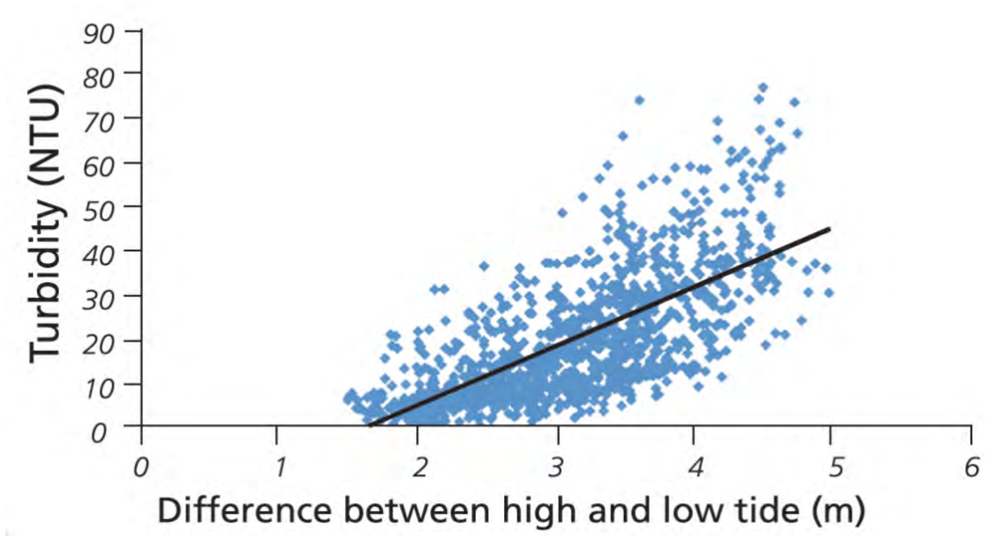


Figure 8.12: The relationship between tidal movement and turbidity in Gladstone Harbour (DEHP, 2014; personal communication). NTU: nephelometric turbidity unit.

9. Guide to the infrastructure supporting the report card

9.1. Data Information Management System

The GHHP Data Information Management System (DIMS) is an essential infrastructure developed by Australian Institute of Marine Science which allows a range of users to store, calculate and visualise report card raw data and results (Figure 9.1). Given the large social, cultural, economic and environment monitoring datasets used to inform a report card, this system helps to manage the data systematically and consistently with a reliable backup system. The DIMS is also an information source for the website that can collate and analyse different data types and produce graphical outputs and tables.

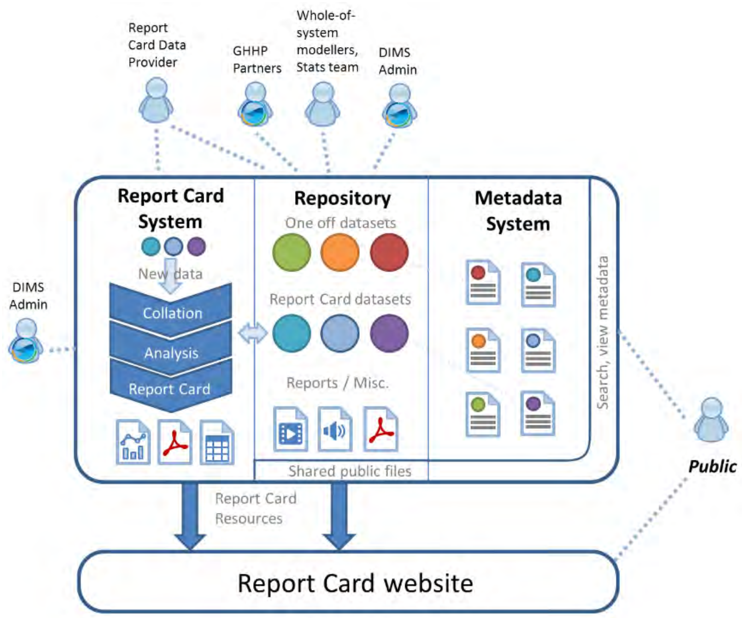


Figure 9.1: Schematic diagram of the links between the report card website and the Data Information Management System (DIMS) to illustrate major components and primary inputs and outputs (Diagram courtesy Australian Institute of Marine Science).

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 generation for review by the ISP. The report card system is based on Java servlet, Ember.js and R programming language (Figure 9.2).

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.

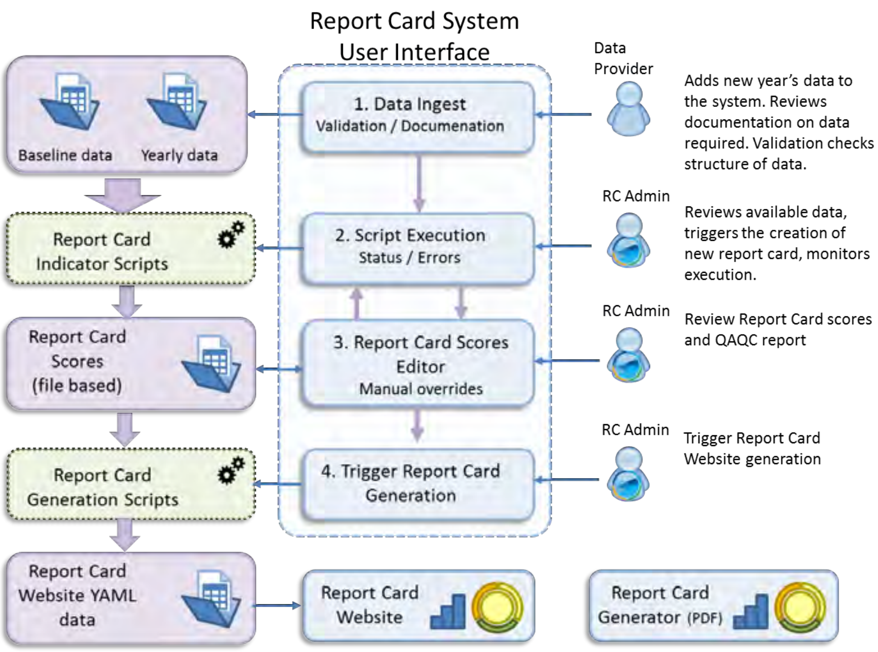


Figure 9.2: Schematic diagram of the report card system showing all data ingestion, script execution and report cards results generation modules (Diagram courtesy Australian Institute of Marine Science).

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 9.3). This approach makes the system highly portable and not dependent on Australian Institute of Marine Science 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.

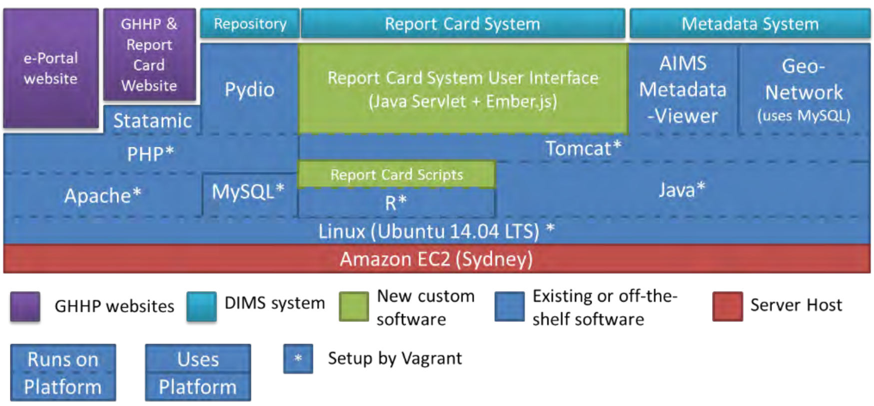


Figure 9.3: Software infrastructure underlying the Data Information Management System (DIMS) operations (Diagram courtesy Australian Institute of Marine Science).

10. Geographical scope

10.1. Environmental reporting zones

The 13 environmental reporting zones in Gladstone Harbour have developed over time from an initial seven zones proposed by Jones et al. (2005) in a risk assessment for contaminants in Gladstone Harbour. In their 2007 Port Curtis Ecosystem Health Report Card, the 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 Ecosystem Health Report Card (vision Environment QLD, 2011) resulting in eight zones. The DEHP developed the current 13 zones (Figure 10.1). These zones were also used to define regionally specific water quality objectives for the Capricorn Coast (DEHP, 2014).

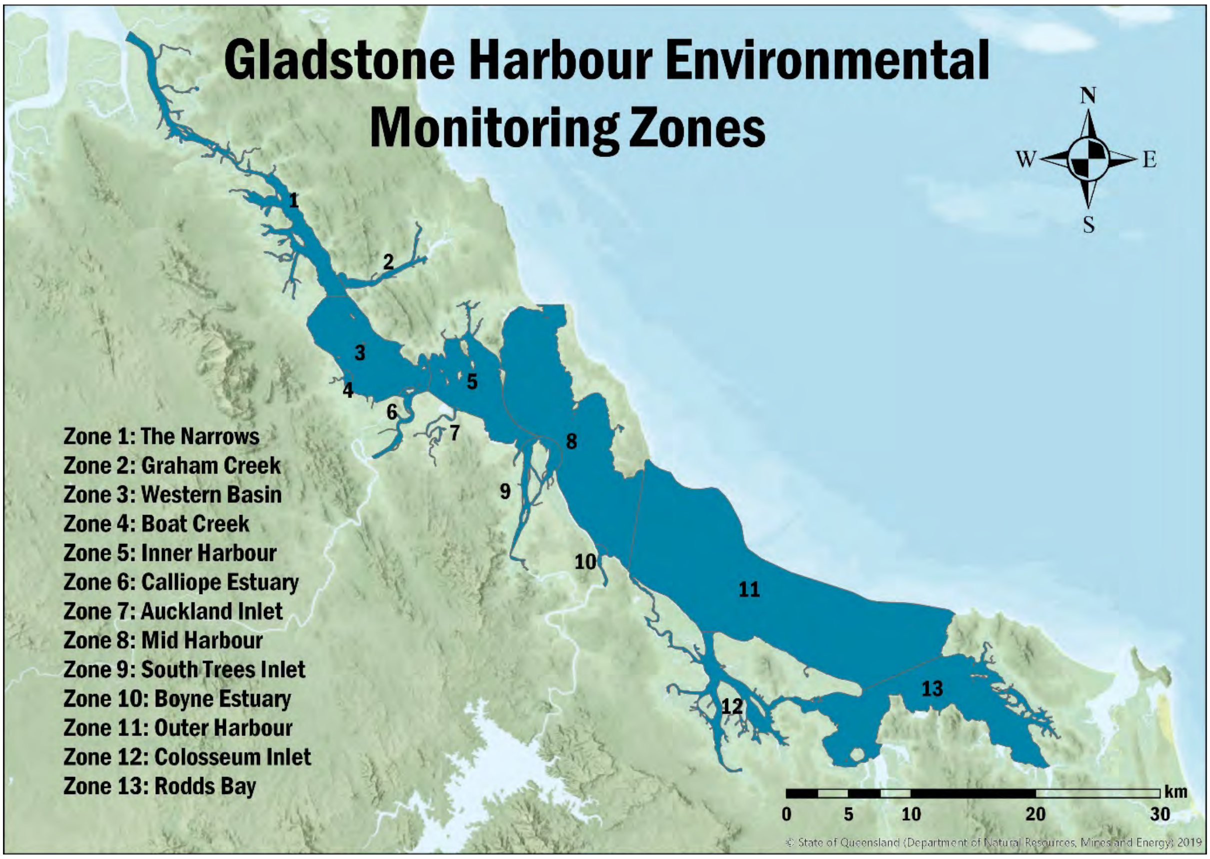


Figure 10.1: The 13 Gladstone Harbour zones for which environmental parameters were measured for the 2019 Gladstone Harbour Report Card.

Figure 10.2: Habitat types and sampling sites in The Narrows.

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

Zone area: 29.25 km^2
Fish health monitoring

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 (Vision Environment QLD, 2011). This zone has one monitored seagrass meadow—an intertidal meadow comprising aggregated patches of seagrass near Black Swan Island.

Figure 10.3: The Narrows photographed from the south with Keppel Bay in the distance.

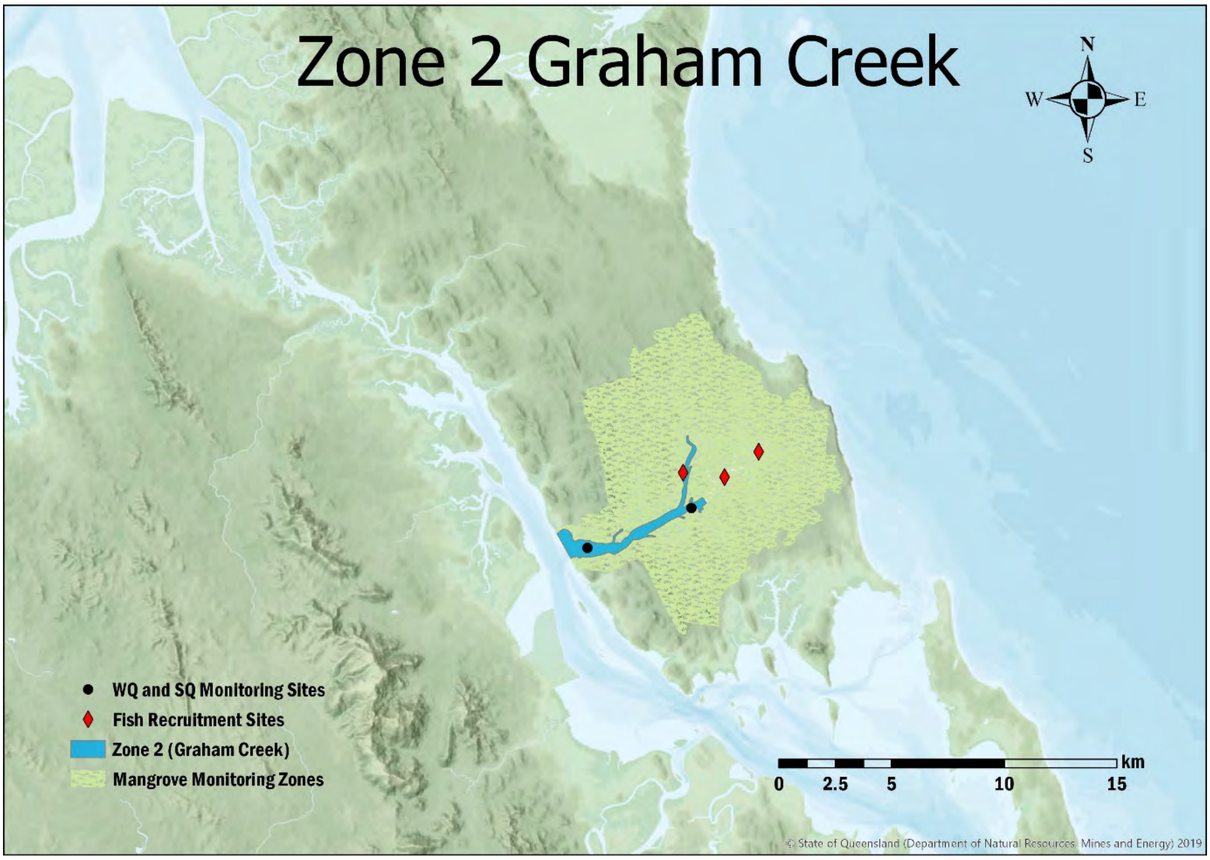


Figure 10.4: Habitat types and sampling sites in Graham Creek.

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

Zone area: 5.80 km^2
Fish health monitoring

Graham Creek is a mangrove-lined tidal inlet located near the south-west corner of Curtis Island. It is approximately 9 km 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 10.5: 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.

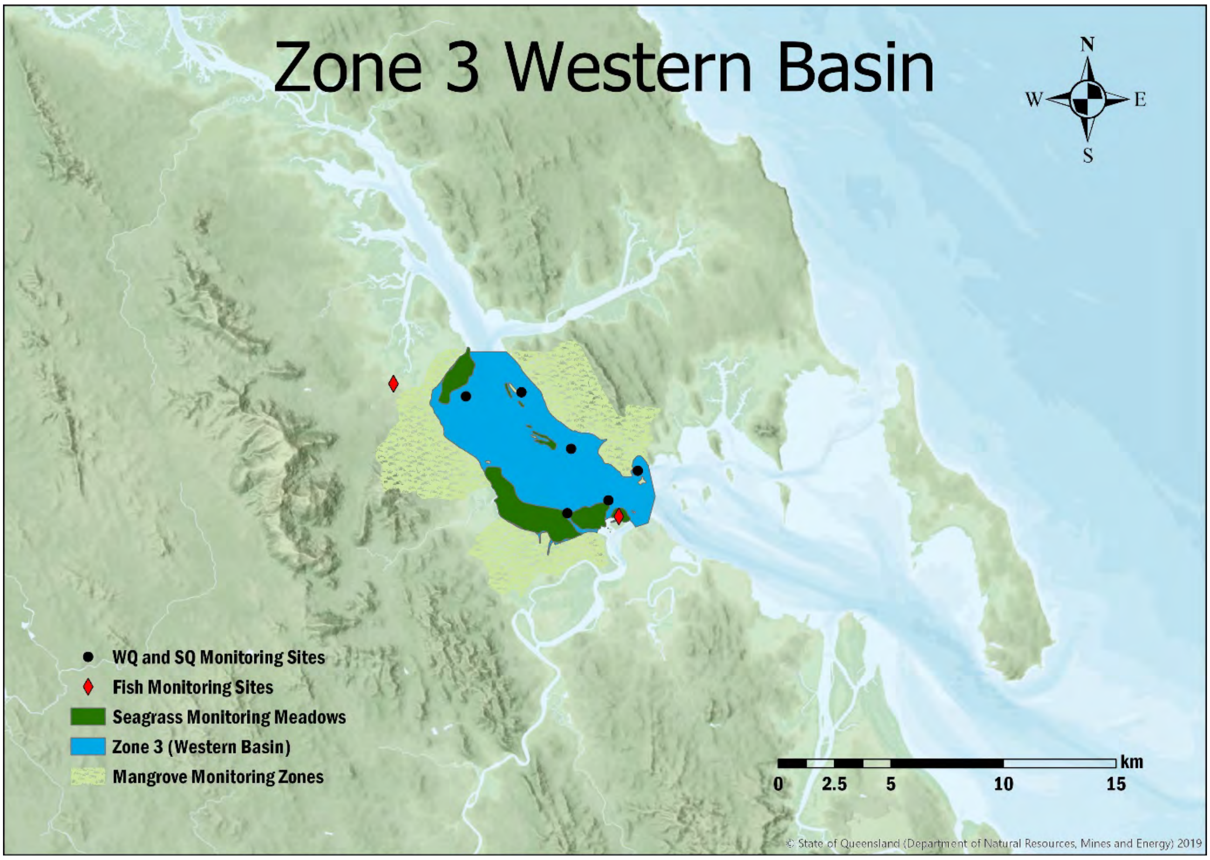


Figure 10.6: Habitat types and sampling sites in the Western Basin.

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

Zone area: 39.19 km^2
Fish health monitoring

The Western Basin is located near the north-western end of Gladstone Harbour. Three large-scale liquid natural gas 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 10.7: The south-western corner of Curtis Island, showing two LNG plants in the foreground and the Western Basin in the distance.

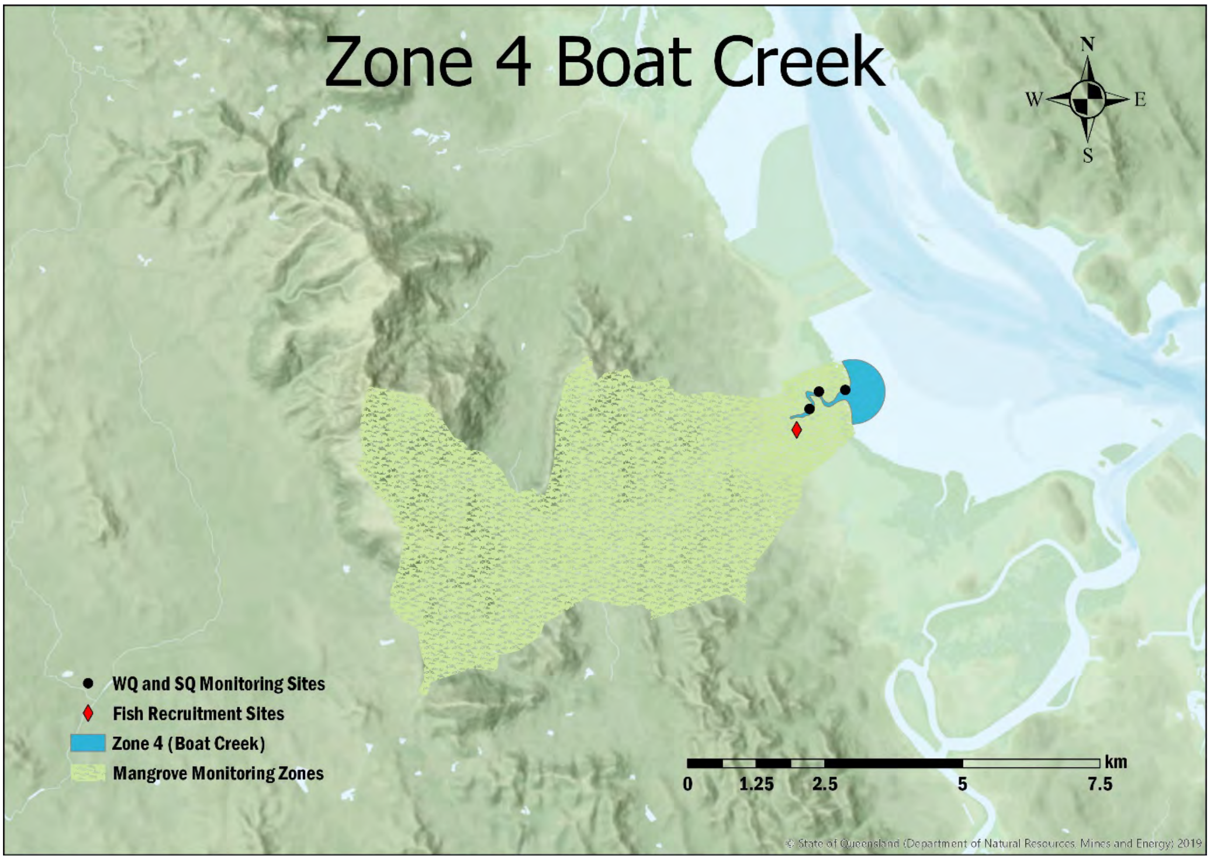


Figure 10.8: Habitat types and sampling sites in Boat Creek.

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

Zone area: 0.75 km^2

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

Figure 10.9: Inlet to Boat Creek photographed from the Western Basin.

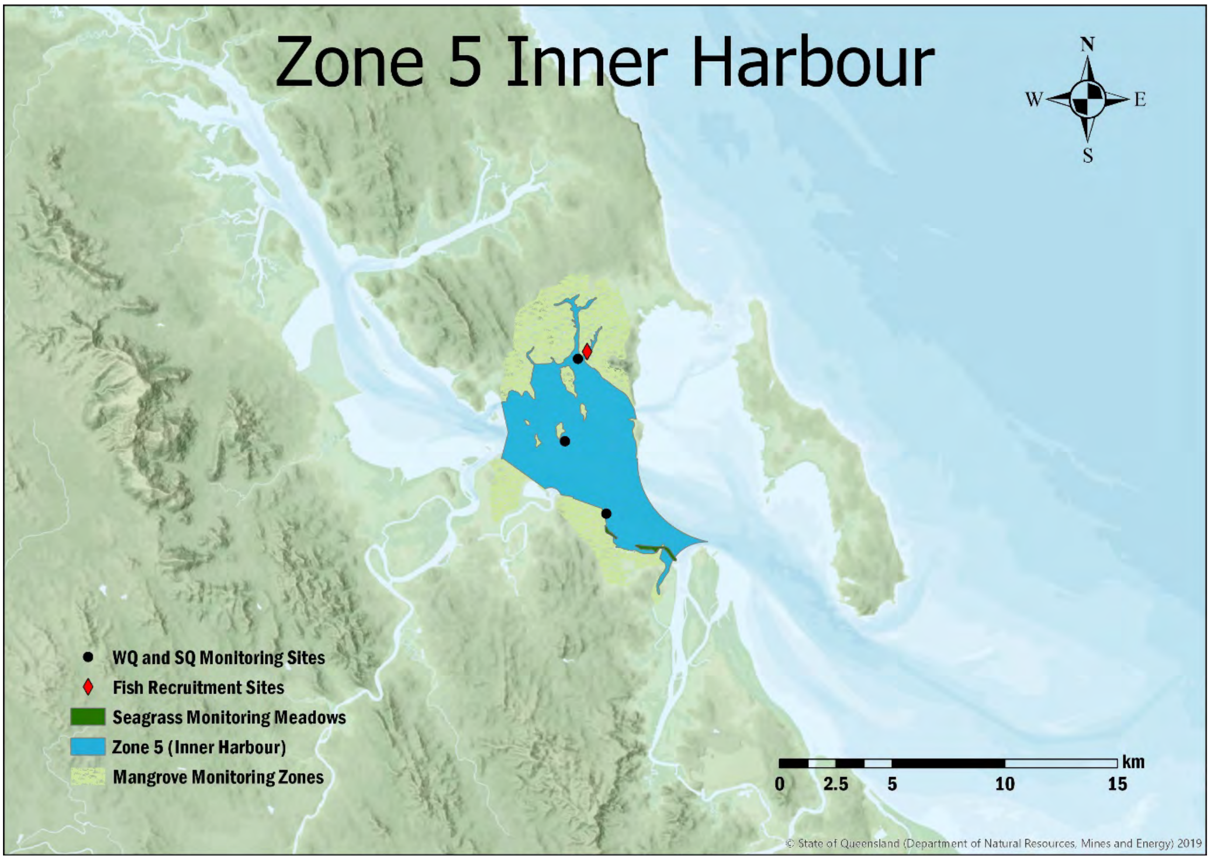


Figure 10.10: Habitat types and sampling sites in the Inner Harbour.

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

Zone area: 33.68 km^2
Fish health monitoring

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.

Figure 10.11: 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 Terminal on the right.

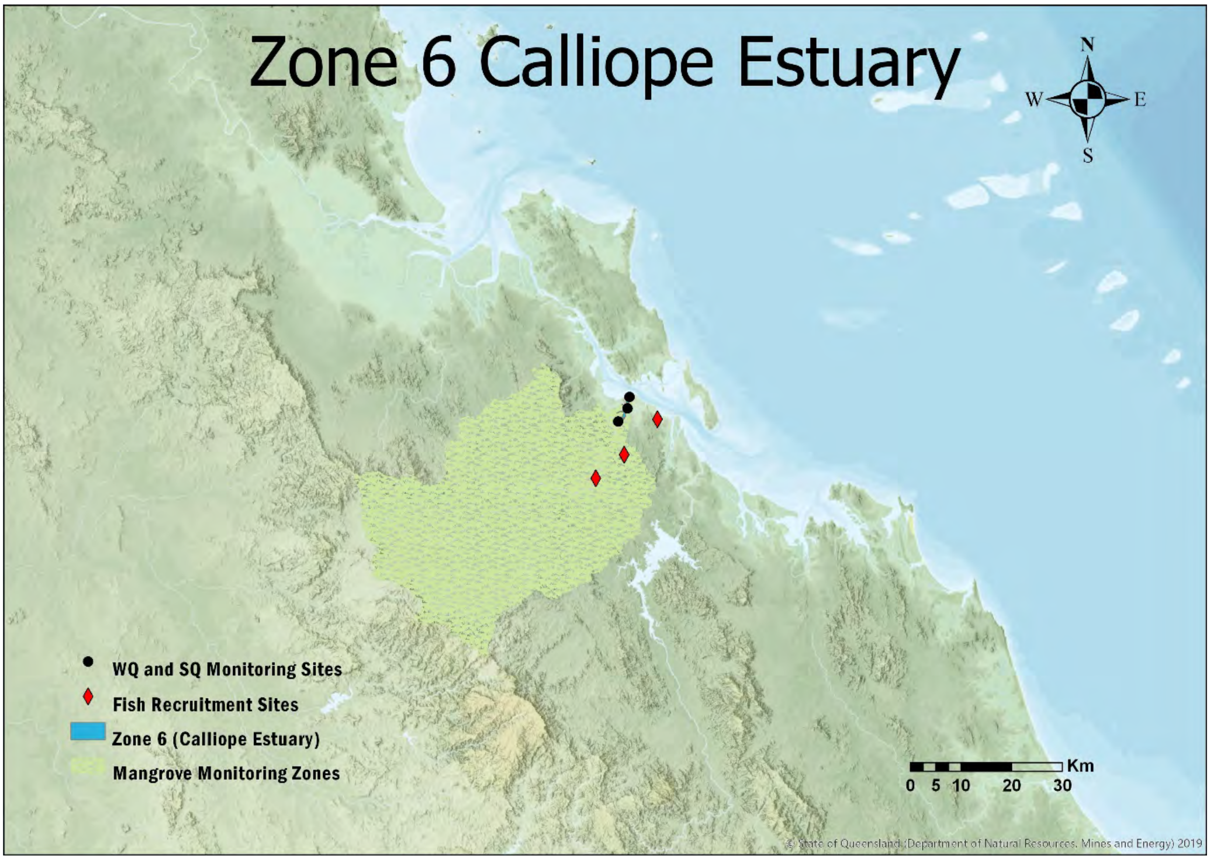


Figure 10.12: Habitat types and sampling sites in Calliope Estuary.

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

Zone area: 7.71 km^2
Fish health monitoring

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 4 km upstream from the river mouth, and has been operating since 1976.

Figure 10.13: The Gladstone coal-fired power station, on the banks of the Calliope Estuary photographed from the north-east.

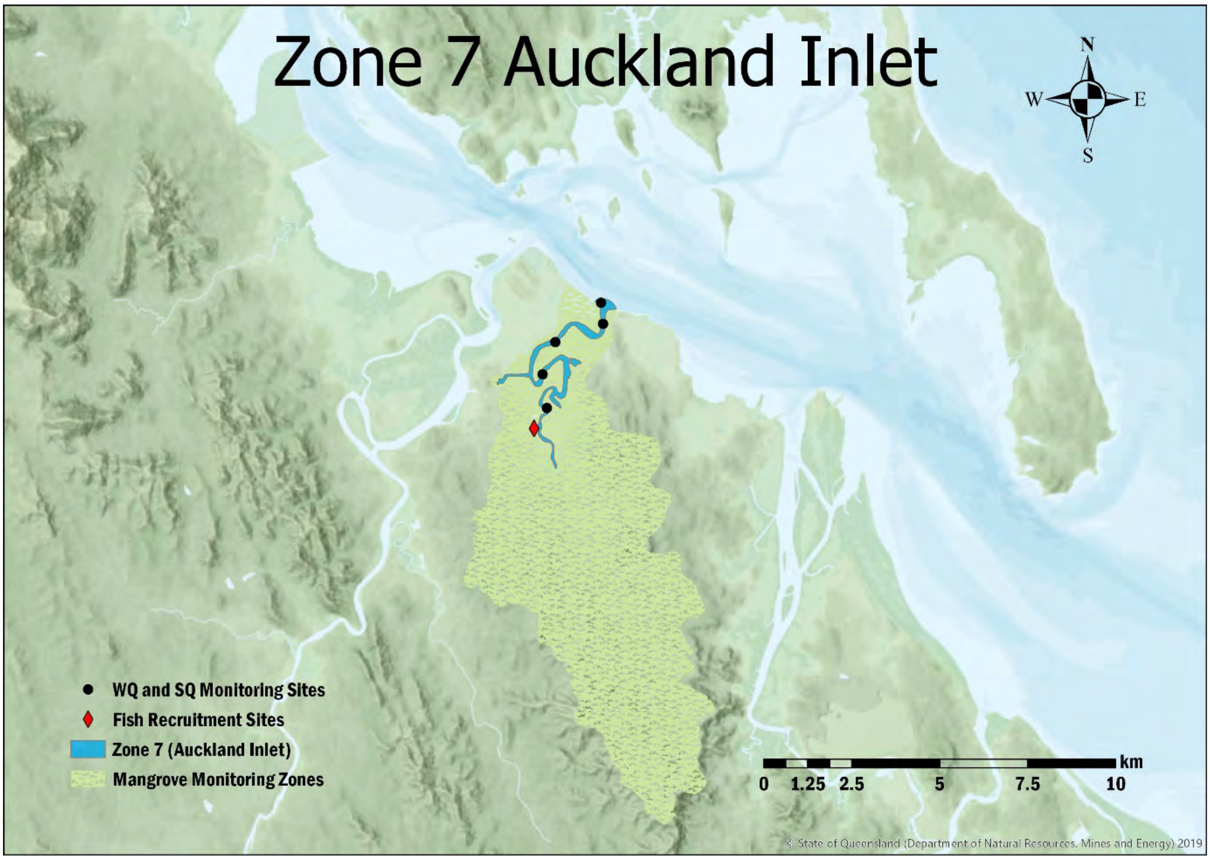


Figure 10.14: Habitat types and sampling sites in Auckland Inlet.

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

Zone area: 1.33 km^2
Fish health monitoring

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

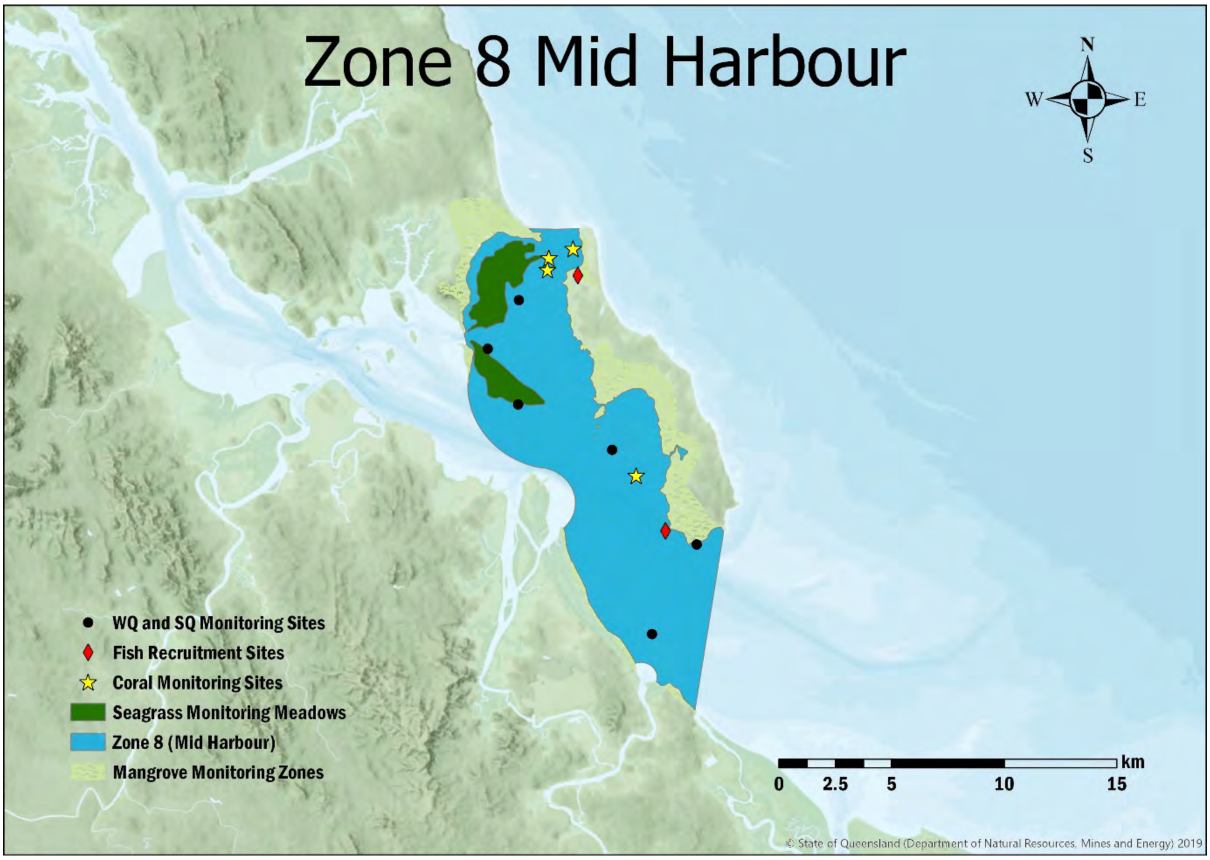


Figure 10.16: Habitat types and sampling sites in the Mid Harbour.

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

Zone area: 95.73 km^2
Fish health monitoring

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

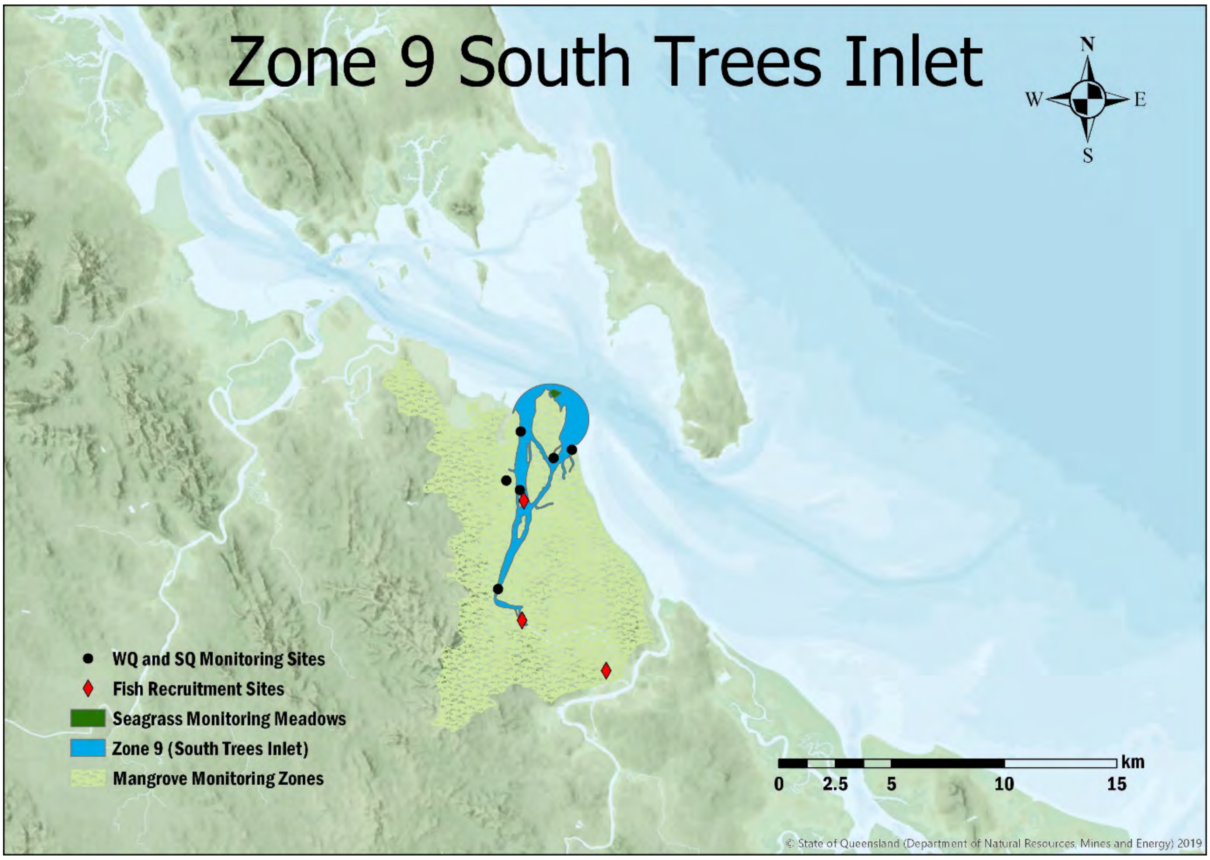


Figure 10.18: Habitat types and sampling sites in South Trees Inlet.

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

Zone area: 9.45 km^2
Fish health monitoring

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 10.9 ha 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 10.19: The mouth of South Trees Inlet photographed from the north, showing South Trees Island in the foreground and Boyne Island in the background.

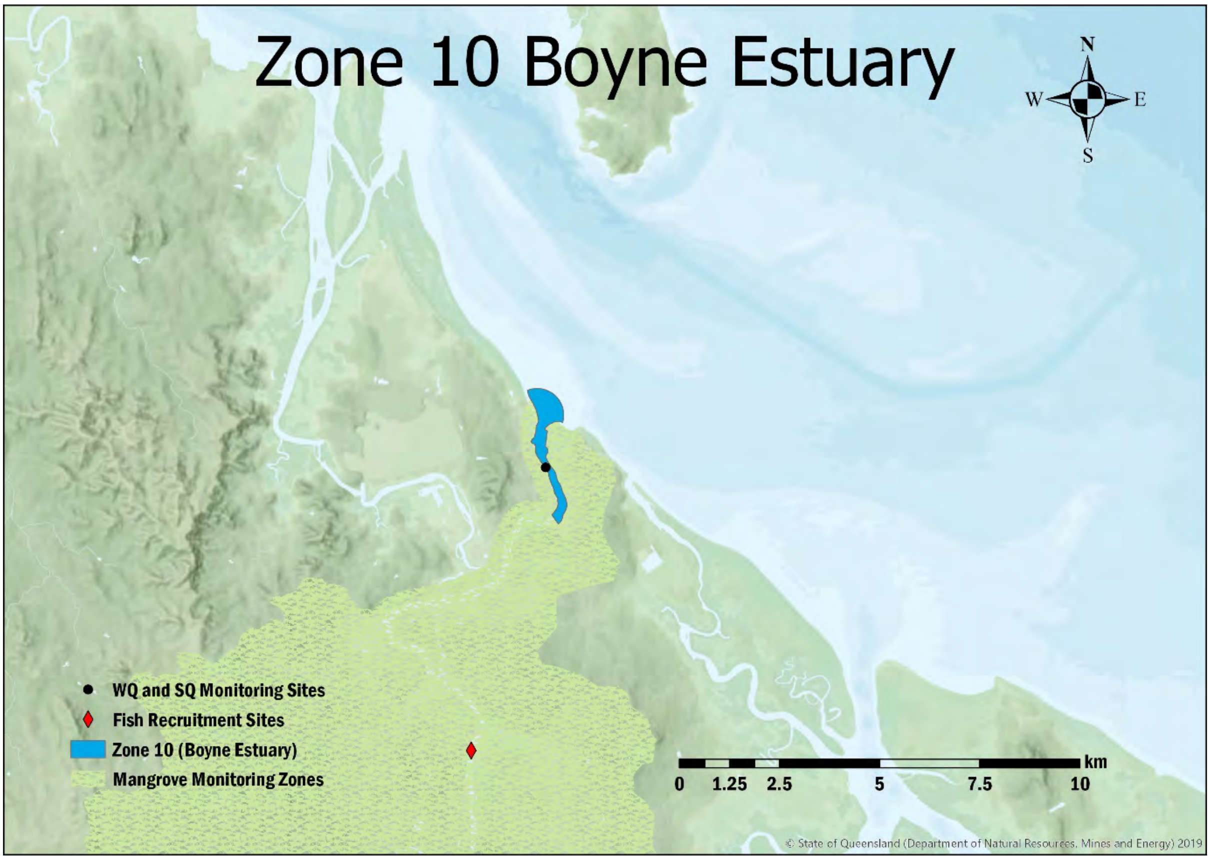


Figure 10.20: Habitat types and sampling sites in Boyne Estuary.

One water and sediment quality monitoring site
Two fish recruitment monitoring sites

Zone area: 3.62 km^2
Fish health monitoring

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

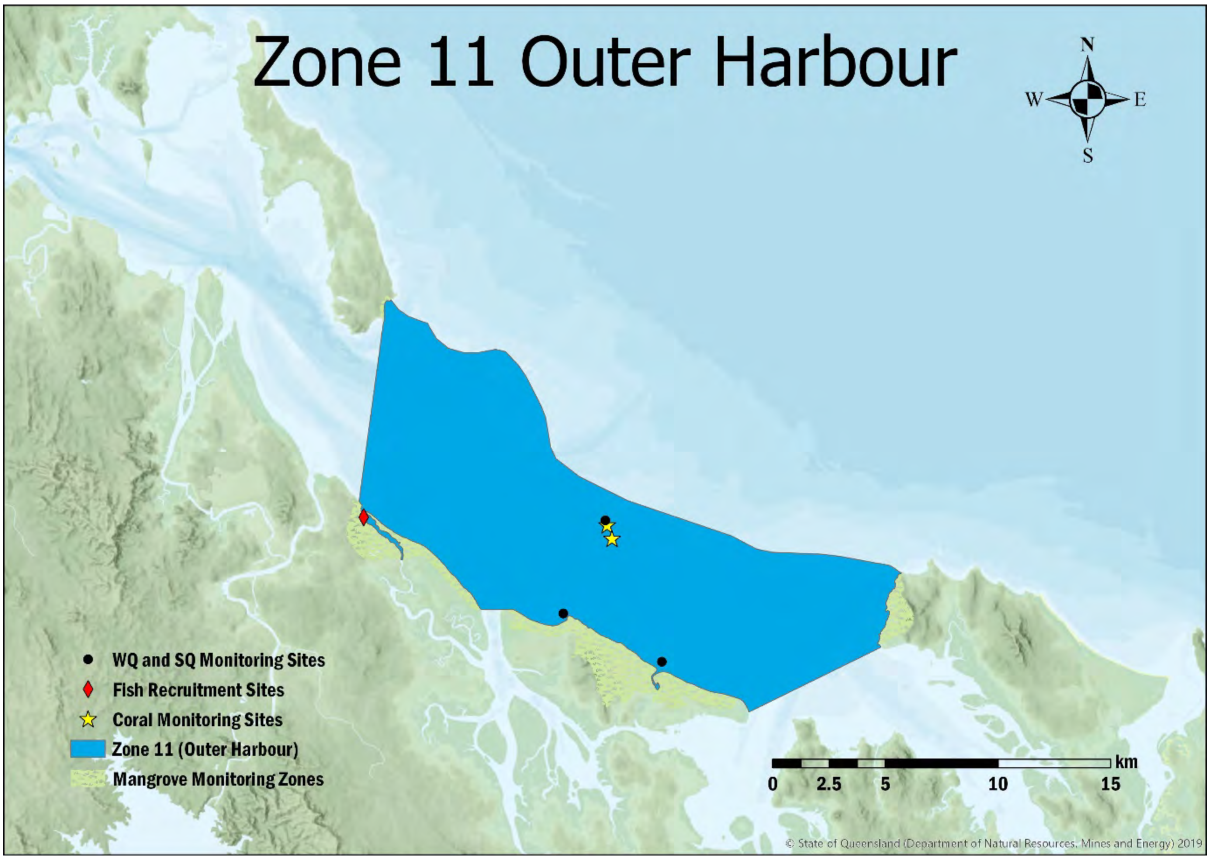


Figure 10.22: Habitat types and sampling sites in the Outer Harbour.

Three water and sediment quality monitoring sites
Two coral monitoring sites

Zone area: 176.97 km^2
Fish health monitoring

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.

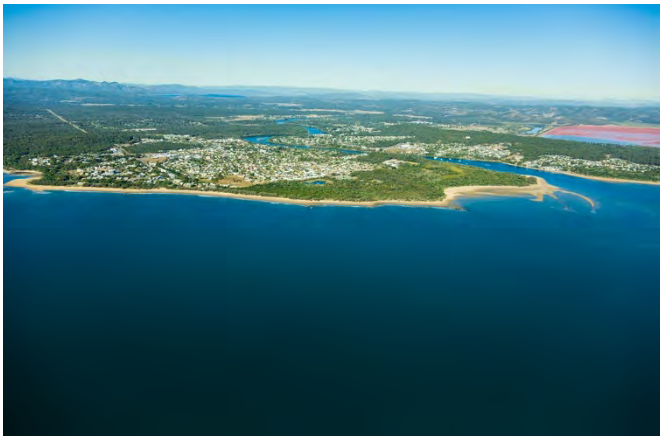


Figure 10.23: The Outer Harbour and Tannum Sands photographed from the north-east. Boyne Island and one of Gladstone's red mud (bauxite) dams are on the right.

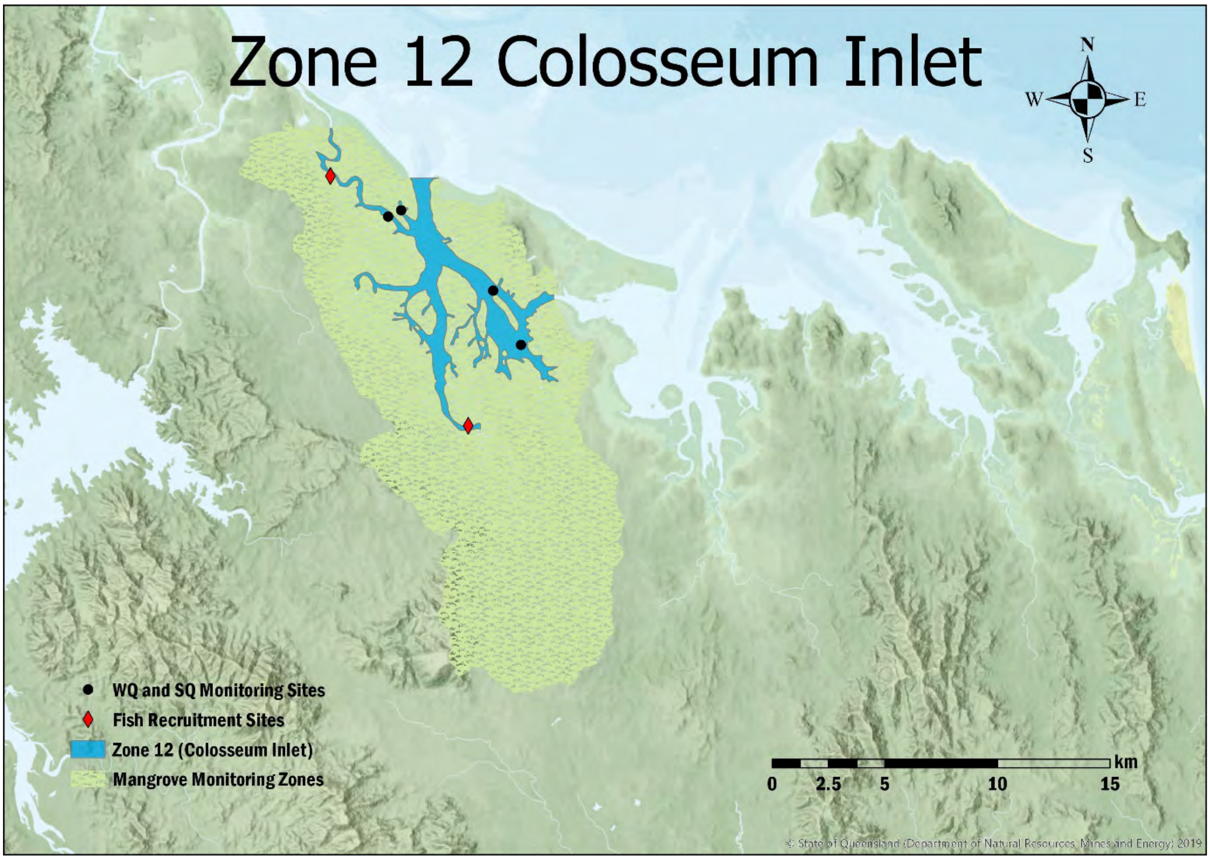


Figure 10.24: Habitat types and sampling sites in Colosseum Inlet.

Four water and sediment quality monitoring sites
Two fish recruitment monitoring sites

Zone area: 18.98 km^2
Fish health monitoring

Colosseum Inlet is an estuarine zone that is sheltered by Hummock Hill Island. Colosseum Inlet connects to 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.

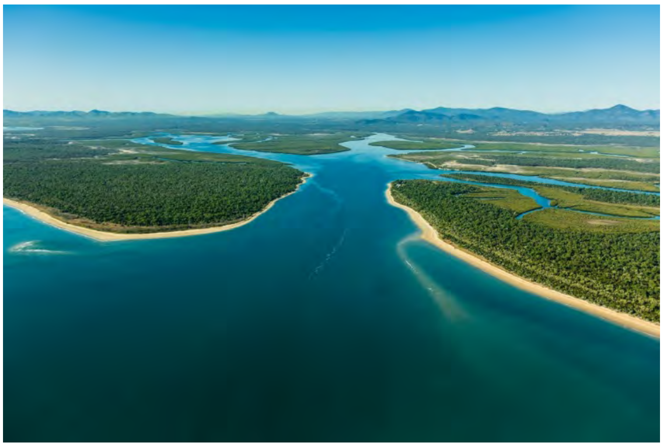


Figure 10.25: The northern entrance to Colosseum Inlet showing Wild Cattle Island on the right and Hummock Hill Island on the left.

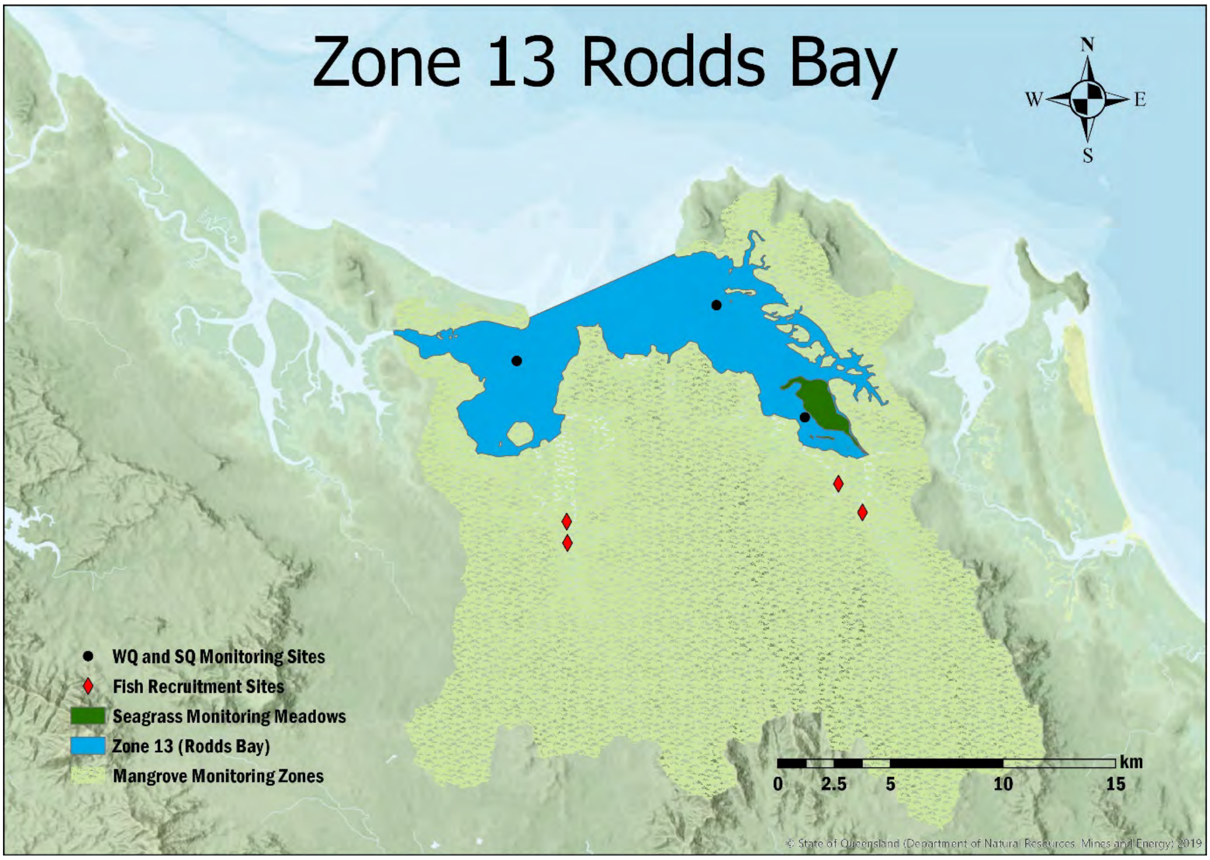


Figure 10.26: Habitat types and sampling sites in Rodds Bay.

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

Zone area: 70.14 km^2
Fish health monitoring

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

10.2. Social, cultural, and economic reporting areas

Data that contributed to the social, cultural ('sense of place') and economic scores were collected from the Gladstone Region. Participants in the CATI survey were selected from within the Gladstone 4680 postcode area (Figure 10.28). Hotel occupancy rates were based on the Gladstone Local Government Area. The Gladstone Ports Corporation 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 10.29).

However, for the marine safety incidents and oil spills social indicator, data originated from Gladstone Maritime Region which includes 1868 km of mainland coastline from Double Island Point to St. Lawrence, 132 km of island coastline and 26,190 km 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).

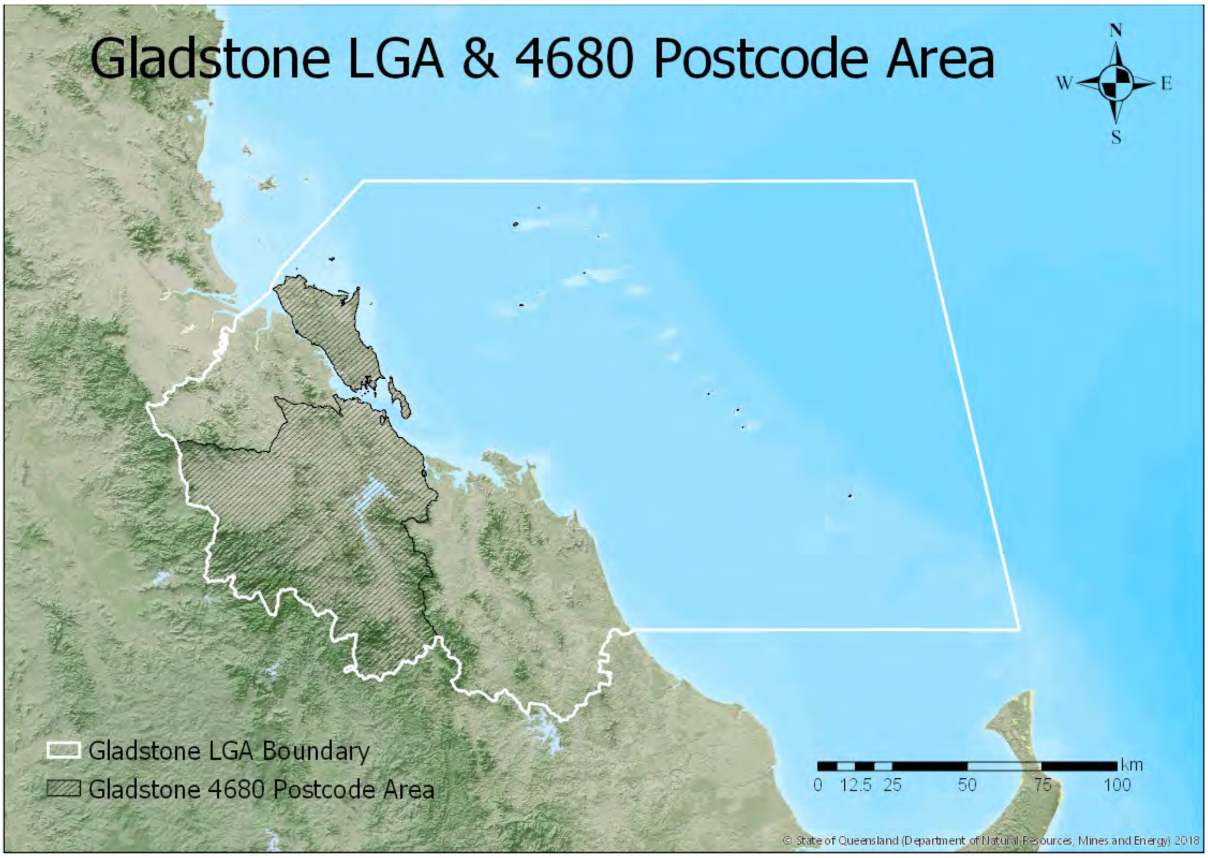


Figure 10.28: The Gladstone Region showing the mainland extent of the Gladstone Local Government Area and the Gladstone 4680 postcode area. Both were used to define areas from which some social, cultural, and economic data were collected.

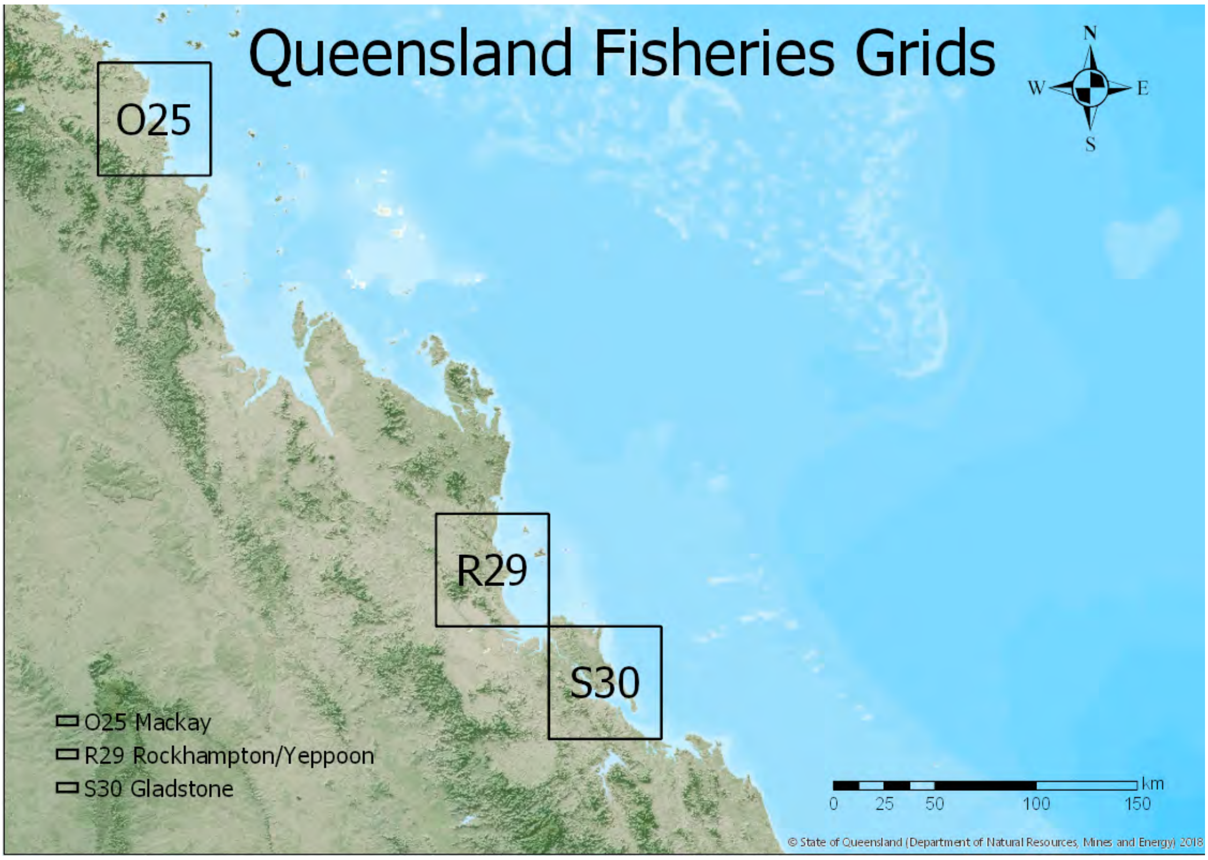


Figure 10.29: The Queensland Fisheries S30 (Gladstone), R29 (Rockhampton and Yeppoon) and O25 (Mackay) Grids. Data from these grids are used to calculate the commercial fishing indicator.

Data for the Indigenous cultural heritage indicator group were collected from four zones within the Gladstone Local Government Area boundary: The Narrows, Facing Island, Gladstone Central and Wild Cattle Creek (Figure 10.30).

The Narrows

The Narrows is the largest zone. It extends from Deception Creek to the Calliope River anabranch to the south and covers approximately 430 km^2 of the mainland and parts of Curtis Island. The score for the Narrows is based on six sites documented in 2016, three sites documented in 2017 and one site documented in 2018. The cultural locus site is a two-kilometre-long quarry site which was used by Traditional Owners to quarry silcrete 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 seven kilometres east of the Gladstone Central Business District (CBD). The island covers approximately 57 km^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 were 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 173 km^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 had 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 area 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 Barney Point. A total of six sites have been identified for annual surveys within this zone since 2016 of which five were revisited in 2018.

Wild Cattle Creek

The Wild Cattle Creek zone covers approximately 92 km^2, running south along the shore from the mouth of the Boyne River, near Tannum Sands, for about 23 km. 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 area 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.

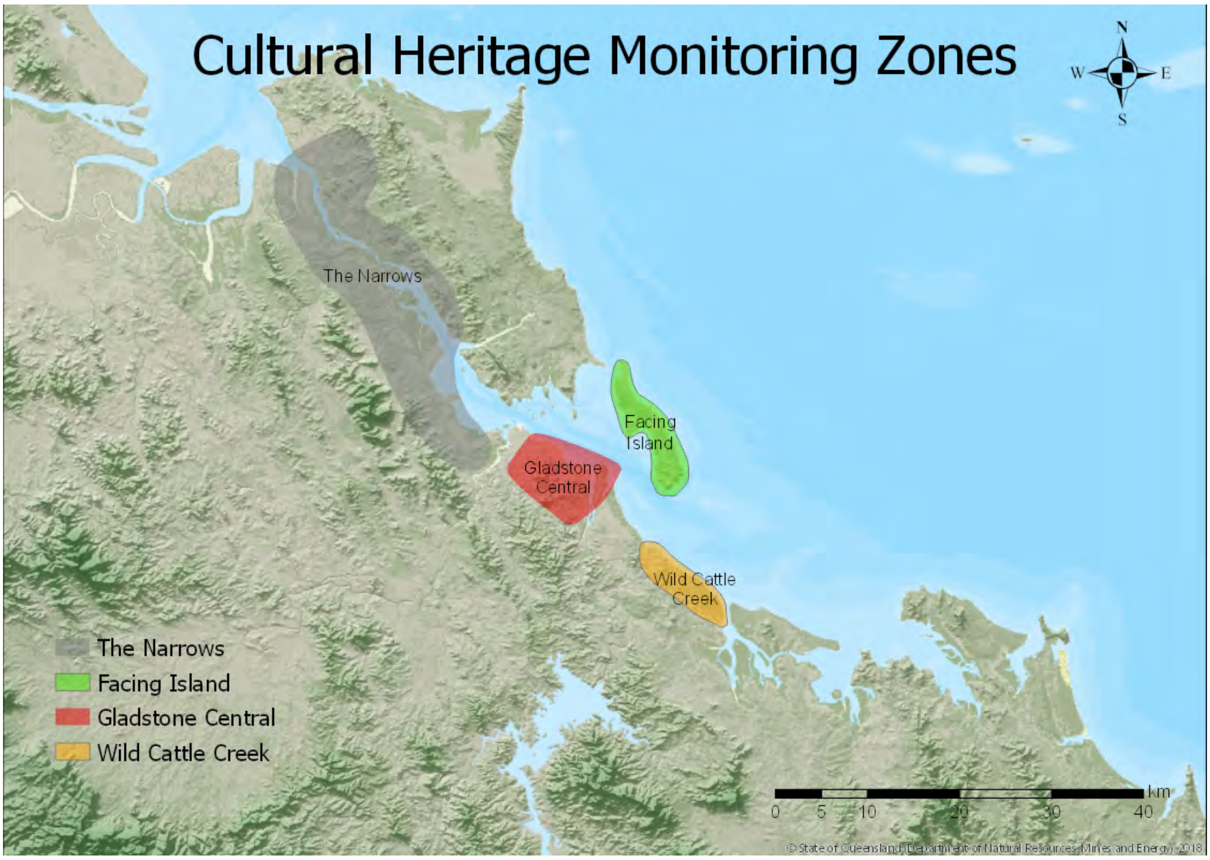


Figure 10.30: The four reporting zones from which data used to inform the Indigenous cultural heritage indicators for 2019 report card were collected.

11. References

Adams, S. M., Brown, A. M., & Goede, R. W. (1993). *A quantitative health assessment index for rapid evaluation of fish condition in the field.* Transactions of the American Fisheries Society, 122, 63-73.

Alberts-Hubatsch, H., Lee, S.Y., Meynecke, J.-O., Diele, K., Nordhaus, I. & Wolff, M. (2016). *Life-history, movement, and habitat use of Scylla serrata (Decapoda, Portunidae): current knowledge and future challenges*. Hydrobiologia, 763, 5-21.

Andersen, L. Norton, J. (2001). *Port Curtis mud crab shell disease: nature, distribution and management*. FRDC Project No. 98/210. CQUniversity, Gladstone.

Andersen, L.E., Norton, J.H. & Levy, N.H. (2000). *A new shell disease in the mud crab Scylla serrata from Port Curtis, Queensland (Australia)*. Diseases of Aquatic Organisms, 43, 233-239.

Andersen, L., Storey, A.W., Sinkinson, A., Dytlewski, N., (2003). *Transplanted oysters and resident mud crabs as biomonitors in Spillway Creek*. CQUniversity, Gladstone.

Angel, B., Hales, L.T., Simpson, S.L, Apte, S.C, Chariton, A., Shearer, D. & Jolley, D.F. (2010). *Spatial variability of cadmium, copper, manganese, nickel and zinc in the Port Curtis Estuary, Queensland, Australia.* Marine and Freshwater Research 61, 170-183.

Angel, B.M., Jarolimek, C.V., King, J.J., Hales, L.T., Simpson, S.L., Jung, R.F. & Apte, S.C. (2012). *Metal concentrations in the waters and sediments of Port Curtis, Queensland*. CSIRO Wealth from Oceans Flagship Technical Report.

ANZECC. (1992). *Australian water quality guidelines for fresh and marine waters*. Australian and New Zealand Environment and Conservation Council, Canberra.

ANZECC. (1998). *Interim ocean disposal guidelines*. Australian and New Zealand Environment and Conservation Council, Canberra.

ANZECC/ARMCANZ. (2000). *Australian and New Zealand guidelines for fresh and marine water quality*. Australia and New Zealand Environment and Conservation Council and Agriculture and Resource Management Council of Australia and New Zealand, Canberra.

ANZG. (2018). *Australian and New Zealand guidelines for fresh and marine water quality.* Australian and New Zealand Governments and Australian State and Territory Governments, Canberra. Available at www.waterquality.gov.au/anz-guidelines.

APHA. (2005). *Standard methods for the examination of water and wastewater* (21st ed.). Port City Press, Baltimore.

Baird, M. & Margvelasvili, N. (2015). *Receiving water and sediment scenarios*. Draft technical report. CSIRO, Australia.

Bartley, R., Waters, D., Turner, R., Kroon, F., Wilkinson, S., Garzon-Garcia, A., Kuhnert, P., Lewis, S., Smith, R., Bainbridge, Z., Olley, J., Brooks, A., Burton, J., Brodie, J. & Waterhouse, J. (2017). *Scientific Consensus Statement 2017: A synthesis of the science of land-based water quality impacts on the Great Barrier Reef, Chapter 2: Sources of sediment, nutrients, pesticides and other pollutants to the Great Barrier Reef*. State of Queensland, 2017.

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

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

Botte, A., Seguin, C., Nahrgang, J., Zaidi, M., Guery, J. & Leignel, V. (2022). Lead in the marine environment: concentrations and effects on invertebrates. *Ecotoxicology*, 31, 194-207

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

Bureau of Meteorology, Australian Government (2023), http://www.bom.gov.au/

Butcher, P.A. (2004). *Mud crab (Scylla serrata) and marine park management in estuaries of the Solitary Islands Marine Park, New South Wales.* PhD thesis, University of New England, Armidale.

Carter A.B., Chartrand K.M., Wells J.N. & Rasheed M.A. (2019). *Gladstone Healthy Harbour Partnership 2019 Report Card, ISP011: Seagrass*. Centre for Tropical Water & Aquatic Ecosystem Research Publication 19/15, James Cook University, Cairns, 63

Carter, A.B., Coles, R., Jarvis, J., Bryant, C., Smith, T. & Rasheed, M. (2023). *A report card approach to describe temporal and spatial trends in parameters for coastal seagrass habitats*, Nature Scientific Reports, 13:2295

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

Cempel, M., & Nikel, G., (2006). *Nickel: A review of its sources and environmental toxicology*. Polish Journal of Environmental Studies, 15(3), 375-382.

Cheal, A., Macneil, A., Cripps, E., Emslie, M., Jonker, M., Schaffelke, B. & Sweatman, H. (2010). *Coral-macroalgal phase shifts or reef resilience: Links with diversity and functional roles of herbivorous fishes on the Great Barrier Reef*, Coral Reefs. 29. 1005-1015

Commonwealth of Australia. (2013). *Independent Review of the Port of Gladstone: Report on Findings*. Commonwealth of Australia, Canberra.

Council of Australian Governments Standing Council on Environment and Water. (2013). *Australian and New Zealand guidelines for fresh and marine water quality guidelines for the protection of aquatic systems*. Aquatic ecosystems toxicant trigger values: Manganese – marine.

Cowled, B. (2016). *Final review of the use of fish health methods worldwide and their potential use in Gladstone Harbour*. Report prepared for Gladstone Healthy Harbour Partnership.

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.

Davies, J., Bryant, C., Carter, A. and Rasheed, M. (2016). *Seagrasses in Port Curtis and Rodds Bay 2015: Annual long-term monitoring*. Centre for Tropical Water and Aquatic Ecosystem Research (TropWATER), Publication 16/04, James Cook University, Cairns, 66.

Dennis, M.M., Diggles, B.K., Faulder, R., Olyott, L., Pyecroft, S.B., Gilbert, G.E. & Landos, M. (2016). *Pathology of finfish and mud crabs Scylla serrata during a mortality event associated with a harbour development project in Port Curtis, Australia*. Diseases of Aquatic Organisms, 121(3), 173-188.

Department of Environment and Heritage Protection. (2009). Queensland Water Quality Guidelines, Version 3, ISBN 978-0-9806986-0-2. DEHP, Brisbane.

Department of Environment and Heritage Protection. (2014). Environmental Protection (Water) Policy 2009: Environmental values and waste quality objectives Curtis Island, Calliope River and Boyne River basins. Environmental Policy and Planning Division, DEHP, Brisbane.

Department of Environment and Science. (2018). *Monitoring and sampling manual: Environmental Protection (Water) Policy*. State of Queensland.

Department of Environment and Science (2023) *WetlandInfo*. State of Queensland, *https://wetlandinfo.des.qld.gov.au/*

Department of Natural Resources, Mines and Energy. (2015). Water Monitoring Data Portal. [Online] Available from: <https://www.dnrm.qld.gov.au/water/water-monitoring-and-data/portal> (Accessed in August 2022).

Department of Resources (2022), *Queensland Spatial Catalogue – QSpatial,* State of Queensland, https://qldspatial.information.qld.gov.au/catalogue/

Department of Sustainability, Environment, Water, Population and Communities. (2013). *Independent review of the Port of Gladstone: Report on findings.* DSEWPaC, Canberra.

De Valck, J., 2022. *Final report on the status of the Social, Cultural (Sense of place) and Economic components for the 2022 Gladstone Harbour Report Card*. CQUniversity. Draft report to the Gladstone Healthy Harbour Partnership, July 2022.

DHI Water and Environment. (2013). *Gladstone coral desktop study: Desktop study of the distribution and ecological value of corals and coral reef in the Gladstone region and wider bioregion*. Report prepared for the Gladstone Ports Corporation Limited by DHI Water and Environment. Singapore.

Dougall, C., McCloskey, G.L., Ellis, R., Shaw, M., Waters, D. & Carroll, C. (2014). *Modelling reductions of pollutant loads due to improved management practices in the Great Barrier Reef catchments* – Fitzroy NRM region, Technical Report, Volume 6. Queensland Department of Natural Resources and Mines, Rockhampton (ISBN: 978-0-7345-0444-9).

Duke, N.C. & Mackenzie, J. (2019). *Project ISP018-2019: Development of mangrove indicators for the 2019 Gladstone Harbour Report Card*. Report to Gladstone Healthy Harbour Partnership by TropWATER Centre. Publication 19/34, James Cook University, Townsville, 38 pp.

Erftemeijer, P., Riegl, B., Hoeksema, B. & Todd, P. (2012). *Environmental impacts of dredging and other sediment disturbances on corals: A review.* Marine Pollution Bulleton, Volume 64, Issue 9, pages 1737-1765.

Fishes of Australia, https://fishesofaustralia.net.au/

Flint, N., Anastasi, A., De Valck, J., Chua, E., Rose, A. & Jackson, E.L. (2017a). *Developing mud crab indicators for the Gladstone Harbour Report Card*. Final Report to the Gladstone Healthy Harbour Partnership, CQUniversity, August 2017.

Flint, N., Anastasi, A., Irving, A., De Valck, J., Chua, E., Rose, A., French, K. & Jackson, E.L. (2018). *Fish health indicators for the Gladstone Harbour Report Card, Final Report to the Gladstone Healthy Harbour Partnership*. CQUniversity Australia, Queensland.

Flint, N., De Valck, J., Anastasi, A., and Jackson, E.L. (2019). *Mud crab indicators for the Gladstone Harbour Report Card*. Report to the Gladstone Healthy Harbour Partnership. CQUniversity, Rockhampton.

Flint, N., Rolfe, J., Jones, C.E., Sellens, C., Johnston, N.D. & Ukkola, L. (2017b). *An ecosystem health index for a large and variable river basin: Methodology, challenges and continuous improvement in Queensland's Fitzroy Basin*. Ecological Indicators, 73, 626-636.

Foster, N.L., Box, S.J. & Mumby, P.J. (2008). *Competitive effects of macroalgae on the fecundity of the reef-building coral Montastrea annularis*. Marine Ecology Progress Series, 367, 143-152.

Fox, D.R. (2013). *Statistical issues associated with the development of an ecosystem report card. Report prepared for GHHP by Environmetrics Australia*, Melbourne.

Garelick, H., Jones, H., Dybowska, A. & Valsami-Jones, E. (2008). *Arsenic pollution sources*. Reviews of Environmental Contamination and Toxicology, 197, 17-60.

Garratt, J. R. (1993). *Sensitivity of Climate Simulations to Land-Surface and Atmospheric Boundary Layer Treatments – A Review.* Journal of Climate. 419-448. 10.1175

GHHP. (2019). *Technical report, Gladstone Harbour Report Card 2019*, GHHP technical report No. 6. Gladstone Healthy Harbour Partnership, Gladstone.

GHHP. (2020). *Technical report, Gladstone Harbour Report Card 2020*, GHHP technical report No. 7. Gladstone Healthy Harbour Partnership, Gladstone.

GHHP. (2021). *Technical report, Gladstone Harbour Report Card 2021*, GHHP technical report No. 8. Gladstone Healthy Harbour Partnership, Gladstone.

Golding, L.A., Angel, B.M., Batley, G.E., Apte, S.C., Krassoi, R. & Doyle, C.J. (2014). *Derivation of a water quality guideline for aluminium in marine waters*. Environmental Toxicology and Chemistry, 34, 141-151. doi:10.1002/etc.2771.

Greer, L. & Kabir, Z. (2012) *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, CQUniversity Australia, Rockhampton.

Hale, J. & Box, P. (2014). *Identification and development of a water quality improvement and monitoring program for the major catchments supplying Port Curtis*. A report for Gladstone Ports Corporation's Biodiversity Offset Strategy.

Hansler, M., Schultz, M. and Uthpala, P. (2020). *Water and Sediment Quality Indicators for the 2018 Gladstone Harbour Report Card*. Gladstone Healthy Harbour Partnership, Gladstone.

Harrison, S. (1991). *Local extinction in a metapopulation context: an empirical evaluation*. Biological Journal of the Linnean Society. 42, 73-88. 10.1111

James. A., Pitchford. J.W. & Brindley. J. (2003) *The relationship between plankton blooms, the hatching of fish larvae, and recruitment.* Ecological Modelling. 160, 77-90. 10.1016

Jebreen, E., Helmke, S., Lunow, C., Bullock, C., Gribble, N., Whybird, O. & Coles, R. (2008). *Fisheries long term monitoring program, mud crab (*Scylla serrata) *Report: 2000–2002*. Department of Primary Industries and Fisheries, Brisbane, Australia.

Jones, M.A., Stauber, J., Apte, S., Simpson, S., Vicente-Beckett, V., Johnson, R. & Duivenvoorden, L. (2005). *A risk assessment approach to contaminants in Port Curtis, Queensland, Australia,* Marine Pollution Bulletin, 51, 448-458.

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

King, M. (2007). *Fisheries biology: Assessment and management*. Wiley-Blackwell. New York.

Knuckey, I.A., (1999). *Mud crab (*Scylla serrata*) population dynamics in the Northern Territory, Australia and their relationship to the commercial fishery.* Northern Territory University, Darwin, Australia.

Koushlesh, S.K., Sinha, A., & Kumari, K. (2018). *Length-weight relationship and relative condition factor of five indigenous fish species from Torsa River, West Bengal, India.* Journal of Applied Ichthyology, 34, 169-171.

Kroon, F.J., Streten, C., & Harries, S.J. (2016) *The use of biomarkers in fish health assessment worldwide and their potential use in Gladstone Harbour*. Australian Institute of Marine Science, Townsville.

Le Cren, E.D., (1951). *The length-weight relationship and seasonal gonad weight and condition in the Perch Perca fluviatilis.* Journal of Animal Ecology, 20, pp. 201-219.

Lirman, D. (2001). *Competition between macroalgae and corals: Effects of herbivore exclusion and increased algal biomass on coral survivorship and growth*, Coral Reefs. 19, pp. 392-399. doi:10.1007/s003380000125

Lockwood, C.L., Mortimer, R.J.G., Stewart, D.I., Mayes, W.M., Peacock, C.L., Polya, D.A. & Burke, I.T. (2014). *Mobilisation of arsenic from bauxite residue (red mud) affected soils: Effect of pH and redox conditions*. Applied Geochemistry, 51, 268-277.

Logan, M. (2016). *Provision of final environmental grades and scores for 2016 Gladstone Harbour Report Card*. Report prepared by the Australian Institute of Marine Science for Gladstone Healthy Harbour Partnership. 9 November 2016, 113 pp.

Mackay-Whitsunday Healthy Rivers to Reef Partnership. (2018). *Mackay-Whitsunday report card program design 2017 to 2022*. Mackay-Whitsunday Healthy Rivers to Reef Partnership, Mackay.

McCormack, C., Rasheed, M., Davies, J., Carter, A., Sankey, T. & Tol, S. (2013). *Long term seagrass monitoring in the Port Curtis Western Basin: Quarterly Seagrass Assessments and Permanent Transect Monitoring Progress Report November 2009 to November 2012*. Centre for Tropical Water & Aquatic Ecosystem Research (TropWATER) Publication, James Cook University, Cairns, 88 pp.

McIntosh, E.J., Poiner, I.R. & ISP Members. (2014). *Gladstone Harbour Report Card framework recommendations - March 2014*. Report prepared for the Gladstone Healthy Harbour Partnership Management Committee, Gladstone.

Morrow., K.M., Bromhall, K., Motti, C.A., Munn, C.B., Bourne, D.G. (2017). *Allelochemicals produced by brown macroalgae of the Lobophora genus are active against coral larvae and associated bacteria, supporting pathogenic shifts to vibrio dominance.* Applied and Environmental Microbiology 83: e02391-16. https://doi.org/10.1128/AEM.02391-16.

Mumby, P.J., Hastings A. & Edwards H.J. (2007). *Thresholds and the Resilience of Caribbean Coral Reefs.* Nature 450 (7166): 98–101. doi:10.1038/nature06252.

Mumby, P.J. & Steneck, R.S. (2008). *Coral reef management and conservation in light of rapidly evolving ecological paradigms.* Trends in Ecology & Evolution, 23 (10), 555–63. doi: 10.1016/j.tree.2008.06.011.

Mumby, P.J., Steneck, R.S. & Hastings, A. (2013). *Evidence for and against the Existence of Alternate Attractors on Coral Reefs*. Oikos 122. doi:10.1111/j.1 600-0706.2012.00262

Pascoe. S., Tobin. R., Windle, J., Cannard, T., Marshall, N., Kabir, Z. & Flint, N. (2014). *Developing a Social, Cultural and Economic Report Card for a Regional Industrial Harbour*. PLOS ONE. 11, 10.1371

PCIMP. (2019). *Port Curtis Integrated Monitoring Program Monitoring approach and methodology: water and sediment quality monitoring, version 4*. PCIMP, Gladstone Australia.

Pillans, S., Pillans, R.D., Johnstone, R.W., Kraft, P.G., Haywood, M.D.E. & Possingham, H.P. (2005). *Effects of marine reserve protection on the mud crab Scylla serrata in a sex-biased fishery in subtropical Australia.* Marine Ecology Progress Series, 295, 201-213.

Rasheed, M.A., Thomas, R., Roelofs, A.J., Neil, K.M. & Kerville, S.P. (2003). *Port Curtis and Rodds Bay seagrass and benthic macro-invertebrate community baseline survey - November/December 2002*. DPI&F, Fisheries Queensland, Cairns.

Rogers, C.S. (1990). Responses of coral reefs and reef organisms to sedimentation. *Marine Ecology Progress Series,* 62, 185-202.

Sawynok, B., Sawynok, S. & Dunlop, A. (2018). *New tools to assess fish health*. Infofish Australia.

Sawynok, B. & Sawynok, S. (2022). *Fish recruitment indicator for the Gladstone Harbour Report Card using data derived from castnet sampling 2022*. Infofish Australia.

Sawynok, S., Sawynok, B. & Sawynok, P. (2022) *Fish condition indicators for the Gladstone Harbour Report Card 2022.* Report on FRDC project 2107-141, Infofish Australia Pty Ltd, Murarrie Queensland.

Schneider, J.C., P.W. Laarman, & H. Gowing. (2000). *Length-weight relationships*. Chapter 17 in Schneider, James C, (ed) (2000), Manual of fisheries survey methods II: with periodic updates, Michigan Department of Natural Resources, Fisheries Special Report 25, Ann Arbor.

Schultz, M, Pinto, U & Hansler, M (2019) *Water and sediment quality indicators for the Gladstone Harbour Report Card 2017.* Gladstone Healthy Harbour Partnership, Gladstone.

Simpson., S.L., Batley., G.B. & Chariton., A.A. (2013). *Revision of the ANZECC/ARMCANZ Sediment Quality Guidelines*. CSIRO Land and Water Science Report 08/07. CSIRO Land and Water.

Smith, T.M., Carter, A.B., & Rasheed, M.A. (2022a). *Gladstone Healthy Harbour Partnership 2022 Report Card Summary, ISP011: Seagrass*. Centre for Tropical Water & Aquatic Ecosystem Research, James Cook University, 4 pp.

Smith, T.M., Reason, C., McKenna, S., & Rasheed, M.A. (2022b). *Seagrasses in Port Curtis and Rodds Bay 2021 Annual long-term monitoring*. Centre for Tropical Water & Aquatic Ecosystem Research (TropWATER) Publication 22/14, James Cook University, Cairns, 52 pp.

Storey, A.W., Andersen, L.E., Lynas, J. & Melville, F. (2007). *Port Curtis Ecosystem Health Report Card*. Port Curtis Integrated Monitoring Program, Centre for Environmental Management, CQUniversity.

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

Terra Rosa Consulting 2016, *Task 9: Final Report: ISP012 – Developing the Cultural Heritage Indicators for the Gladstone Healthy Harbour Partnership*, Terra Rosa Consulting, Western Australia.

Terra Rosa Consulting 2017, *Task 6: Final Report 2017: ISP012-2016: Indigenous Cultural Heritage Indicators for the Gladstone Healthy Harbour Partnership (GHHP) Report Card*, Terra Rosa Consulting, Western Australia.

Terra Rosa Consulting 2018, *Final Report: ISP012-2018: Indigenous cultural heritage indicators for the Gladstone Harbour Report Card*, Terra Rosa Consulting, Western Australia.

Thompson, A., Costello, P. & Davidson, J. (2015). *Developing coral indicators for the Gladstone Harbour Report Card, ISP014: Coral*. Australian Institute of Marine Science, Townsville.

Thompson, A., Costello, P., Davidson, J., Logan, M., Gunn K. & Schaffelke, B. (2016). *Annual report for coral reef monitoring 2014–15*. Report for the Great Barrier Reef Marine Park Authority. Australian Institute of Marine Science, Townsville.

Thompson A., Thompson C., & Davidson J. (2022). *Coral Indicators for the 2022 Gladstone Harbour Report Card 2022: ISP014*. Report prepared for Gladstone Healthy Harbour Partnership. Australian Institute of Marine Science, Townsville.

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

Twigger-Ross. C. L. & Uzzell, D. L. (1996) *Place and Identity Process*. Journal of Environmental Psychology, 16, 205-220, 10.1006

United Nations Environment Programme. (2010). *Final review of scientific information on Cadmium*, United Nations Environment Programme-Chemicals Branch, DTIE [Online] Available from: http://www.unep.org/chemicalsandwaste/Portals/9/Lead_Cadmium/docs/Interim_reviews/UNEP_GC26_INF_11_Add_2_Final_UNEP_Cadmium_review_and_apppendix_Dec_2010.pdf (30 November 2015).

Unsworth, R.K.F., Rasheed, M.A., Chartrand, K.M. & Roelofs, A.J. (2012). *Solar radiation and tidal exposure as environmental drivers of Enhalus acoroides dominated seagrass meadows.* PLoS ONE, 7: e34133.

Van Dam, J., Negri, A., Uthicke, S. & Mueller, J. (2011). *Chemical Pollution on Coral Reefs: Exposure and Ecological Effects*. Ecological Impacts of Toxic Chemicals, pp 187-211.

Vega Thurber, R., Burkepile, D., Correa, A., Thurber, A., Shantz, A., Welsh, R., Pritchard, C. & Rosales, S. (2012). Macroalgae Decrease Growth and Alter Microbial Community Structure of the Reef Building Coral, *Porites astreoides*. *Plos One*. doi:10.1371/journal.pone.0044246

Venables, W.N. (2015). *GHHP barramundi recruitment index project final report*. Gladstone Health Harbour Partnership [Online] Available from: https://dims.ghhp.org.au/repo/data/public/7d9e4c.php (27 January 2016).

Vision Environment Queensland. (2011). *Port Curtis Ecosystem Health Report Card*. Port Curtis Integrated Monitoring Program, Gladstone.

Vision Environment Queensland. (2013a). *Western Basin dredging and disposal program 013 event sampling – March 2013*. Report produced for Gladstone Ports Corporation, Gladstone, Qld.

Vision Environment Queensland. (2013b). *Western Basin Dredging and disposal program water quality monitoring – April 2013*. Report produced for Gladstone Ports Corporation, Gladstone, Qld.

Watson, R.M., Crafford, D., & Avenant-Oldewage, A. (2012). *Evaluation of the fish health assessment index in the Olifants River system, South Africa.* African Journal of Aquatic Science, 37(3), 235-251.

Wesche, S., Lucas, T., Mayer, D., Waltisbuhl, D., & Quinn, R. (2013). *Gladstone Harbour fish health investigation 2011–2012*. Department of Agriculture and Fisheries, Brisbane.

Wet Tropics Healthy Waterways Partnership (2018). *Wet Tropics report card program design: Five-year plan 2018 - 2022*. Wet Tropics Health Waterways Partnership and Terrain NRM, Innisfail.

Whitehead, T. (2020). *Methods for the Townsville Dry Tropics annual report cards.* Dry Tropics Partnership for Healthy Waters, Townsville.

Wilson, S.P. & Anastasi, A. (2010). *A review of manganese in subtropical estuaries: Port Curtis-A case study.* Australasian Journal of Ecotoxicology, 16, 119-133.

Windle, J., De Valck, J., Star, M. & Flint, N. (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.

York, P. & Smith, T. (2013). *Research, monitoring and management of seagrass ecosystems adjacent to port developments in Central Queensland: Literature review and gap analysis*. Deakin University, Waurn Ponds.

Zumdahl, S. & DeCost, G.J. (2010). *Basic chemistry, 7th Edition.* Brooks/Cole, Belmont, USA. ISBN-10: 0538736372.

12. Glossary

Terms and acronyms	Definition
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
CATI	computer-assisted telephone interviewing
Component	The Gladstone Harbour Report Card will report on four components of harbour health: environmental, cultural, social and economic.
CPUE	Catch per unit effort
CSIRO	Commonwealth Scientific and Industrial Research Organisation
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)
GHHP	Gladstone Healthy Harbour Partnership
Guidelines and criteria	Science-based numerical concentration limits or descriptive statements recommended to support a designated water use. Guidelines are not legally enforceable.
Fish Condition (FC)	An automated visual assessment of images captured by fishers using a mobile phone app.
Health Assessment Index (HAI)	A thorough assessment of the health of individual fish based on visual condition and the condition of several internal organs and tissues.
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.
ISP	GHHP Independent Science Panel
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.
MC	GHHP Management Committee

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.
PCIMP	Port Curtis Integrated Monitoring Program
Physicochemical	Physical and chemical forces that influence the environment and the biodiversity and people within e.g. temperature, salinity
Point source	A single, identifiable localised source of a release e.g. a stormwater outlet
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)
VFC	Visual fish condition
WICET	Wiggins Island Coal Export Terminal

Appendix 1: Gladstone Healthy Harbour Partnership 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. 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 CQUniversity	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. CQUniversity Australia, Rockhampton. Download the final report for this project.
ISP005 Social, cultural and economic components CSIRO (2014 – 2015) CQUniversity (2016 – 2022)	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. Download the final report for this project

Project name and institution	Reports and publications
ISP005 Social, cultural and economic components CSIRO (2014 – 2015) CQUniversity (2016 – 2022)	Cannard, Windle, J., Tobin, R. (2016). *Final Report on the Status of Economic, Social and Selected Cultural Indicators for the Gladstone Harbour 2015 Report Card.* 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.* CQUniversity, Rockhampton. 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.* CQUniversity, Rockhampton. Download the final report for this project. Windle, J., De Valck, J., Star M. and Flint, N. (2018) *Report on the status of the social, cultural ('sense of place') and economic components for the Gladstone Harbour 2018 Report Card*. CQUniversity, Rockhampton. Download the final report for this project. De Valck, J., Star, M. & Flint, N. (2019) *Report on the status of the social, cultural ('sense of place') and economic components for the Gladstone Harbour 2019 Report Card.* CQUniversity, Rockhampton. Download the final report for this project. De Valck, J., (2022) *Final report on the status of the Social, Cultural ('sense of place') and Economic components for the 2022 Gladstone Harbour Report Card.* CQUniversity. Report to the Gladstone Healthy Harbour Partnership, July 2022. Download the final summary report for this project.

Project name and institution	Reports and publications
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.
ISP007 Development of connectivity indicators for the Gladstone Healthy Harbour Report Card CSIRO Wealth from Oceans Flagship, University of Queensland	Condie, S., Herzfeld, M., Andrewartha, J., Gorton, B., & Hock, K. (2015). *Project ISP007: Development of connectivity indicators for the 2014 Gladstone Harbour Report Card*. CSIRO Wealth from Oceans Flagship, Hobart, University of Queensland. Download the final report for this project. Condie, S., Herzfeld, M., Andrewartha, J., Gorton, B., & Hock, K. (2015). *Connectivity indicators for the 2015 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 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 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.

Project name and institution	Reports and publications
ISP008 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.* Australian Institute of Marine Science, Townsville. Download the final report for this project.
ISP009 Development of a Data Information Management System for the Gladstone Harbour Report Card monitoring data	Australian Institute of Marine Science. (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 Centre for Tropical Water & Aquatic Ecosystem Research (James Cook University)	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*. Centre for Tropical Water & Aquatic Ecosystem, James Cook University. Download the final report for this project. Carter, A.B., Jarvis, J.C., Bryant, C.V., & Rasheed, M.A. (2015). *Gladstone Healthy Harbour Partnership 2015 Report Card ISP011: Seagrass final report*. Centre for Tropical Water & Aquatic Ecosystem Research, James Cook University, Cairns. Download the final report for this project. Carter, A.B., 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, 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, James Cook University, Cairns. Download the final report for this project.

Project name and institution	Reports and publications
ISP011 Seagrass indicators Centre for Tropical Water & Aquatic Ecosystem Research (James Cook University)	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, James Cook University, Cairns. Download the final report for this project. Carter AB, Chartrand KM, Wells JN & Rasheed MA (2019) *Gladstone Healthy Harbour Partnership 2019 Report Card, ISP011: Seagrass*. Centre for Tropical Water & Aquatic Ecosystems Research, James Cook University, Cairns. Download the final report for this project. Carter A.B., Bryant C.V., Smith, T., Rasheed M.A. (2020) *Gladstone Healthy Harbour Partnership 2020 Report Card Summary, ISP011: Seagrass*. Centre for Tropical Water & Aquatic Ecosystem Research, Cairns. Download the final summary report for this project. Smith, T., Carter A.B. & Rasheed M.A., (2021) *Gladstone Healthy Harbour Partnership 2020 Report Card Summary, ISP011: Seagrass*. Centre for Tropical Water & Aquatic Ecosystem Research, Cairns. Download the final summary report for this project. Smith, T., Carter A.B. & Rasheed M.A., (2022) *Gladstone Healthy Harbour Partnership 2022 Report Card Summary, ISP011: Seagrass*. Centre for Tropical Water & Aquatic Ecosystem Research, Cairns. Download the final summary report for this project.

Project name and institution	Reports and publications
ISP012 Cultural heritage indicators Terra Rosa Consulting	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. Terra Rossa Consulting. (2017). *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. 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 Fish recruitment indicators Infofish Australia Pty Ltd 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, Gladstone. Download the final report for this project. Sawynok, B. & Venables, B. (2016) *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.

Project name and institution	Reports and publications
ISP013 Fish recruitment indicators Infofish Australia Pty Ltd and Dr Bill Venables	Sawynok, B. & Sawynok, S. (2019) *Fish recruitment indicators for the Gladstone Harbour Report Card using data derived from castnet sampling 2019.* Report for the Gladstone Healthy Harbour Partnership, Gladstone. Download the final report for this project. Sawynok, B. & Sawynok, S. (2020) *Fish recruitment indicators for the Gladstone Harbour Report Card using data derived from castnet sampling 2020.* Report for the Gladstone Healthy Harbour Partnership, Gladstone. Download the final report for this project. Sawynok, B. & Sawynok, S. (2021) *Fish recruitment indicators for the Gladstone Harbour Report Card using data derived from castnet sampling 2021.* Report for the Gladstone Healthy Harbour Partnership, Gladstone. Download the final report for this project. Sawynok, B. & Sawynok, S. (2022) *Fish recruitment indicators for the Gladstone Harbour Report Card using data derived from castnet sampling 2022.* Report for the Gladstone Healthy Harbour Partnership, Gladstone. Download the report for this project.
ISP014 Coral indicators 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. Download the final report for this project.

Project name and institution	Reports and publications
ISP014 Coral indicators Australian Institute of Marine Science	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. Costello P., Thompson A., Davidson J. (2019) *Coral Indicators for the 2019 Gladstone Harbour Report Card 2019: ISP014.* Report prepared for Gladstone Healthy Harbour Partnership. Australian Institute of Marine Science, Townsville. Download the final report for this project. Costello P., Thompson A., Davidson J. (2020) *Coral Indicators for the 2020 Gladstone Harbour Report Card 2020: ISP014.* Report prepared for Gladstone Healthy Harbour Partnership. Australian Institute of Marine Science, Townsville. Download the final report for this project. Thompson A., Costello P. & Davidson J. (2021) *Coral Indicators for the 2021 Gladstone Harbour Report Card 2021: ISP014.* Report prepared for Gladstone Healthy Harbour Partnership. Australian Institute of Marine Science, Townsville. Download the final report for this project. Thompson A, Thompson C, Davidson J (2022) *Coral Indicators for the 2022 Gladstone Harbour Report Card 2022: 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.

Project name and institution	Reports and publications
ISP015 Mud crabs indicators CQUniversity	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. CQUniversity, Rockhampton. 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, Rockhampton. Download the final report for this project. Flint, N., De Valck, J., Anastasi, A., and Jackson, E.L. (2019) *Mud crab indicators for the Gladstone Harbour Report Card.* Report to the Gladstone Healthy Harbour Partnership. CQUniversity, Rockhampton. Download the final report for this project. Flint, N., De Valck, J., Anastasi, A., and Jackson, E.L. (2020) Mud crab indicators for the Gladstone Harbour Report Card. *Report to the Gladstone Healthy Harbour Partnership.* CQUniversity, Rockhampton. Download the final report for this project. Flint, N., De Valck, J. & Anastasi, A., (2021) *Mud crab indicators for the Gladstone Harbour Report Card.* Report to the Gladstone Healthy Harbour Partnership. CQUniversity, Rockhampton. Download the final report for this project. Flint, N., De Valck, J. & Anastasi, A., (2022). *Mud crab indicators for the Gladstone Harbour Report Card.* Report to the Gladstone Healthy Harbour Partnership. CQUniversity, Rockhampton. Download the final report for this project.

Project name and institution	Reports and publications
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 GHHP Gladstone fish health research program (b) Australian Institute of Marine Sciences	Kroon, F.J., Streten, C., & Harries, S.J. (2016) *The use of biomarkers in fish health assessment worldwide and their potential use in Gladstone Harbour.* Australian Institute of Marine Science, Townsville. Download the final report for this project.
ISP016 GHHP Gladstone fish health research program (c) Infofish Australia Pty Ltd	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.
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. James Cook University, Townsville. Download the final report for this project. Duke N.C., and Mackenzie J. (2019) *Project ISP018-2019: Development of mangrove indicators for the 2019 Gladstone Harbour Report Card*. Report to Gladstone Healthy Harbour Partnership by TropWATER Centre. James Cook University, Townsville. Download the final report for this project.

Project name and institution	Reports and publications
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. Download the final report for this project.
ISP020 Further development of R scripts to calculate, aggregate and integrate cultural heritage indicators with Bayesian model and Data Information Management System	Pascoe, S. & Venables, B. (2017) Further *Development of R scripts to calculate, aggregate and integrate Cultural heritage indicators with GHHP Data Information Management System*. CSIRO, Brisbane. Download the final report for this project.
ISP023a Fish health indicators CQUniversity	Flint, N., Irving, A., Anastasi, A., De Valck, J. and Jackson, E.L. (2019). *A fish health indicator for the 2019 Gladstone Harbour Report Card*, final report to the Gladstone Healthy Harbour *Partnership*. CQUniversity, Rockhampton. Download the final report for this project. Flint, N., Irving, A., Anastasi, A., De Valck, J. and Jackson, E.L. (2020) *A Fish Health Indicator for the 2020 Gladstone Harbour Report Card, final report to the Gladstone Healthy Harbour Partnership*. CQUniversity, Rockhampton. Download the final report for this project. Flint, N., Irving, A., Anastasi, A., & De Valck, J. (2021) *A Fish Health Indicator for the 2021 Gladstone Harbour Report Card: Project Report ISP023-2021.* CQUniversity, Rockhampton. Download the final report for this project.

Project name and institution	Reports and publications
ISP023b Visual fish health indicators Infofish Australia Pty Ltd	Sawynock, S., Sawynock, B., Dunlop, A. & Sawynock, P. (2019) *Visual fish health indicators for the Gladstone Harbour Report Card 2019*. Infofish Australia Pty Ltd, Rockhampton Queensland. Download the final report for this project. Sawynock, S., Sawynock, B., Dunlop, A. & Sawynock, P. (2020) *Visual fish health indicators for the Gladstone Harbour Report Card 2020*. Infofish Australia Pty Ltd, Rockhampton Queensland. Download the final report for this project. Sawynock, S., Sawynock, B., Reid, J. & Sawynock, P. (2021) *Visual fish health indicators for the Gladstone Harbour Report Card 2021*. Infofish Australia Pty Ltd, Rockhampton Queensland. Download the final report for this project. Sawynock, S., Sawynock, B. & Sawynock, P. (2022) *Fish condition indicators for the Gladstone Harbour Report Card 2022.* Infofish Australia Pty Ltd, Murarrie Queensland. Download the final report for this project.
Water and Sediment Quality Reports Gladstone Healthy Harbour Partnership. Data provided by Port Curtis Integrated Monitoring Program.	Schultz, M., Uthpala, P., & Hansler, M. (2019) *Water and Sediment Quality Indicators for the Gladstone Harbour Report Card 2017.* Gladstone Healthy Harbour Partnership, Gladstone. Download the final report for this project. Hansler, M., Schultz, M. and Uthpala, P. (2020) *Water and Sediment Quality Indicators for the Gladstone Harbour Report Card 2018.* Gladstone Healthy Harbour Partnership, Gladstone. Download the final report for this project.

Appendix 2: Water quality objectives and guidelines used to calculate water quality scores

Zone	Physicochemical					Nutrients			Metals					
	Level of Protection	Turbidity		pH range										
		Dry (NTU)	Wet (NTU)	<40 ms/cm	>40 ms/cm	TN (µg/L)	TP (µg/L)	Chl-*a* (µg/L)	Al (µg/L)	Cu (µg/L)	Pb (µg/L)	Mn (µg/L)	Ni (µg/L)	Zn (µg/L)
1. The Narrows	HEV	7	15	7.2–8.2	7.4–8.3	170	20	1	24	1.3	4.4	80	7	15
2. Graham Creek	MD	8	13	7.2–8.2	7.4–8.3	170	20	1	24	1.3	4.4	80	7	15
3. Western Basin	MD	8	13	7.2–8.2	7.4–8.3	170	18	1	24	1.3	4.4	80	7	15
4. Boat Creek	MD	14	25	7.2–8.2	7.4–8.3	190	22	2	24	1.3	4.4	80	7	15
5. Inner Harbour	MD	8	13	7.2–8.2	7.4–8.3	160	21	1	24	1.3	4.4	80	7	15
6.Calliope Estuary	MD	11	11	7.2–8.2	7.4–8.3	175	22	1.7	24	1.3	4.4	80	7	15
7.Auckland Inlet	MD	6	8	7.2–8.2	7.4–8.3	160	16	1.9	24	1.3	4.4	80	7	15
8.Mid Harbour	MD	4	9	7.2–8.2	7.4–8.3	135	14	1	24	1.3	4.4	80	7	15
9. South Trees Inlet	MD	11	13	7.2–8.2	7.4–8.3	170	20	1.1	24	1.3	4.4	80	7	15
10. Boyne Estuary	MD	3	5	7.2–8.2	7.4–8.3	120	11	0.8	24	1.3	4.4	80	7	15
11. Outer Harbour	MD	3	7	8.0–8.2		130	13	1	24	1.3	4.4	80	7	15
12. Colosseum Inlet	HEV	3	7	7.2–8.2	7.4–8.3	130	10	0.8	24	1.3	4.4	80	7	15
13. Rodds Bay	HEV	4	5	7.2–8.2	7.4–8.3	160	13	1	24	1.3	4.4	80	7	15

Turbidity: The 50th percentile from the guideline values is applied to all harbour zones. Dry season guidelines apply from May to October. Wet season guidelines apply from November to April. NTU: nephelometric turbidity unit.

pH range: The pH range falls between the 20th and 80th percentile of the guideline values. Different guideline values are applied for conductivity measurements of <40 ms/cm and >40 ms/cm.

Nutrients: For all nutrients, total nitrogen (TN), total phosphorus (TP) and chlorophyll-*a* (Chl-*a*) the 50th percentile from the guideline values is applied.

Aluminium: The aluminium (Al) guideline for moderately disturbed (MD) systems (24 µg/L, 95% species protection) is applied to all harbour zones.

Manganese: The manganese (Mn) guideline (80 µg/L) from the ANZG (2018) water quality guidelines is applied to all harbour zones.

Other Metals: The 95% species protection value from the ANZG (2018) water quality guidelines is applied to copper (Cu), lead (Pb), and zinc (Zn) while the 99% species protection value is applied to nickel (Ni). Trigger values were selected for moderately disturbed systems.

Appendix 3: Sediment quality guidelines used to calculate sediment quality scores

Indicator	Measure	Concentration (mg/kg)	Guideline based on
Metals and metalloid	Arsenic (As)	20	ANZG, 2018
	Cadmium (Cd)	1.5	ANZG, 2018
	Copper (Cu)	65	ANZG, 2018
	Lead (Pb)	50	ANZG, 2018
	Mercury (Hg)	0.15	ANZG, 2018
	Nickel (Ni)	21	ANZG, 2018
	Zinc (Zn)	200	ANZG, 2018

Appendix 4: Data filtering methods for Natural Resource Management (NRM) area litter metric report card

By: Jordan Gacutan (UNSW, Sydney)

Prepared for: Fitzroy Basin Association (FBA) [host of Gladstone Healthy Harbour Partnership in 2021-22]

On behalf of: Tangaroa Blue Foundation and UNSW, Sydney

Summary

The following brief provides an overview of the methods used to process the Australian Marine Debris Initiative (AMDI) database (henceforth **'raw data'**) to a '**custom dataset'**, as in input for the model described in Whitehead and Venables (2019).

Rationale:

- Support continued monitoring of litter to detect changes due to source reduction / policy implementation within Great Barrier Reef catchments.
- Standardise litter reporting across NRMs, supported by the AMDI database.
- Implementation of Australian Marine Debris Initiative in reporting and decision-making.
- Support the UN Sustainable Development Goals [14.1.1, marine plastic pollution].

Figures

Tables

Description

This project extends the statistical model and analyses presented in the report "Litter Score and Grade Proposal for Townsville". The existing model has been implemented for the Natural Resource Management (NRM) area 'Dry Tropics' (DT). The model, and required data processing, have been extended to the 'Wet Tropics' (WT) and 'Mackay-Whitsunday-Isaac' (MWI) NRMs.

In December 2020, Tangaroa Blue Foundation (TBF) and UNSW, Sydney were asked to provide a data pipeline, to process raw data from the AMDI dataset for use in a statistical model. The pipeline facilitates the extraction and processing of data for future reporting needs. Tasks to be performed by UNSW, Sydney are described in the '**data sharing agreement**' between Tangaroa Blue Foundation, UNSW, Sydney, and the report card body.

The data pipeline involves filtering (1) data quality, (2) spatially to the reporting area, and (3) model use, described in Figure A1. Treatment of **ReefClean** data is described in Section 1.

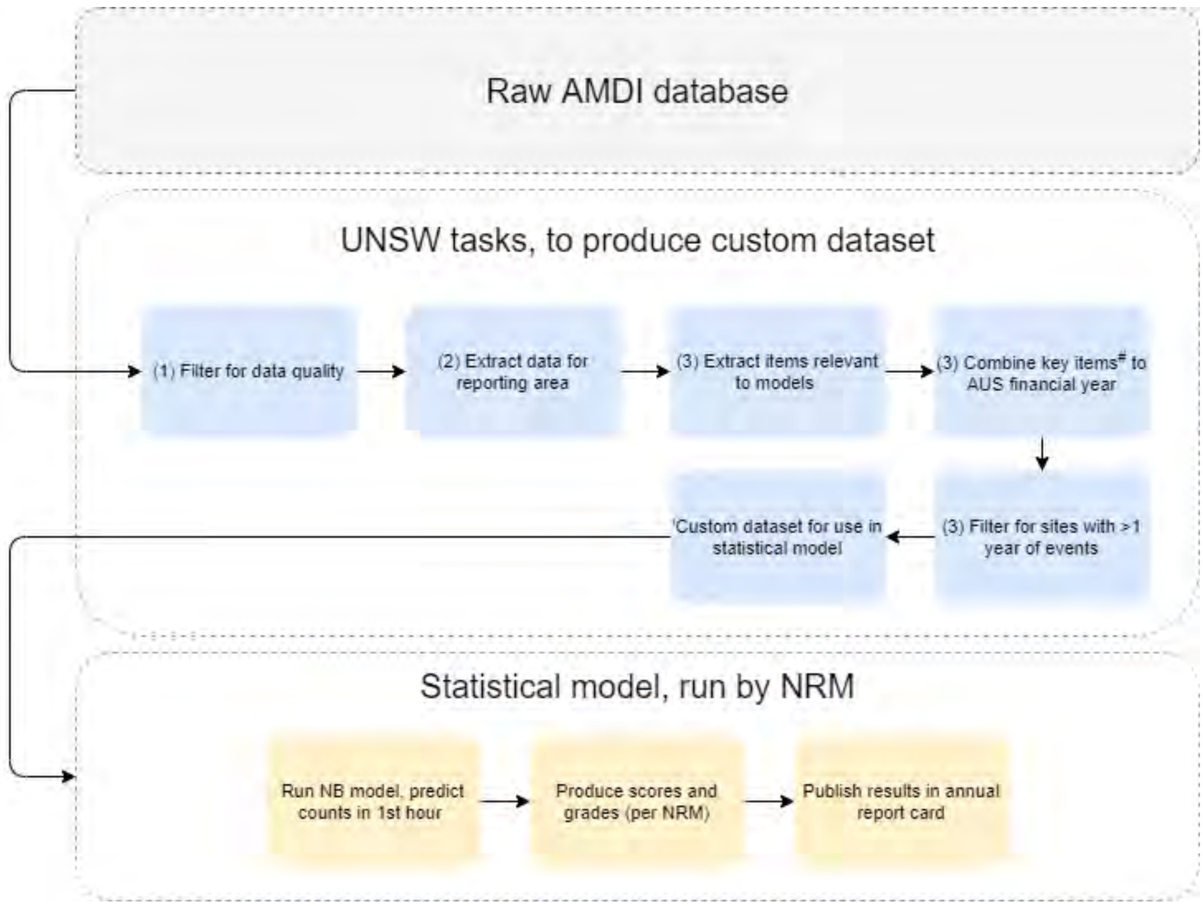


Figure A1. Data pipeline for project, to extract key items# (plastic bags, plastic bottles, single-use cutlery, and cigarettes) from the Australian Marine Debris Initiative (AMDI) database for annual use in a statistical model, for production of litter scores and grades. NRM = Natural Resource Management area, NB = Negative binomial.

Filter for data quality

Filtering for data quality is taken from methods and related scripts of the publication, 'Continental trends in marine debris revealed by a decade of citizen science' (*in prep*). The filters used are presented in Table A1. As the work in is in preparation, scripts are currently unavailable.

ReefClean data was identified and processed separately, aggregating all transects and debris collected in surrounding areas, to align with data from community clean-ups stored within the AMDI database. Loss of resolution was justified by model needs.

Table A1. Data quality filters used to process the Australian Marine Debris Initiative database. Filters are in sequential order.

Cleaning theme	Tool used	Cleaning step	Examples / Description
Original database	DB Browser for SQL lite	Original database (Downloaded January 2021)	N/A
Limit to Australia	ArcMap 10.6	Remove foreign entries	Hawaii / Tonga / NZ / PNG / Timor Leste
	ArcMap 10.6 / Nearmap	Remove Australian external territories	Christmas island / Norfolk Island / Cocos Islands
Limit timeframe	DB Browser for SQL lite	Filter for Jan 2009 - Dec 2018	-
Clean by event entries	DB Browser for SQLite / R	Remove duplicate sites	-
		Clean-up time < 0.25 hours	Non-exhaustive clean-up.
		One volunteer, < 1 kg	A single volunteer collecting less than 1 kg indicates a non-exhaustive or informal clean-up
Clean by event entries	R / Excel	One volunteer, > 10 hours	Single volunteer cleaning more than 10 hours (indicates multiple days / weeks / months collecting)
		Not a clean-up	Daily walk / hike / Anecdotal as described in notes
		Estimated / incomplete	Stated in event notes
		Anecdotal (stated in notes)	Stated in event notes
		Clean-up over multiple days / weeks / month	Stated in notes, hours reported > 24
		Data quality poor	Number of volunteers / time / date or other details missing.
		Single item reported	Stated in event notes
		Timor Leste	Incorrectly entered as Australian site w/ incorrect coordinates
		Remove fishing line bin entries	Fishing bin Initiative hosted in the AMDI database
Event clean (Ratios of variables used to clean database)	R	bags / volunteer > 8	Volunteers collected more than 8 bags each (accuracy of data)
		Weight / volunteer > 10 & wt /bag > 10	Volunteers collected more than 10 bags weighing 10 kg each (accuracy of data)
		Hours per volunteer > 10 (i.e. each volunteer worked + 10 hrs)	Indicates poor data quality or multiple clean-ups over a longer timeframe
Clean events by item entries	R	Single item	Single item reported at the event (not in notes)
		Components < 10	Less than 5 item categories reported
		Estimated (div 10, integers)	Entries with integers divisible by 10 (estimated item categories > 50%)

Extract data for reporting areas

Processed data was classified according to NRM reporting areas and 'Water Type', as defined in Environmental Protection (Water) Policy 2009 (Qld, s. 12). Reporting areas and water types were classified by provided spatial data. Provided data and **custom dataset** were manipulated in ArcMap 10.7.

Table A2. Provided shapefiles used to classify data by NRM reporting needs.

Shapefile name	**Providing organisation**
FPRH_Catchments	Fitzroy Partnership for River Health (FPRH)
2013_14 WQ Zones All Zones	Gladstone Healthy Harbour Partnership (GHHP)

Manipulate extracted data for use in model

To align with model structure, the following steps were performed:

a) Policy relevant items (plastic bags, plastic pottles, single-use items) were extracted.
b) Events were classified to financial year. Multiple events per site, per year were classified as 'Replicates'.
c) To avoid model collapse, sites with less than **one financial year** were filtered from analysis.

The resulting data was then provided to each NRM.

Appendix 5: Gladstone litter clean-up site data from 2014 to 2022

Table A3: Gladstone litter clean-up sites from 2014 to 2022 (financial years (FYs)) sourced from the Australian Marine Debris Initiative (AMDI) Database. Volunteer (vol.) number and hours are detailed for sites that were surveyed in 2021-22. Volunteer hours are presented as the number of volunteers x the number of hours done by each volunteer. The number of times a particular site was surveyed in past is represented by the corresponding number. Note, FY is displayed as per 2022 = 2021-22. *ReefClean survey sites (sites were surveyed using unstandardised methodology before the ReefClean program was launched in early 2019).

		2022 Survey			Past Surveys (no.)							
Zone	**Site**	**Vol. No.**	**Vol. Hours**	**No. of surveys**	**2021**	**2020**	**2019**	**2018**	**2017**	**2016**	**2015**	**2014**
The Narrows	Phillipies Landing Rd							4				
Western Basin	Fisherman's Landing*				1	3	6	6	1	5	2	
Boat Creek	Boat Creek Gladstone*					1		2				
	Yarwun						1					
Inner Harbour	**Barney Point***	**13**	**7**	**4**	9	13	12	6	5			
	Gladstone CBD				24	4						
	Hopper Road					4						
	Reg Tanna Park				2		1					
	Urban Surrounds				4							
	Mark Fulton Drive Channel*					1						
Callipe Estuary	Calliope River						3					
Auckland Inlet	Albion Park Mangroves					1						
	Auckland Creek (Site ID 2185)					1	14	1	1			
	Auckland Creek (Site ID 2798)						1	1				
	Auckland Creek (Site ID 2799)				1	2	1					
	Auckland Creek (Site ID 3440)					1						
	Briffany Creek								1	2		
	Briffney Creek						1	1				
	Bulgwon Park					1						

	Chappel St Mangroves					1					
	Glenlyon Rd					1					
	Hazelbrook Park						1				
	Lake Callemondah					6	1	3	2	3	
	Police Creek*				2	1	1				
	Tigalee Creek (Site ID 2254)							4			
	Tigalee Creek (Site ID 2444)						2	4	4		
	Tigalee Creek (Site ID 2796)							1			
	Tigalee Creek (Site ID 2797)						1				
	Tondoon Botanic Gardens					1		1			
	Wild Place								2		
	William Miskin Park Mangroves					1					
	Auckland Creek (Site ID 3402)*	**6**	**5.75**	**3**	1	3	1				
	Memorial Park Gladstone*				1						
Mid Harbour	Back Beach									1	
	Canoe Point (Site ID 2754)					1					
	Canoe Point (Site ID 796)*	**42**	**14**	**5**	6	10	27	7	8	2	2
	Canoe Point Reserve						2	1			
	East Beach	**28**	**1**	**1**		1					1
	Esplanade Beach*	**14**	**4**	**1**	1	1	3			2	
	Facing Island North Point*	**25**	**2.5**	**1**				2			
	North East Shore*				3	1	1	3	2	7	3
	North West Shore*					2		1			
	South End Back Beach*	**14**	**2**	**1**						1	
	South End Conservation Park Beach					6					
	Tannum Sands Main Beach	**25**	**4**	**2**	2	11	14	5	3	1	
South Trees Inlet	Lillys Beach North End*				8	3	5	7			
	Wapentake Wetlands					3		1			
Boyne Estuary	Boyne Island Conservation Site							2			

	Boyne Riverfront								1			
	Bray Park to Boyne River mouth						1	2		2	1	
	Canoe Point Conservation Area*				2	2						
	Eastern Foreshore*	**8**	**5**	**3**	1	3	2	2				
	Lilleys Beach*	**76**	**34**	**16**	5	7	12	16	8	4	3	1
	Lions Park						2					
	Truck Bay							1				
	Wyndham Park						5					
	Ibis Park*						1					
Outer Harbour	**Wild Cattle Creek Boat Ramp**	**1**	**1**	**1**		1	3	2				
	Wild Cattle Creek Mouth	**1**	**1**	**1**		3	7	11	3	4	3	
	Wild Cattle Creek Mouth, Tannum Sands				1							
	Wild Cattle Creek Trail						1					
	Wild Cattle Island Beach NTH	**29**	**36**	**10**	4	4						
	Wild Cattle Island National Park NTH					2						
Colosseum Inlet	The Sands							1				
Rodds Bay	The Esplanade Beach				1		1	2				