Gladstone Healthy Harbour Partnership

TECHNICAL REPORT

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GLADSTONE HARBOUR REPORT CARD 2019

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 Alex Carter, Tropical Water & Aquatic Ecosystem Research, James Cook University
Ms Kathryn Chartrand, Tropical Water & Aquatic Ecosystem Research, James Cook University
Ms Jaclyn Wells, Tropical Water & Aquatic Ecosystem Research, James Cook University
Dr Michael Rasheed, Tropical Water & Aquatic Ecosystem Research, James Cook University

Corals

Mr Paul Costello, Australian Institute of Marine Science
Mr Angus 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, Central Queensland University
Assoc. Prof. Andrew Irving, Central Queensland University
Dr Amie Anastasi, Central Queensland University
Dr Jeremy De Valck, Central Queensland University
Dr Emma Jackson, Central Queensland University

Fish health (Infofish)

Mr Stefan Sawynok, Infofish Australia
Mr Bill Sawynok, Infofish Australia
Mr Aaron Dunlop, Infofish Australia
Mr Phoenix Sawynok, Infofish Australia

Fish (bream recruitment)

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

Mud crabs

Dr Nicole Flint, Central Queensland University
Dr Jeremy De Valck, Central Queensland University
Dr Amie Anastasi, Central Queensland University
Dr Emma Jackson, Central Queensland University

Social, Cultural and Economic components

Dr Jeremy De Valck, Central Queensland University
Dr Megan Star, Central Queensland University
Dr Nicole Flint, Central Queensland University

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The current members of the ISP are:

Prof. John Rolfe (Chair)	Professor of Regional Economic Development, School of Business and Law, Central Queensland University
Assoc. Prof. Eva Abal	Director, UQ Water; Chief Scientific Officer, Great Barrier Reef Foundation; Program Director – Sustainable Water, Global Change Institute, The University of Queensland
Dr Richard Brinkman	Research Program Leader – Sustainable Coastal Ecosystems and Industries in Tropical Australia, Australian Institute of Marine Science
Dr Rob Coles	Principal Research Scientist – Seagrass Ecology, Centre for Tropical Water and Ecosystem Research, James Cook University
Dr Melissa Dobbie	Independent Statistical Consultant
Dr Jenny Stauber	Chief Research Scientist – CSIRO Land and Water
Ms Jane Waterhouse	Senior Partner, C_2O Consulting; Research Fellow TropWATER, James Cook University
Dr Erin Bohensky	Senior Research Scientist CSIRO Livelihoods and Adaptive Development, Townsville

Past members of the ISP (2013–2018) are:

Dr Ian Poiner	Chair, Advisory Board, Integrated Marine Observation System, Australia; Chair, Marine National Facility, Australia; Chair, Board, Reef and Rainforest Research Centre Ltd (ISP Chair to 30 June 2016)
Dr Britta Schaffelke	Research Program Leader – A Healthy and Sustainable Great Barrier Reef, Australian Institute of Marine Science
Dr Susan Rockloff	Lecturer in Sociology – School of Human, Health and Social Sciences, Central Queensland University
Prof. Michele Burford	Executive Deputy Director – Australian Rivers Institute, Griffith University
Prof. Bronwyn Harch	Deputy Director Research – Institute for Future Environments, Queensland University of Technology
Mr Frans Hoogerwerf	Independent Dredging Consultant and Director, Hoogerwerf Maritime Pty Ltd
Dr Nadine Marshall	Senior Social Scientist – CSIRO Land and Water Flagship
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Gladstone Healthy Harbour Partnership partners

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

Management Committee representatives

Community

Chair, Mr Paul Birch (Fitzroy Basin Association)
Mr Gerry Graham (Gladstone Region Environmental Advisory Network)
Ms Elyse Riethmuller (Fitzroy Basin Association)
Mr Brent McLellan (GIDARJIL)

Government

Councillor Desley O'Grady (Gladstone Regional Council)
Ms Rachel Darcy (Queensland Department of Environment and Heritage Protection)
Ms Angela Stokes (Australian Government, Department of the Environment)

Industry

Mr Patrick Hastings (Gladstone Industry Leadership Group)
Dr Megan Ellis (Gladstone Ports Cooperation)
Mr Alan Hayter (Conoco Phillips)

Research

Professor Owen Nevin (Central Queensland University, Gladstone)

Disclaimer

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Executive summary

Context

The 2019 Gladstone Harbour Report Card reports on the environmental health of 13 reporting zones in and around Gladstone Harbour and the overall Environmental, Social, Cultural and Economic health of the harbour. This report card covers monitoring undertaken in the period 1 July 2018 to 30 June 2019. 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 2019 Gladstone Harbour Report Card for each component of harbour health.

Overall component grades

The overall component scores and grades for the 2019 report card were: Environmental 0.60 (C), Social 0.67 (B), Cultural 0.60 (C) and Economic 0.73 (B) (Figure 2). All overall component scores were similar to the scores recorded in 2018. Owing to the addition of fish health to the fish and crabs indicator group, direct comparisons with the 2018 Environmental score were not possible. However, the addition of fish health completes the Environmental Component, and will make these comparisons possible in future years.

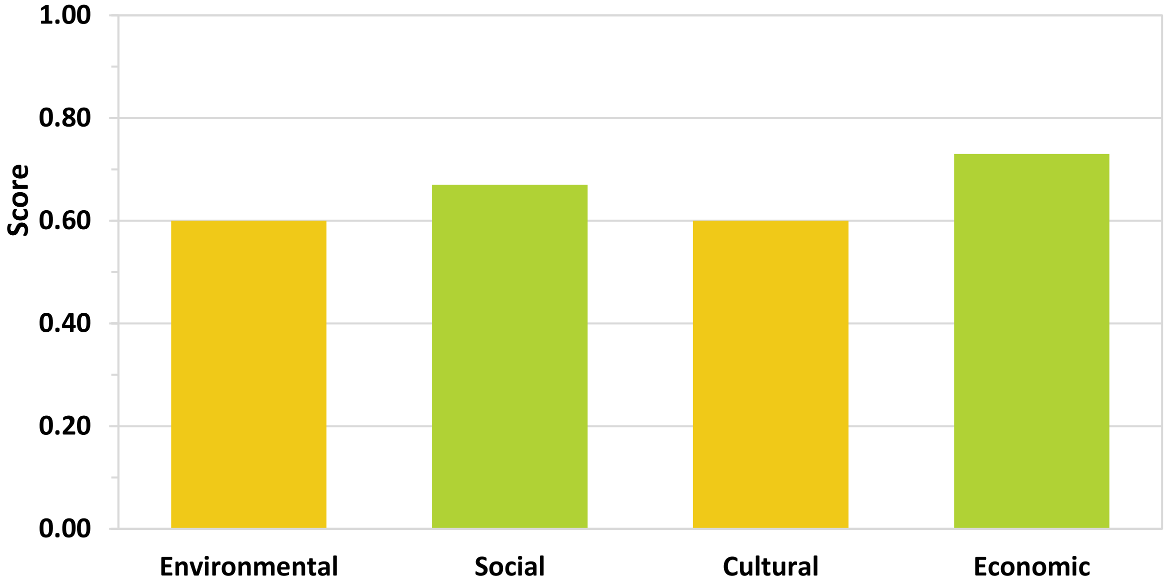


Figure 2: Overall scores for each of the four components of Gladstone Harbour Health in 2019.

Environmental health

Within the Environmental component, the water and sediment quality indicator group received a score of 0.88 (A), habitats a score of 0.45 (D), and fish and crabs a score of 0.48 (C) (Table 1). Water and sediment quality scores were similar to the previous year 0.86 (A). Habitats improved from 0.41 (D) in 2018 to 0.45 (D) in 2019 as a result of an improved seagrass score but the overall grade (D) remained poor. The score for fish and crabs was lower than the previous year. While the new fish health indicator received a good score, the scores for fish recruitment were considerably lower than in 2018.

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

Zone	Indicator groups		
	Water and sediment quality	Habitats (seagrass, corals and mangroves)	Fish and crabs
1. The Narrows	0.83	0.68	0.50
2. Graham Creek	0.85	0.64	0.44
3. Western Basin	0.88	0.60	0.41
4. Boat Creek	0.80	0.46	0.50
5. Inner Harbour	0.87	0.38	0.45
6. Calliope Estuary	0.88	0.58	0.47
7. Auckland Inlet	0.86	0.65	0.61
8. Mid Harbour	0.90	0.42	0.41
9. South Trees Inlet	0.89	0.75	0.47
10. Boyne Estuary	0.94	0.26	0.51
11. Outer Harbour	0.95	0.42	0.69
12. Colosseum Inlet	0.92	0.72	0.54
13. Rodds Bay	0.90	0.57	0.46
Harbour score	**0.88**	**0.45**	**0.48**

Water and sediment quality

The water quality indicator received a score of 0.81 (B) and sediment quality a score of 0.95 (A). These were comparable to the 2018 results of 0.76 (B) and 0.95 (A). Since the first full report card in 2015, water quality has consistently been rated as good and sediment quality has consistently been rated as very good.

Water quality

Water quality was relatively uniform across the harbour. All zones received a good or very good score (Table 2). Compared to the previous year, the score for the physico-chemical group decreased in most zones as a result of lower scores for turbidity (which indicate higher levels of turbidity). The overall score for nutrients of 0.61 (C) was higher than the 2018 score of 0.47 (D) due to the cumulative effects of higher scores for all three measures (total nitrogen, total phosphorous and chlorophyll-*a*). Dissolved metal scores of 0.98 – 1.00 (A) were uniformly very good for the fifth consecutive year.

Table 2: Water quality scores for the 2019 Gladstone Harbour Report Card. Scores from 2018 and 2017 are shown for comparison.

Zone	Physico-chemical score	Nutrients score	Dissolved metals score	Zone score 2019	*Zone score 2018*	*Zone score 2017*
1. The Narrows	0.78	0.44	1.00	0.74	*0.71*	*0.71*
2. Graham Creek	0.85	0.51	1.00	0.79	*0.78*	*0.88*
3. Western Basin	0.85	0.48	0.98	0.77	*0.72*	*0.77*
4. Boat Creek	0.66	0.39	0.98	0.68	*0.63*	*0.59*
5. Inner Harbour	0.84	0.61	0.99	0.82	*0.80*	*0.79*
6. Calliope Estuary	0.82	0.60	0.99	0.80	*0.76*	*0.77*
7. Auckland Inlet	0.73	0.60	0.99	0.77	*0.74*	*0.79*
8. Mid Harbour	0.84	0.73	1.00	0.86	*0.81*	*0.79*
9. South Trees Inlet	0.89	0.61	1.00	0.83	*0.76*	*0.84*
10. Boyne Estuary	0.89	0.75	1.00	0.88	*0.79*	*0.83*
11. Outer Harbour	0.95	0.85	1.00	0.93	*0.92*	*0.90*
12. Colosseum Inlet	0.93	0.72	1.00	0.88	*0.83*	*0.83*
13. Rodds Bay	0.78	0.71	1.00	0.83	*0.74*	*0.75*
Harbour score	**0.83**	**0.61**	**1.00**	**0.81**	***0.76***	***0.78***

Sediment quality

Sediment quality was uniformly 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). Sediment mercury—which was not included in the 2018 report card—was found at very low concentrations and was well below the guideline value.

Table 3: Sediment quality scores for the 2019 Gladstone Harbour Report Card. Scores from 2018 and 2017 are shown for comparison.

Zone	Metals and metalloid score	Zone score 2019	*Zone score 2018*	*Zone score 2017*
1. The Narrows	0.92	0.92	*0.90*	*0.92*
2. Graham Creek	0.91	0.91	*0.94*	*0.92*
3. Western Basin	0.98	0.98	*0.98*	*0.97*
4. Boat Creek	0.92	0.92	*0.91*	*0.98*
5. Inner Harbour	0.92	0.92	*0.95*	*0.93*
6. Calliope Estuary	0.96	0.96	*0.95*	*0.94*
7. Auckland Inlet	0.94	0.94	*0.91*	*0.87*
8. Mid Harbour	0.94	0.94	*0.95*	*0.95*
9. South Trees Inlet	0.96	0.96	*0.94*	*0.98*
10. Boyne Estuary	0.99	0.99	*0.97*	*0.97*
11. Outer Harbour	0.97	0.97	*0.96*	*0.97*
12. Colosseum Inlet	0.96	0.96	*0.99*	*0.99*
13. Rodds Bay	0.98	0.98	*0.97*	*0.95*
Harbour score	**0.95**	**0.95**	***0.95***	***0.95***

Habitats

The overall score for habitats remained poor 0.45 (D) although it did improve from 0.41 (D) in 2018 as a result of an improved seagrass score. The seagrass score improved from 0.40 (D) in 2018 to 0.59 (C) in 2019. The coral score 0.18 (E) was lower than that recorded in 2018. The overall score for mangroves of 0.57 (C) was similar to the previous year.

Seagrass

Fourteen representative meadows across six monitoring zones were assessed to determine the condition of seagrass in Gladstone Harbour. 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 2019 was 0.59 (C) indicating a satisfactory overall condition (Table 4). This result was a marked improvement from previous report cards in which overall seagrass condition was poor. At the zone level, scores improved at all six monitoring zones compared to 2018. Ten of the fourteen monitored meadows were in satisfactory, good or very good condition. The harbour's seagrass meadows are currently recovering following several years of poor condition. Results suggest that improvements in seagrass condition were largely a result of environmental factors, that were characterized by drier than average conditions.

Table 4: Seagrass scores for the 2019 Gladstone Harbour Report Card. Scores from 2018 and 2017 are shown for comparison.

Zone	Meadow	Biomass score	Area score	Species composition score	Overall meadow score	Zone score 2019	*Zone score 2018*	*Zone score 2017*
1. The Narrows	21	0.75	0.91	0.67	0.71	0.71	*0.42*	*0.59*
3. Western Basin	4	1.00	0.82	0.43	0.62	0.69	*0.45*	*0.50*
	5	0.91	0.74	0.54	0.64			
	6	0.95	0.76	0.43	0.59			
	7	0.94	0.91	1.00	0.91			
	8	1.00	0.55	0.22	0.38			
	52–57	0.97	0.98	1.00	0.97			
5. Inner Harbour	58	0.21	0.57	0.56	0.21	0.21	*0.09*	*0.00*
8. Mid Harbour	43	0.45	0.75	0.62	0.45	0.52	*0.46*	*0.34*
	48	0.91	0.76	0.44	0.60			
9. South Trees Inlet	60	0.89	0.93	0.95	0.89	0.89	*0.85*	*0.75*
13. Rodds Bay	94	0.53	0.56	0.65	0.53	0.49	*0.10*	*0.19*
	96	0.72	1.00	0.65	0.69			
	104	0.44	0.27	0.64	0.27			
Harbour score						**0.59**	***0.40***	***0.39***

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 was used to assess the state of a reef while the other sub-indicators measure a reef's potential to recover.

In 2019, corals were in very poor condition with an overall score of 0.18 (E)—a decline from the 2017 score. 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). Although coral cover and change in hard coral cover scores were broadly consistent with previous years, juvenile density and macroalgal cover scores decreased considerably. 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 of Gladstone Harbour.

Table 5: Coral indicator scores for the 2019 Gladstone Harbour Report Card. Scores from 2018 and 2017 are shown for comparison.

Zone	Coral cover	Macroalgal cover	Juvenile density	Change in hard coral cover	Zone score 2019	*Zone score 2018*	*Zone score 2017*
8. Mid Harbour	0.09	0.02	0.24	0.42	0.19	*0.28*	*0.34*
11. Outer Harbour	0.07	0.00	0.22	0.40	0.17	*0.20*	*0.23*
Harbour score	**0.08**	**0.01**	**0.23**	**0.41**	**0.18**	***0.24***	***0.28***

Mangroves

Three measures of mangrove health were assessed: 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) slightly lower than the score of 0.60 (C) in 2018. This may be a result of the drier conditions which prevailed during the 2018–19 reporting year. Four zones were considered to be in good condition and seven zones were considered satisfactory (Table 6). Two zones, Boat Creek 0.46 (D) and Boyne Estuary 0.26 (D), received poor overall scores. Severe flood impacts affecting the shoreline trees were observed in Boyne Estuary.

Table 6: Overall mangrove zone and harbour scores for the 2019 reporting year. Scores from 2018 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***

Fish and crabs

The overall score for fish and crabs was 0.48 (D). This was primarily a result of the bream recruitment score which declined from a 0.66 (B) in 2018 to 0.27 (D) in 2019. The mud crabs indicator received a poor score of 0.47 (D), while the new fish health indicator received a good score 0.69 (B). The addition of fish health for the 2019 report card completes the fish and crabs indicator group.

Fish Health

The harbour score for fish health was 0.69 (B) which was the aggregate of two fish health projects:

1. **Visual Fish Condition:** An automated visual assessment is made from images captured by fishers using a mobile phone app. Length and weight data are also recorded at the time of capture.
2. **Fish Health Assessment Index**: A thorough assessment of the health of individual fish based on visual condition and the condition of several organs and tissues.

Both projects assessed the health of fish species commonly caught in Gladstone Harbour. However, there were some differences in the species assessed as a result of the different fishing methods used. The overall score for Visual Fish Condition was 0.69 (B), identical to the score of 0.69 (B) for the Fish Health Assessment Index (HAI). The HAI was calculated from scoring and summing visual inspection scores for external and internal measures (Table 7). The scores for Visual Fish Condition (Table 8) are derived from two metrics: an external assessment of fish health (FVA) which includes skin, eyes, fins parasites and deformities, and a Fish Body Condition (FBC). Measures of fish 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.

While scores for the HAI and FVA ranged from satisfactory to very good there were some poor scores for FBC. This may be a result of climatic conditions. During the reporting year, there was little or no freshwater flow from rivers and creeks into Gladstone Harbour, which can negatively impact food availability for fish.

Table 7: Overall Fish Health Assessment Index species and harbour scores for 2019.

Fish Health Assessment Index (HAI)	HAI Score 2019	**Harbour Score**
Bream	0.78	**0.69**
Barred Javelin	0.77	
Barramundi	0.58	
Blue Catfish	0.60	
Mullet	0.73	

Table 8: Overall Visual Fish Condition species and harbour scores for 2019.

Visual Fish Condition	FVA	FBC	VFC Score 2019	**Harbour Score**
Yellow-finned Bream	0.96	0.25	0.61	**0.69**
Pikey Bream	0.96	0.65	0.81	
Barred Javelin	0.97	1.00	0.99	
Dusky Flathead	0.98	0.06	0.52	
Mangrove Jack	0.96	0.15	0.56	

FVA – Fish Visual Assessment; FBC – Fish Body Condition

Fish Recruitment

Fish recruitment was measured in two species: yellow-finned bream *Acanthopagrus australis* and pikey bream *Acanthopagrus pacificus*. The overall score for 2019 was 0.27 (D) which is the lowest score for fish recruitment since it was included in the report card in 2016 (Table 9). This may be a response to the prevailing climatic conditions. During the survey months there was little or no freshwater flow at most sites. Rainfall recorded at Gladstone Airport in the 2018–19 reporting year totalled 593 mm, well below the annual average of 875 mm, and was the lowest recorded since the first full report card in 2015.

Table 9: Bream recruitment score for 12 harbour zones and the overall harbour score from 2016 to 2019.

Zone	2019	*2018*	*2017*	*2016*
1. The Narrows	0.18	*0.58*	*0.75*	*0.30*
2. Graham Creek	0.17	*0.77*	*0.58*	*0.44*
3. Western Basin	0.13	*0.79*	*0.78*	*0.36*
4. Boat Creek	0.32	*0.61*	*0.47*	*0.36*
5. Inner Harbour	0.16	*0.67*	*0.64*	*0.33*
6. Calliope Estuary	0.28	*0.70*	*0.79*	*0.43*
7. Auckland Inlet	0.53	*0.87*	*0.91*	*0.53*
8. Mid Harbour	0.12	*0.58*	*0.71*	*0.29*
9. South Trees Inlet	0.25	*0.69*	*0.71*	*0.43*
10. Boyne Estuary	0.32	*0.52*	*0.74*	*0.54*
11. Outer Harbour	Not surveyed	*Not surveyed*	*Not surveyed*	*Not surveyed*
12. Colosseum Inlet	0.39	*0.61*	*0.71*	*0.45*
13. Rodds Bay	0.33	*0.59*	*0.74*	*0.58*
Harbour score	**0.27**	***0.66***	***0.71***	***0.40***

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 examined 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 2019 was 0.47 (D), a similar result to 2018 (Table 10). Sub-indicator scores also revealed a comparable pattern to the previous year. Sex ratio was very poor in all six zones where this could be calculated. Abundance scores ranged from very good to very poor however the overall score was poor. Scores for prevalence of rust lesions were good to very good indicating low levels of this condition within the harbour. As only one mud crab was caught in Auckland Creek a score was not calculated for this zone.

Table 10: Mud crab scores for the 2019 Gladstone Harbour Report Card. Scores from 2018 and 2017 are shown for comparison.

Zone	Sex Ratio	Abundance (CPUE)	Prevalence of rust lesions	Zone score 2019	*Zone score 2018*	*Zone score 2017*
1. The Narrows	0.00	1.00	0.90	0.63	*0.66*	*0.66*
2. Graham Creek	0.24	0.12	1.00	0.45	*0.44*	*0.61*
4. Boat Creek	0.05	0.46	0.94	0.48	*0.51*	*0.70*
5. Inner Harbour	0.08	0.67	0.70	0.48	*0.52*	*0.87*
6. Calliope Estuary	0.00	0.29	1.00	0.43	*0.52*	*0.47*
7. Auckland Inlet	NC	0.00	NC	NC	*NC*	*0.25*
13. Rodds Bay	0.12	0.27	0.70	0.36	*0.38*	*0.36*
Harbour score	0.08	0.47	0.87	0.47	*0.49*	*0.55*

Social health

The overall score for Social health in 2019 was 0.67 (B)—identical to the 2018 score. This score was based on three indicator groups: harbour usability 0.64 (C), harbour access 0.67 (B) and liveability and wellbeing 0.70 (B) (Table 11). All indicator scores were similar to those in recorded in 2018 and the overall Social health of the harbour has remained stable since 2015. This suggests that people living in the Gladstone region 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 2019 Gladstone Harbour Report Card. Scores from 2018 and 2017 are shown for comparison.

Indicator groups	Social indicators	2019 Score	2019 Score	*2018 Score*	*2017 Score*
Harbour usability	Satisfaction with harbour recreational activities	0.71	0.64	*0.63*	*0.62*
	Perceptions of air and water quality	0.58			
	Perceptions of harbour safety for human use	0.63			
Harbour access	Satisfaction with access to the harbour	0.73	0.67	*0.67*	*0.66*
	Satisfaction with boat ramps and public spaces	0.65			
	Perceptions of harbour health	0.63			
	Perceptions of barriers to access	0.66			
Liveability and wellbeing	Liveability and wellbeing	0.70	0.70	*0.70*	*0.66*
Overall score			**0.67**	***0.67***	***0.66***

Cultural health

The overall score for the Cultural health of Gladstone was 0.60 (C). Two indicator groups for Cultural health were assessed: 'sense of place' 0.66 (B) (Table 12) and Indigenous cultural heritage 0.54 (C).

The overall 'sense of place' score was similar to the 2018 score. This result suggests that the community expectations of the Gladstone Harbour area are mostly being met.

Scores for the Indigenous cultural heritage indicator have remained relatively stable since it was included in the report card in 2016. As a result, this indicator will only be monitored every second year and no new monitoring was conducted in 2019. The overall Indigenous cultural heritage score of 0.54 (C) is based on site surveys conducted in 2016, 2017 and 2018 and the scores are identical to those reported in 2018 (Table 13).

Table 12: Scores for the 'sense of place' indicator group, 2016 to 2019.

Indicator group	Indicators	2019 Score	2019 Score	2018 Score	*2017 Score*	*2016 Score*
'Sense of Place'	Place attachment	0.58	0.66	0.65	*0.65*	*0.66*
	Continuity	0.58				
	Pride in the region	0.74				
	Wellbeing	0.61				
	Appreciation of the harbour	0.83				
	Values	0.66				

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

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

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

Economic health

The overall score for the Economic component was 0.73 (B), which was similar to the scores received in the previous four report cards. The 2019 score was determined by the scores from three indicator groups: economic performance 0.90 (A), economic stimulus 0.58 (C) and economic value 0.76 (B) (Table 14). While the overall economic health of Gladstone remained good, this score was influenced by reduced employment opportunities, and a lower score for socio-economic status. Commercial fishing received a poor score due to low gross value production and a lower net fishery productivity score. Shipping activity and tourism remained strong in 2019.

Table 14: Scores for the economic indicator groups from 2016 to 2019.

Indicator group	Indicators	2019 Score	2019 Score	*2018 Score*	*2017 Score*	*2016 Score*
Economic performance	Shipping activity	0.90	0.90	*0.90*	*0.90*	*0.87*
	Tourism	0.90				
	Commercial fishing	0.36				
Economic stimulus	Employment	0.44	0.58	*0.58*	*0.67*	*0.74*
	Socio-economic status	0.64				
Economic value (recreation)	Land-based recreation	0.77	0.74	*0.74*	*0.73*	*0.73*
	Recreational fishing	0.71				
	Beach recreation	0.76				
	Water-based recreation	0.76				
Overall score			**0.73**	***0.72***	***0.74***	***0.75***

1. Introduction

1.1 The Gladstone Healthy Harbour Partnership

1.1.1. Overview

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

The GHHP partnership currently has 21 partners comprising 13 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 on 6 November 2013 when partner representatives agreed to work together to achieve the GHHP vision.

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

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

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

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

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

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

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

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

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

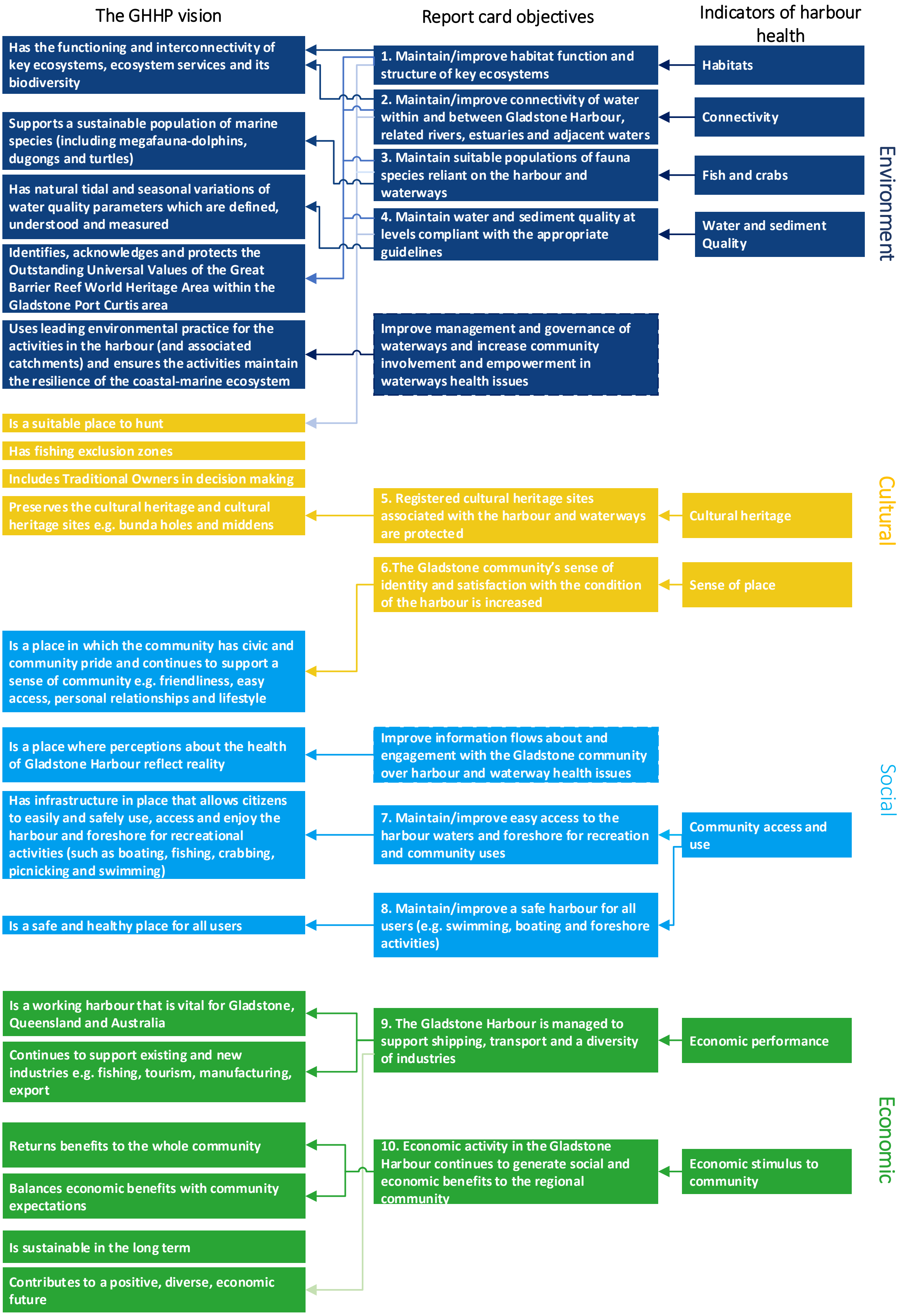


Figure 1.1: The Gladstone Harbour Report Card objectives and harbour health indicators were developed from the GHHP vision statements for the Environmental, Cultural, Social and Economic components of Gladstone Harbour health.

1.1.3. The four components of harbour health

The Gladstone Harbour Report Card to reports on Environmental, Social, Cultural and Economic health (Figure 1.2). Stakeholder and community consultation identified these four components as important to the community during workshops conducted by GHHP in 2013.

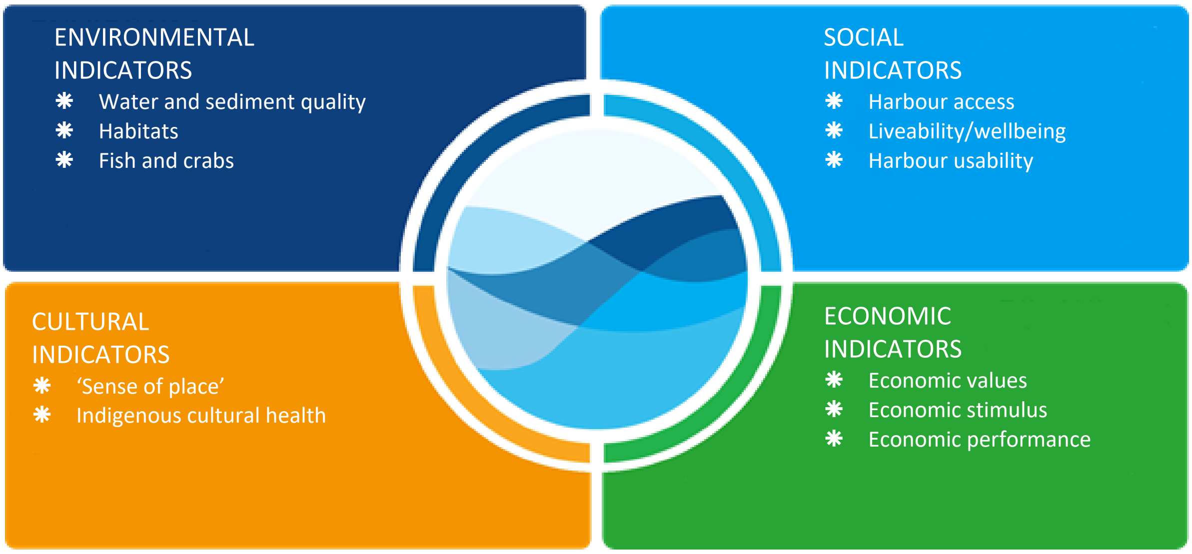


Figure 1.2: The four components of harbour health.

1.2. The science program

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

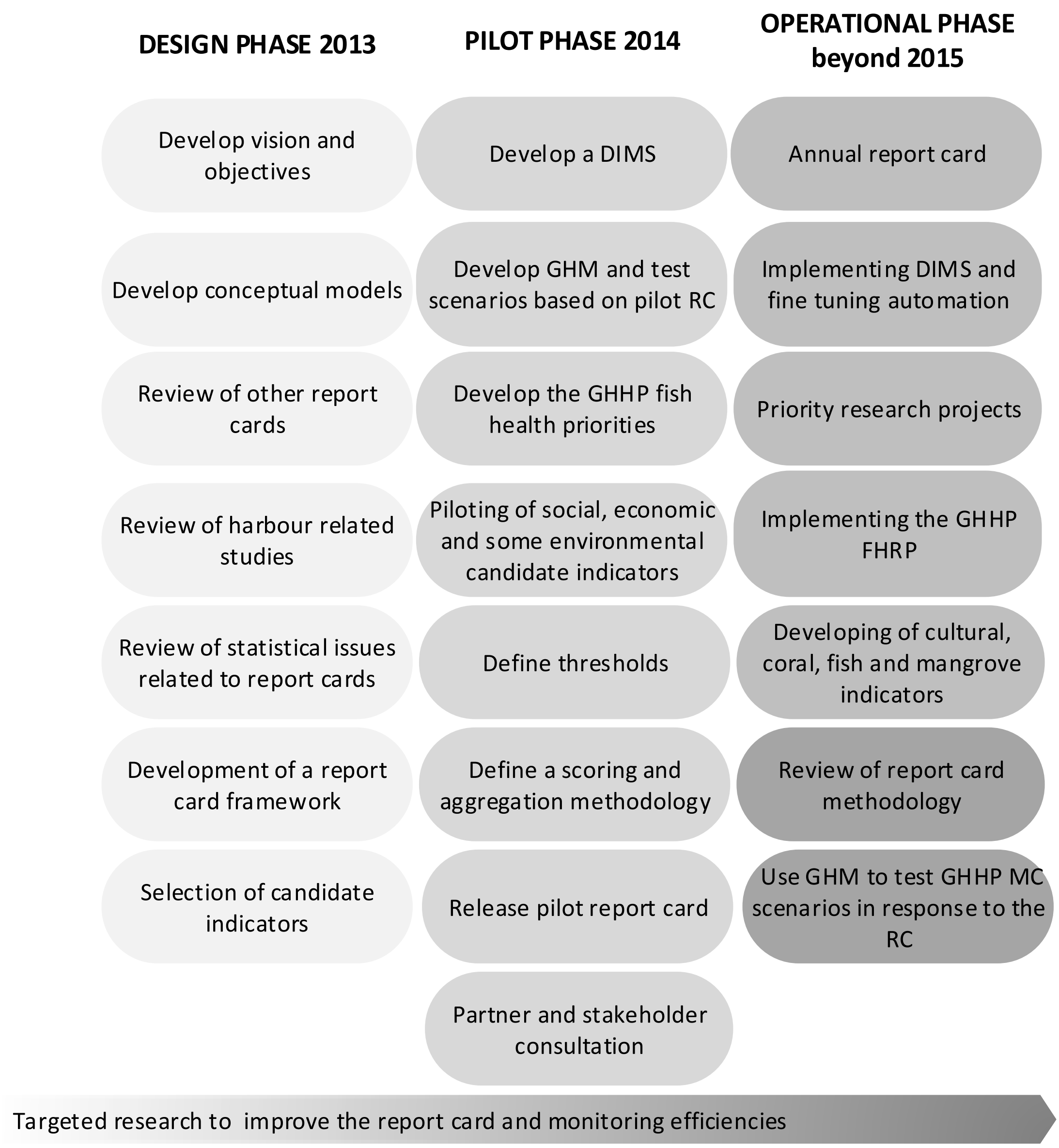


Figure 1.3: The three phases of the GHHP science program. DIMS = Data Information Management System, GHM = Gladstone Harbour Model, RC = Report Card, MC = Management Committee, FHRP = Fish Health Research Program.

1.3. Reporting periods

The reporting period for the 2019 Gladstone Harbour Report Card was 1 July 2018 to 30 June 2019. This allows the significant environmental changes that occur in the wetter summer months to be captured in the annual data. However, some data collected prior to the 2018–19 financial year for the Social and Economic components were used as they were the most up-to-date, available data.

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 2015 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.

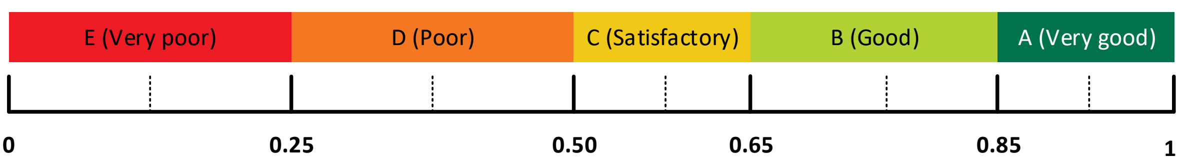


Figure 2.1: Grade ranges used in the 2019 Gladstone Harbour Report Card.

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 2018–19 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 2018–19 reporting year. The annual site means were used to develop indexed scores between 0 and 1 compared with relevant guidelines (Figure 2.2; DEHP water quality objectives or 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).

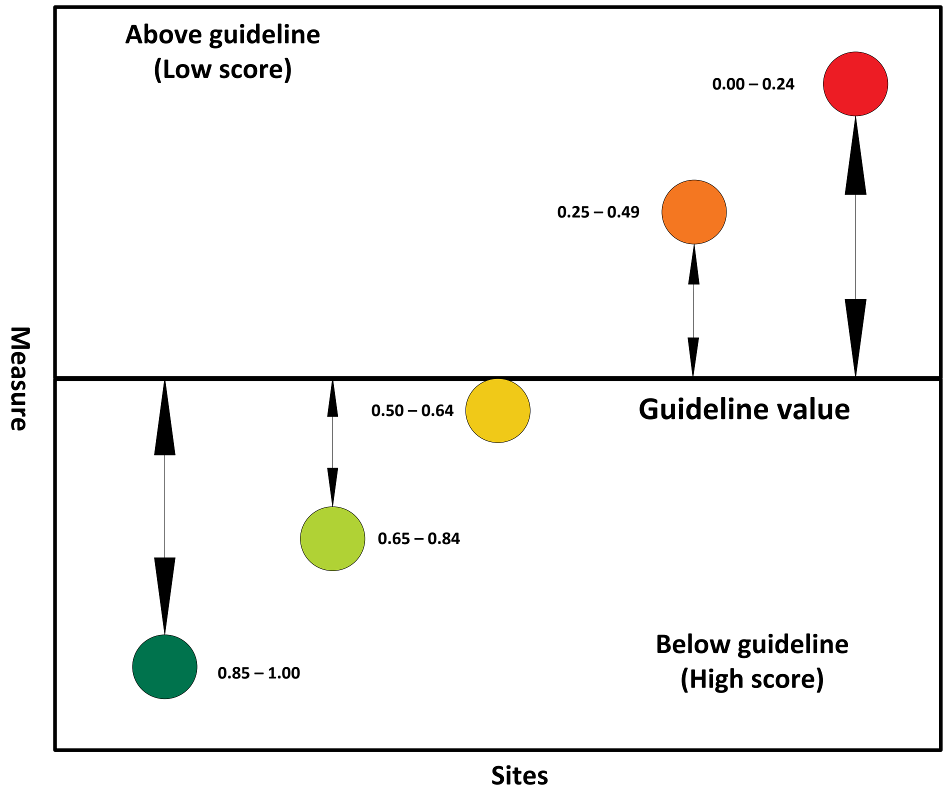


Figure 2.2: Water and sediment quality measures are scored relative to zone and measure specific guideline values.

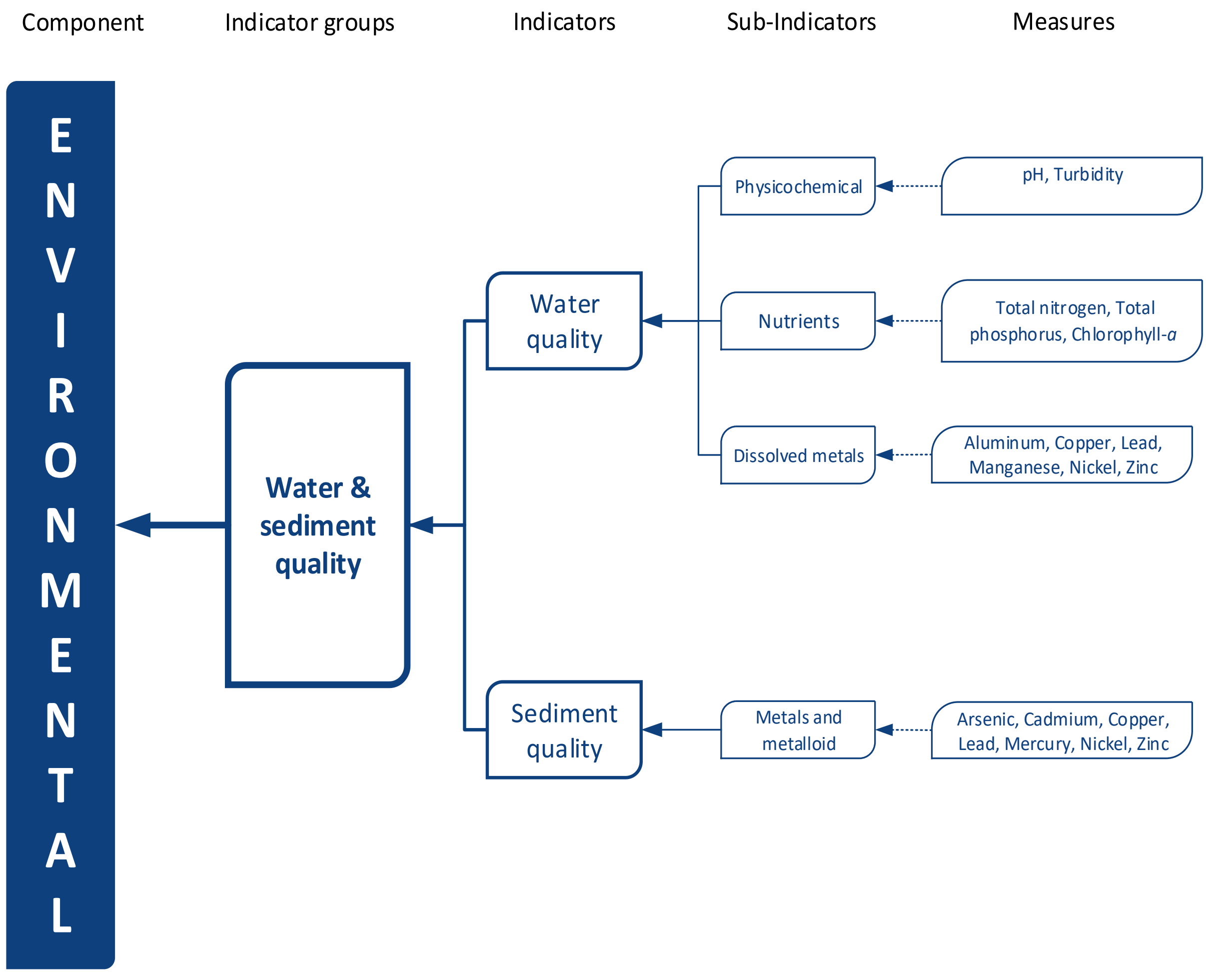


Figure 2.3a: The levels of aggregation used to determine the environmental scores and grades in the 2019 Gladstone Harbour Report Card. There are 3 environmental indicator groups, 8 indicators, 19 sub-indicators and 47 measures.

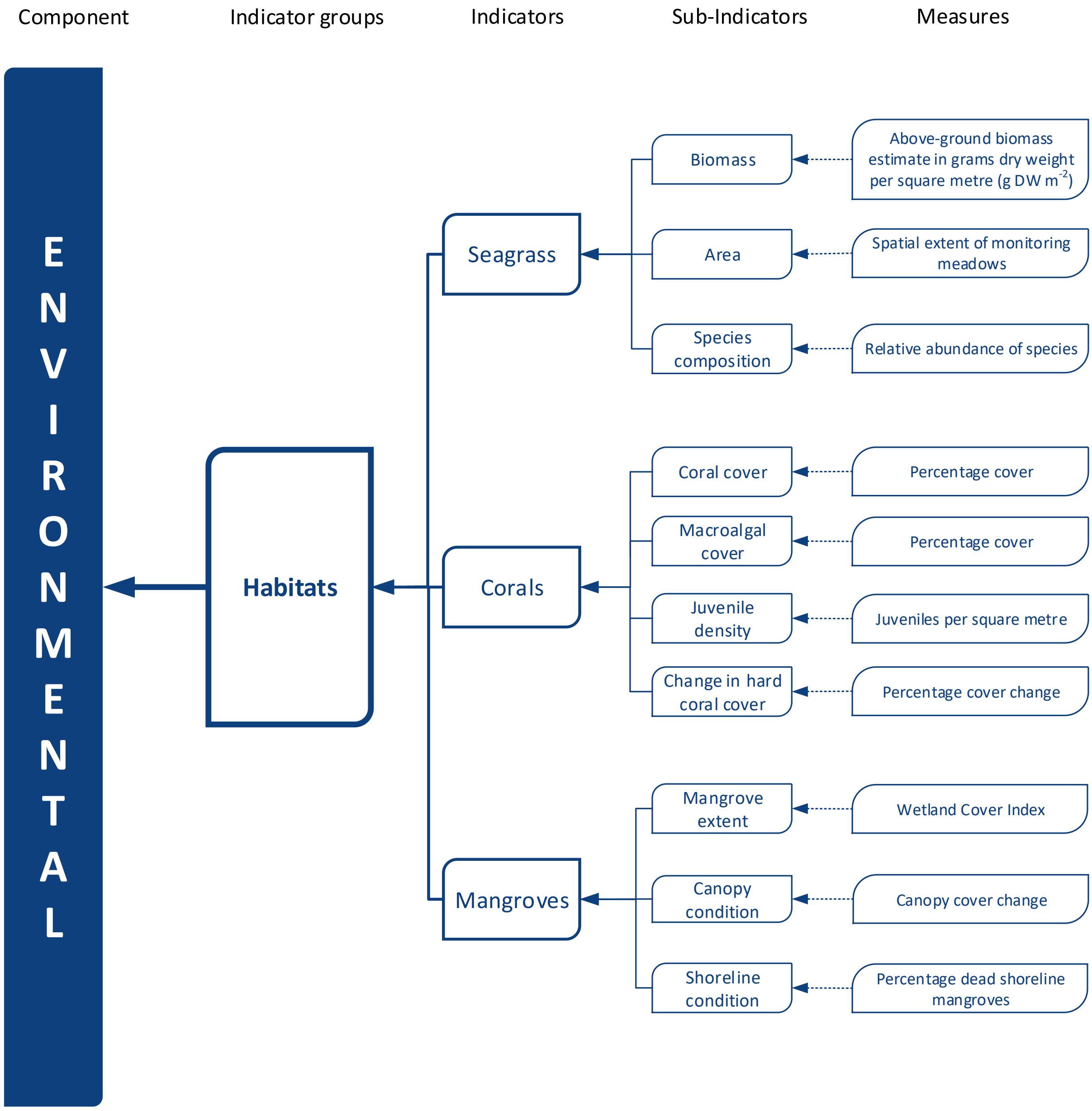


Figure 2.3b: The levels of aggregation used to determine the environmental scores and grades in the 2019 Gladstone Harbour Report Card. There are 3 environmental indicator groups, 8 indicators, 19 sub-indicators and 47 measures.

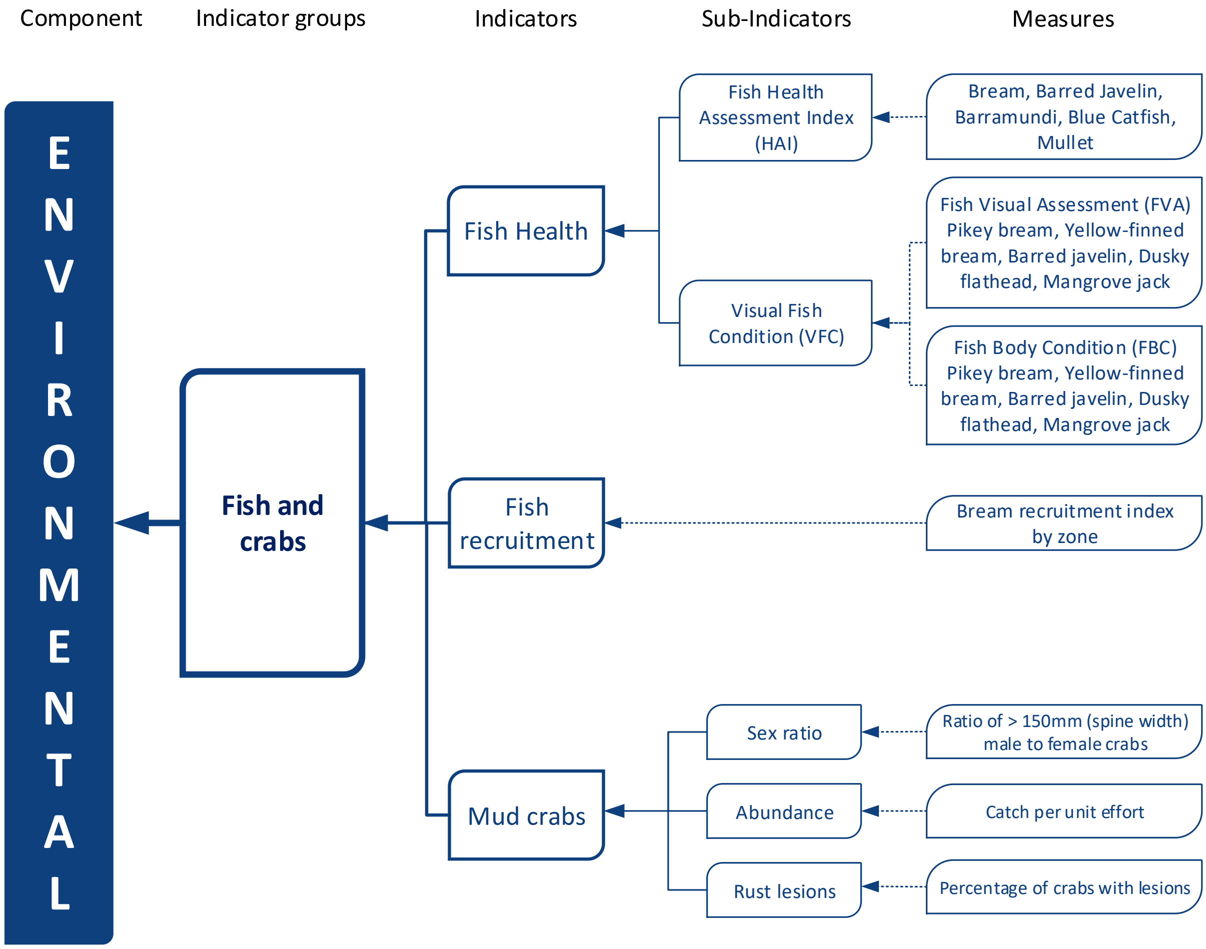


Figure 2.3c: The levels of aggregation used to determine the environmental scores and grades in the 2019 Gladstone Harbour Report Card. There are 3 environmental indicator groups, 8 indicators, 19 sub-indicators and 47 measures.

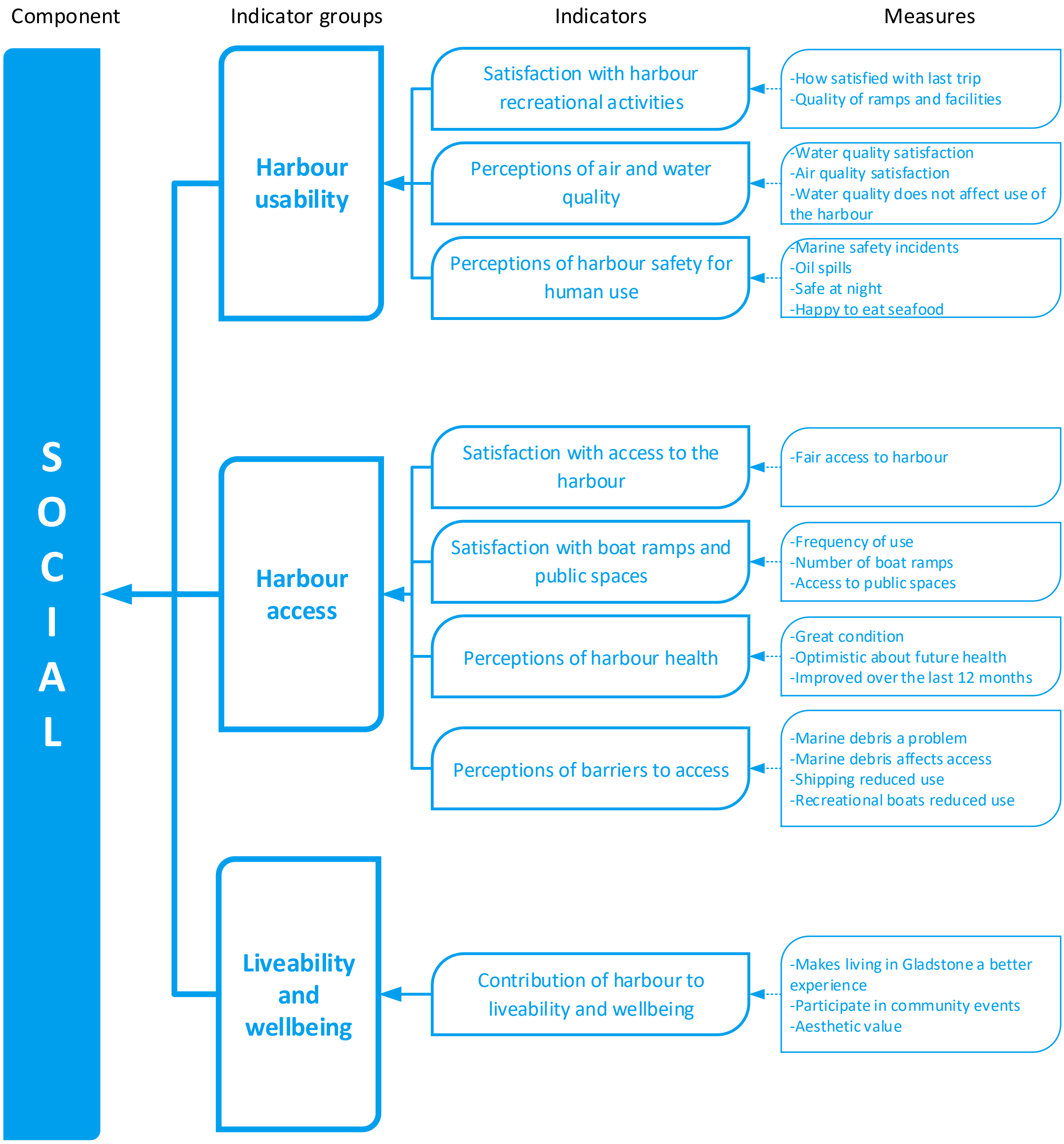


Figure 2.4: The levels of aggregation used to determine the social scores and grades in the 2019 Gladstone Harbour Report Card. There are 3 social indicator groups, 8 indicators and 23 measures.

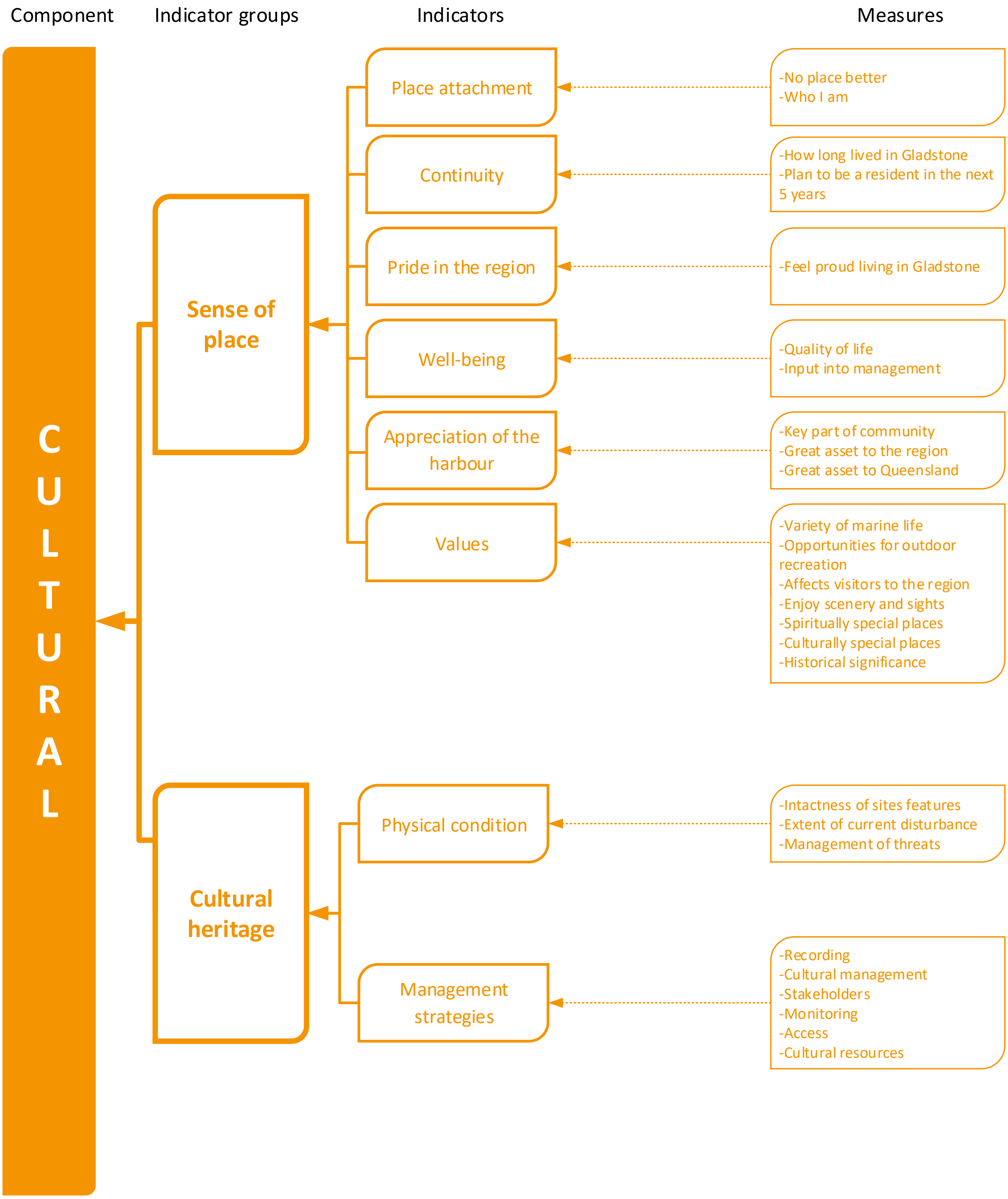


Figure 2.5: The levels of aggregation used to determine the cultural grades and scores in the 2019 Gladstone Harbour Report Card. There are 2 cultural indicator groups, 8 indicators and 26 measures.

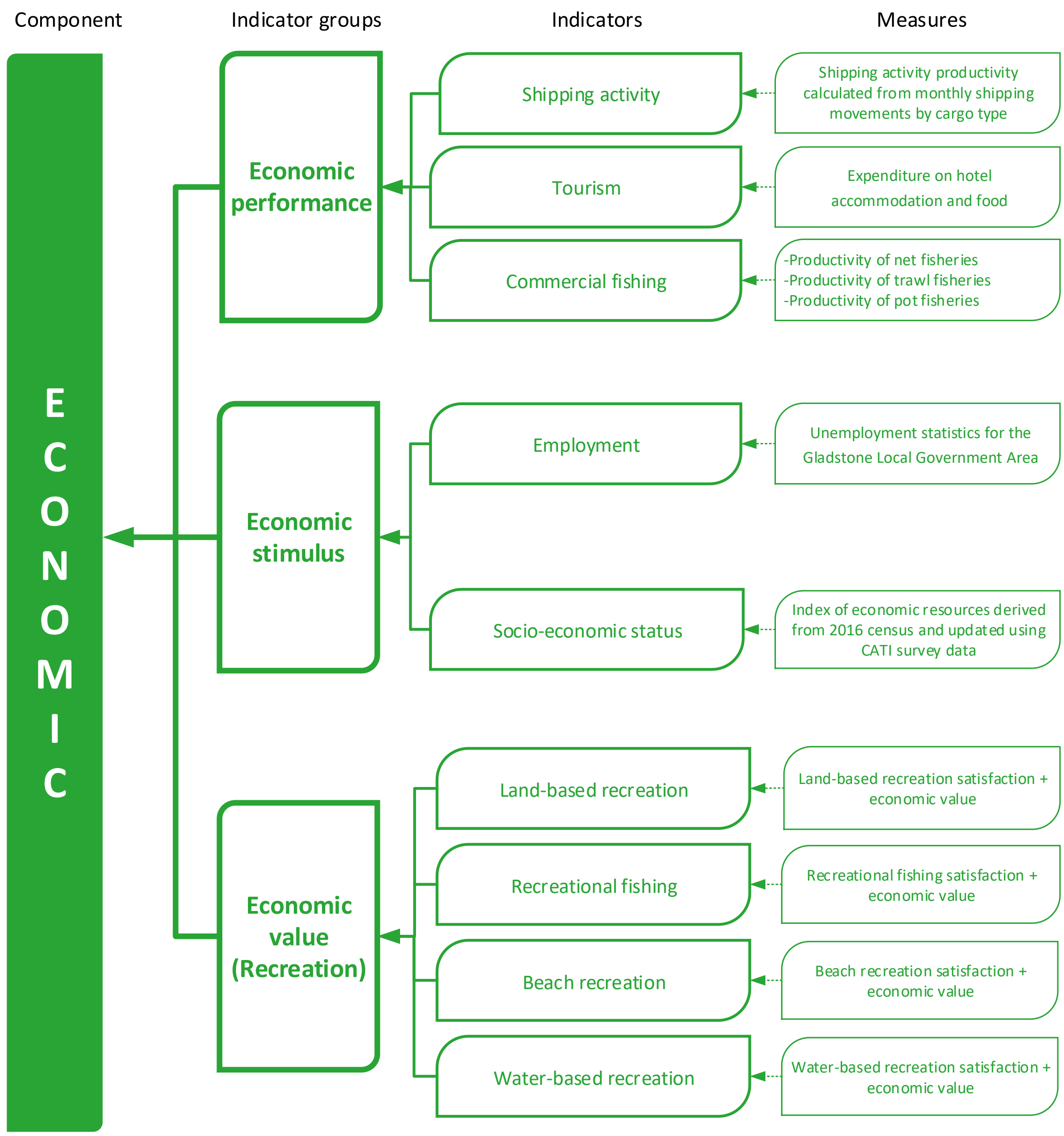


Figure 2.6: The levels of aggregation used to determine the economic scores and grades in the 2019 Gladstone Harbour Report Card. CATI = computer-assisted telephone interviewing. There are 3 economic indicator groups, 9 indicators and 11 measures.

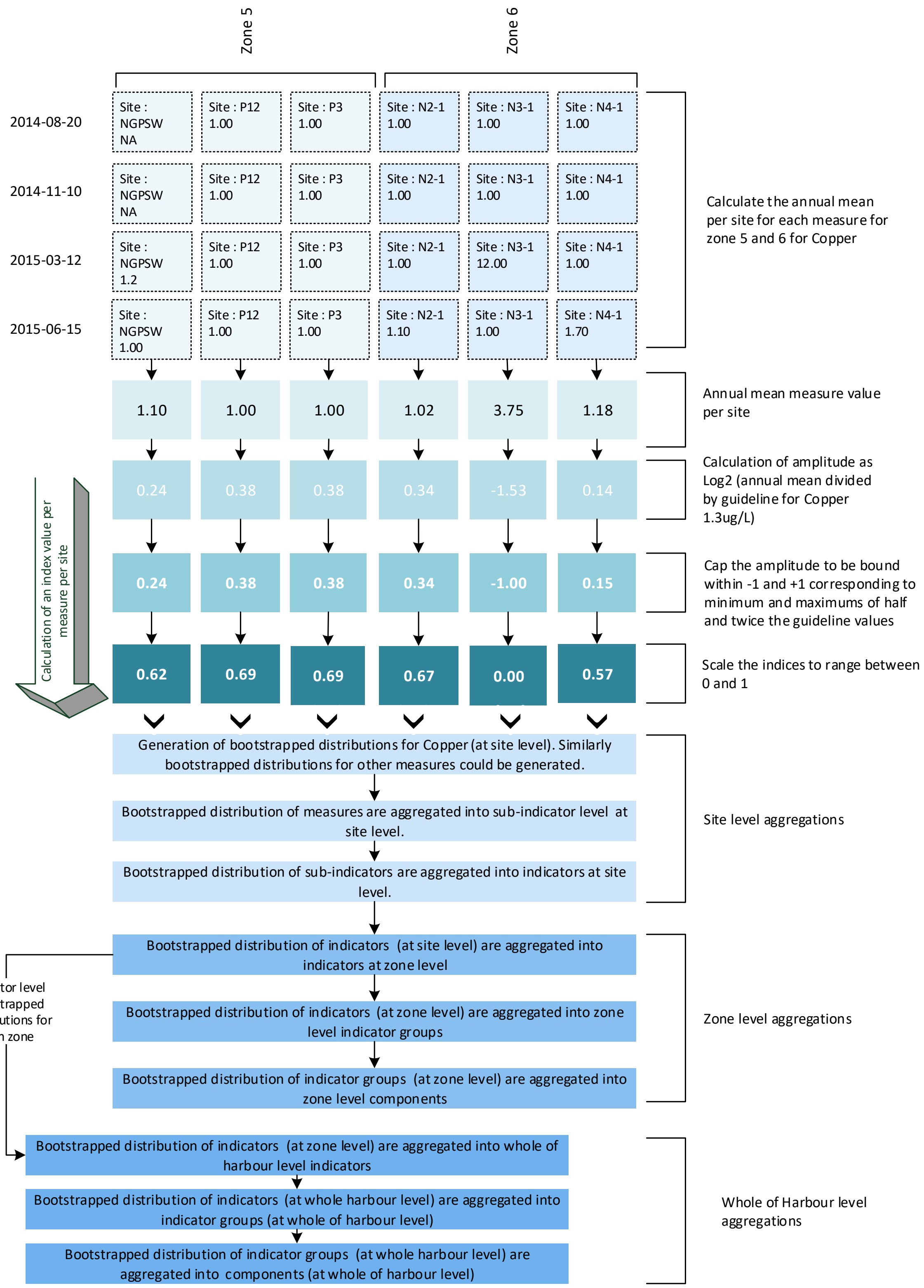


Figure 2.7: Aggregation of report card scores—a worked example using the water quality measure for copper in zones 5 and 6.

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, Social and Economic components received high confidence ratings while the Cultural component remained at a moderate rating.

The Environmental component received a high confidence rating for the first time in 2019. This was because the inclusion of fish health completes the Environmental component and other aspects of the program have matured. Confidence ratings for the eight environmental indicators are shown in Table 2.2. Six of the eight received high confidence ratings and two, fish health and water quality, received a moderate confidence rating.

Table 2.2: Confidence ratings for individual environmental indicators in 2019.

Indicator	Confidence	Reason
Water Quality	Moderate	Only 'far-field' sites were reported on and these were sampled only four times a year. Positive laboratory and field blanks occurred in 11.2% of the lab blank and field blank data. NOx and orthophosphate were excluded (see Section 4.1.1 for detail).
Sediment Quality	High	Appropriate methodology and sampling frequency, few laboratory issues since the pilot report card in 2014.
Seagrass	High	Consistent methods used over five years of monitoring. Minor changes to scoring in 2018.
Corals	High	Consistent methods used over five years of monitoring. Minor changes to scoring in 2018.
Mangroves	High	Two years of monitoring, high quality data and consistent with other mangrove monitoring programs in Queensland.
Fish Health	Moderate	Two years of monitoring (2018 development and 2019 report card) and the program is based on previous fish health studies. The two fish health projects had similar results. However, the benchmarks used are preliminary and may require refinement.
Fish Recruitment	High	Four years of monitoring with consistent methods and data analysis.
Mud Crabs	High	Three years of monitoring with an appropriate methodology. The benchmarks are based on local populations.

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 and an online version of the survey in 2019. There were some differences between the CATI and online survey responses, although score differences were minor. 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 well beyond the harbour. Despite these minor issues it was considered that overall the grade for the Social component was based on a complete set of indicators with no major issues regarding data availability, adequacy or quality.

The Cultural component consisting of Indigenous cultural heritage and ‘sense of place’, 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 was conducted in 2019 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 report card. Other data that contribute to the economic grade came from a variety of reputable sources. However, there are ongoing issues with the definition of a tourist and separating the effects of Gladstone Harbour from Gladstone City in the tourism indicator. The grade for the Economic component was based on a complete set of indicators and there were no major issues with data availability, adequacy or quality.

3. Geographical scope

3.1. Environmental reporting zones

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

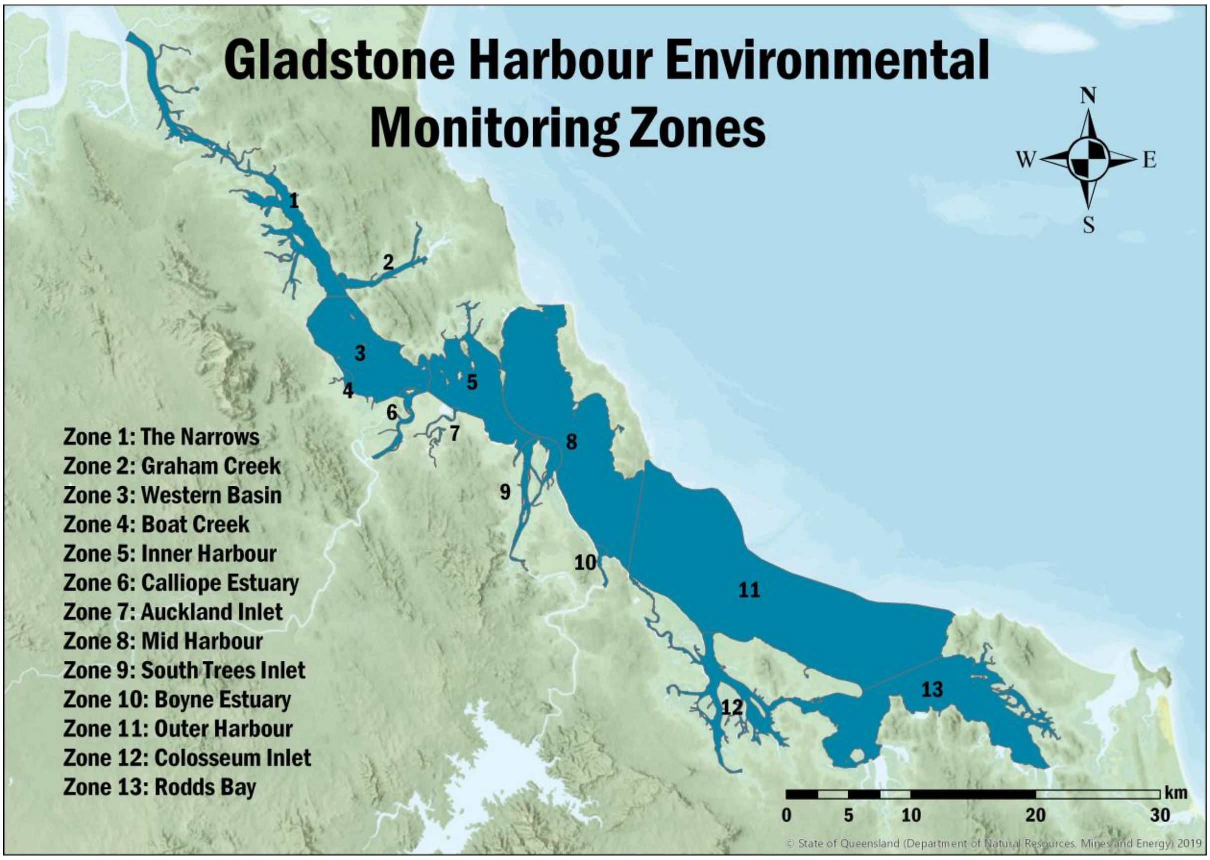


Figure 3.1: The 13 Gladstone Harbour zones for which environmental parameters were measured for the 2019 Gladstone Harbour Report Card.

Figure 3.2: 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 (PCIMP, 2010). This zone has one monitored seagrass meadow—an intertidal meadow comprising aggregated patches of seagrass near Black Swan Island.

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

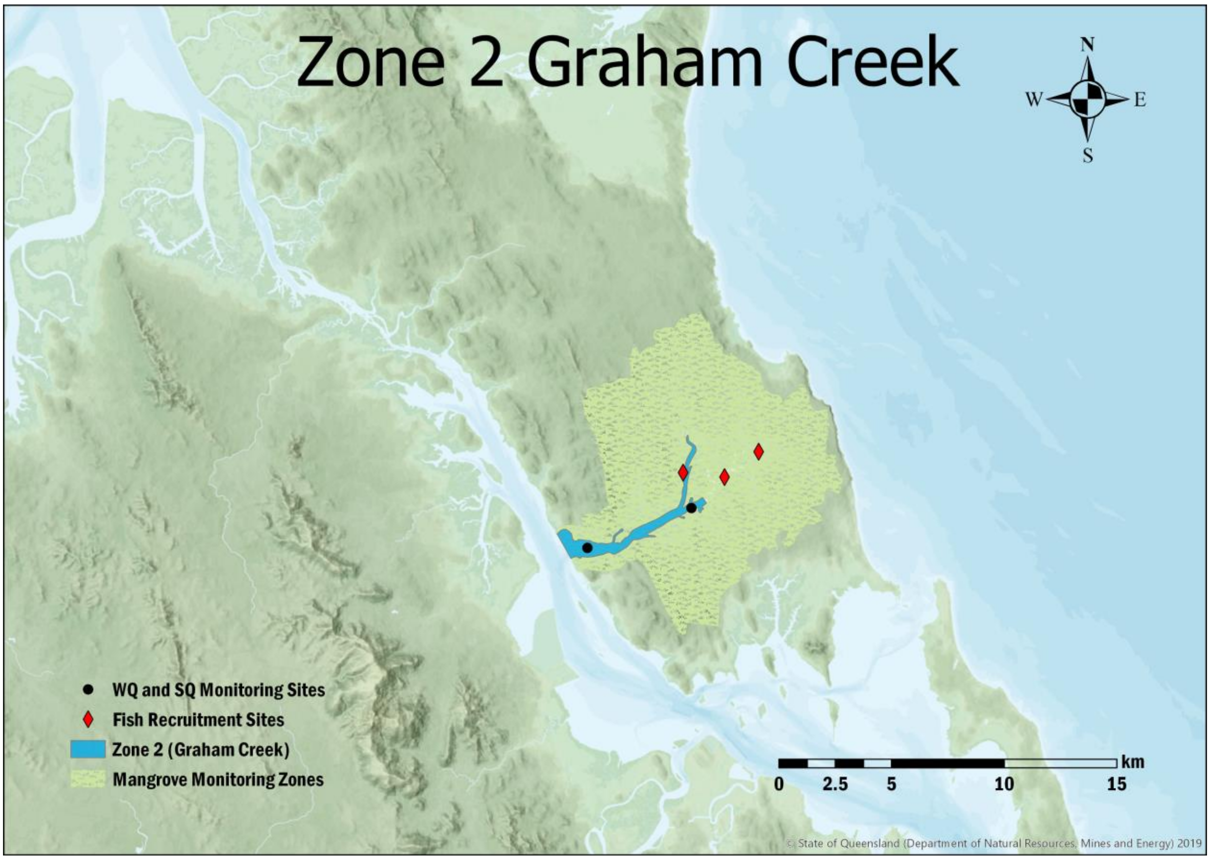


Figure 3.4: Habitat types and sampling sites in Graham Creek.

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

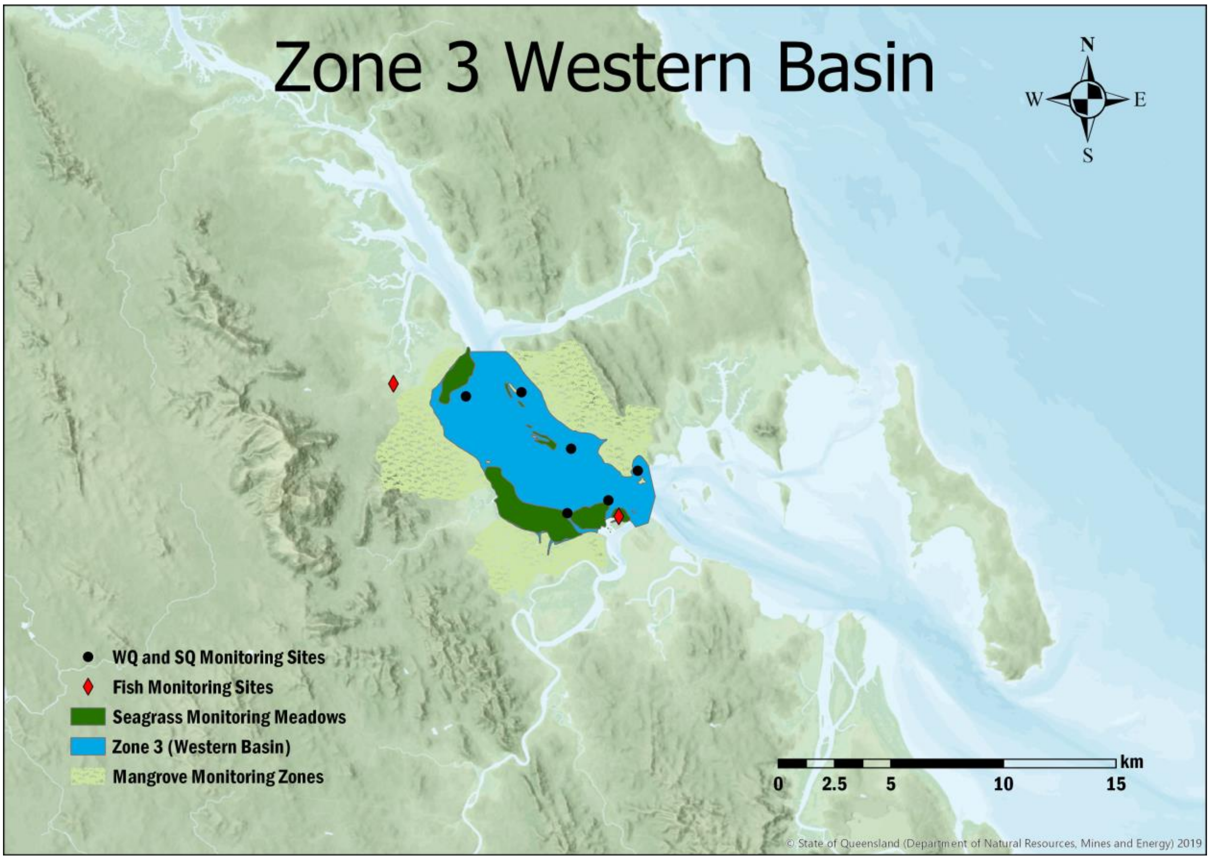


Figure 3.6: Habitat types and sampling sites in the Western Basin.

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

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

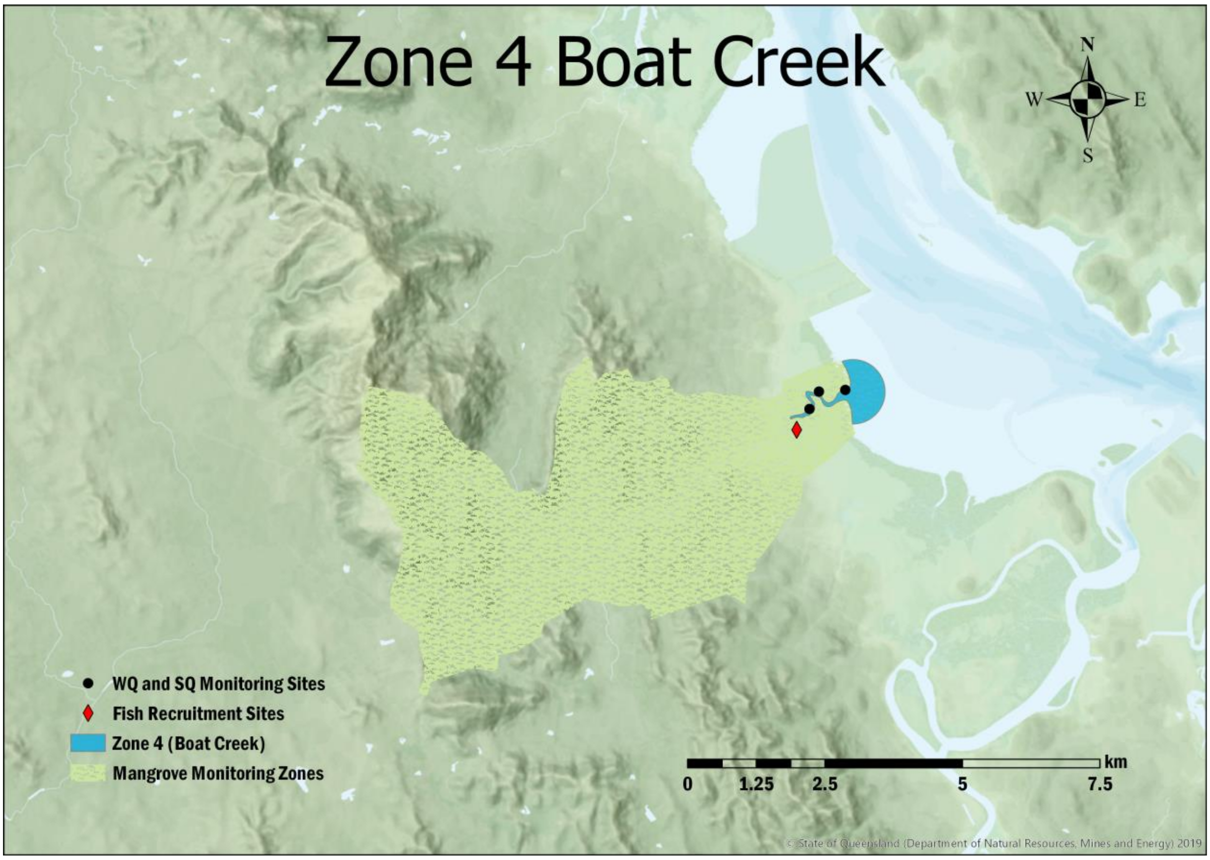


Figure 3.8: Habitat types and sampling sites in Boat Creek.

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 9km), 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 3.9: Inlet to Boat Creek photographed from the Western Basin.

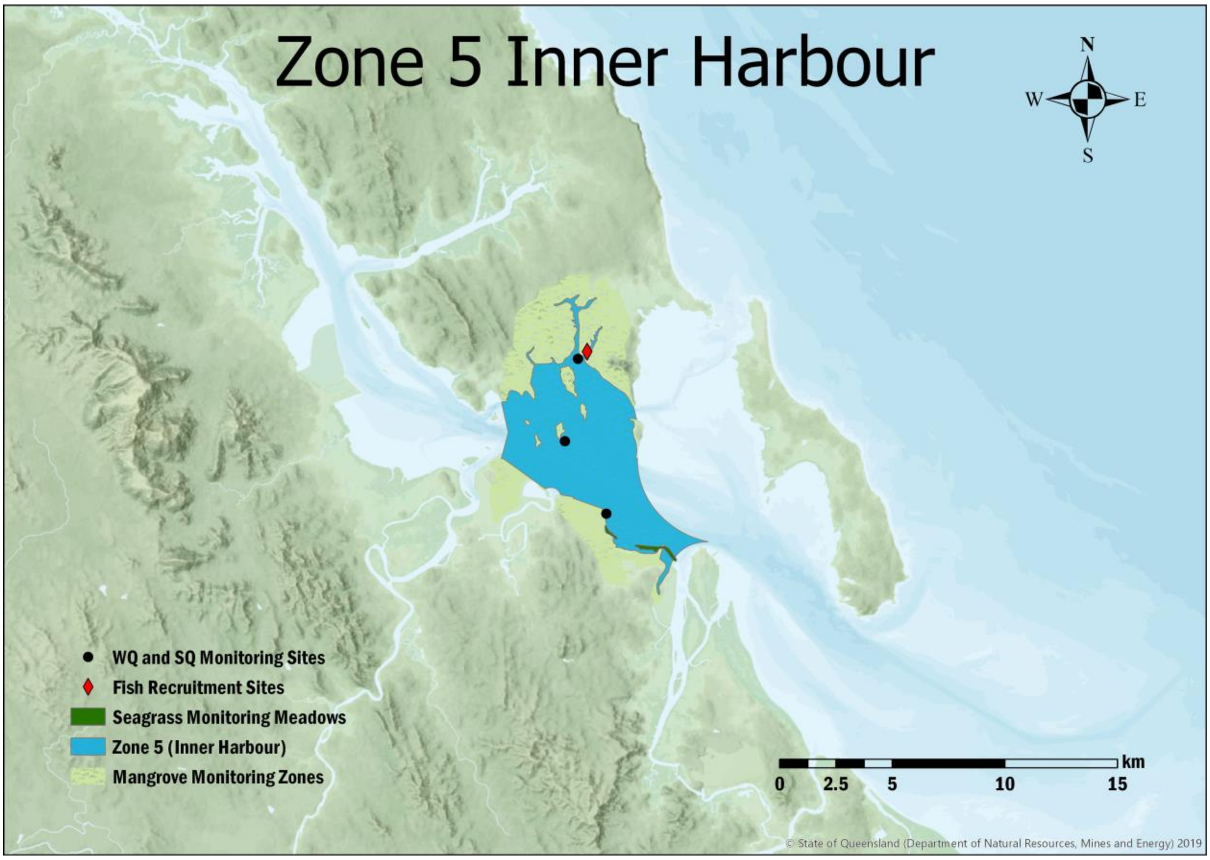


Figure 3.10: Habitat types and sampling sites in the Inner Harbour.

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. The Quoin Island Turtle Rehabilitation Centre is located in the centre of this zone and the Barney Point Coal Terminal is located on the south-east banks of the zone.

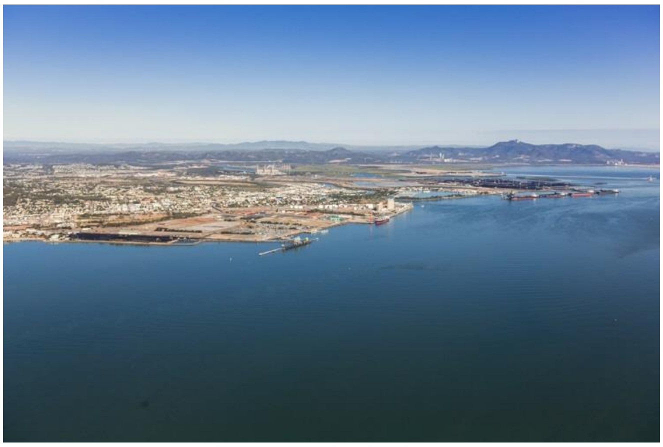


Figure 3.11: The Inner Harbour photographed from the north-east, with Auckland Point wharves and the City of Gladstone on the left and the RG Tanna coal loading facility on the right.

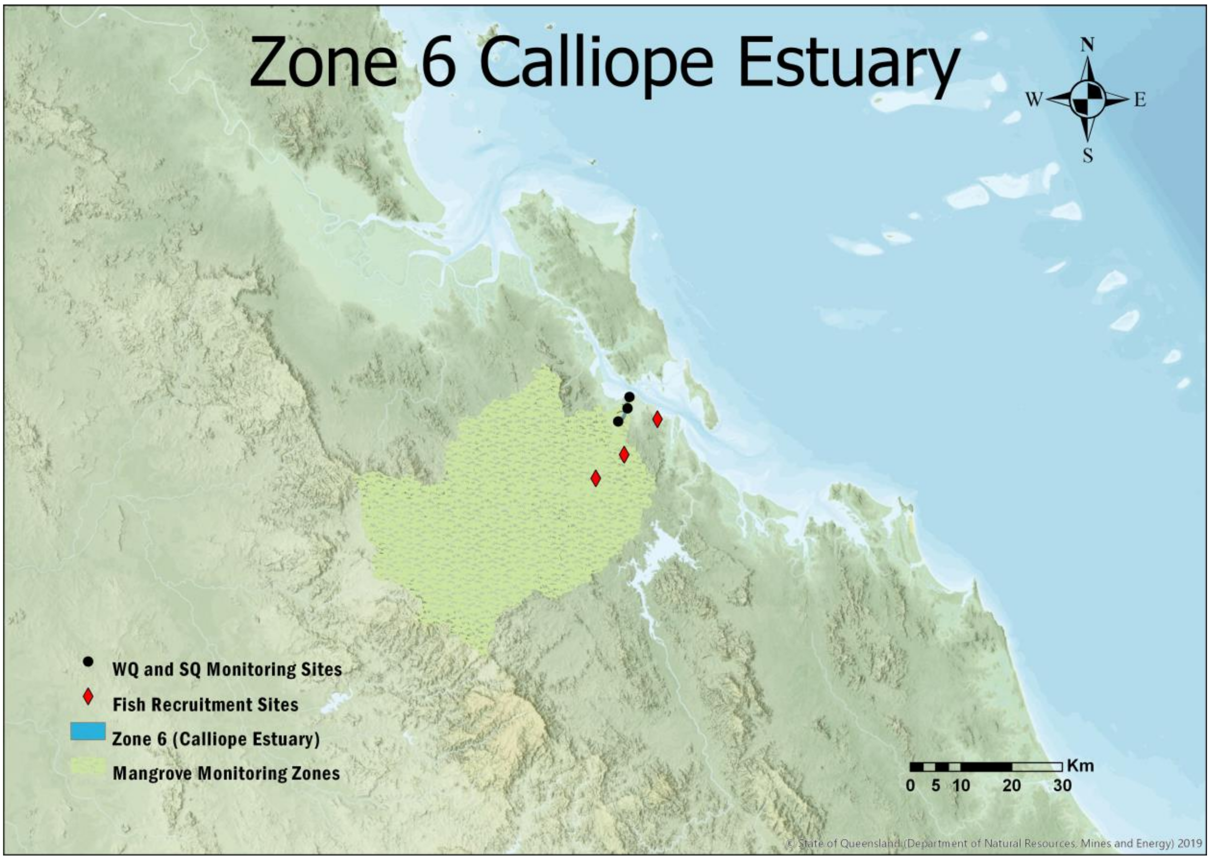


Figure 3.12: Habitat types and sampling sites in Calliope Estuary.

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

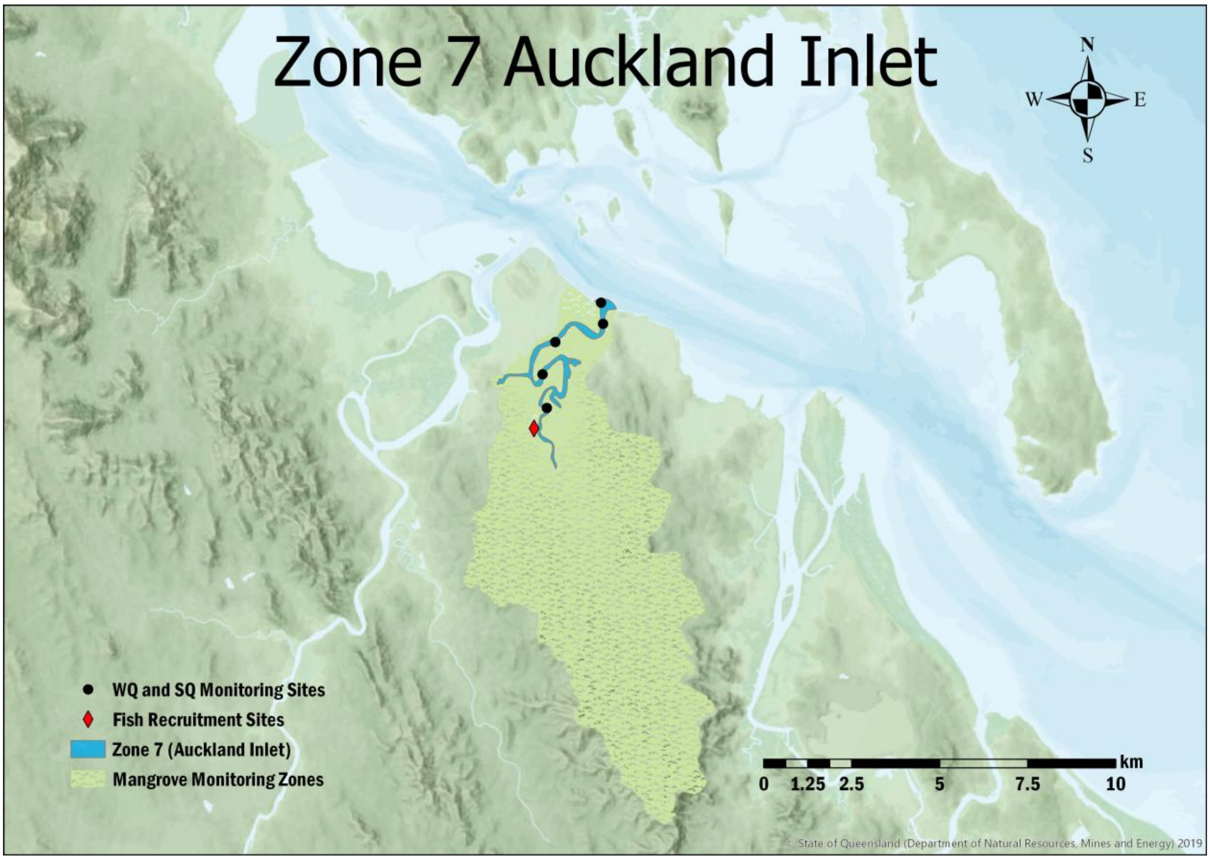


Figure 3.14: Habitat types and sampling sites in Auckland Inlet.

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

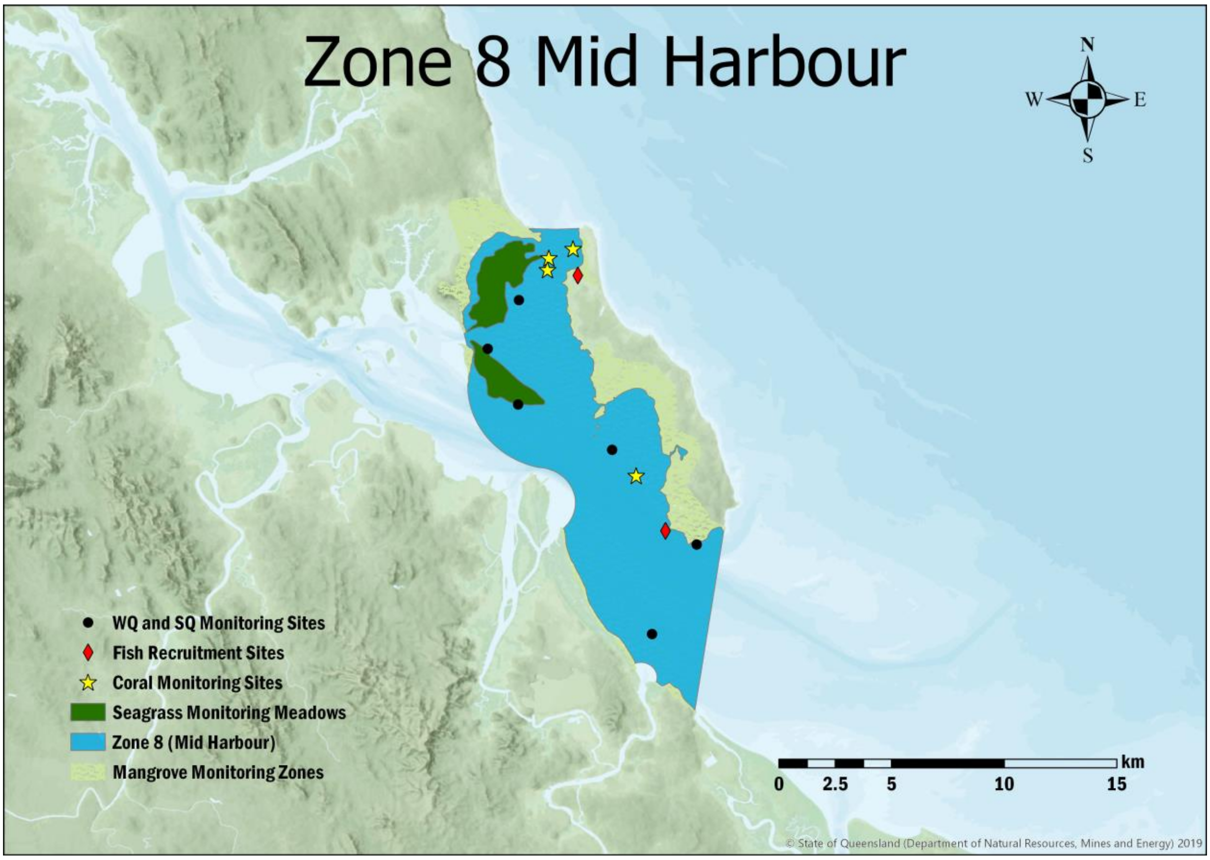


Figure 3.16: Habitat types and sampling sites in the Mid Harbour.

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.

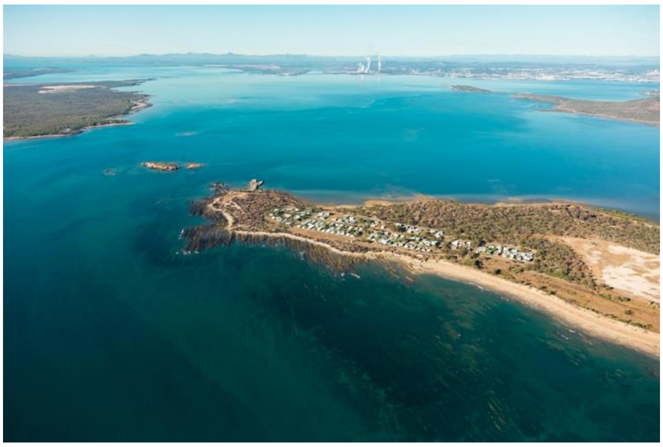


Figure 3.17: The Mid Harbour photographed from north-east. Curtis Island is in the foreground and the Inner Harbour is in the background.

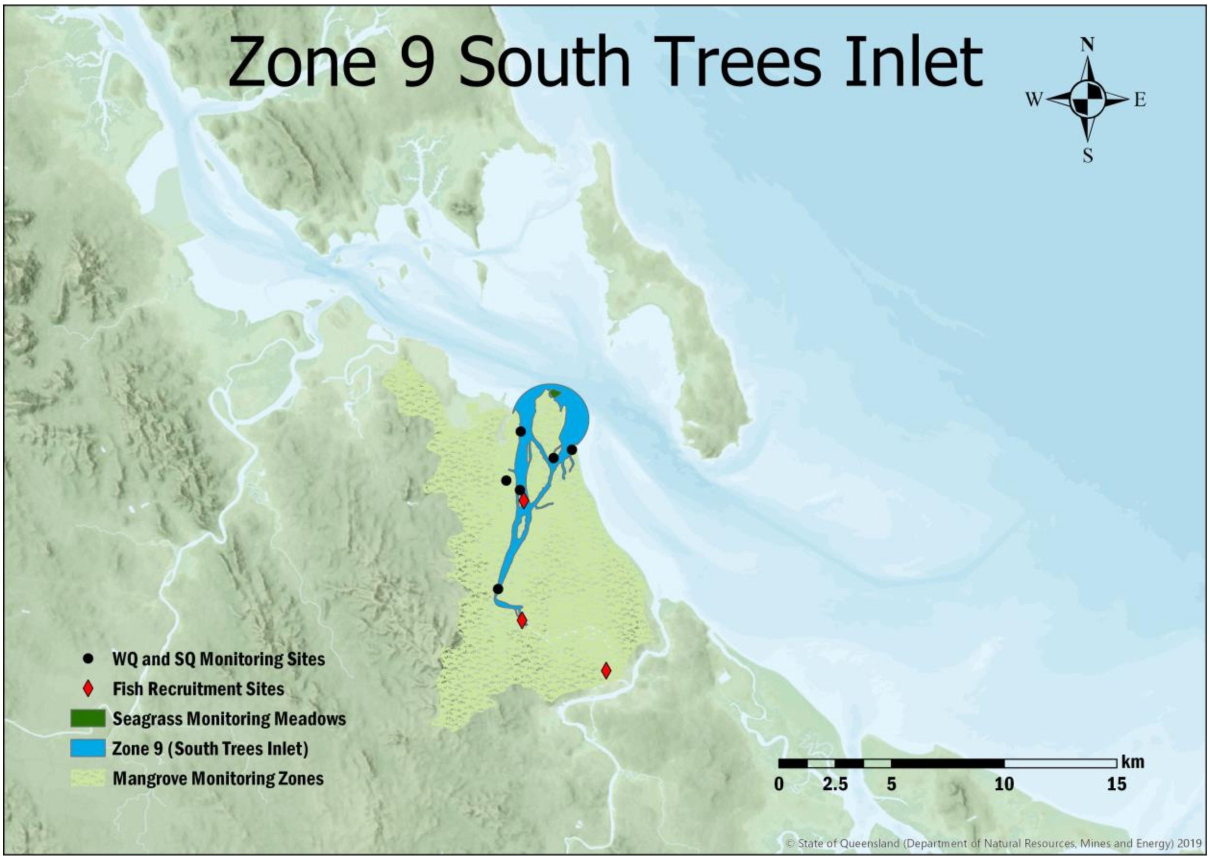


Figure 3.18: Habitat types and sampling sites in South Trees Inlet.

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

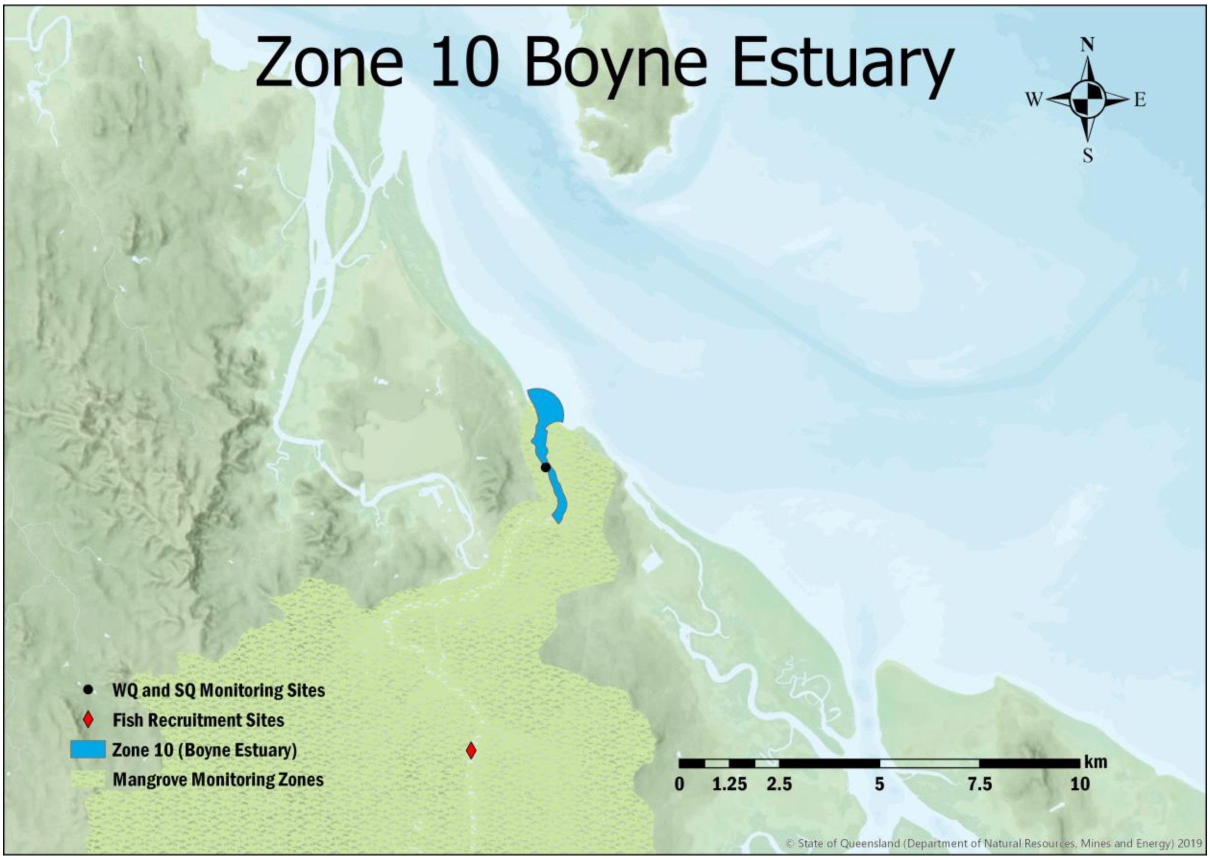


Figure 3.20: Habitat types and sampling sites in Boyne Estuary.

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

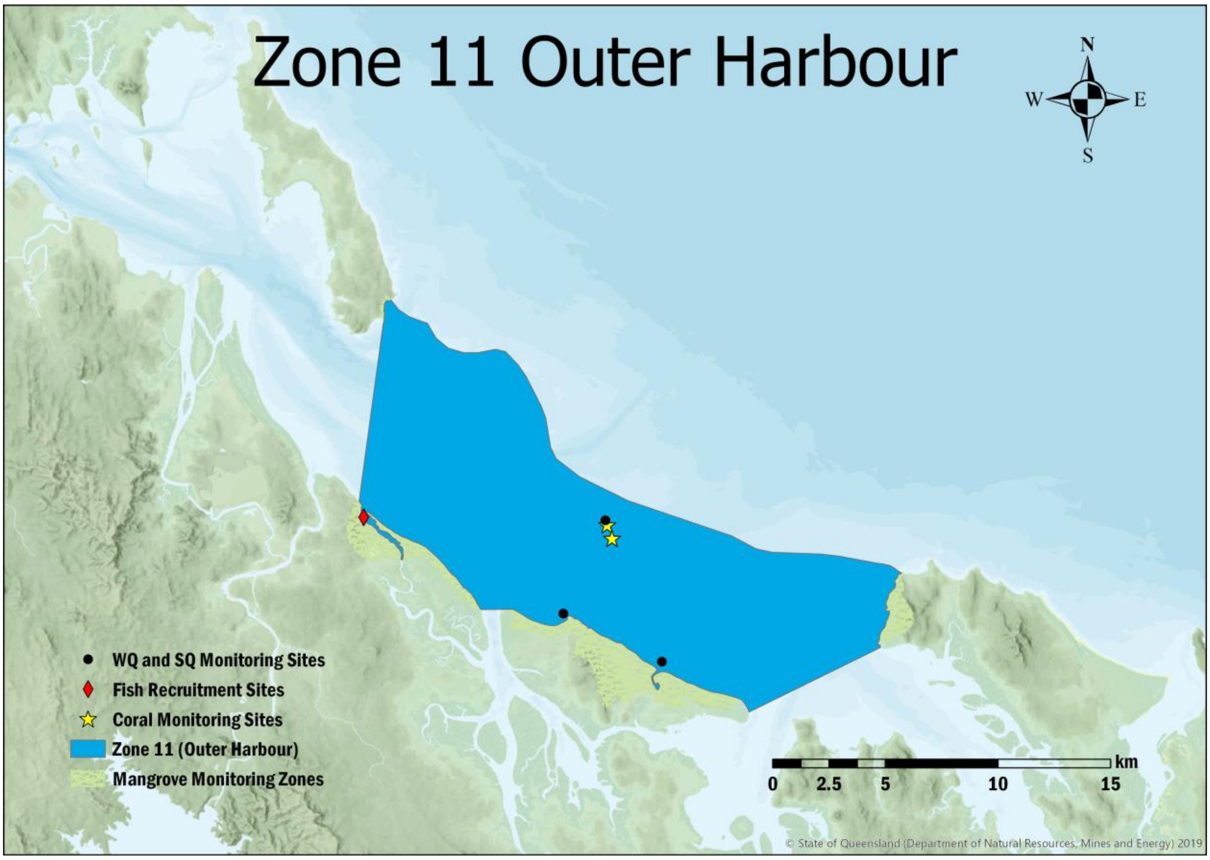


Figure 3.22: Habitat types and sampling sites in the Outer Harbour.

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.

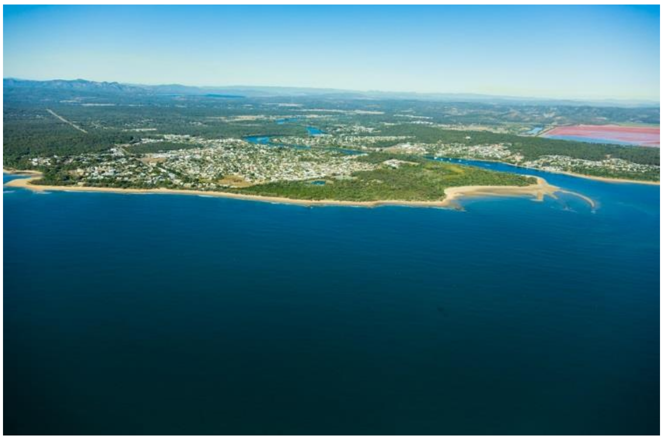


Figure 3.23: The Outer Harbour and Tannum Sands photographed from the north-east. Boyne Island and one of Gladstone's red mud (bauxite) dams are on the right.

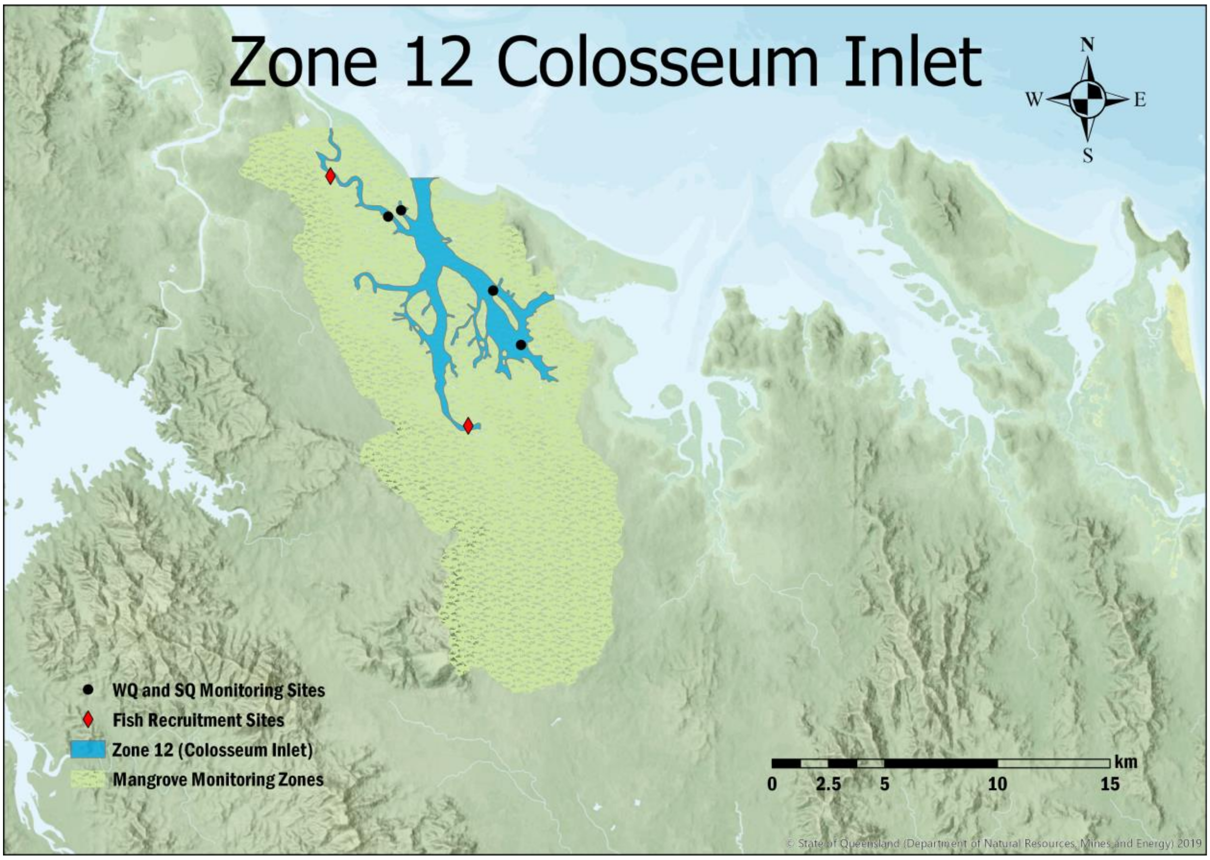


Figure 3.24: Habitat types and sampling sites in Colosseum Inlet.

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 both the Outer Harbour and Rodds Bay zones. The inlet has several large tributaries branching off the main creek and all are lined with mangroves and salt pan areas. There are no urban or industrial areas along the coastline of this zone.

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

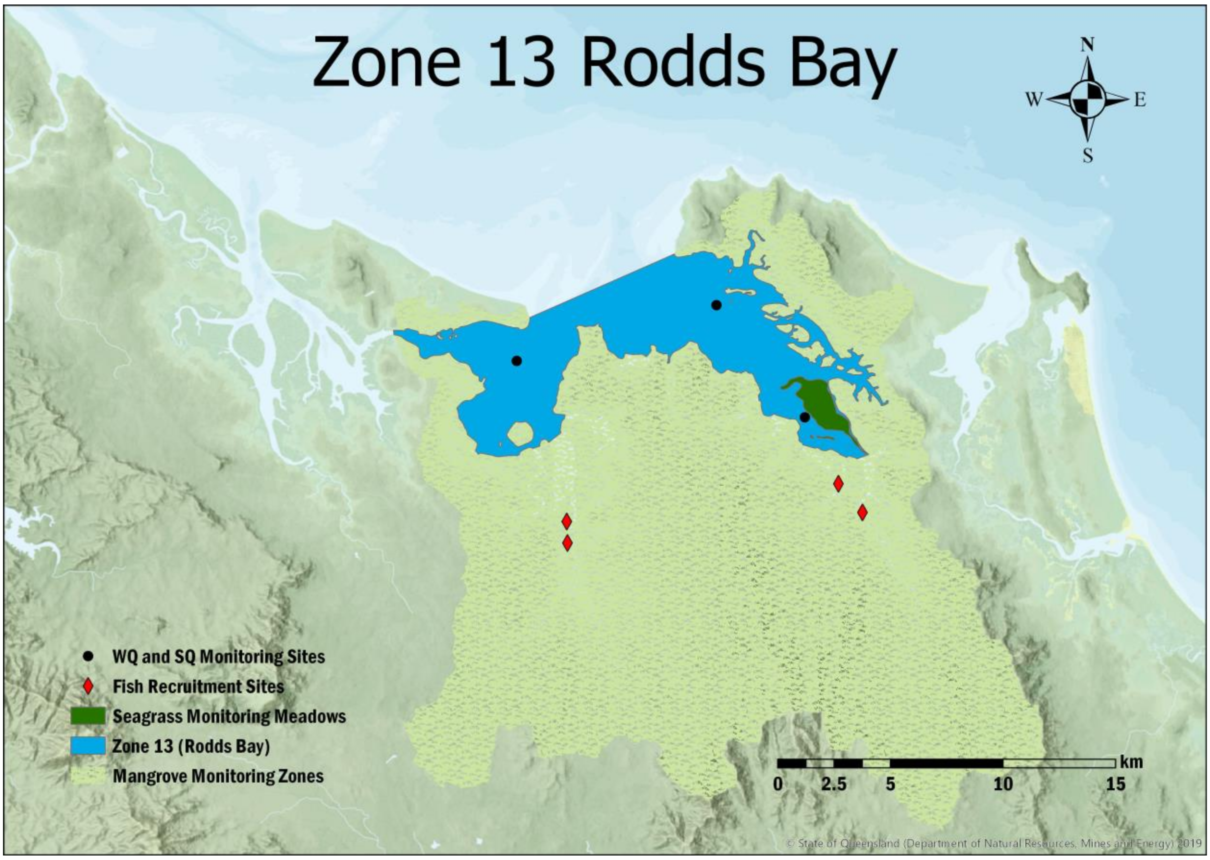


Figure 3.26: Habitat types and sampling sites in Rodds Bay.

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

3.2. Social, cultural and economic reporting areas

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

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

However, for the marine safety incidents and oil spills social indicator, data originated from Gladstone Maritime Region which includes 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).

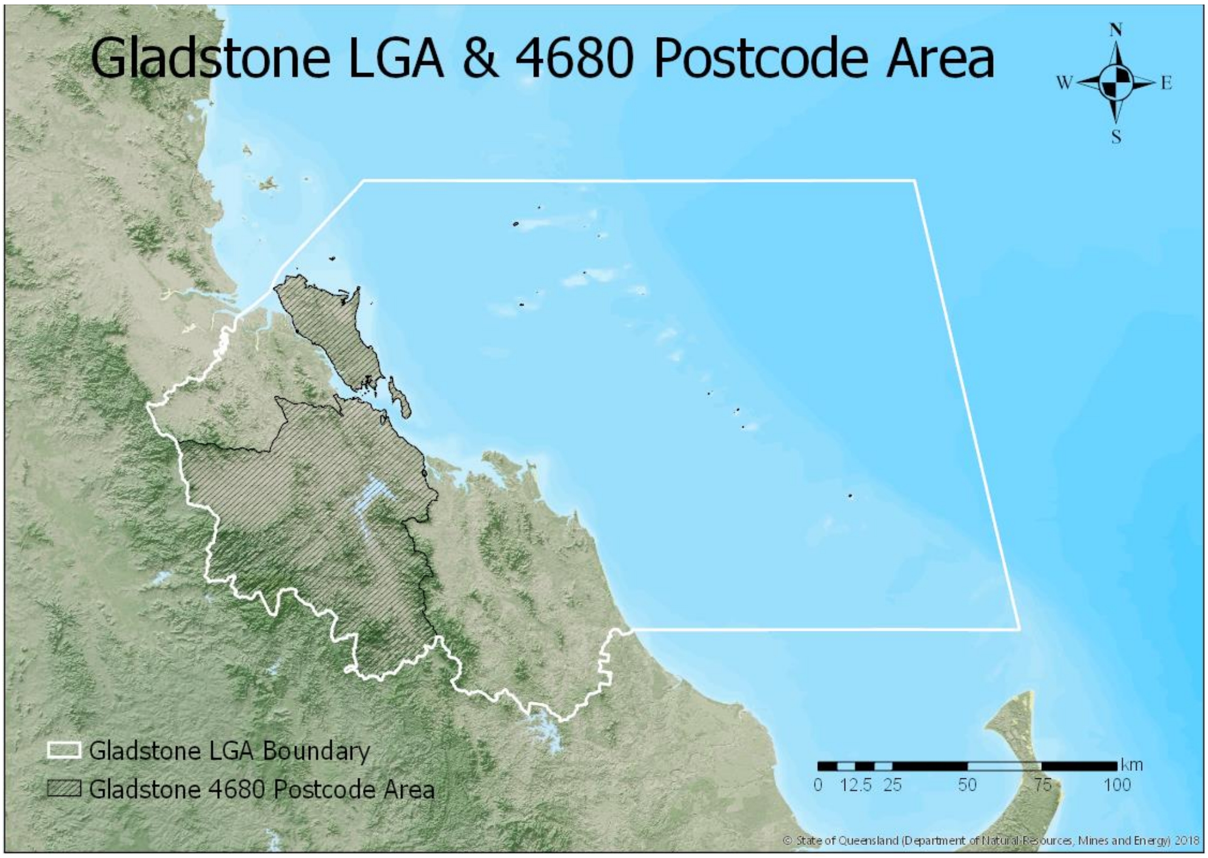


Figure 3.28: The Gladstone Region showing the mainland extent of the Gladstone Local Government Area (LGA) and the Gladstone 4680 postcode area. Both were used to define areas from which some social, cultural and economic data were collected.

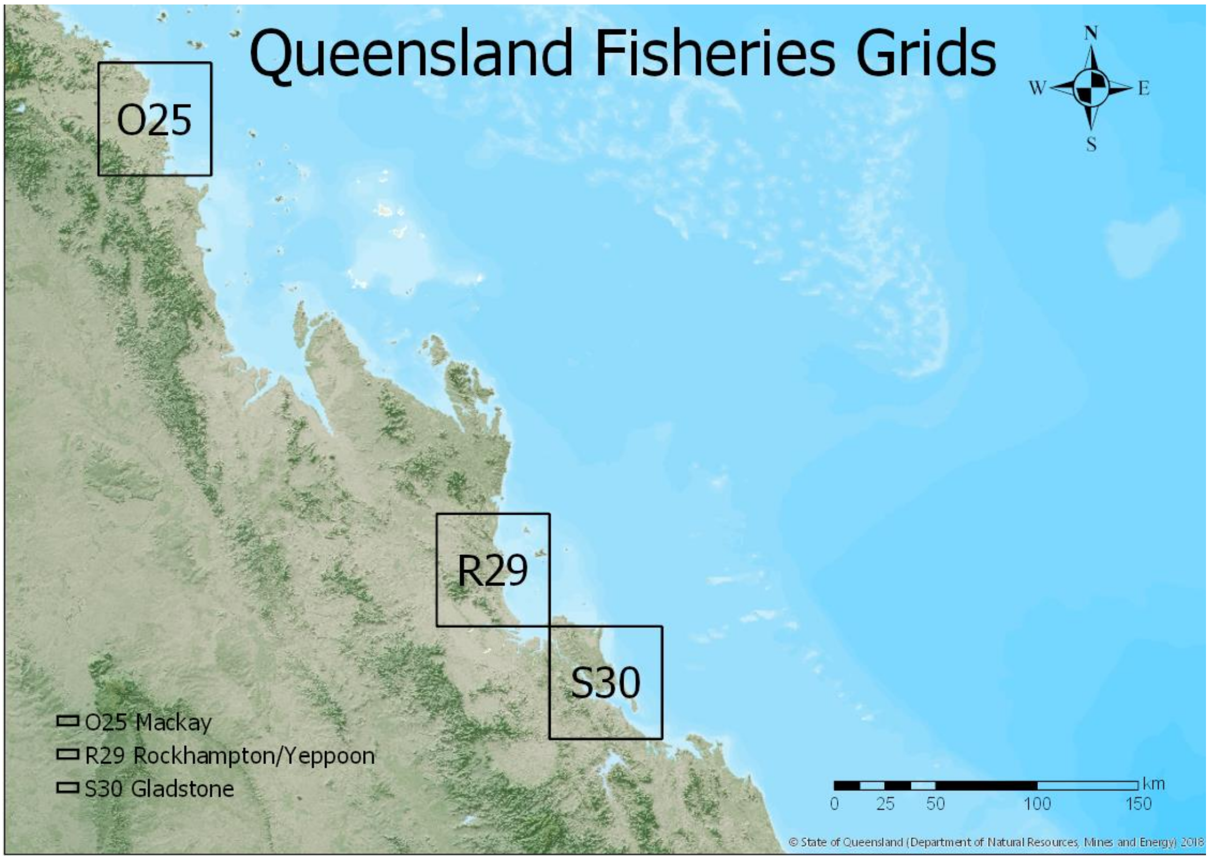


Figure 3.29: The Queensland Fisheries S30 (Gladstone), R29 (Rockhampton and Yeppoon) and O25 (Mackay) Grids. Data from these grids are used to calculate the commercial fishing indicator.

Data for the Indigenous cultural heritage indicator group were collected from four zones within the LGA boundary: The Narrows, Facing Island, Gladstone Central and Wild Cattle Creek (Figure 3.30).

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 both 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 2 km 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 7 km 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.

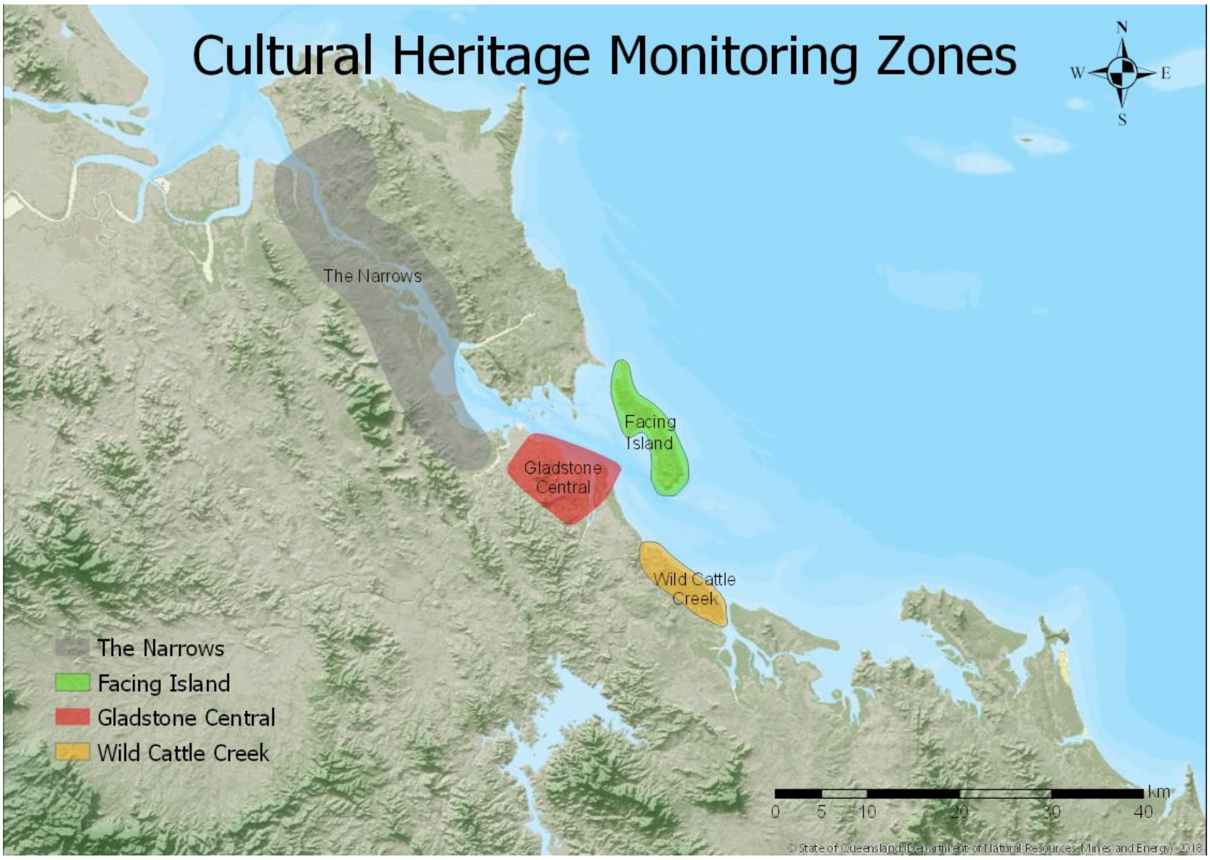


Figure 3.30: The four reporting zones from which data used to inform the Indigenous cultural heritage indicators for 2019 report card were collected.

4. The Environmental component

The Environmental component for the 2019 report card consists of three indicator groups: water and sediment quality, habitats and fish and crabs. In 2019, the fish and crabs indicator group includes fish health, fish recruitment and mud crabs. The addition of fish health completes the Environmental component of the report card.

4.1. Water and sediment quality

Water and sediment quality are important and interconnected aspects of the harbour ecosystem. A healthy water and sediment system sustains the health of a large number of aquatic species, including fish, turtles, dugongs, seagrass, mangroves and benthic invertebrates. Catchment-related, anthropogenic, climatic and other environmental factors play a major role in determining the water and sediment quality recorded in the harbour. The 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:

- DEHP Water Quality Objectives for the Capricorn Curtis Coast (DEHP, 2014a) for pH, turbidity and nutrients;
- ANZG (2018) for metals in water and sediments (except aluminium and manganese);
- Golding et al. (2014) for aluminium in marine waters; and
- COAG Standing Council on Environment and Water (2013) for manganese 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 (HEV) zones in Gladstone Harbour (The Narrows, Colosseum Inlet, Rodds Bay) to 24 µg/L in moderately disturbed (MD) zones (all other zones). This led to similar actual concentrations of aluminium being scored as very poor in HEV zones and very good in MD zones. This created the misleading impression that the aluminium concentrations were far worse in HEV zones than in MD zones. For this reason, the ISP applied the MD guideline of 24 µg/L across all zones for aluminium. For the same reason, the ISP also selected a consistent guideline of 140 µg/L for manganese which was the appropriate guideline for MD systems with coral (COAG Standing Council on Environment and Water, 2013). Manganese guidelines varied between 20 µg/L and 390 µg/L depending on whether the zone was classified as HEV or MD and whether corals were present or absent. 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 is 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, 5667.9:1998 and 5667.10:1998)
- *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)
- *Revision of the ANZECC/ARMCANZ Sediment Quality Guidelines* (Simpson et al., 2013)
- *Queensland Water Quality Guidelines* (DEHP, 2009)
- *Department of Environment and Science Monitoring and Sampling Manual* (DES, 2018)

4.1.1. Water and sediment quality data collection

4.1.1.1. Water quality

Under a data-sharing agreement, PCIMP provided GHHP with water quality data for calculating scores for the 2019 report card. Those data were based on samples collected from 51 sites across the 13 harbour zones in August and November 2018 and March and June 2019 (Figures 3.1–3.27). Methods in this section were provided by PCIMP (Anastasi, 2019).

Eleven water quality parameters were assessed: two physicochemical measures, three nutrient measures and six dissolved metals (Table 4.1). 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.

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 1 L acid-rinsed Nalgene bottle. 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, laboratory blanks and duplicate samples were also collected during sampling in accordance with the standard protocols described above.

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 (NMI) and nutrient samples were sent to the Queensland Health Laboratories with the exception of chlorophyll-*a* samples, which were sent to Australian Laboratory Services. Field blanks, laboratory blanks and duplicate samples were dispatched to the same respective laboratories based on sample type.

Table 4.1: Water quality sub-indicators and measures in the 2019 Gladstone Harbour Report Card.

Indicator	Sub-indicator	Measure	Guideline source
Water quality	Physico-chemical	pH	DEHP, 2014a
		Turbidity	DEHP, 2014a
	Nutrients	Total nitrogen (TN)	DEHP, 2014a
		Total phosphorus (TP)	DEHP, 2014a
		Chlorophyll-*a*	DEHP, 2014a
	Dissolved metals	Aluminium (Al)	Golding et al., 2014
		Copper (Cu)	ANZG, 2018
		Lead (Pb)	ANZG, 2018
		Manganese (Mn)	COAG Standing Council on Environment and Water (2013)
		Nickel (Ni)	ANZG, 2018
		Zinc (Zn)	ANZG, 2018

See Appendix 3 for a full list of WQOs and water quality guidelines.

4.1.1.2. Sediment quality

Six sediment metals and one metalloid (arsenic) were assessed (Table 4.2). Methods in this section were provided by PCIMP (Anastasi, 2019).

Sediment samples were collected from the same 51 harbour monitoring sites used for water quality sampling in May and June 2019. 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, NMI, within their recommended holding times. For quality assurance and quality control (QA/QC), separate grabs were made for duplicate samples at 20% of sites. NMI analysed all samples.

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 (PAHs) have not been included since the first full report card owing to the extremely low concentrations recorded in 2015. Sediment mercury, which was excluded in 2018, was restored to the program as the limit of reporting value (0.01 mg/kg) was at an acceptable level compared to the guideline value (0.15 mg/kg).

Table 4.2: Sediment quality measures in the 2019 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 5 for a full list of sediment quality guidelines.

4.1.1.3. What water and sediment quality measures were not included?

During late September 2019, the ISP held a meeting to discuss QA/QC issues with the raw dataset for 2019 for the water and sediment quality data collected.

Following the meeting, 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 perverse results (e.g. zones with lower WQOs tended to have lower scores and vice versa).
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 2019, the ISP recommended two changes in water quality methodology which were approved by the GHHP Management Committee:

1. When a dissolved metal concentration is higher than the respective total metal concentration, the total metal concentration replaces the dissolved metal. In 2019, this change in methods impacted approximately 3% of dissolved metals in water data. In previous years there were specific rules used to exclude, replace or include dissolved metals in water data, which were time intensive and executed manually.
2. In previous years when an individual measure was below the detection limits, the value of the detection limit was used when calculating scores (i.e. <1 µg/L is represented as 1 µg/L). For the 2019 Gladstone Harbour Report Card, when an individual measure is below detection limits, the value used is equal to half the detection limit value (i.e. <1 µg/L is represented as 0.5 µg/L). This method is consistent with those used by the Department of Environment and Science.

4.1.2. Water and sediment quality measures

A total of 18 water and sediment quality measures were assessed and reported in the 2019 Gladstone Harbour Report Card. These measures were recommended by the GHHP Independent Science Panel 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.

4.1.2.1. Physicochemical indicators

pH

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

Turbidity

Turbidity is a measure of water clarity and is affected by the levels of suspended sediment (sand, silt and clay), organic matter and plankton in the water. Coloured substances such as pigments and tannins from decaying plant matter may also 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.

4.1.2.2. 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 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 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.

4.1.2.3. 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 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 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 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 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.

Manganese

Manganese 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).

Nickel

Nickel 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 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.

4.1.3. Water and sediment quality results

4.1.3.1. Water quality

The overall water quality score was derived from three sub-indicator groups: physicochemical, nutrients and dissolved metals. The physicochemical group comprised pH and turbidity; the nutrients group comprised 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 2019 report card was a 0.81 (B). Four zones—Mid Harbour, Boyne Estuary, Outer Harbour and Colosseum Inlet—received very good scores (Table 4.3). The remaining nine zones received good overall scores. As in previous years, Boat Creek had the lowest overall score of the 13 environmental monitoring zones.

Table 4.3: Water quality indicator scores for the 2019 Gladstone Harbour Report Card. Scores from 2018 and 2017 are shown for comparison.

Water quality	Physico-chemical score	Nutrients score	Dissolved metals score	Zone score 2019	*Zone score 2018*	*Zone score 2017*
1. The Narrows	0.78	0.44	1.00	0.74	*0.71*	*0.71*
2. Graham Creek	0.85	0.51	1.00	0.79	*0.78*	*0.88*
3. Western Basin	0.85	0.48	0.98	0.77	*0.72*	*0.77*
4. Boat Creek	0.66	0.39	0.98	0.68	*0.63*	*0.59*
5. Inner Harbour	0.84	0.61	0.99	0.82	*0.80*	*0.79*
6. Calliope Estuary	0.82	0.60	0.99	0.80	*0.76*	*0.77*
7. Auckland Inlet	0.73	0.60	0.99	0.77	*0.74*	*0.79*
8. Mid Harbour	0.84	0.73	1.00	0.86	*0.81*	*0.79*
9. South Trees Inlet	0.89	0.61	1.00	0.83	*0.76*	*0.84*
10. Boyne Estuary	0.89	0.75	1.00	0.88	*0.79*	*0.83*
11. Outer Harbour	0.95	0.85	1.00	0.93	*0.92*	*0.90*
12. Colosseum Inlet	0.93	0.72	1.00	0.88	*0.83*	*0.83*
13. Rodds Bay	0.78	0.71	1.00	0.83	*0.74*	*0.75*
Harbour score	**0.83**	**0.61**	**1.00**	**0.81**	***0.76***	***0.78***

The physico-chemical scores for pH were uniformly very good (1.00) in all zones (Table 4.4). The scores for turbidity ranged from poor to very good, with the majority of zones being ranked good or above. Three zones (The Narrows, Calliope Estuary and Rodds Bay) had satisfactory scores, while two zones (Boat Creek and Auckland Inlet) had poor scores.

Like previous report cards, nutrients received the lowest score of 0.61 (C) amongst the water quality sub-indicators. However, nutrient scores also improved compared to the previous year. Ten of the 13 monitoring zones had nutrient scores of satisfactory or better (Table 4.3). 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 0.18 (D) to 0.93 (A) (Table 4.4).

All zones had consistently very good scores (0.98–1.00) for dissolved metals (Table 4.3). The same was true at the measure level as all six metals received very good scores across the 13 zones (Table 4.4).

Table 4.4: Scores for water quality measures for each of the 13 zones in the 2019 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	0.56	0.42	0.52	0.37	1.00	1.00	1.00	1.00	1.00	1.00
2. Graham Creek	1.00	0.71	0.48	0.87	0.18	1.00	1.00	1.00	1.00	1.00	1.00
3. Western Basin	1.00	0.70	0.51	0.68	0.25	0.94	0.95	1.00	1.00	1.00	1.00
4. Boat Creek	1.00	0.32	0.22	0.16	0.78	1.00	0.96	1.00	0.93	1.00	1.00
5. Inner Harbour	1.00	0.68	0.53	0.84	0.47	0.96	1.00	1.00	1.00	1.00	1.00
6. Calliope Estuary	1.00	0.64	0.52	0.78	0.48	1.00	0.94	1.00	1.00	1.00	1.00
7. Auckland Inlet	1.00	0.45	0.42	0.61	0.76	1.00	0.94	1.00	1.00	1.00	1.00
8. Mid Harbour	1.00	0.69	0.59	0.94	0.67	1.00	1.00	1.00	1.00	1.00	1.00
9. South Trees Inlet	1.00	0.78	0.56	0.71	0.55	1.00	1.00	1.00	1.00	1.00	1.00
10. Boyne Estuary	1.00	0.79	0.50	1.00	0.74	1.00	1.00	1.00	1.00	1.00	1.00
11. Outer Harbour	1.00	0.91	0.62	1.00	0.93	1.00	1.00	1.00	1.00	1.00	1.00
12. Colosseum Inlet	1.00	0.86	0.56	1.00	0.60	1.00	1.00	1.00	1.00	1.00	1.00
13. Rodds Bay	1.00	0.56	0.62	0.87	0.64	1.00	1.00	1.00	1.00	1.00	1.00
Harbour score	**1.00**	**0.66**	**0.50**	**0.77**	**0.57**	**0.99**	**0.98**	**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

4.1.3.2. 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 0.95 (A)—identical to both the 2018 and 2017 scores.

Zone scores for sediment quality were all very good, ranging from 0.91 (A) in Grahams Creek to 0.99 (A) in the Outer Harbour (Table 4.5). This was a result of low concentrations of all measures (arsenic, cadmium, copper, lead, mercury, nickel and zinc) (Table 4.6). While zone scores were uniformly very good for most measures, there were a number of good or satisfactory scores for sediment arsenic and nickel. Sediment mercury—which was not included in 2018—received consistently very good scores across the 13 environmental monitoring zones.

Table 4.5: Sediment quality sub-indicator scores for each of the 13 zones in the 2019 Gladstone Harbour Report Card. Overall zone and harbour scores in 2017 and 2018 are shown for comparison.

Zone	Metals and metalloid score	Zone score 2019	*Zone score 2018*	*Zone score 2017*
1. The Narrows	0.92	0.92	*0.90*	*0.92*
2. Graham Creek	0.91	0.91	*0.94*	*0.92*
3. Western Basin	0.98	0.98	*0.98*	*0.97*
4. Boat Creek	0.92	0.92	*0.91*	*0.98*
5. Inner Harbour	0.92	0.92	*0.95*	*0.93*
6. Calliope Estuary	0.96	0.96	*0.95*	*0.94*
7. Auckland Inlet	0.94	0.94	*0.91*	*0.87*
8. Mid Harbour	0.94	0.94	*0.95*	*0.95*
9. South Trees Inlet	0.96	0.96	*0.94*	*0.98*
10. Boyne Estuary	0.99	0.99	*0.97*	*0.97*
11. Outer Harbour	0.97	0.97	*0.96*	*0.97*
12. Colosseum Inlet	0.96	0.96	*0.99*	*0.99*
13. Rodds Bay	0.98	0.98	*0.97*	*0.95*
Harbour score	**0.95**	**0.95**	***0.95***	***0.95***

Table 4.6: Scores for sediment quality measures for each of the 13 zones in the 2019 Gladstone Harbour Report Card.

	Metals and metalloid						
Zone	Arsenic	Cadmium	Copper	Lead	Mercury	Nickel	Zinc
1. The Narrows	0.86	1.00	1.00	1.00	1.00	0.56	1.00
2. Graham Creek	0.80	1.00	1.00	1.00	1.00	0.57	1.00
3. Western Basin	0.90	1.00	1.00	1.00	1.00	0.97	1.00
4. Boat Creek	0.86	1.00	0.97	1.00	1.00	0.64	1.00
5. Inner Harbour	0.55	1.00	1.00	1.00	1.00	0.90	1.00
6. Calliope Estuary	0.94	1.00	1.00	1.00	1.00	0.76	1.00
7. Auckland Inlet	0.86	1.00	0.98	1.00	1.00	0.73	1.00
8. Mid Harbour	0.60	1.00	1.00	1.00	1.00	1.00	1.00
9. South Trees Inlet	0.84	1.00	1.00	1.00	1.00	0.86	1.00
10. Boyne Estuary	0.96	1.00	1.00	1.00	1.00	1.00	1.00
11. Outer Harbour	0.78	1.00	1.00	1.00	1.00	1.00	1.00
12. Colosseum Inlet	0.76	1.00	1.00	1.00	1.00	0.98	1.00
13. Rodds Bay	0.83	1.00	1.00	1.00	1.00	1.00	1.00
Harbour score	**0.81**	**1.00**	**1.00**	**1.00**	**1.00**	**0.85**	**1.00**

4.1.4. 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) in all years (Figure 4.1). In 2019, water quality was relatively uniform across the harbour, with all zones receiving a good or very good score overall. Compared to the previous year, scores for the physicochemical group declined in twelve zones as a result of lower scores for turbidity. In contrast, nutrient and dissolved metal scores improved at all thirteen monitoring zones compared to the previous year. Improvements in the dissolved metals scores were due to improved copper scores resulting from the updated scoring methods (see Section 4.1.1.3). Despite improvements in nutrient scores, the nutrient sub-indicator maintained the lowest score of the three sub-indicators for the fifth successive 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.

Improved nutrient scores may have resulted from the lower-than-average rainfall and minimal discharge from the Boyne and Calliope rivers (Figures 9.4 to 9.7). Since 2017, Boat Creek has consistently received the lowest nutrient, physico-chemical (turbidity) and overall zone score (Table 4.3). In contrast, Outer Harbour received the highest nutrient, physico-chemical (turbidity) and overall zone score for the third consecutive year. These results indicate that the more ocean-influenced zones (such as Outer Harbour) have lower nutrient loads and improved water clarity compared to other zones. The small and shallow nature of Boat Creek, which is prone to the resuspension of sediments owing to wind and tidal movement, likely influences the higher nutrient concentrations and turbidity values exhibited in this zone. The 2019 results of Boat Creek and the Outer Harbour are consistent with additional analyses completed by Schultz et al. (2019) on the 2017 Gladstone Harbour Report Card data.

For additional information, please refer to the *Water and Sediment Quality Indicators for the Gladstone Harbour Report Card* reports on the GHHP website. 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.

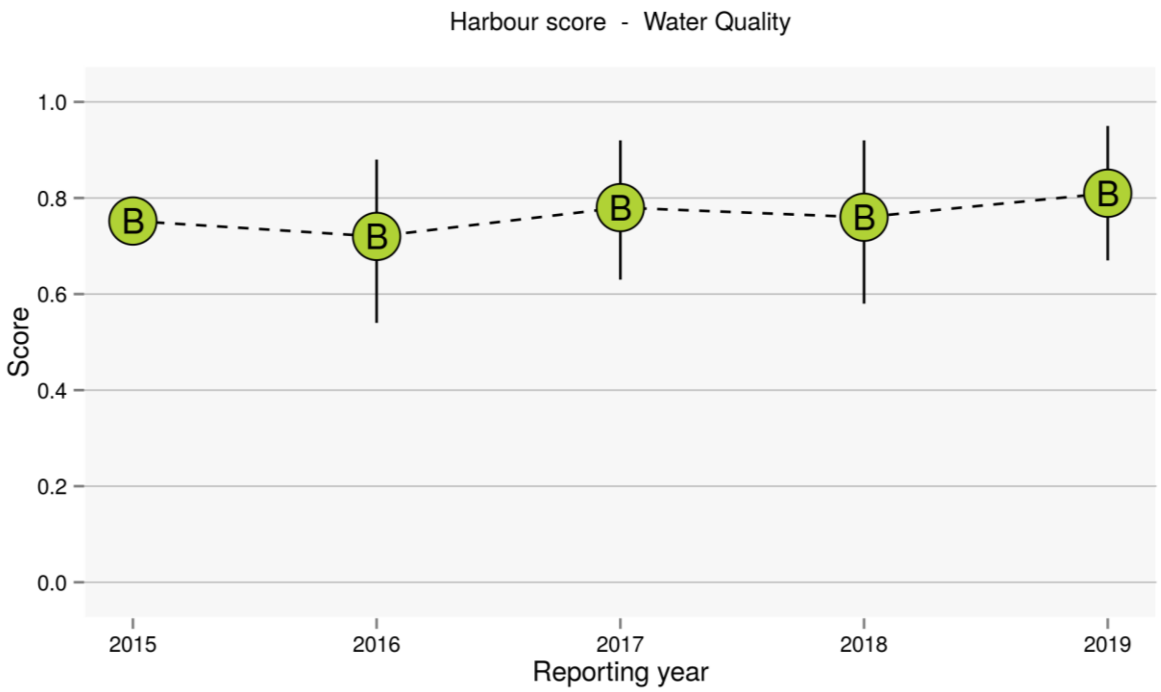


Figure 4.1: Trends in the harbour score for water quality, 2015–2019.

Sediment quality scores were uniformly very good across all Gladstone Harbour reporting zones as it has been in all previous report cards (Figure 4.2). This is a result of low concentrations of all measures (arsenic, cadmium, copper, lead, mercury, 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 a 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.

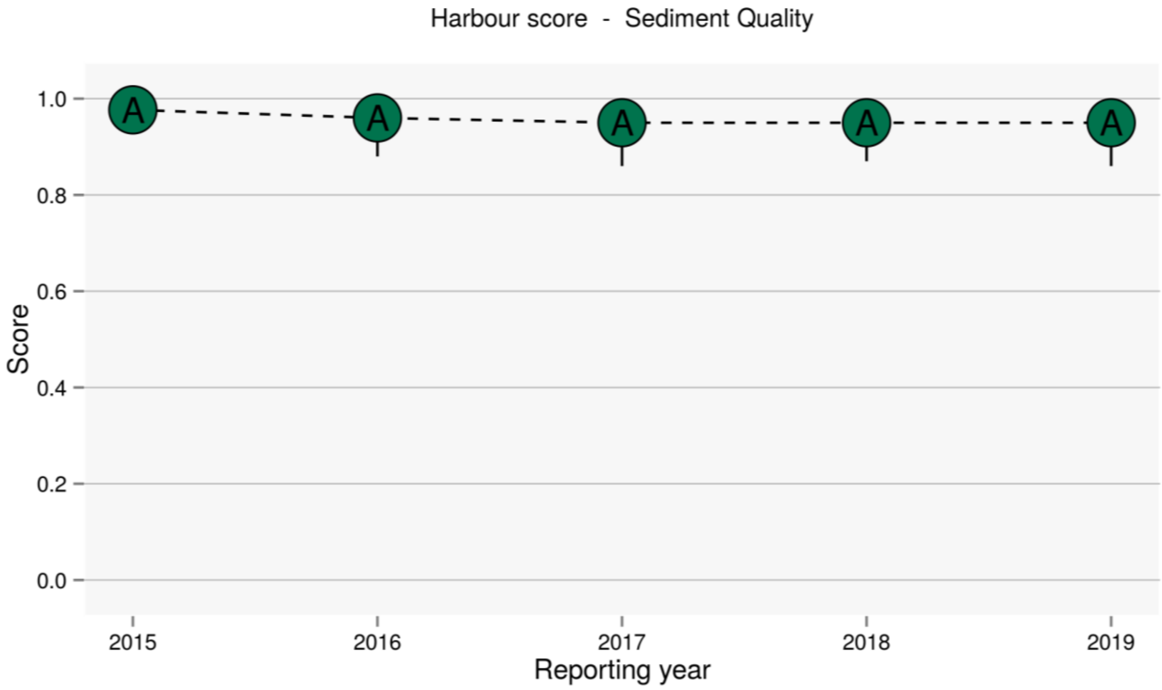


Figure 4.2: Trends in the harbour score for sediment quality, 2015–2019.

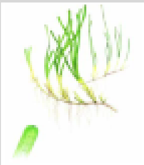
4.2. Habitats

4.2.1. Seagrass

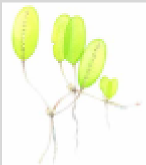
What is seagrass?

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 leaves and a buried root-like 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 the following five species of seagrass:

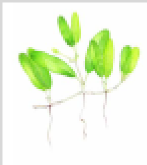
Zostera muelleri subsp. *capricorni*
Halophila ovalis
Halophila decipiens
Halophila spinulosa
Halodule uninervis (wide and narrow leaf)



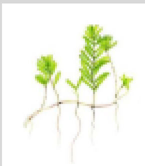
Zostera muelleri subsp. *capricorni*



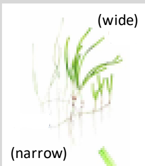
Halophila ovalis



Halophila decipiens



Halophila spinulosa



Halodule uninervis

Seagrass meadows are one of the most important habitat types within Gladstone Harbour. Within the GHHP reporting area, there are 14 monitored seagrass meadows. These are located within six harbour zones: The Narrows, Western Basin, Inner Harbour, Mid Harbour, South Trees Inlet and Rodds Bay. The area and distribution of the seagrass meadows can vary annually, but at peak distribution seagrass meadows in Gladstone Harbour can cover approximately 12,000 ha (Davies et al., 2016). This area can include intertidal, shallow subtidal and deep-water habitats. Seagrasses can inhabit various substrata from mud to rock. The most extensive seagrass meadows occur on soft substrata such as sand and mud. Seagrass meadows provide a range of important ecosystem functions, such as sediment stabilisation, nutrient cycling and carbon sequestration (Figure 4.3). They also provide nursery areas for juvenile fishes and foraging areas for dugongs, turtles and large fish such as adult barramundi.

Seagrasses are highly sensitive to reductions in available light and are susceptible to changes in a range of water quality parameters that affect light penetration. High nutrient levels from agricultural or urban run-off can cause algal blooms that shade seagrass. Increases in water turbidity from suspended sediments can reduce both seagrass growth and the size and extent of 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 within the following sections are drawn from a seagrass monitoring project that commenced in 2002 (Carter et al., 2019). 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.

4.2.2. *Seagrass data collection*

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

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

Three sub-indicators of seagrass health were measured to calculate the seagrass scores for the Gladstone Harbour report card:

Why species composition is important

Figure 4.3: 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** – 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

Biomass and species composition

Above-ground biomass was determined 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 ($gDWm^{-2}$).

Area

The total area of the monitored seagrass meadows was determined with ArcGIS 10.4. For each meadow a mapping precision estimate ranging from ≤5 m to ±50 m was determined based on the mapping methodology (Table 4.7). Spatial data from the survey were entered into the Gladstone Harbour GIS as seagrass meadow layers (see Carter et al., 2019).

Table 4.7: Mapping precision and mapping methodology for seagrass meadows for seagrass surveys conducted in November 2018 (Source: Bryant et al., 2014).

Mapping precision	Mapping method
≤5 m	Meadow boundary mapped in detail by GPS from helicopter, Intertidal meadows completely exposed or visible at low tide.
10 m	Meadow boundary determined from helicopter and boat surveys, Inshore boundaries interpreted from helicopter sites, Offshore boundaries interpreted from survey sites and aerial photography, Moderately high density of mapping and survey sites.
20 m	Meadow boundaries determined from helicopter and boat surveys, Inshore boundaries interpreted from helicopter sites, Offshore boundaries interpreted from boat survey sites, Lower density of survey sites for some sections of boundary.
50 m	Meadow boundaries determined from boat surveys, Low density of survey sites for some sections of boundary.

4.2.3. Development of seagrass indicators and scoring

Seagrass scores for the Gladstone Harbour Report Card were determined 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 determine seagrass grades, threshold levels for each grade (A to E) were developed based on:

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

Threshold ranges were developed for the meadow types for the sub-indicators biomass, area and species composition (Table 4.8). Scores for each sub-indicator were determined based on these thresholds and a score between 0.00 and 1.00 was calculated to fit the GHHP range (Carter et al., 2015a).

Between 2015 and 2017 the overall 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 of this method. The new method still defines overall meadow condition as the lowest indicator score when this score is either meadow area or biomass; however, where species composition is the lowest score, the overall meadow score is 50% of the species composition score and 50% of the next lowest score (area or biomass). This change was applied to correct an anomaly noted in the 2017 report card where the Inner Harbour received a score of zero owing to a 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.

Table 4.8: 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.

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

4.2.4. Seagrass results

The overall seagrass score in the 2019 reporting year was 0.59 (C), indicating a satisfactory overall condition for seagrass. This result is an improvement from previous report cards (2015–2018) in which overall seagrass condition was poor. At the zone level, overall condition scores improved at all monitoring zones from the previous report card. The Narrows and Western Basin improved from a poor condition to a good condition; Mid Harbour was satisfactory improving from a poor condition; Rodds Bay improved from very poor to poor; and scores improved for both South Trees and Inner Harbour although overall condition remained the same (very good and very poor, respectively) compared to 2018. Overall, ten of the 14 monitored meadows were in satisfactory, good or very good condition (Table 4.9).

Table 4.9: Seagrass sub-indicator, overall meadow, overall zone and harbour scores in 2019. Overall zone and harbour scores from 2018 and 2017 are shown for comparison.

Zone	Meadow	Biomass score	Area score	Species composition score	Overall meadow score	Zone score 2019	*Zone score 2018*	*Zone score 2017*
1. The Narrows	21	0.75	0.91	0.67	0.71†	0.71	*0.42*	*0.59*
3. Western Basin	4	1.00	0.82	0.43	0.62†	0.69	*0.45*	*0.50*
	5	0.91	0.74	0.54	0.64†			
	6	0.95	0.76	0.43	0.59†			
	7	0.94	0.91	1.00	0.91			
	8	1.00	0.55	0.22	0.38†			
	52–57	0.97	0.98	1.00	0.97			
5. Inner Harbour	58	0.21	0.57	0.56	0.21	0.21	*0.09*	*0.00*
8. Mid Harbour	43	0.45	0.75	0.62	0.45	0.52	*0.46*	*0.34*
	48	0.91	0.76	0.44	0.60†			
9. South Trees Inlet	60	0.89	0.93	0.95	0.89	0.89	*0.85*	*0.75*
13. Rodds Bay	94	0.53	0.56	0.65	0.53	0.49	*0.10*	*0.19*
	96	0.72	1.00	0.65	0.69†			
	104	0.44	0.27	0.64	0.27			
Harbour score						**0.59**	***0.40***	***0.39***

† Where species composition is the lowest of the three indicators, it contributes 50% of the overall meadow score with the remaining 50% coming from the lowest score of either biomass or area scores

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 0.71 (B), an improvement from a poor condition in the previous year and the highest overall condition score since 2012. Improvement in the overall condition resulted from improvements in biomass as the overall score was an average of the biomass and species composition score. The species composition score was 0.67 (B) while area was 0.91 (A). This is the second consecutive year that area has increased—an approximately 40 ha expansion.

Zone 3 – Western Basin

Western Basin contains six monitored seagrass meadows, five of which are intertidal and one subtidal. The overall condition improved at this zone from 0.45 (D) in 2018 to 0.69 (B) in 2019. This result was largely driven by improvements in meadow area and species composition. However, there was also a considerable increase in biomass at all six meadows, all of which received very good scores. Individual meadows exhibited other marked improvements. Meadow 7, which was completely absent in 2018, re-established and was in a very good condition. Meadow 4 and Meadow 6 went from a poor condition in 2018 to a satisfactory condition. Meadow 52–57 received very good scores for all measures, with biomass and species composition receiving the highest possible score (1.00, A).

Zone 5 – Inner Harbour

Inner Harbour has one monitored meadow in the south-east corner of the zone near South Trees Inlet. In 2019 the overall meadow condition remained very poor 0.21 (D) a result of extremely low biomass (<10% of the baseline) for the fourth successive reporting year. Meadow area also continued to decline and received 0.57 (C). This is the first time since 2012 that area was less than 0.65 (B) and only a thin fragment the meadow's historical extent (~70 ha) remains. Species composition improved from very poor to satisfactory due to the reappearance of the previously dominant species *Z. muelleri* subsp. *capricorni*.

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 improved from poor to satisfactory (0.52, C). Meadow 43 and Meadow 48 showed poor (0.45, D) and satisfactory (0.60, C) overall conditions respectively. The primary driver for Pelican Banks was a poor biomass score of 0.45 (D). Although poor, biomass at this zone has shown incremental improvement since 2016. Area was good (0.75, B) and species composition was satisfactory (0.62, C). The overall satisfactory condition at Meadow 48 resulted from a combination of good area (0.76, B) and poor species composition (0.44, D). The higher prevalence of smaller, colonising species (*H. spinulosa* and *H. ovalis*) of seagrass has resulted in a satisfactory or lesser condition at Meadow 48 since 2013.

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 remains very good (0.89, A), having improved for the third consecutive year from a poor condition (0.48, D) in 2016. All three indicators were very good, with overall scores being determined by biomass. Area has remained above the baseline value (~6 ha) for the fifth consecutive year and the meadow was almost entirely made up of the dominant species *Z. muelleri* subsp. *capricorni* (93%) with the remaining fraction the less persistent species *H. uninervis*.

Zone 13 – Rodds Bay

There are three intertidal monitoring meadows in Rodds Bay—Meadows 94, 96 and 104. The overall condition of this zone improved from very poor (0.10, E) in 2018 to poor (0.49, D) in 2019. The marked change in the overall zone score at Rodds Bay resulted from cumulative improvements at the three monitored meadows. Species composition improved at two meadows. Area increased at Meadows 94, 96 and 104. Biomass also improved at all three meadows, most notably at Meadow 96 where biomass improved from very poor (0.23, E) to good (0.72, B). This is the first time since 2010 that a monitored meadow in Rodds Bay has been in a good condition (Meadow 96).

4.2.5. Seagrass conclusions

The overall condition of monitored seagrass meadows in Gladstone Harbour was satisfactory in the 2019 reporting year. This is the first time that the overall seagrass condition was better than poor since seagrass reporting began for GHHP in 2015. Likewise, overall scores increased in every monitoring zone. Most notably, The Narrows and Western Basin improved from a poor to a good condition and Rodds Bay (0.49, D) showed substantial recovery from the very poor conditions of the last three years.

Environmental conditions such as rainfall and Calliope River discharge are key influences on the seagrass meadow condition of Gladstone Harbour (McCormack et al., 2013). The preceding year (2018) was characterized by dry, benign weather conditions with minimal Calliope River discharge and very low rainfall (Figures 9.4 to 9.7). Seagrass condition improved in both the Gladstone Harbour zones and Rodds Bay—located 50 km southeast of Western Basin—suggesting that environmental conditions and not anthropogenic factors had the greatest influence on changes in seagrass communities. Improvements in seagrass meadow condition scores also occurred in Cairns, Townsville and Hay's Point deepwater meadow following the favourable conditions of 2018 (e.g. Bryant et al., 2019; Rasheed et al., 2019; York & Rasheed, 2019 cited in Carter et al., 2019). Other weather-related cycles in seagrass decline and recovery have occurred since 2002 (Table 4.10). In 2010 and 2011, there were significant declines in seagrass during and immediately following years of above-average rainfall and flow from the Calliope River. Years such as this, with mostly poor and very poor meadow scores, occurred in both Gladstone Harbour zones and Rodds Bay. Extensive declines were also evident in seagrass communities spanning from Cairns to Abbot Point following higher-than-average rainfall between 2009 and 2011 (e.g. Reason & Rasheed, 2018a; Reason & Rasheed, 2018b; Bryant & Rasheed, 2018; Davey & Rasheed, 2018 cited in Carter et al., 2019). Findings within Gladstone Harbour and across Queensland's eastern coast further indicate that lower than average rainfall and river discharge provided ideal conditions for seagrass recovery in the 2019 reporting year.

Despite condition improvements in the majority of seagrass meadows, species composition was the lowest indicator score in half of the monitored meadows. In four of these cases the overall meadow score was poor or satisfactory despite having good to very good biomass and area. The continued dominance of less persistent *Halophila* species is hindering the full recovery of these meadows. Favourable conditions in the 2019 reporting year did, however, result in slight increases in the contribution of *Z. muelleri* subsp. *capricorni* to overall biomass. If dry and benign weather conditions continue, larger more persistent seagrass species should continue to have a greater contribution to the overall meadow biomass.

Although widespread seagrass recovery can take up to five years (Preen et al., 1995), recovery can be rapid if favourable conditions for seagrass growth prevail (Rasheed, 1999). Gladstone Harbour and Rodds Bay seagrass meadows are currently recovering following several years of poor condition (Figure 4.4). Under ideal weather conditions in the 2019 reporting year, all three seagrass sub-indicators generally improved within each of the 14 monitored meadows. However, the higher prevalence of *Halophila* species in meadows that were historically dominated by *Z. muelleri* subsp. *capricorni* indicates these meadows may have reduced resilience to future impacts. Nevertheless, the positive improvement in all six monitoring zones provides a strong foundation for seagrass recovery in the Gladstone area if favourable environmental conditions continue.

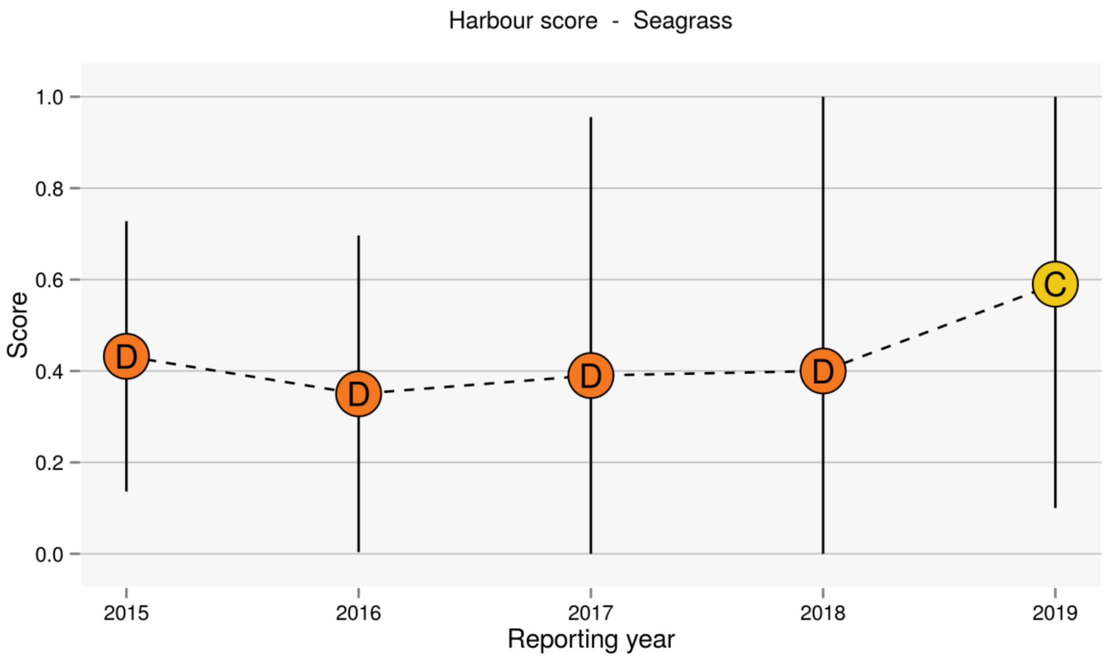


Figure 4.4: Trends in the harbour score for seagrass, 2015–2019.

Table 4.10: Grades for individual seagrass monitoring meadows from annual (November) surveys, 2002–2018 (Source: Carter et al., 2019).

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

4.2.6. Corals

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

Reefs within the GHHP monitoring zones include fringing, platform, headland and rubble fields with both hard and soft corals (BMT WBM, 2013). Within the Gladstone Harbour area, reefs have been recorded in the intertidal zones that have suitable substrata and sufficient light penetration around Turtle, Quoin, Rat, Facing and Curtis islands and at Seal Rocks. Coral communities have also been recorded within deeper channels (>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 both natural and anthropogenic pressures that can operate at global (e.g. climate change, El Niño Southern Oscillation), regional or local scales. These pressures include negative effects from large-scale flooding, sedimentation, urban pollution and agricultural run-off. Coral reef communities within Gladstone Harbour can be exposed to freshwater run-off, elevated turbidity and nutrient levels, and can be vulnerable to the negative impacts of sediments and increases in macroalgal cover (DHI, 2013).

Four sub-indicators of coral health were measured to calculate the coral score for the 2019 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.

4.2.7. 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 3.16 and 3.22).

Coral monitoring

Coral monitoring was conducted between 28 and 29 April 2019 and included the following three methodologies:

1. Photo point intercept transects

The methodology outlined below closely follows that outlined in the AIMS Long-term Monitoring Program (Jonker et al., 2008). At each 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.

4.2.8. 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 4.11 and Figure 4.5). The lowest score of 0.00 was set to represent the worst condition that could be expected in the local environment (Table 4.11 and Figure 4.5). 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 4.11). 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 4.7 of that report indicates soft coral cover in the middle harbour ranged between ~4% and 40%.

However, it should be noted that while the thresholds and bounds were originally selected to be consistent with MMP reporting 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 C/D threshold for coral communities in Gladstone Harbour (Table 4.11).

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 4.11).

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 4.11: 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.

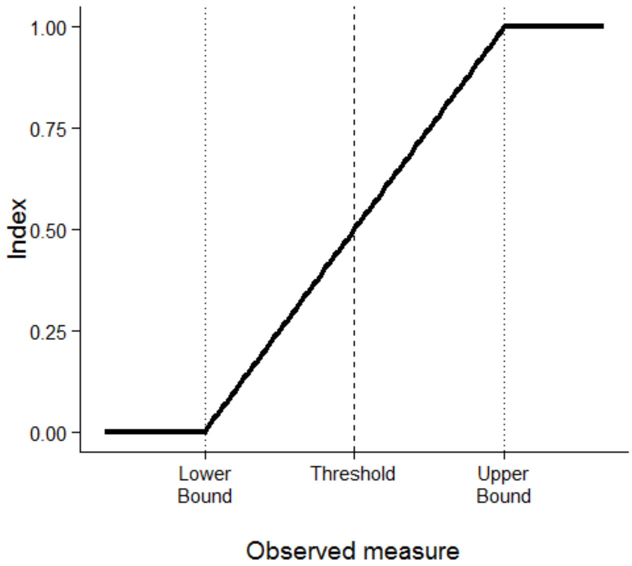


Figure 4.5: Generic scoring of the coral sub-indicators based on the threshold and bounds outlined in Table 4.11.

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.

4.2.9. Coral results

The overall score for the 2019 report card was 0.18 (E)—a continued decline since the 2017 score of 0.28 (D). 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 at most of the surveyed reefs. Coral cover (0.08, E) received a similar score to 2018 while juvenile density (0.23, E) and macroalgae cover (0.01, E) declined. The overall score for change in hard coral cover remained poor (0.41, D), however, this was an increase compared to the previous year. Both the Mid Harbour and the Outer Harbour demonstrated very poor coral condition and received scores of 0.19 and 0.18 (E) respectively (Table 4.12).

Coral cover (%) was very low at all reefs and substantially lower than the 40% threshold required to receive a C (Table 4.13). All six monitored reefs had very poor scores for the fifth consecutive year (Table 4.14). The present cover 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).

The mean cover of macroalgae demonstrated a sharp increase at all reefs in 2019, resulting in an overall very poor score (0.02, E) for the fifth consecutive year (Table 4.14). Rat Island (0.09, E) was the only reef that scored above 0.00, with macroalgal cover ranging from ~19% to ~77% across the six reefs (Table 4.13). Three reefs—Facing Island, Rat Island and Seal Rocks South—continued along the downward trend for macroalgal cover while the other three reefs declined despite the improving condition exhibited in the preceding years. Macroalgae communities in the Outer Harbour continue to be dominated by the brown macroalgae, *Sargassum* and *Lobophora*. Species composition in the Mid Harbour has been more variable, with Rat Island and Farmers Reef dominated by the red macroalgae *Asparagopsis*. Macroalgal communities at Facing Island and Manning Reef were composed predominantly of brown macroalgae.

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. For the first time since monitoring began in 2015, juvenile density was in a very poor condition (0.23, E) at the harbour level (Table 4.12). Scores for juvenile coral density ranged from very poor at Facing Island (0.16, E) to poor at Farmers Reef and Rat Island (0.31, D). Compared to 2018, juvenile density scores declined at four reefs, showed no change at Facing Island and slightly increased at Rat Island.

The overall change in hard coral cover score remained poor (0.41, D), however, it showed some improvement compared to the overall score in 2018 (0.32, D). This was largely driven by Facing Island and Rat Island, which showed substantial improvement and received good (0.67, B) and satisfactory (0.59, C) scores respectively (Table 4.13). Change in hard coral cover remained poor at Manning Reef and both Outer Harbour reefs. Only Farmers Reef showed a substantial decline from 2018—from a satisfactory score (0.53, C) to a very poor score (0.13, E) (Table 4.14).

Table 4.12: Coral sub-indicator scores for the Mid Harbour and Outer Harbour and overall zone and harbour scores (Costello et al., 2019).

Zone	Coral cover	Macroalgal cover	Juvenile density	Change in hard coral cover	Overall score
8. Mid Harbour	0.09	0.02	0.24	0.42	0.19
11. Outer Harbour	0.07	0.00	0.22	0.40	0.17
Harbour score	**0.08**	**0.01**	**0.23**	**0.41**	**0.18**

Table 4.13: Individual coral sub-indicator values and scores by reef (Costello et al., 2019).

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	13.50	0.17	40.50	0.00	1.48	0.16	4.84	0.67
Farmers Reef	3.50	0.04	27.13	0.00	2.83	0.31	0.38	0.13
Manning Reef	0.63	0.01	64.25	0.00	1.55	0.17	0.51	0.29
Rat Island	10.88	0.14	18.88	0.09	2.81	0.31	3.82	0.59
11. Outer Harbour								
Seal Rocks North	1.00	0.01	76.70	0.00	1.73	0.19	0.38	0.46
Seal Rocks South	10.88	0.14	58.75	0.00	2.40	0.26	4.07	0.33

4.2.10. Coral conclusions

The overall score for corals remained very poor (0.18, E) in 2019 (Figure 4.6; Table 4.12). Although coral cover and change in hard coral cover scores were broadly consistent with previous years, juvenile density and macroalgal cover scores decreased considerably compared to 2018 (Table 4.14).

Initial 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.

Although coral cover has remained low since monitoring began in 2015, it is the recovery potential of these reefs that best describes overall condition (Costello et al., 2019). Results strongly suggest a continued shift from coral to macroalgal dominance within Gladstone Harbour. The persistent high cover of macroalgae may be affecting coral recruitment processes by occupying available space for juvenile settlement. Change in hard coral cover is also likely to be influenced by coral-macroalgae interactions as genera such as *Lobophora* have direct negative impacts on living corals (e.g. Lirman, 2001; Vega Thurber et al., 2012 cited in Costello et al., 2019). While Rat Island and Facing Island showed substantial improvement in the change in hard coral cover sub-indicator in 2019, the overall poor condition indicates this sub-indicator continues to fall short of modelled expectations. The widespread presence of the bio-eroding sponge *Cliona orientalis* continues to be the most significant contributor to coral mortality within the harbour (Table 4.15) and is also contributing to the poor score for the change in hard coral cover sub-indicator. Scores for macroalgal cover, juvenile density and change in hard coral cover highlight the limited recovery potential of corals in Gladstone Harbour.

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. Reefs monitored by GHHP were most similar to severely impacted reefs, such as Peak and Pelican islands (Keppel Bay) and Daydream and Double Cone islands (the Whitsundays). Keppel Bay inshore reefs were most impacted by the 2011 flood while those in the Whitsundays were impacted by TC Debbie in 2017. These coral communities, along with those in Gladstone Harbour, shared characteristics such as low coral cover, high macroalgae cover or a combination of the two (Costello et al., 2019).

Corals in Gladstone Harbour were in very poor condition and demonstrated limited recovery potential in 2019. As such recovery will be largely dependent on connectivity with populations of living corals beyond the harbour. While recent surveys in the harbour revealed some promising signs—juvenile diversity was greater than the living adult genera within the harbour—settlement and growth rates of coral larva are likely to be low if the high macroalgal cover and its associated negative pressures persist.

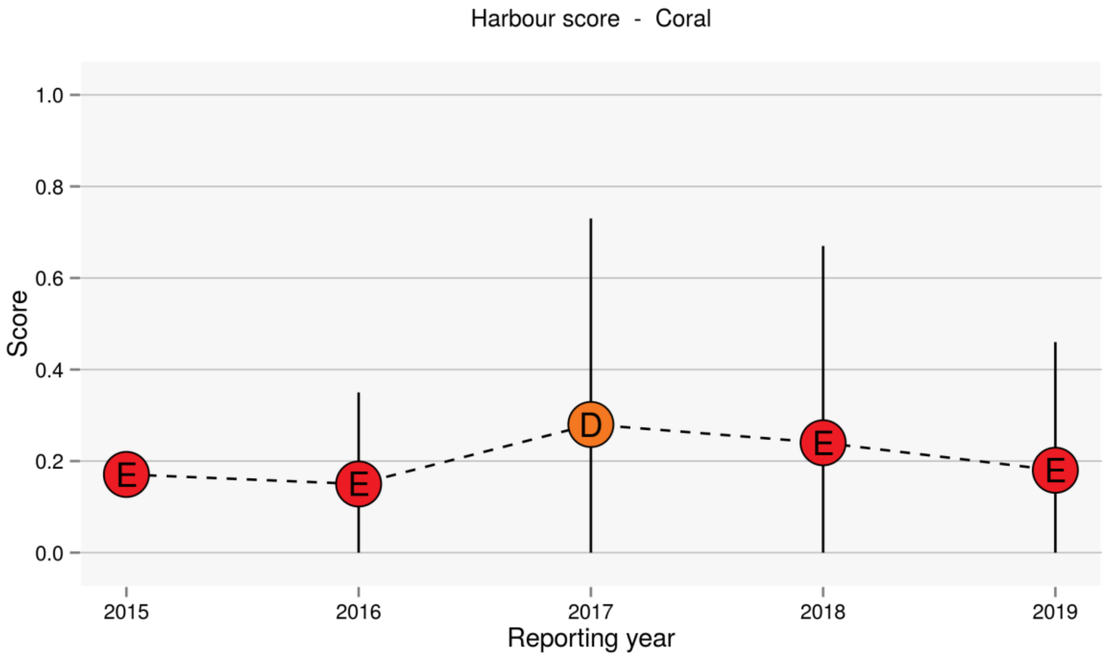


Figure 4.6: Trends in the harbour score for coral, 2015–2019.

Table 4.14: A comparison of coral sub-indicator scores for the Mid Harbour and Outer Harbour for surveys conducted from 2015 to 2019 (Costello et al., 2019).

Zone	Reef	Year	Scores				Reef Score
			Coral cover	Juvenile density	Macroalgal cover	Change in hard coral cover	
8. Mid Harbour	Facing Island	2015	*0.16*	*0.41*	*0.00*		*0.19*
		2016	*0.08*	*0.46*	*0.00*		*0.18*
		2017	*0.12*	*0.25*	*0.00*	*0.50*	*0.22*
		2018	*0.11*	*0.16*	*0.46*	*0.33*	*0.27*
		2019	0.17	0.16	0.00	0.67	0.25
	Farmers Reef	2015	*0.06*	*0.26*	*1.00*		*0.44*
		2016	*0.09*	*0.39*	*0.00*		*0.16*
		2017	*0.09*	*0.53*	*0.95*	*0.50*	*0.52*
		2018	*0.04*	*0.53*	*0.17*	*0.33*	*0.27*
		2019	0.04	0.31	0.00	0.13	0.12
	Manning Reef	2015	*0.00*	*0.12*	*0.00*		*0.04*
		2016	*0.00*	*0.33*	*0.00*		*0.11*
		2017	*0.01*	*0.22*	*0.00*	*0.51*	*0.18*
		2018	*0.00*	*0.40*	*0.00*	*0.27*	*0.17*
		2019	0.01	0.17	0.00	0.29	0.12
	Rat Island	2015	*0.08*	*0.11*	*0.50*		*0.23*
		2016	*0.07*	*0.46*	*0.29*		*0.27*
		2017	*0.08*	*0.31*	*1.00*	*0.24*	*0.41*
		2018	*0.09*	*0.28*	*1.00*	*0.26*	*0.41*
		2019	0.14	0.31	0.09	0.59	0.28
11. Outer Harbour	Seal Rocks North	2015	*0.00*	*0.42*	*0.00*		*0.14*
		2016	*0.00*	*0.47*	*0.00*		*0.16*
		2017	*0.01*	*0.36*	*0.00*	*0.25*	*0.15*
		2018	*0.01*	*0.42*	*0.00*	*0.34*	*0.19*
		2019	0.01	0.19	0.00	0.46	0.17
	Seal Rocks South	2015	*0.10*	*0.25*	*0.00*		*0.12*
		2016	*0.17*	*0.32*	*0.00*		*0.16*
		2017	*0.12*	*0.51*	*0.00*	*0.50*	*0.28*
		2018	*0.09*	*0.48*	*0.00*	*0.33*	*0.22*
		2019	0.14	0.26	0.00	0.33	0.18

Note: Juvenile density sub-indicator scores are based on the current methodology (established in 2018) and have been back calculated to previous years to allow comparison. Reef scores for previous years have also been adjusted accordingly.

Table 4.15: Causes of coral mortality at time of survey. Survey area of 200 m^2 at each reef. Data from 2018 included for comparison. No data are included for Manning Reef or Seal Rocks North as ongoing mortality was absent in 2019. Bio-eroding sponge is primarily *Cliona orientalis* (Costello et al., 2019).

Reef	Year	Damage	Genus	Colonies affected
Facing Island	2018	Bio-eroding sponge	*Cyphastrea*	1
			Porites	13
	2019	Bio-eroding sponge	*Porites*	17
Farmers Reef	2018	Bio-eroding sponge	*Cyphastrea*	12
			Plesiastrea	1
	2019	Unknown	*Cyphastrea*	5
			Turbinaria	1
Rat Island	2018	Bio-eroding sponge	*Cyphastrea*	6
			Turbinaria	5
	2019	Bio-eroding sponge	*Cyphastrea*	6
			Plesiastrea	2
			Turbinaria	2
Seal Rocks South	2018	Bio-eroding sponge	*Turbinaria*	5
		Atramentous necrosis (coral disease)	*Montipora*	1
	2019	Bleaching	*Pocillopora*	1
		Bio-eroding sponge	*Turbinaria*	8

4.2.11. Mangroves

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

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

4.2.12. Mangrove data collection

Mangrove assessment area

Unlike the other environmental indicators, which are aquatic, mangroves exist in tidal wetlands which are not covered in the 13 GHHP environmental reporting zones. To report on mangroves, the existing zones have been expanded to include the tidal wetland areas. As mangrove health can be influenced by the surrounding catchment area, the expanded zones are split where necessary to conform to the sub-catchment areas derived from the Queensland Government drainage sub-basin areas (Department of Natural Resources Mines and Energy, 2009). This results in the expanded zones being split into a total of 22 sub-zones (Table 4.16; Figure 4.7). For all mangrove indicators the zone score is calculated as the average of the sub-zone scores.

Table 4.16: GHHP environmental reporting zones and mangrove monitoring sub-zones.

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

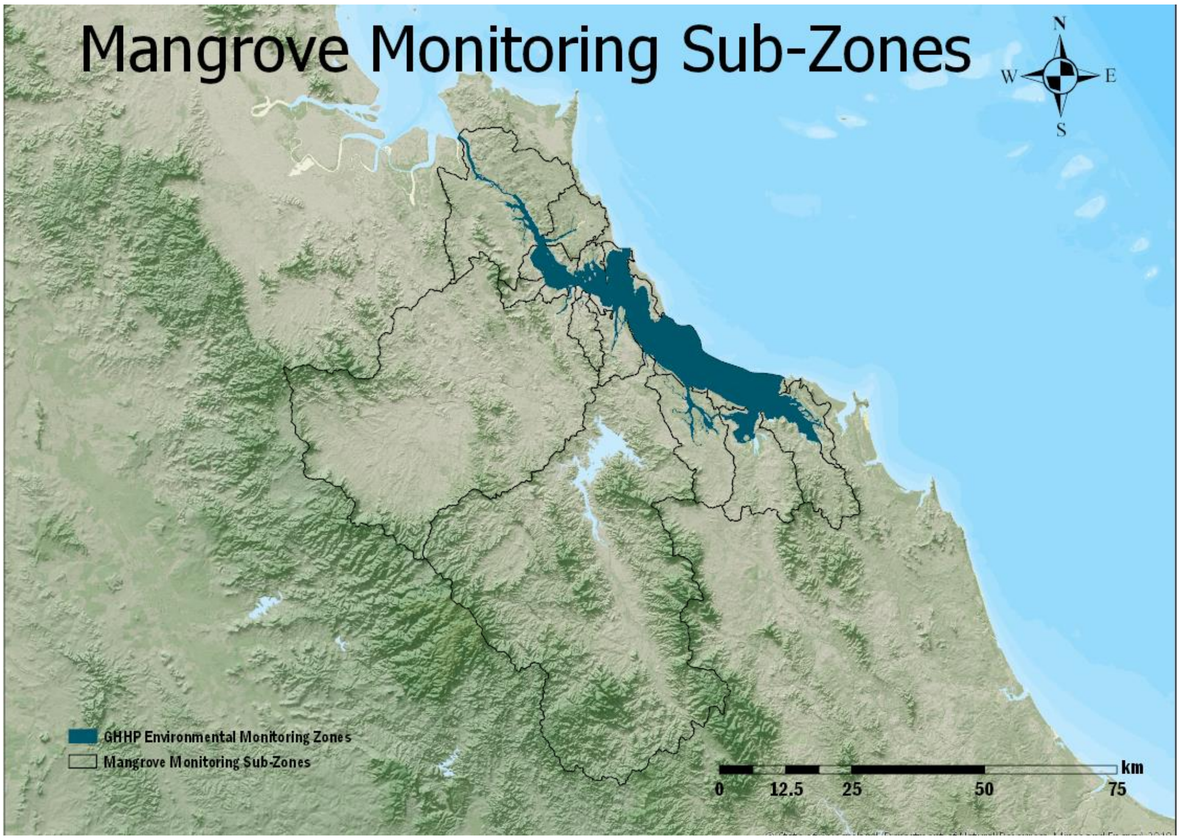


Figure 4.7: Mangrove sub-zones.

Mangrove data collection

All mangrove data used to derive the report card grades and scores for the three mangrove indicators was derived from either satellite imagery (extent and canopy) or aerial photography (shoreline) following the Shoreline Video Assessment Method (Mackenzie et al., 2016). Baselines for extent and canopy were derived from satellite imagery and no baseline was used for shoreline as the metric is derived statistically from the 2018–19 aerial imagery (Table 4.17).

Table 4.17: Mangrove indicators and data used to calculate the 2019 mangrove grades and scores.

Indicator	2019 data	Baseline data
Extent Change in the WCI from the 5 year mean and the year before	2018–19 satellite imagery (Landsat 8)	2013–14 to 2017–18 satellite imagery (Landsat 8)
Canopy Variation in NDVI from the 5 year mean and the year before	2018–19 satellite imagery (Landsat 8)	2013–14 to 2017–18 satellite imagery (Landsat 8)
Shoreline Percent live/dead tress each 50 m interval of mangrove shoreline	June 2019 helicopter filming of 22 sub-zones	No baseline, score calculated statistically (see Table 4.20)

Satellite imagery

To determine scores for the extent and canopy sub-indicators Landsat 8 images with a 30 m spatial resolution (Gladstone Harbour: path 91, row 76. Rodds Bay: path 91, row 7) for the 2013–14 to 2018–19 period were used. Masks and models created in a previous study were used (Duke et al., 2017) to analyse the satellite imagery.

Aerial photography

An aerial shoreline survey of shorelines bordering the 22 mangrove sub-zones was undertaken in June 2019. Either a Nikon D800E or D850 camera with a 50 mm lens was used to take overlapping high-resolution photographs of the shoreline. All images were taken from an open R44 helicopter flying perpendicular to the shoreline at an altitude of approximately 150 m.

4.2.13. Development of mangrove indicators and scoring

Mangrove extent

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

The raw WCI score is calculated as the relative proportion of mangrove within the tidal wetland area in each mangrove sub-zone (Table 4.18) determined from 2017 mapping.

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

To determine mangrove loss and gain, the 2018–19 NDVI classification (number of points that were mangrove or saltmarsh/saltpan) was compared to the 2013–14 maximum value for all points as follows.

Mangrove loss: NDVI 2013–14 ≥ $Mang_{MIN}$ and the 2018 SPOT classification = saltmarsh/saltpan or water.

Mangrove gain: NDVI 2013–14 < $Mang_{MIN}$ and the 2018 SPOT classification = Mangrove

Percent change represents the relative net change in mangrove area between 2013–14 and 2018–19, with the values adjusted to reflect tidal area loss owing to erosion.

The grading system for mangrove extent (Table 4.18) is based on the WCI score for 2018–19 and the observed change between 2013–14 and 2018–19.

Table 4.18: Mangrove extent scoring classification system.

	A Very good (0.85–1.00)	B Good (0.65–0.84)	C Satisfactory (0.50–0.64)	D Poor (0.25–0.49)	E Very poor (0.00–0.24)
Wetland Cover Index (WCI) 2017–18	WCI = 0.85– 1.00	WCI = 0.65–0.84	WCI = 0.50–0.64	WCI = 0.25–0.49	WCI = 0.00–0.24
Mangrove loss 2013–14 to 2017–18	0–1.5% Loss	1.6–3.5% Loss	3.6–5.0% Loss	5.1–7.5% Loss	>7.5% Loss
Wetland Cover Index nett mangrove extent change (gain & loss) 2013–14 to 2017–18	0–1.5% Deviation	1.6–3.5% Deviation	3.6–5.0% Deviation	5.1–7.5% Deviation	>7.5% Deviation

Canopy condition

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

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

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

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

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

Greenest pixel values (maximum NDVI value) were derived at each point of the point layer. For each point, a total of five greenest pixel values were derived for each year. A mangrove extent layer presented in Duke et al. (2017), which had high classification accuracy but high degrees of omission error, was used to derive a threshold of mangrove NDVI values. Based on the standard deviation of the mean mangrove NDVI values, it was determined that 0.3 was the minimum mangrove NDVI value for the GHHP region. A maximum value for NDVI 0.75 was determined and this range was used to derive the report card grades range (Table 4.19).

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

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

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

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

Table 4.19: Classification of canopy condition scores derived from NDVI values 2013–14 to 2017–18.

	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)
Mean NDVI 2017–18	0.81–0.73	0.72–0.63	0.62–0.55	0.54–43	0.42–0.30
Mean NDVI change 2016–17 to 2017–18	Mean inter-annual NDVI difference significantly ($p<0.05$) greater than regional mean and effect size (Cohen's d) > 0.70	Mean inter-annual NDVI difference significantly ($p<0.05$) greater than regional mean and effect size (Cohen's d) 0.69 to 0.30	Mean inter-annual NDVI difference not significantly ($p>0.05$) different from regional mean. OR Mean inter-annual NDVI difference significantly ($p<0.05$) greater than regional mean and effect size (Cohen's d) 0.29 to 0.0	Mean inter-annual NDVI difference significantly ($p<0.05$) less than regional mean and effect size (Cohen's d) –0.01 to –0.50	Mean inter-annual NDVI difference significantly ($p<0.05$) less than regional mean and effect size (Cohen's d) –0.51 to –1.0
Mean 5-year NDVI change 2013–14 to 2017–18					

Shoreline condition

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

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

The oblique aerial image assessment provided a representation of the proportion of shoreline fringe mangrove forest with dead mangroves present within each of the GHHP water quality zones. A chi-square goodness-of-fit analysis with unequal proportions was conducted on dead mangrove frequency using SPSS v.24 to test the hypothesis that the frequency of observations of shoreline mangrove with dead individuals in each mangrove sub-zone was the same as the expected frequency for the overall study area. Where the observed frequency of fringing mangroves with dead mangrove individuals present in the target zone (O) was significantly higher or lower than the expected overall frequency (E), Cramér's V (SQRT(X2/n) was calculated as a measure of effect size. The effect size based on the value of Cramér's V was classified following Cohen (1988), where scores less than 0.5 represent low to moderate effect size and scores greater than or equal to 0.5 represent a large effect size. Scores were assigned based on the results of the chi-square analysis and the resulting Cramér's V following Table 4.20.

Table 4.20: Classification of shoreline condition scores.

	A Very good (0.85–1.00)	B Good (0.65–0.84)	C Satisfactory (0.50–0.64)	D Poor (0.25–0.49)	E Very poor (0.00–0.24)
Shoreline condition score (Dead mangrove frequency)	0–7.5%	7.6–17.5%	17.6–25%	25.1–37.5%	>37.5%
Seasonally adjusted Shoreline condition score (Relative dead mangrove frequency)	Observed dead mangrove frequency significantly greater than expected harbour value ($p<0.05$), Cramér's V 1.0 to 0.7	Observed dead mangrove frequency significantly greater than expected harbour value ($p<0.05$), Cramér's V 0.69 to 0.30	Observed dead mangrove frequency not significantly different from expected harbour value ($p<0.05$) OR Observed dead mangrove frequency significantly greater than expected harbour value ($p<0.05$), Cramér's V 0.29 to 0.0	Observed dead mangrove frequency significantly less than expected harbour value ($p<0.05$), Cramér's V < 0.30 to 0.69	Observed dead mangrove frequency significantly less than expected harbour value ($p<0.05$), Cramér's V 0.7 to 1.0

4.2.14. Mangrove results

The overall score for mangroves in Gladstone Harbour was 0.57 (C). Three zones were considered to be in good condition and eight zones were considered satisfactory (Table 4.21). 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 4.21: Overall mangrove zone and harbour scores for the 2019 reporting year.

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***

Mangrove extent

This indicator is derived from estimates to changes to mangrove canopy cover between 2013–14 and 2018–19 relative to saltmarsh and saltpan within tidal wetlands. Mangrove extent scores indicate a net gain or loss in mangrove area relative to saltmarsh and salt pan within the sub-zone. Colosseum Inlet (0.85, A) had a very good score, eight zones had good scores and two zones had satisfactory scores. Only two zones, Mid Harbour (0.39, D) and Boyne Estuary (0.39, D), had poor scores indicating a nett loss of mangrove area, compared to the previous year and the five-year baseline (Table 4.22).

Table 4.22: Wetland cover index, change scores and overall zone scores for mangrove extent.

Zone	Mangrove sub-zone	WCI 2018–19	WCI change score	Mangrove loss score	Sub-zone score	Zone extent score
1. The Narrows	1a. Mainland	0.60	0.96	0.86	0.81	0.79
	1b. Curtis Island	0.60	0.82	0.88	0.77	
2. Graham Creek	2. Graham Creek	0.75	0.83	0.90	0.83	0.83
3. Western Basin	3a. Mainland	0.44	0.95	0.76	0.72	0.76
	3b. Curtis Island	0.64	0.82	0.94	0.80	
4. Boat Creek	4. Boat Creek	0.40	0.68	0.55	0.54	0.54
5. Inner Harbour	5a. Enfield Creek	0.54	0.75	0.94	0.74	0.62
	5b. Barney Point	0.25	0.46	0.75	0.49	
6. Calliope Estuary	6. Calliope Estuary	0.82	0.86	0.71	0.80	0.80
7. Auckland Inlet	7. Auckland Inlet	0.63	0.94	0.70	0.76	0.76
8. Mid Harbour	8a. Curtis Island	0.30	0.63	0.88	0.60	0.39
	8b. Facing Island	0.27	0.30	0.00	0.18	
9. South Trees Inlet	9. South Trees Inlet	0.59	0.97	0.80	0.79	0.76
10. Boyne Estuary	10. Boyne Estuary	0.68	0.35	0.15	0.39	0.39
11. Outer Harbour	11a. Wild Cattle Creek	0.93	0.90	0.92	0.92	0.76
	11b. Split End	0.50	0.76	0.52	0.59	
12. Colosseum Inlet	12a Colosseum Creek	0.70	0.99	0.84	0.84	0.85
	12b. Hummock Hill	0.71	0.95	0.88	0.85	
13. Rodds Bay	13a. East	0.73	0.92	0.78	0.81	0.68
	13b. West	0.66	0.74	0.58	0.66	
	13c. Pancake Creek	0.61	0.84	0.66	0.70	
	13d. Hummock Hill	0.46	0.67	0.46	0.53	
Harbour score						**0.69**

Canopy condition

This indicator was calculated from estimates for the NDVI value of mangrove forest canopies within the 13 environmental reporting zones. The overall score for canopy condition was 0.49 (D). One zone Colosseum Inlet received a good score (0.67, B), Boyne Estuary (0.19, E) received a very poor score, four zones (Graham Creek, Western Basin, Boat Creek, Calliope Estuary) received poor sores and the remaining seven zones received satisfactory scores. (Table 4.23).

Table 4.23: Canopy condition, NDVI scores, one and five-year change and overall scores for canopy condition.

Zone	Mangrove sub-zone	2019 NDVI score	1-year change	5-year change	Sub-zone score	Zone score
1. The Narrows	1a. Mainland	0.63	0.61	0.34	0.53	0.55
	1b. Curtis Island	0.60	0.77	0.31	0.56	
2. Graham Creek	2. Graham Creek	0.65	0.25	0.11	0.34	0.34
3. Western Basin	3a. Mainland	0.70	0.32	0.15	0.35	0.39
	3b. Curtis Island	0.72	0.41	0.26	0.43	
4. Boat Creek	4. Boat Creek	0.66	0.61	0.09	0.38	0.38
5. Inner Harbour	5a. Enfield Creek	0.70	0.21	0.70	0.67	0.51
	5b. Barney Point	0.53	0.34	0.33	0.35	
6. Calliope Estuary	6. Calliope Estuary	0.67	0.29	0.43	0.48	0.48
7. Auckland Inlet	7. Auckland Inlet	0.57	0.41	0.86	0.57	0.57
8. Mid Harbour	8a. Curtis Island	0.61	0.57	0.78	0.60	0.63
	8b. Facing Island	0.64	0.36	0.75	0.65	
9. South Trees Inlet	9. South Trees Inlet	0.66	0.00	0.47	0.50	0.50
10. Boyne Estuary	10. Boyne Estuary	0.56	0.55	0.00	0.19	0.19
11. Outer Harbour	11a. Wild Cattle Creek	0.60	0.48	0.58	0.55	0.64
	11b. Split End	0.63	0.62	0.91	0.73	
12. Colosseum Inlet	12a Colosseum Creek	0.68	0.55	0.70	0.65	0.67
	12b. Hummock Hill	0.71	0.66	0.70	0.69	
13. Rodds Bay	13a. East	0.74	0.46	0.59	0.59	0.57
	13b. West	0.67	0.26	0.56	0.50	
	13c. Pancake Creek	0.68	0.43	0.66	0.59	
	13d. Hummock Hill	0.63	0.43	0.71	0.59	
Harbour score						**0.49**

Shoreline condition

Across the 13 environmental reporting zones approximately 8,000 shoreline points were assessed for the presence of dead mangroves. Mangroves were identified at about 90% of these points and the overall proportion of shoreline with dead mangroves present was approximately 15%. Boyne Estuary had the highest proportion of dead mangroves (~40%) and had a report card score of 0.19 (D). This was the only zone with a very poor score, three zones Western Basin (0.37, D), Boat Creek (0.46, D) and Calliope Estuary (0.47, D) had poor scores. All remaining zones had scores of satisfactory or above with three zones, Grahams Creek (0.76, B), Rodds Bay (0.67, B) and Colosseum Inlet (0.65, B) receiving good scores (Table 4.24).

Table 4.24: Estimates of shoreline condition for harbour environmental monitoring zones and sub-zones.

Zone	Mangrove sub-zone	Dead mangrove frequency score	Seasonally adjusted dead mangrove frequency score	Sub-zone shoreline condition score	Zone shoreline condition score
1. The Narrows	1a. Mainland	0.57	0.45	0.51	0.60
	1b. Curtis Island	0.81	0.59	0.70	
2. Graham Creek	2. Graham Creek	0.88	0.64	0.76	0.76
3. Western Basin	3a. Mainland	0.36	0.32	0.34	0.37
	3b. Curtis Island	0.43	0.37	0.40	
4. Boat Creek	4. Boat Creek	0.50	0.41	0.46	0.46
5. Inner Harbour	5a. Enfield Creek	0.72	0.54	0.63	0.53
	5b. Barney Point	0.45	0.38	0.42	
6. Calliope Estuary	6. Calliope Estuary	0.52	0.43	0.47	0.47
7. Auckland Inlet	7. Auckland Inlet	0.70	0.53	0.62	0.62
8. Mid Harbour	8a. Curtis Island	0.85	0.62	0.73	0.63
	8b. Facing Island	0.59	0.46	0.52	
9. South Trees Inlet	9. South Trees Inlet	0.57	0.45	0.51	0.51
10. Boyne Estuary	10. Boyne Estuary	0.16	0.21	0.19	0.19
11. Outer Harbour	11a. Wild Cattle Creek	0.60	0.56	0.54	0.58
	11b. Split End	0.71	0.47	0.63	
12. Colosseum Inlet	12a Colosseum Creek	0.72	0.54	0.63	0.64
	12b. Hummock Hill	0.76	0.56	0.66	
13. Rodds Bay	13a. East	0.74	0.56	0.65	0.67
	13b. West	0.78	0.58	0.68	
	13c. Pancake Creek	0.74	0.55	0.65	
	13d. Hummock Hill	0.80	0.59	0.70	
Harbour score					**0.54**

4.2.15. Mangrove conclusions

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

The overall score for mangroves in 2019, 0.57 (C) was similar to that observed in 2018, 0.60 (C). The zones with the highest overall scores were Colosseum Inlet (0.72, B), Outer Harbour (0.66, B), The Narrows (0.65, B) and Auckland Inlet (0.65, B) all of which were in good condition. The condition of mangroves at Auckland Inlet is likely to have been improved by higher levels of nutrients that occur in urbane estuarine waters (Figure 4.8). However, it is important to note that these areas are being measured from a 2013–14 baseline and considerable clearing and other habitat modification has occurred in these areas in the past (Duke et al., 2003).

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

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

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

Two zones Boat Creek (0.46, D), and Boyne Estuary (0.26, D) received poor scores. Both zones received low scores for canopy condition which have declined from the previous year (Table 4.22). The decline in canopy condition may be a result of the low levels of rainfall that occurred in Gladstone over the course of the reporting year. The Boyne Estuary also contained areas of dieback indicative of flood and erosion damage, which was first observed in the 2018 surveys, that resulted in a very poor score for shoreline condition (Table 4.22). The slow recovery of mangroves in this area may have been exacerbated by access tracks, clearing and cutting of dead vegetation which is preventing and inhibiting seedling recruitment and re-establishment.

The remaining eight zones all had a satisfactory overall condition (Table 4.21) however Graham Creek, Western Basin, and Calliope Estuary all received poor scores for mangrove canopy condition. While this decline may be indicative of the low rainfall that occurred over the reporting year, dieback and damage to mangrove trees along the estuarine margins (shoreline condition) was also observed (Figure 4.10).

Figure 4.10: Shoreline erosion affecting mangrove shoreline condition at the northern edge of The Narrows and at the mouth of South Trees Inlet.

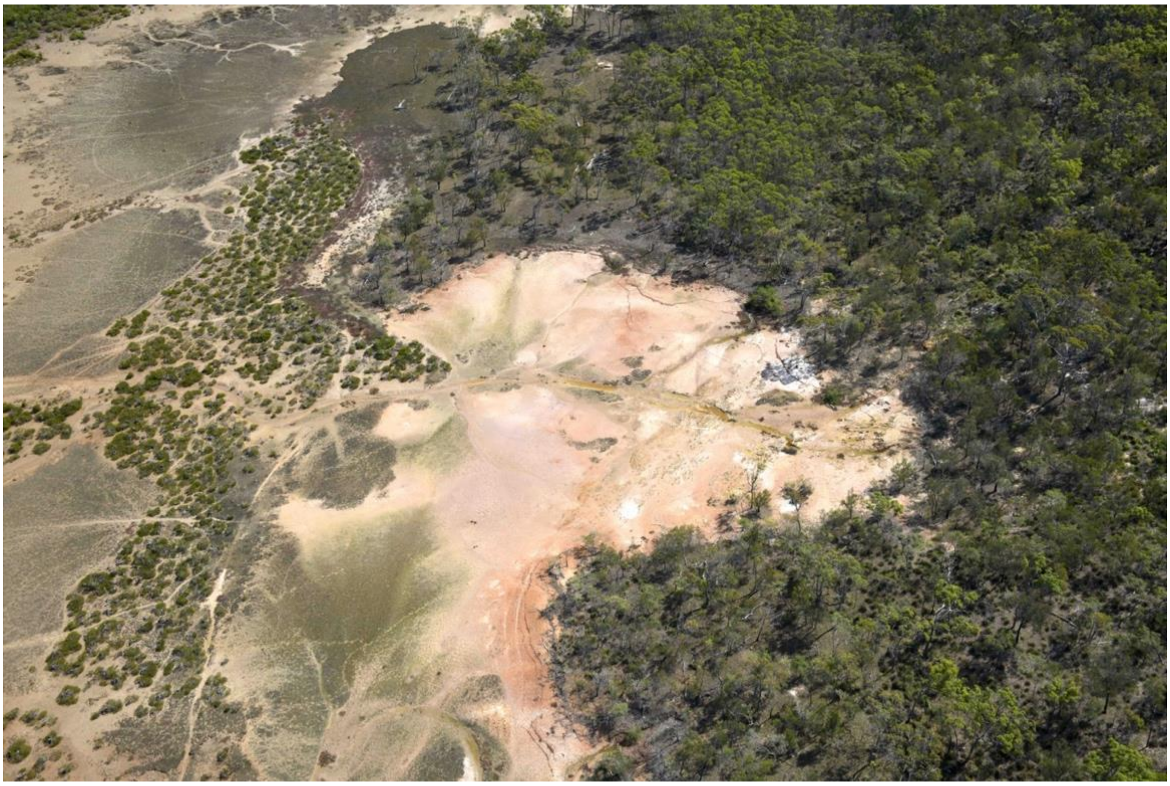


Figure 4.11: Terrestrial retreat, scouring and saline intrusion observed in the northern mainland section of The Narrows (Zone 1a).

Indicators of terrestrial retreat and scouring were evident throughout the GHHP environmental monitoring zones. Figure 4.11 shows scouring and erosion of upland marginal vegetation accompanied by saline intrusion in the northern mainland section of The Narrows (Zone 1a).

4.3. Fish and crabs

4.3.1 Fish health

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.

Figure 4.12: Pikey bream caught during Gladstone Harbour fish monitoring 2018 (CQU photo).

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.

In 2019 fish health was assessed by two separate fish monitoring projects:

1. Visual Fish Condition (Automated visual assessment using mobile phones)
2. Health Assessment Index (Gross pathological analysis)

Relying on a citizen science approach for data collection the Visual Fish Condition (VFC) provides a less detailed assessment of fish health when compared to the Health Assessment Index (HAI). However, this approach incurs significantly lower costs and by using data collected during fishing competitions like the Boyne Tanum Hook-up 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 VFC scores are based on two separate metrics, the first is an external assessment of fish health the Fish Visual Assessment. This includes skin, eyes, fins parasites and deformities. The second metric is a body condition 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.

4.3.2 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 that while these species would generally be restricted to the harbour, the recorded movements were still larger than the spatial scale of the 13 environmental monitoring zone. 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.

Visual 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 benthic feeders such as sea mullet 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 the Fish Visual Assessment was collected using the Track My Fish App (Figure 4.13). 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 recorded for fish caught at the Boyne Tanum Hook-up
- Weight of fish (g) caught at the Boyne Tanum Hook-up

Data was collected over the course of the 2018–19 reporting year (01/07/2018–30/06/2019) 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 by members of the Gladstone Sports Fishing Club during normal fishing trips
- Data collected by the general public when reporting the recapture of tagged fish
- Data collected at the live weigh-in section of the Boyne Tanum Hook-up (3–5 May 2019)
- Data collected by Infofish in monitoring zones where the minimum of 25 samples was not achieved by the methods outlined above.

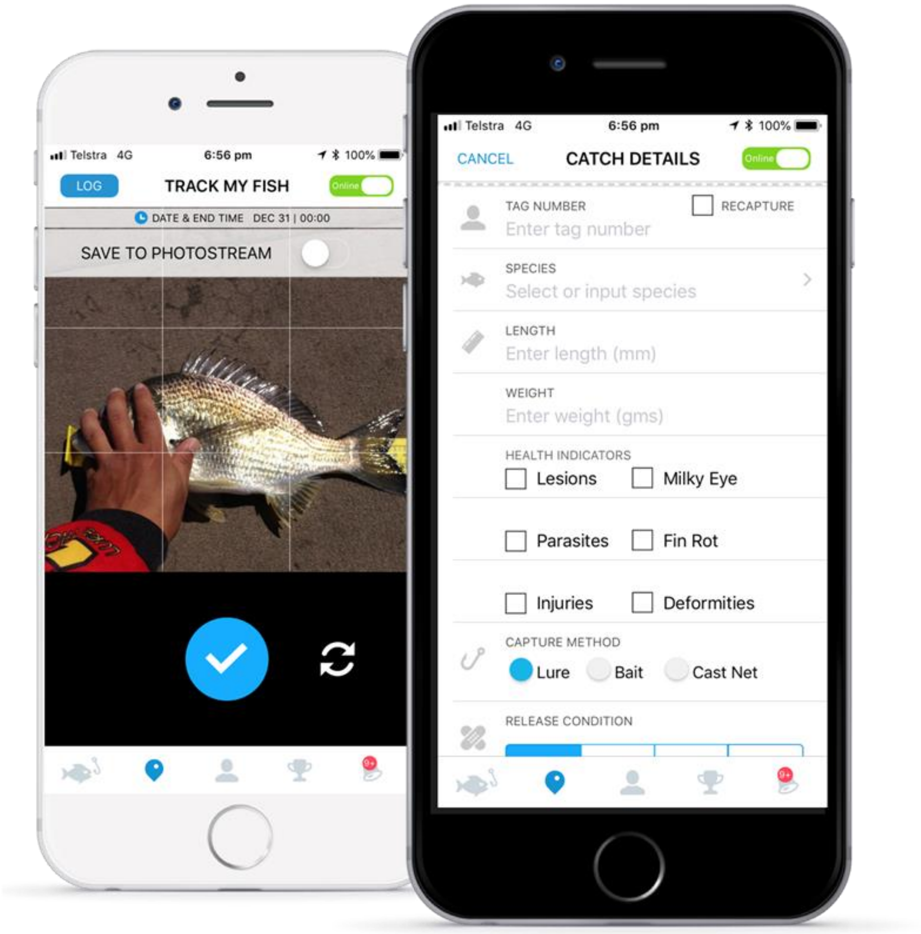


Figure 4.13: Data for the Visual Fish Condition Index was collected by fishers using the Trackmyfish app.

Over the course of the study period, 1 July 2018 to 30 June 2019 a total of 840 images were captured using the Trackmyfish app. This included 419 images from the Boyne Tanum Hook-up, 317 from the Gladstone Sports Fishing Club, 79 from Infofish Australia and 25 from recaptures reported by the fishing public. The total number of images for each target species is presented in Figure 4.14. While a small number of images were collected in all months the majority of images were collected in May, involving 434 in total with 419 of these images being from the Boyne Tanum Hook-up fishing competition. Human and machine Fish Visual assessments were made for each condition with close to 100% agreement between the two.

Data for Fish Body Condition was collected from the live weigh in section of the Boyne Tanum Hook-up where weight and overall length was recorded (n = 482). No length weight data was collected for barramundi and while the Fish Visual Assessment results are presented for this species an overall Visual Fish Condition score is not provided and the barramundi results do not contribute to the overall score for Visual Fish Condition.

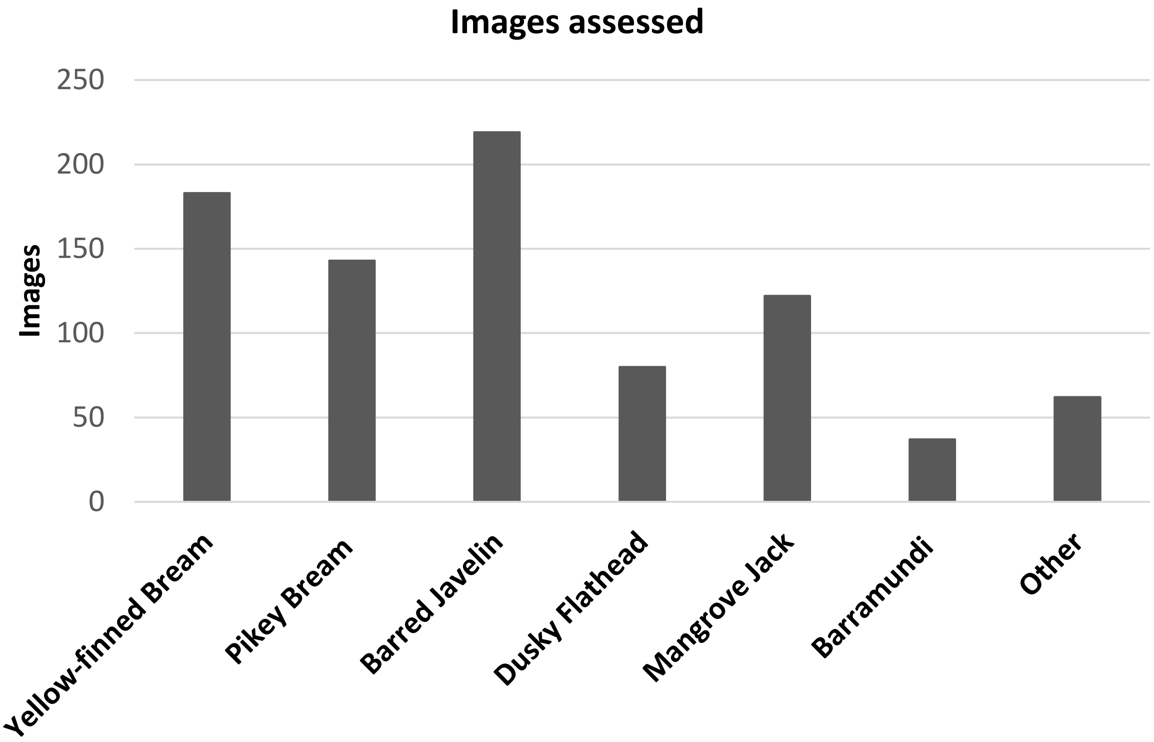


Figure 4.14: Number of images of each of the 5 target species captured using the Trackmyfish App over the 2019 reporting year.

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 / species groups 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.

Sampling was conducted during the 2018-19 reporting year in Gladstone Harbour in Spring 2018 and Autumn 2019 and at a reference site at Stanage Bay in Spring 2018. 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 fish were released alive and target species were euthanised for laboratory analysis and gill arch samples were collected and fixed in 10% formalin. All euthanised fish were individually bagged in an ice slurry and returned to the laboratory on the same day.

A total of 568 fish from 45 species were caught across Gladstone Harbour and the reference sites at Baffle Creek and Stanage Bay during sampling conducted in Spring 2018 and Autumn 2019. The species caught at the most sites and in the highest numbers were the four target species: barred javelin, blue catfish, barramundi and sea mullet and the non-target blue threadfin. The fifth target species 'bream' (yellow-finned and pikey) were caught in far fewer numbers. In total, 246 of the five target species groups were retained for health assessment, from all sampling sites.

4.3.3. Development of fish health indicators and scoring

Visual Fish Condition

The Fish Visual Assessment is based on the Fish Health Assessment index developed by Adams et al. (1993). However, unlike the Health Assessment Index in which the fish is euthanised and both external and internal health parameters are assessed. The Fish Visual Assessment 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 4.25).

To calculate the Fish Visual Assessment 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 scores by standardising the scores to have a range of 0 to 1.

Table 4.25: Scoring for five variable conditions used in the Fish Visual Assessment in 2019

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 Fulton's K index

$$FI = \frac{WEIGHT \times 10^3}{LENGTH \times 10^3}$$

To determine the report card scores the historical data for each species a Fulton's K value was calculated for each fish. All values for each species were then scaled to have a range of 0 to 1 using the following formula:

$$score = \frac{mean([FI\ species|\ year]) - \min(FI\ species])}{\max([FI\ species]) - \min(FI\ species])}$$

The grade range for each species was determined by calculating the percentiles for the GHHP grading range from the historical data (Table 4.26). To determine the report card score the 2019 species average was compared to the calculated grading range.

Table 4.26: Score range used to determine the Fish Body Condition grade in 2019

Species	Fish Body Condition grade range				
	E (0.0 – 0.24)	D (0.25 -0.49)	C (0.50 – 0.64)	B (0.65 – 0.84)	A (0.85 -1.00)
Yellow-finned bream	0.0 – 0.19	0.20 – 0.28	0.29 – 0.38	0.39 – 0.77	0.78 – 1.00
Pikey bream	0.0 – 0.48	0.49 – 0.61	0.62 – 0.63	0.64 – 0.77	0.78 – 1.00
Barred javelin	0.0 – 0.31	0.32 – 0.65	0.66 – 0.71	0.72 – 0.90	0.91 – 1.00
Dusky flathead	0.0 – 0.10	0.11 – 0.30	0.31 – 0.38	0. 39 – 0.45	0.46 – 1.00
Mangrove jack	0.0 – 0.11	0.12 – 0.28	0.29 – 0.33	0.34 – 0.43	0.44 – 1.00

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 4.27). The total Health Assessment Index 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 Health Assessment Index 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 Health Assessment Index 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 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.

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 2019 report card were calculated using data from Spring 2018 and Autumn 2019 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 4.27: Scoring for nine variable conditions used in the Health Assessment Index in 2019 (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

4.3.4. Fish health results

The overall score for fish health for 2019 was 0.69 (B), made up from a visual fish condition score of 0.69 and an overall score of 0.69 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.

Visual Fish Condition

The overall score for visual fish condition was 0.69 (B) comprised of an overall harbour score for Fish Visual Assessment of 0.97 (A) and a lower score for Fish Body Condition. All species assessed for FVA received very good scores ranging from 0.96 to 0.98 (Table 4.28). Barramundi received a similar score to the other species (0.96, A) but as there was no body condition data for this species the score was not included in the calculation of either the overall FVA or the overall Visual Fish Condition.

Table 4.28: The Visual Fish Condition score calculated from the mean of the Fish Visual Assessment (FVA) and Fish Body Condition (FBC) for five species of fish caught in Gladstone Harbour in 2019. While barramundi was assessed for FVA, as no data for FBC was available this species does not contribute to the overall harbour score.

Fish Species	Fish Visual Assessment	Fish Body Condition	Visual Fish Condition
Yellow-finned bream	0.96	0.25	0.61
Pikey bream	0.96	0.65	0.81
Barred javelin	0.97	1.00	0.99
Dusky flathead	0.98	0.06	0.52
Mangrove jack	0.96	0.15	0.56
Barramundi*	0.96	NA	NA
Harbour Score			**0.69**

*Not used in the calculation of the overall score

Overall detection of visible pathologies was low, with no incidence of parasites or deformities detected and only three incidences of eye health issues detected (Table 4.29). For all species the most commonly detected conditions were fins where detection ranged from 13% in dusky flathead to 31% in yellow-finned bream. Detection of skin health issues ranged from 6% in yellow-finned bream to 24% in barramundi (Table 4.29). However, the severity of these conditions was low (Tables 4.30 and 4.31).

Table 4.29: Number of visual fish health incidences detected and species scores for six species of fish in 2019.

Species	N	Fins	Skin	Eyes	Parasites	Deformities
Yellow-finned Bream	183	57 (31%)	10 (6%)	1 (0.5%)	0	0
Pikey Bream	143	34 (24%)	22 (15%)	2 (1%)	0	0
Barred Javelin	219	42 (19%)	37 (17%)	0	0	0
Dusky Flathead	80	10 (13%)	8 (10%)	0	0	0
Mangrove Jack	122	34 (28%)	24 (20%)	0	0	0
Barramundi*	36	10 (27%)	9 (24%)	0	0	0
Total	783	187 (24%)	110 (14%)	3 (0.4%)		

*Barramundi were not included in the calculation of report card scores for FVC owing to the absence of fish body condition data.

Table 4.30: Fin condition recorded for six species of fish in 2019.

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)
Yellow-finned Bream	126 (69%)	51 (28%)	6 (3%)	0
Pikey Bream	109 (76%)	26 (18%)	8 (6%)	0
Barred Javelin	177 (81%)	38 (17%)	4 (2%)	0
Dusky Flathead	70 (88%)	10 (12%)	0	0
Mangrove Jack	88 (72%)	29 (24%)	5 (4%)	0
Barramundi*	27 (75%)	9 (25%)	0	0

*Barramundi were not included in the calculation of report card scores for FVC owing to the absence of fish body condition data.

Table 4.31: Skin condition recorded for six species of fish in 2019.

Condition (Score) / Species	Normal no aberrations (0)	Mild skin aberrations (10)	Moderate skin aberrations (20)	Severe skin aberrations (30)
Yellow-finned Bream	173 (94.5%)	9 (5%)	1 (0.5%)	0
Pikey Bream	121 (85%)	22 (15%)	0	0
Barred Javelin	182 (83%)	33 (15%)	4 (2%)	0
Dusky Flathead	72 (90%)	6 (8%)	2 (2%)	0
Mangrove Jack	98 (80%)	24 (20%)	0	0
Barramundi*	28 (76%)	8 (22%)	1 (2%)	0

*Barramundi were not included in the calculation of report card scores for FVC owing to the absence of fish body condition data.

Fish Body Condition Index

Fish body condition was calculated for fish presented at The Boyne Tanum Hook-up live weigh in between 3 May and 5 May 2019. Weight (g) and length (mm) was recorded for 482 fish from five species (Figure 4.15) and Fulton's K was calculated for all species using this data (Table 4.32). The historic mean for all species was calculated from data collected at the Boyne Tanum Hook-up from 2003 to 2018 where data was available for all years except for 2009 and 2011. The sample sizes for mangrove jack were small between 2003 and 2010 which may reduce the reliability of the historic mean.

The overall harbour score for Fish Body Condition was 0.42 (D). The species scores were highly variable ranging from very poor to very good. Barred javelin had a very good score of 1.00 (A) as a result of having the highest Fulton's K measured for this species over the baseline period (Table 4.32). Conversely dusky flathead (0.06, E) had a very poor score as a result of the second lowest value of Fulton's K recorded since 2003. Mangrove jack (0.15, E) also received a very poor score, yellow-finned bream (0.25, D) received a poor score and pikey bream (0.65, B) received a good score.

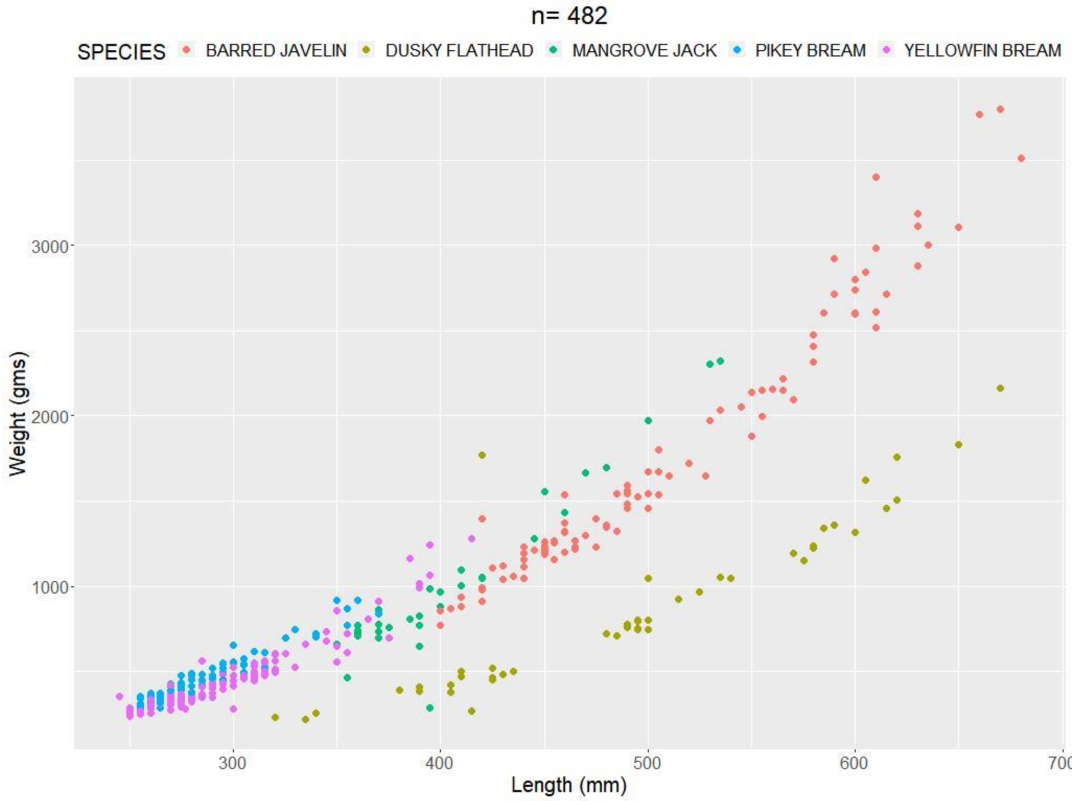


Figure 4.15: Length weight relationship for five fish species (n = 482) from the Boyne Tanum Hook-up, 3 to 5 May 2019.

Table 4.32: Fulton's Condition Index calculated for five species in 2019 and the historic species means from 2003 to 2018.

Species	(N)	Fulton's Condition Index			
		Min	Max	Mean	Historic Mean*
Yellow-finned bream	192	0.93	3.15	1.45	1.45
Pikey bream	85	1.09	2.63	1.65	1.58
Barred javelin	110	1.94	5.71	3.40	2.58
Dusky flathead	59	0.65	4.21	1.72	1.75
Mangrove jack	36	1.31	4.35	2.47	2.59

*Historic mean includes all years 2003 to 2018 with the exception of 2009 and 2011 when data was unavailable.

Health Assessment Index

The overall Health Assessment Index score was 0.69 (B). Three of the five monitored fish species received good scores: bream (0.78, B), barred javelin (0.77, B), and mullet (0.73, B). The remaining two species barramundi (0.58, C) and blue catfish (0.60, C) received satisfactory scores (Table 4.33).

The overall HAI score was the average scores for nine measures (Table 4.34). Overall scores for external pathologies; skin, eyes and fins were low. For example, the highest average score for skin was blue catfish at 1.88. The highest score in all species except for barramundi was for the liver and while barramundi had the highest score for liver (13.91) it also had the highest score for parasites (14.17).

The percentage of fish with a detectable pathology (any score greater than 0) indicated that there were more detections of liver or parasite issues than for other parameters in all species (Tables 4.35 and 4.36). Overall the lowest percentage of detections was for eyes, spleen and hindgut.

Table 4.33: Overall Health Assessment Index scores for five fish species and the overall score for Gladstone Harbour in 2019.

Species	Bream	Barred javelin	Barramundi	Blue catfish	Mullet
Species score	0.78	0.77	0.58	0.60	0.73
Harbour Score	**0.69**				

Table 4.34: Average measures and HAI total scores for fish caught in Gladstone Harbour in Spring 2018 and Autumn 2019. Bream includes yellow-finned bream and pikey bream and mullet includes sea mullet and diamond scale mullet. Organ scores ranged from 0 to 30 and HAI scores ranged from 0 to a possible maximum of 270.

Taxa / Measure	Barramundi (n = 23)	Bream (n = 9)	Barred javelin (n = 63)	Blue catfish (n = 48)	Mullet (n = 80)
Skin	1.74	1.11	0.32	1.88	0.75
Eyes	2.61	0	0.48	0	1.13
Fins	0.43	0	0.63	1.49	1.00
Gills	0	0	0	0.63	0.38
Spleen	1.30	0	0	1.25	2.63
Kidney	0	0	0	9.38	5.63
Hindgut	1.30	0	0.32	0.21	0.50
Liver	13.91	13.33	8.73	9.38	6.88
Parasites	14.17	3.33	0	0	4.00
HAI score	35.22	23.33	23.81	34.17	26.38

Table 4.35: Number of Health Assessment Index positive score (0 – 30) detected for shin, eye, fins and gills for five target groups in the 2019 reporting year.

Species	N	Skin	Eyes	Fins	Gills
Barramundi	23	3 (13%)	2 (9%)	1 (4%)	0
Barred Javelin	63	2 (3%)	1 (2%)	4 (6%)	0
Blue Catfish	48	9 (19%)	0	5 (10%)	1 (2%)
Breams	9	1 (11%)	0	0	0
Mullet	80	4 (5%)	3 (4%)	8 (10%)	1 (1%)
Total	223	19 (9%)	6 (3%)	18 (8%)	2 (1%)

Table 4.36: Number of Health Assessment Index positive score (0 – 30) detected for spleen, kidney, hindgut, liver and parasites for five target groups in the 2019 reporting year.

Species	N	Spleen	Kidney	Hindgut	Liver	Parasites
Barramundi	23	1 (4%)	0	2 (9%)	14 (61%)	17 (74%)
Barred Javelin	63	0	0	2 (3%)	21 (33%)	28 (44%)
Blue Catfish	48	2 (4%)	15 (21%)	1 (2%)	23 (48%)	16 (3%)
Breams	9	0	0	0	4 (44%)	3 (3%)
Mullet	80	7 (9%)	15 (19%)	4 (5%)	30 (38%)	24 (30%)
Total	223	10 (4%)	30 (13%)	9 (4%)	92 (41%)	88 (39%)

Overall

The overall score for fish health in 2019 was the aggregation of the two fish health projects (Table 4.37). 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 4.37: Overall fish health scores for Gladstone Harbour in 2019.

Visual Fish Condition	Fish Health Assessment Index	Overall Fish Health 2019
0.69	0.69	**0.69**

4.3.5. Fish health conclusions

Visual Fish Condition

The overall scores for Visual Fish Condition ranged from very good for barred javelin to satisfactory for yellow-finned bream, dusky flathead and mangrove jack. Pikey bream received a good score. All fish received a very good score for Fish Visual Assessment. While the Fish Visual Assessment scores are not directly comparable with the Health Assessment Index scores, some comparisons can be made by comparing the level of detection of common external measures.

Noting that different fish species were assessed in the two studies—the overall detection levels for three external variable conditions; skin, eyes and fins (Tables 4.29 and 4.35) were generally low. The Fish Visual Assessment reported 14% of all fish sampled had a positive score for skin condition, while the Health Assessment Index reported 9% of the total fish sampled had a positive score for skin. Similarly, the Fish Visual Assessment reported <1 % of fish had a positive score for eyes and the Health Assessment Index reported 3% of the total fish sampled had a positive score for eyes. However, there was a greater difference with the detection of fin issues (FVA 24% and HAI 8 %).

The reason for this discrepancy is not clear but could relate to the difference in species composition as fins and other external parameter scores varied between species (Tables 4.29 and 4.35). The difference may also have been a result of differences in handling procedures. Sawynok et al. (2019) notes that the condition of fish brought into the Boyne Tanum HookUp weighing station, where they were assessed, may have been influenced by the fact that they were transported from locations around the harbour and may have spent several hours in containers making them more susceptible to fin and skin damage.

While it is clear that the rate of detection of visual fish health conditions is low in both studies the differences noted above require further investigation.

With all fish species receiving very good scores for Fish Visual Assessment (0.96 to 0.98) the variation in the overall Visual Fish Condition score was a result of variation in Fish Body Condition scores. These scores ranged from 0.06 (E) in dusky flathead to 1.00 (A) in barred javelin. The poor body condition score for yellow-finned bream (0.25, D) and the very poor scores for dusky flathead and mangrove jack (0.15, E) may be attributable to climate variation. The 2018-19 reporting year was characterised by lower than average rainfall and freshwater inflow into the harbour (Figures 9.4 to 9.7), which can be associated with reduced productivity in estuaries (Loneragan & Bunn, 2009). Bycatch of banana prawns, a prey species for breams and mangrove jack, in the fish recruitment study was at its lowest level since monitoring commenced in 2016 (Sawynok et al., 2019). However, the reason for the very good score for barred javelin and the good score for pikey bream are not understood and require further investigation.

Health Assessment Index

The monitoring conducted by CQU in the 2018–19 reporting year demonstrates that the Health Assessment Index is suitable for monitoring fish health in Gladstone Harbour and for calculating report card scores. The pilot benchmark score of 10 and worst-case scenario baseline of 70 were based on the best available information. However, if information becomes available in the future that is more species and harbour specific updating the benchmark and worst-case scenario should be considered.

In 2018-19 two sampling events (Spring 2018 and Autumn 2019) were conducted to provide information on any differences in fish health that related to season. The only significant difference in fish health that related to season was for barred javelin, which had a lower HAI (better health) in in Spring 2018 when compared to Autumn 2019. In other species, season did not appear to influence HAI score. However, this is based on sampling conducted in one report card year only. Further sampling conducted in Spring and Autumn should be conducted in future years to confirm this relationship.

4.3.6. 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 and 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 2018–19 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)

4.3.7. Fish recruitment data collection

Data for the two bream species were collected monthly from 26 sites across 12 harbour zones between December 2018 and March 2019 (Figure 4.16). The Outer Harbour zone was excluded from the surveys as there were no suitable bream habitats (Table 4.38). Where possible within each zone, a minimum of two sites were selected to cover the upper tidal limit and another selected within the daily tidal influence. Each survey was completed within two weeks following the largest spring tides as recruitment of fish into nursery habitats is influenced by these large tides. A species fork length up to 100 mm defined juvenile or year 0 recruits (Sawynok and Sawynok, 2018).

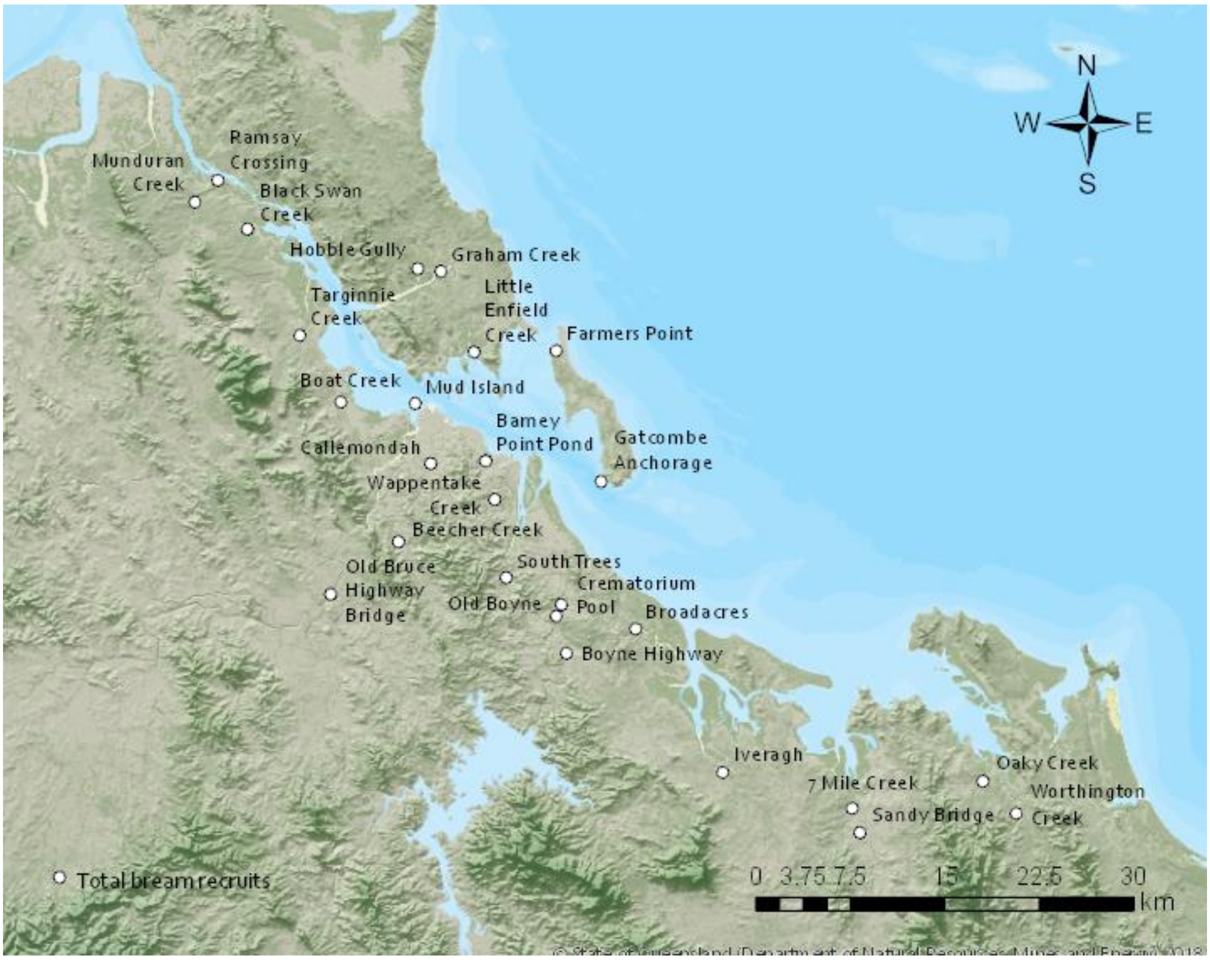


Figure 4.16: Bream nursery habitats surveyed around Gladstone Harbour between December 2018 and March 2019.

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, 2019) (Figure 4.17).

Figure 4.17: Fish recruitment surveys using in castnets (Photos courtesy Bill Sawynok).

Table 4.38: Number of sites surveyed and number of juvenile bream caught and released in each GHHP monitoring zone.

Harbour zone	Sites	Yellow-finned bream	Pikey bream
Zone 1. The Narrows	Ramsay Crossing	4	26
	Munduran Creek	8	1
	Black Swan Creek	2	21
	Targinnie Creek	2	0
Zone 2. Graham Creek	Graham Creek	0	0
	Hobble Gully	0	20
Zone 3. Western Basin	Mud Island	0	0
Zone 4. Boat Creek	Boat Creek	3	3
Zone 5. Inner Harbour	Little Enfield Creek	2	6
	Barney Point Pond	0	0
Zone 6. Calliope Estuary	Beecher Creek	7	10
	Old Bruce Highway Bridge	1	12
Zone 7. Auckland Inlet	Callemondah	15	34
Zone 8. Mid Harbour	Farmers Point	0	0
	Gatcombe Anchorage	0	0
Zone 9. South Trees Inlet	Wappentake Creek	5	1
	South Trees	13	11
	Crematorium Pool	16	9
Zone 10. Boyne Estuary	Old Boyne	10	3
	Boyne Highway	51	0
Zone 11. Outer Harbour	*Not surveyed*		
Zone 12. Colosseum Inlet	Broadacres	13	8
	Iveragh	18	5
Zone 13. Rodds Bay	Oaky Creek	27	10
	7 Mile Creek	17	9
	Worthington Creek	7	2
	Sandy Bridge	27	5
Total	**26 sites**	**248**	**196**

4.3.8. 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. A number of potential environmental predictors related to fish habitats were also tested to determine if they helped to explain variation in the juvenile catch data. The estimates were aggregated (using 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.

4.3.9. Fish recruitment results

Overall the fish recruitment score for 2019 was 0.27 (D), indicating a poor condition. Of the 12 zones monitored, six zones had very poor scores, five zones had poor scores and one zone had a satisfactory score. All zone scores were lower than the previous year (Table 4.39) and the overall score was the lowest recorded since fish recruitment first appeared in the report card in 2016 (Figure 4.18).

The total number of bream caught in the 2019 reporting year was 444, 48% lower than the 775 bream caught in the 2018 reporting year. The total number of yellow-finned bream was 248 down from 346 in the previous year a reduction of 28%. The total number of pikey bream was 196 down from 429 in 2018 a reduction in the catch of 54%. The total number of casts in 2019 (2080) was identical to the number of casts in 2018.

Table 4.39: Fish recruitment scores for all harbour zones and overall harbour score for fish recruitment.

Zone	2019	*2018*	*2017*	*2016*	*2015**
1. The Narrows	0.18	*0.58*	*0.75*	*0.30*	*0.86*
2. Graham Creek	0.17	*0.77*	*0.58*	*0.44*	*0.72*
3. Western Basin	0.13	*0.79*	*0.78*	*0.36*	*Not surveyed*
4. Boat Creek	0.32	*0.61*	*0.47*	*0.36*	*0.80*
5. Inner Harbour	0.16	*0.66*	*0.64*	*0.33*	*0.80*
6. Calliope Estuary	0.28	*0.70*	*0.79*	*0.43*	*0.70*
7. Auckland Inlet	0.53	*0.86*	*0.91*	*0.53*	*0.80*
8. Mid Harbour	0.12	*0.59*	*0.71*	*0.29*	*Not surveyed*
9. South Trees Inlet	0.25	*0.69*	*0.71*	*0.43*	*0.72*
10. Boyne Estuary	0.32	*0.52*	*0.74*	*0.54*	*0.69*
11. Outer Harbour	Not surveyed	*Not surveyed*	*Not surveyed*	*Not surveyed*	*Not surveyed*
12. Colosseum Inlet	0.39	*0.61*	*0.71*	*0.45*	*Not surveyed*
13. Rodds Bay	0.33	*0.59*	*0.74*	*0.58*	*Not surveyed*
Harbour score	**0.27**	***0.66***	***0.71***	***0.40***	***0.80***

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

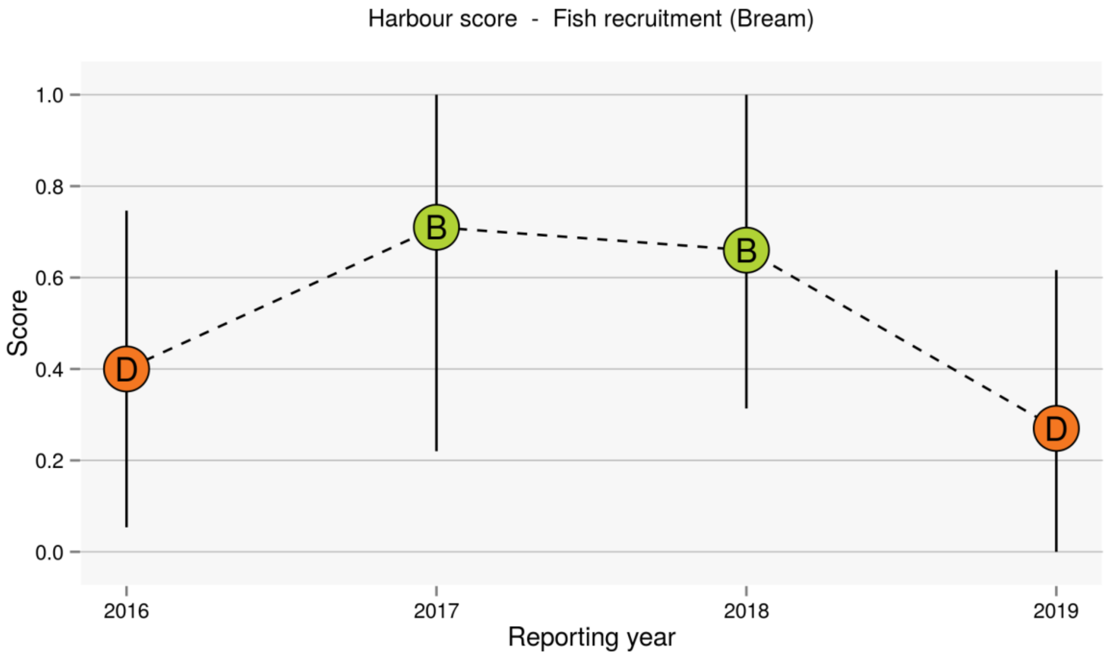


Figure 4.18: Trends in the harbour score for fish recruitment, 2016–2019.

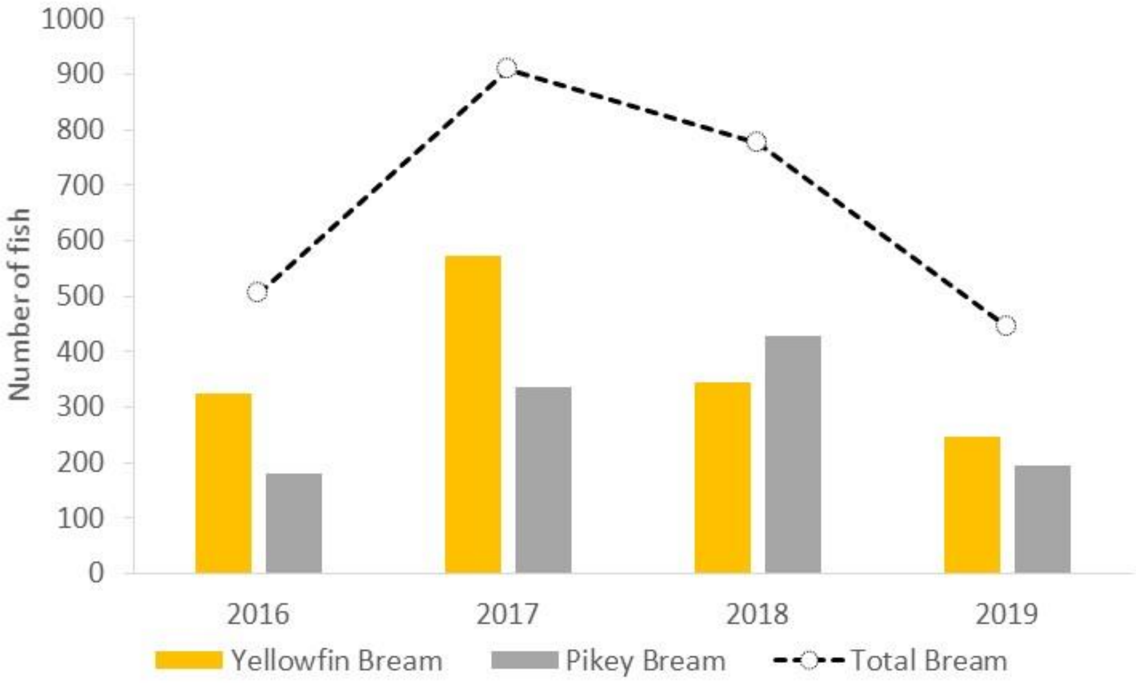


Figure 4.19: Yellow-finned and pikey bream recruits for 2016, 2017, 2018 and 2019 fish recruitment surveys.

The ratio of yellow-finned bream (56% of the total bream catch) to pikey bream (44% of the total catch) changed from the previous year where more pikey bream (55%) were caught than yellow-finned bream (45%) (Figure 4.19). The results were more similar to 2016 and 2017 when more yellow-finned than pikey bream were caught.

4.3.10. Fish recruitment conclusions

Recruitment plays a key role in a fishery population. The 2019 score of 0.27 (D) is the lowest recorded since 2016 when it was first included in the report card. The overall score may be a response to the prevailing climatic conditions as during the survey months there was little or no freshwater flow at most sites. Rainfall recorded at Gladstone Airport was only 70 mm for all of January and February, well below the monthly averages of 250 mm for that period. Freshwater inflows have been clearly linked to estuarine productivity with productivity declining in drier years (Loneragan & Bunn, 2009).

4.3.11. Mud crab

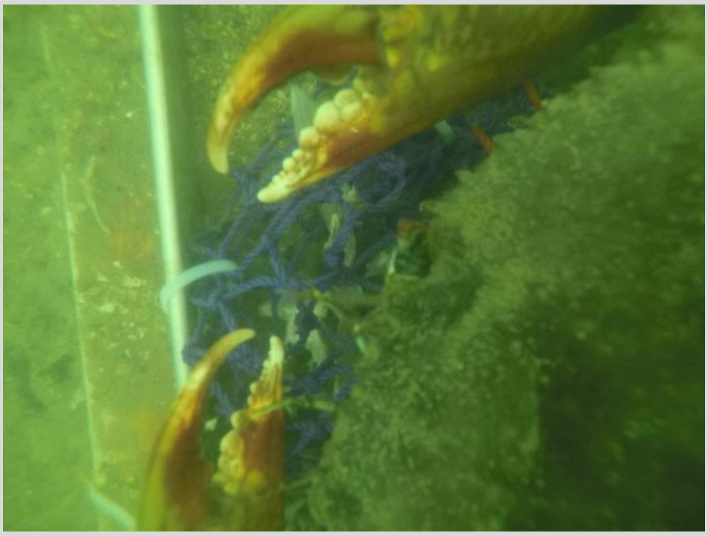


Figure 4.20: Mud crab feeding at a Baited Retrievable Underwater Video during the pilot study in 2017 (Photo courtesy of CQUniversity Australia).

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.

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 both suitable indicators of mud crab health and a methodology for determining report card scores (Figure 4.20).

4.3.12. 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 4.40). Two sites were excluded from future monitoring. Rodds Bay site A was excluded owing to insufficient mud crab habitat to accommodate the number of pots required and South Trees Inlet owing to a very low catch rate in the initial survey.

Table 4.40: 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 2019—a summer (warm, wet season) survey from 14–17 February and a winter (cool, dry season) survey from 27–30 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. All surveys were conducted on days when low tide fell between 10.30 am and 3.00 pm. 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.

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

- Species;
- Sex;
- Carapace width (notch to notch) (mm);
- Weight (g);
- Abnormalities: type, body location, dimensions of rust spot lesions, grade of rust spot lesion (Source: Andersen et al., 2000);
- Presence or absence of mating scars on male mud crabs; and
- Seafood grade: A, B or C.

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.

4.3.13. Development of mud crab indicators and scoring

A literature search for potential mud crab indicators identified nine classes of potential mud crab indicators (Table 4.41). 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 4.41: 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 four indicators were selected for the report card:

1. Sex ratio: based on legal size limit

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

2. Abundance: catch per unit effort (CPUE)

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

3. Visual health: prevalence of rust lesions

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

4. Biomass: body condition index

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

The report card scores were calculated using a methodology similar to that used in the South East Queensland Report Card (Fox, 2013) and the Fitzroy Basin Report Card (Flint et al., 2017b). The indices for sex ratio, abundance and visual health were calculated and compared to a benchmark and a worst-case scenario (Table 4.42). 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. 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 a fourth sub-indicator and recommended that biomass not be included due to complications in assessment.

Table 4.42: Calculation of mud crab scores for the 2019 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., 2019b) **(2)**	25th percentile of Long-Term Monitoring Program data **(0.25)**	1–((x-B)/(WCS-B)) Where: x=recorded CPUE B=benchmark (2) WCS=worst-case scenario (0.25)
Abundance (CPUE)	75th percentile of the combined 2017, 2018 & 2019 scores **(2.12)**	Catch rate of < 1 crab per allowable 4 pots **(0.25)**	1–((x-B)/(WCS-B)) Where: x=recorded CPUE B=benchmark (2.12) 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)
Biomass	NA	NA	ISP recommended to not include for report card purposes

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., 2019b). 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 2017–2019, the benchmark for 2019 was 2.12 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.

4.3.14. Mud crab results

The overall mud crab score for the 2019 report card was 0.47 (D). This was a result of very poor scores for sex ratio (0.00–0.24), abundance scores ranging from very poor to very good (0.00–1.00) and good to very good scores for prevalence of rust lesions (0.70–1.00) (Table 4.43).

For the second consecutive year, the zone with the highest overall score was The Narrows (0.63, D). This was a result of a very good scores for abundance (1.00, A) and prevalence of rust lesions (0.90, A) and, in common with most zones, a very poor score (0.00, E) for sex ratio. Five zones—Graham Creek (0.45, D), Boat Creek (0.48, D), Inner Harbour (0.48, D), Calliope Estuary (0.43, D) and Rodds Bay (0.36, D)—received poor scores (Table 4.43). An overall score for Auckland Creek was not calculated, as only one crab was caught in this zone over the two sampling periods.

Table 4.43: Mud crab sub-indicator, zone and harbour scores for the 2019 Gladstone Harbour Report Card. Zone and harbour scores from 2017 and 2018 are shown for comparison.

Zone	Sex Ratio	Abundance (CPUE)	Prevalence of rust lesions	Zone score 2019	*Zone score 2018*	*Zone score 2017*
1. The Narrows	0.00	1.00	0.90	0.63	*0.66*	*0.66*
2. Graham Creek	0.24	0.12	1.00	0.45	*0.44*	*0.61*
4. Boat Creek	0.05	0.46	0.94	0.48	*0.51*	*0.70*
5. Inner Harbour	0.08	0.67	0.70	0.48	*0.52*	*0.87*
6. Calliope Estuary	0.00	0.29	1.00	0.43	*0.52*	*0.47*
7. Auckland Inlet	NC	0.00	NC	NC	*NC*	*0.25*
13. Rodds Bay	0.12	0.27	0.70	0.36	*0.38*	*0.36*
Harbour score	0.08	0.47	0.87	0.47	*0.49*	*0.55*

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

Sex ratio (based on legal size limit)

In 2019, six zones received very poor scores (0.00 to 0.24, E) for sex ratio. A score for Auckland Creek could not be calculated for the second consecutive year. The Narrows and Calliope Estuary had the lowest scores (0.00, E) while Graham Creek had the highest score (0.24, E) (Table 4.43). The latter was based on a ratio of 0.33 males to 1 female crab (Table 4.44). When the two sampling periods were combined, all zones had more than two females to every one male crab. Overall, the harbour score for sex ratio was comparable to the previous year (0.08, E).

Table 4.44: Size and sex of mud crabs caught and released in February and June 2019. Note, figures for sex ratio represent actual male-to-female crab ratios and not GHHP scores.

Zone name	February 2019			June 2019		
	Males > 143mm	Females > 143mm	Sex ratio	Males > 143mm	Females > 143mm	Sex ratio
1. The Narrows	4	17	0.24	3	66	0.05
2. Graham Creek	2	0	NC	2	6	0.33
4. Boat Creek	1	2	0.50	2	7	0.29
5. Inner Harbour	2	7	0.29	9	21	0.43
6. Calliope Estuary	2	11	0.18	2	8	0.25
7. Auckland Inlet	0	0	NC	1	0	NC
13. Rodds Bay	5	9	0.56	2	6	0.33
Harbour average			**0.45**			**0.28**

NC: Not calculated

Abundance: catch per unit effort (CPUE)

For the third consecutive year the highest catch rate was recorded in The Narrows—the only zone to have a very good score (1.00, A)—where there was an average of 2.8 mud crabs per pot (Tables 4.43 and 4.45). The Inner Harbour received a good score (0.67, B) based on an average catch of 1.5 crabs per pot. Three zones—Boat Creek, Calliope Estuary and Rodds Bay—had poor scores and the remaining two zones, Auckland Inlet and Rodds Bay, had very poor scores. Overall the harbour score for abundance was comparable to 2018, showing a slight increase from 0.46 to 0.47 (D) in 2019.

Table 4.45: Catch per unit effort (CPUE) for pots set in seven harbour zones during the February and June 2019 mud crab surveys.

Zone name	February 2019			June 2019		
	Pots	Crabs caught	CPUE	Pots	Crabs caught	CPUE
1. The Narrows	20	32	1.60	20	80	4.00
2. Graham Creek	20	7	0.35	20	12	0.60
4. Boat Creek	15	11	0.73	16	24	1.50
5. Inner Harbour	20	17	0.85	20	43	2.15
6. Calliope Estuary	20	20	1.00	20	12	0.60
7. Auckland Inlet	20	0	0.00	20	1	0.05
13. Rodds Bay	20	19	0.95	20	11	0.55
Harbour average			**0.91**			**1.35**

Visual health: prevalence of rust lesions

A low incidence of rust lesions was recorded across the harbour resulting in very good scores in four zones (The Narrows, Graham Creek, Boat Creek and Calliope Estuary) and good scores in two zones (Inner Harbour and Rodds Bay). A score for prevalence of rust lesions was not calculated in Auckland Inlet owing to the insufficient number of crabs caught, however, the one crab caught in this zone had no lesions (Table 4.43 and 4.46). The zone with the lowest incidence of lesions was Graham Creek (0%) while the zones with the highest incidence of lesions were Inner Harbour and Rodds Bay (~15% each).

Overall, the prevalence of rust lesions harbour score in 2019 was comparable to the 2017 score (0.86, A), however, lower than the score in 2018 (0.98, A).

Table 4.46: Percentage of mud crabs with external lesions (rust spot) recorded during the February and June 2019 mud crab monitoring.

Zone name	February 2019			June 2019		
	Mud crabs with lesions	Mud crabs without lesions	% with lesions	Mud crabs with lesions	Mud crabs without lesions	% with lesions
1. The Narrows	4	28	12.50	4	76	5.00
2. Graham Creek	0	7	0.00	0	12	0.00
4. Boat Creek	0	11	0.00	2	22	8.33
5. Inner Harbour	1	16	5.88	7	36	16.30
6. Calliope Estuary	1	19	5.00	0	12	0.00
7. Auckland Inlet	0	0	NC	0	1	0.00
13. Rodds Bay	0	19	0.00	4	7	36.40
Harbour average			**3.90%**			**9.43%**

NC: Not calculated

4.3.15. 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 0.47 (D) was slightly lower than the 2018 score 0.49 (D) (Figure 4.21). This result was driven by a mix of lower zone scores for abundance and/or prevalence of rust lesions (Table 4.43).

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 2019, all 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 six 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.

Despite a slight improvement in the overall abundance score, the harbour score for abundance remained poor. However, caution is required in interpreting the abundance scores as CPUE data can be highly variable. 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. All six of the zones where this measure could be calculated received good or very good scores (Table 4.43). These scores indicate a low prevalence of rust spot lesions across the harbour. The average incidence of rust spot lesions across the seven monitored zones was 6.8% for the combined February and June survey periods, substantially lower than the 37% incidence recorded in 2012 (Dennis et al., 2016) or the 22% recorded in the late 1990s by Andersen et al. (2000).

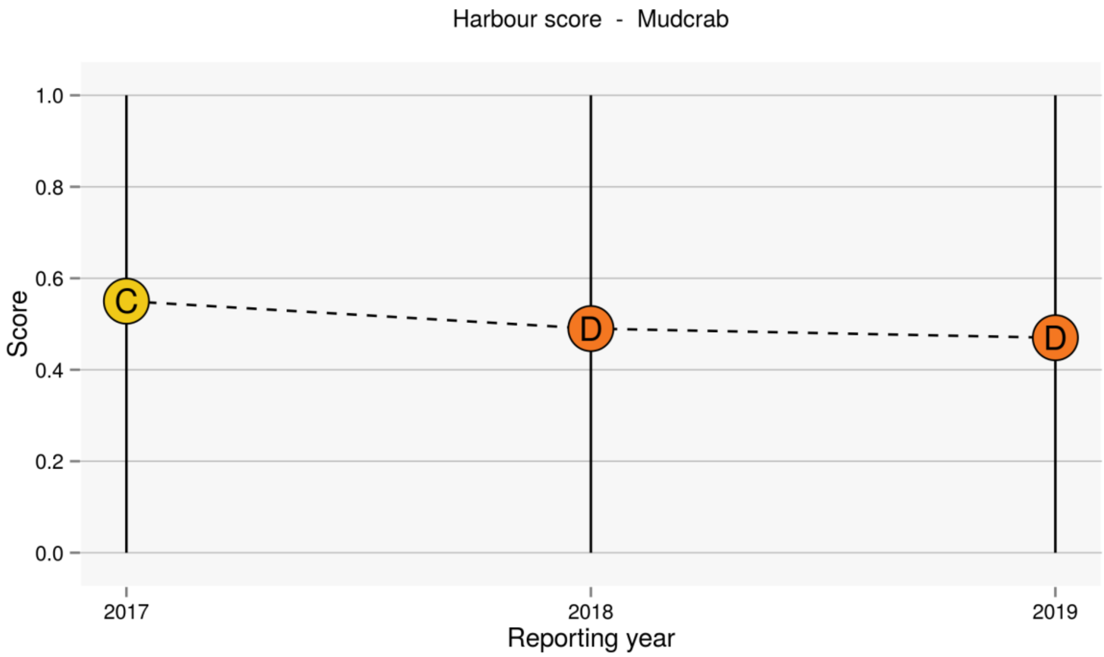


Figure 4.21: Trends in the harbour score for mud crabs, 2017–2019.

4.4. Environmental component and indicator groups results

The overall Environmental component score for the 2019 report card was 0.60 (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 habitat and aggregating the two fish health indicators, fish recruitment and mud crab health for the fish and crabs indicator group. The overall harbour scores for the three indicator groups were: water and sediment quality 0.88 (A), habitats 0.45 (D) and fish and crabs 0.48 (D) (Table 4.47).

The zone scores for the habitat indicators group only include the habitat indicators present in each zone. While mangroves are present in all zones, coral is only present in two zones and seagrass is present in six zones. The health of other important habitat types, such as benthic habitat which occurs in all zones, was not measured. 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.

Table 4.47: Environmental indicator group scores and overall environmental scores for the 13 harbour zones and the overall harbour scores.

Zone	Indicator groups		
	Water and sediment quality	Habitats (seagrass, corals and mangroves)	Fish and crabs
1. The Narrows	0.83	0.68*	0.50~
2. Graham Creek	0.85	0.64	0.44~
3. Western Basin	0.88	0.60*	0.41
4. Boat Creek	0.80	0.46	0.50~
5. Inner Harbour	0.87	0.38*	0.45~
6. Calliope Estuary	0.88	0.58	0.47~
7. Auckland Inlet	0.86	0.65	0.61
8. Mid Harbour	0.90	0.42*#	0.41
9. South Trees Inlet	0.89	0.75*	0.47
10. Boyne Estuary	0.94	0.26	0.51
11. Outer Harbour	0.95	0.42#	0.69
12. Colosseum Inlet	0.92	0.72	0.54
13. Rodds Bay	0.90	0.57*	0.46~
Harbour score	**0.88**	**0.45**	**0.48**

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

5. The Social component

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

5.1. Data collection

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

A Computer Assisted Telephone Interview (CATI) survey of residents from the Gladstone 4680 postcode area was conducted in June 2019 (Figure 3.28). Participants were contacted using a random dialling technique. Both landline and mobile phone users were contacted for the surveys. Note that prior to 2016, the CATI survey was restricted to landlines. Trained research interviewers administered the survey, which had been thoroughly monitored for data QA/QC. The survey questions were largely qualitative and related to the GHHP social, cultural (sense of place) and economic objectives. All questions were designed to be answered on a 10-point agree–disagree scale. In the CATI survey, each participant was asked a specific question to suggest the first three words that come to their mind when thinking about Gladstone Harbour. The responses were cleaned and used to develop a word cloud (more details in Pascoe et al., 2014).

An additional 38 responses were collected using an online version of the CATI survey in 2019. Both online and CATI survey formats were identical (e.g. questions, question order, etc.). The online respondent list was generated using a community database of citizens local to Gladstone who had registered their interest for Gladstone-related surveys. There were no notable events that may have influenced the opinions of respondents during the survey period. A total of 439 responses were used for the 2019 Gladstone Harbour Report Card after CATI responses (n = 401) and online survey responses (n = 38) were combined.

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 5.1: The indicator groups, indicators and measures used to determine social scores for the 2019 report card (Source: De Valck et al., 2019).

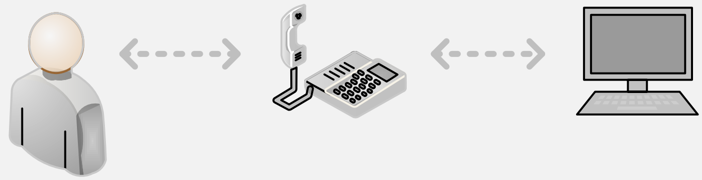
Indicator Groups	Indicators	Measures	Data Source	Baseline data
Harbour usability	Satisfaction with harbour recreational activities	How satisfied with the last recreational trip	CATI Survey (avg. Q11b, Q12b1, Q15b, Q25)	10-point scale
		Quality of ramps and facilities	CATI Survey (avg. Q28, Q28a)	10-point scale
	Perceptions of air and water quality	Water quality satisfaction	CATI Survey (Q40)	10-point scale
		Air quality satisfaction	CATI Survey (Q41)	10-point scale
		Water quality does not affect use of the harbour	CATI Survey (Q42)	10-point scale
	Perceptions of harbour safety for human use	Marine safety incidents	*Marine incidents in Queensland 2018* Department of Transport & Main Roads, Maritime Safety Queensland	Data 2009-2018 (calendar year). Rate of incidents in Gladstone maritime region compared to other Qld regions
		Oil spills	Queensland Dept. Transport and Main Roads, *Maritime Safety Queensland Branch, 2017-2018 and 2018-2019*	Data 2009-2018 (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 boat ramps and public spaces	Frequency of use	CATI Survey (Q8)	10-point scale
		Number of boat 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
	Perceptions of barriers to access	Marine debris a problem	CATI Survey (Q36)	10-point scale
		Marine debris affects access	CATI Survey (Q37)	10-point scale
		Shipping reduced use	CATI Survey (Q31)	10-point scale
		Recreational boats reduced use	CATI Survey (Q32)	10-point scale
Liveability and wellbeing	Contribution of harbour to liveability and wellbeing	Makes living in Gladstone a better experience	CATI Survey (Q45)	10-point scale
		Participate in community events	CATI Survey (Q46)	10-point scale
		Aesthetic value	CATI Survey (Q45a, Q45b)	10-point scale

5.2. 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 2019 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 and the results of the word-cloud analysis. 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.

5.3. Results

A total of 439 respondents participated in the 2019 CATI survey. The majority of responses were obtained via the CATI only survey (91%) while a small fraction (9%) were collected using the online survey. There were some differences between CATI and online survey responses, however, score differences were minor. CATI only respondents were recruited through mobile phones (66%) and landlines (34%) based on their postcodes. There were slightly more female respondents (51.5%) than male respondents. Despite the increasing trend of previous years, the younger age groups (18 to 34 yrs) were underrepresented while older age groups (45 to 65+ yrs) were somewhat overrepresented compared to the 2016 ABS census data (Figure 5.1). This highlights the need to shift to more modern technologies, such as the online survey. There was approximately twice as many respondents aged 18–24 yrs using the online survey compared to the CATI only survey. The online survey also showed a superior response rate and shorter average survey length—24.8% versus 5% and 17 minutes versus 21 minutes respectively—compared to the CATI only survey.

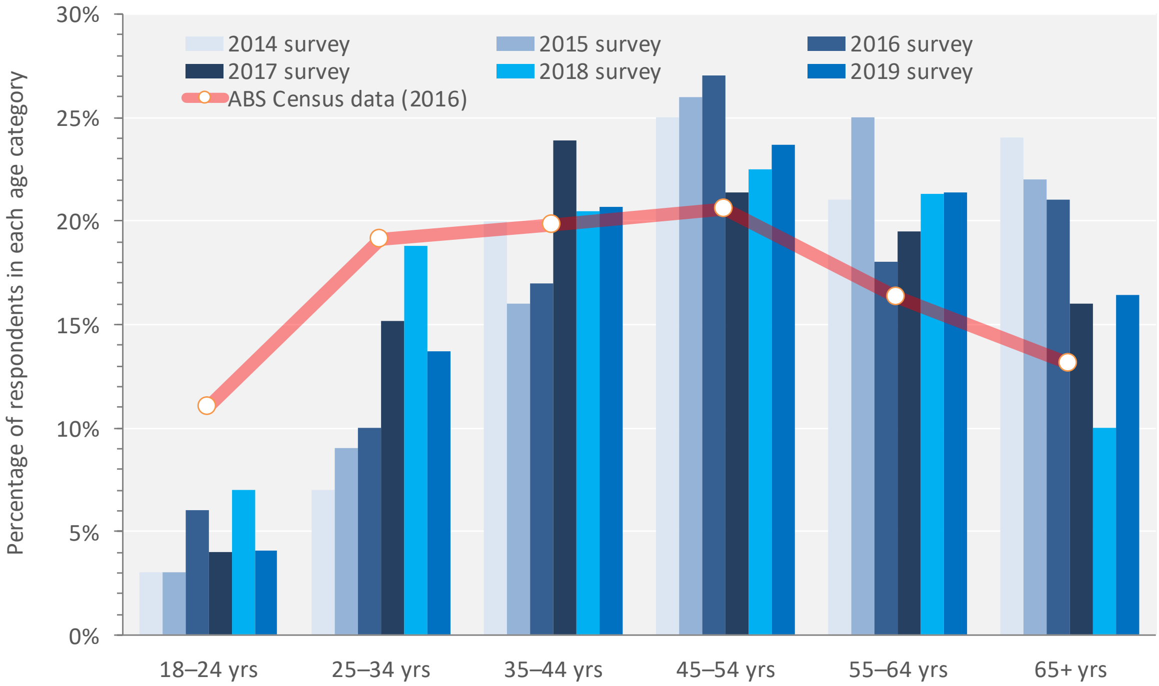


Figure 5.1: Distribution of age groups of the CATI participants since monitoring began in 2014.

In 2019, the highest annual income household bracket in Gladstone was two categories: $130,000–$181,999 and >$182,000. In 2014, 2015 and 2016 reporting years the highest representation was in the over $156,000 annual household income bracket (Windle et al., 2017) with $78,000–$103,999 being the highest representation in 2017 and 2018 (Windle et., 2018). The income brackets were changed during the 2016 ABS Census and now contain fewer categories (7 income categories) than the 2011 census (9 income categories).

In 2019 the majority of respondents own their home without a mortgage (36%) or with a mortgage (42%). The proportion of respondents renting decreased from 30% in 2018 to 22% in 2019, the same as in 2017.

Usage of the harbour for recreation, and boat ownership increased to 94% and 35% respectively in 2019. In 2018, usage of the harbour for recreation was 86% while boat ownership was 30%. Use of boat ramps has also shown a considerable increase, from 41% in 2018 to 51% in 2019.

The Traditional Owner representation in the 2019 CATI survey was 9%, somewhat lower than in previous years. This was higher than the representation of Indigenous residents in Gladstone who make up 4% of the population, based on 2016 ABS census data.

The overall score for the Social component in the 2019 Gladstone Harbour Report Card was 0.67 (B), which the same as previous year's score. 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 0.64 (C), harbour access a score of 0.67 (B) and liveability and wellbeing a score of 0.70 (B) (Figure 5.2). The scores for harbour access and liveability and wellbeing were identical to 2018 scores. The score for harbour 0.64 (C) in 2019 was similar to the 2018 score.

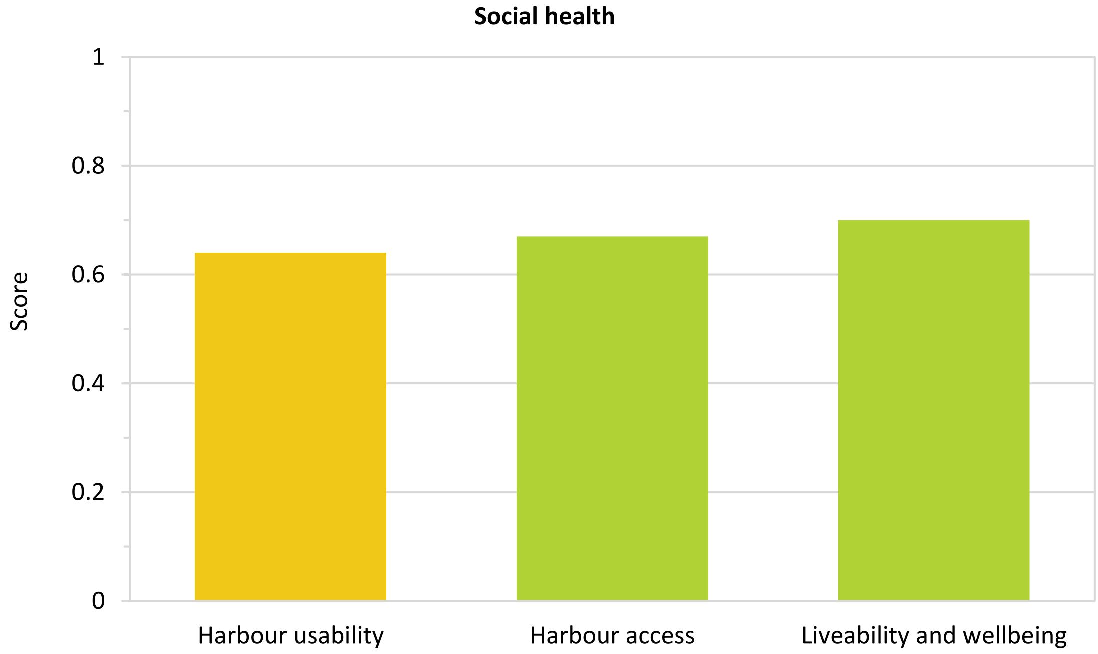


Figure 5.2: Indicator group scores within the Social component of harbour health in the 2019 Gladstone Harbour Report Card.

Harbour usability

The scores for the three indicators of harbour usability ranged from 0.58 (C) for *perceptions of air and water quality*, up to 0.63 (C) and 0.71 (B) for *perceptions of harbour safety for human use* and *satisfaction with harbour recreational activities* respectively (Figure 5.3). The overall score for the harbour usability has been relatively stable since monitoring began in 2014 (Figure 5.4).

Scores from two measures, *how satisfied with the last recreational trip* (0.74) and *quality of boat ramps and facilities* (0.67) 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 0.71 (B) was similar to the 2018 score.

The score for the *perceptions of air and water quality* indicator has steadily increased since monitoring began in 2014 0.46 (D) to 0.58 (C) in 2019. The three measure scores for this indicator remained broadly consistent to the previous year: *water quality satisfaction* was 0.58 (C), *air quality satisfaction* was 0.48 (D) and *water quality does not affect use of the harbour* was 0.67 (B).

The score for the *perceptions of harbour safety for human use* indicator improved for the third consecutive year and received a satisfactory score (0.63, C). This indicator has two measures based purely on the secondary data and another two based on satisfaction ratings from the CATI survey. *Marine safety incidents* was satisfactory 0.54 (C) while *oil spills* received a good score 0.66 (B)—a first for this measure and marked improvement on the 2017 score 0.38 (D). There were eight oils spills reported in the Gladstone maritime region in the current reporting year, with only two taking place within GHHP reporting zones. The other two measures in this indicator, *safety at night* and *happy to eat seafood*, scored similarly to 2018 and received 0.62 (C) and 0.68 (B) scores respectively.

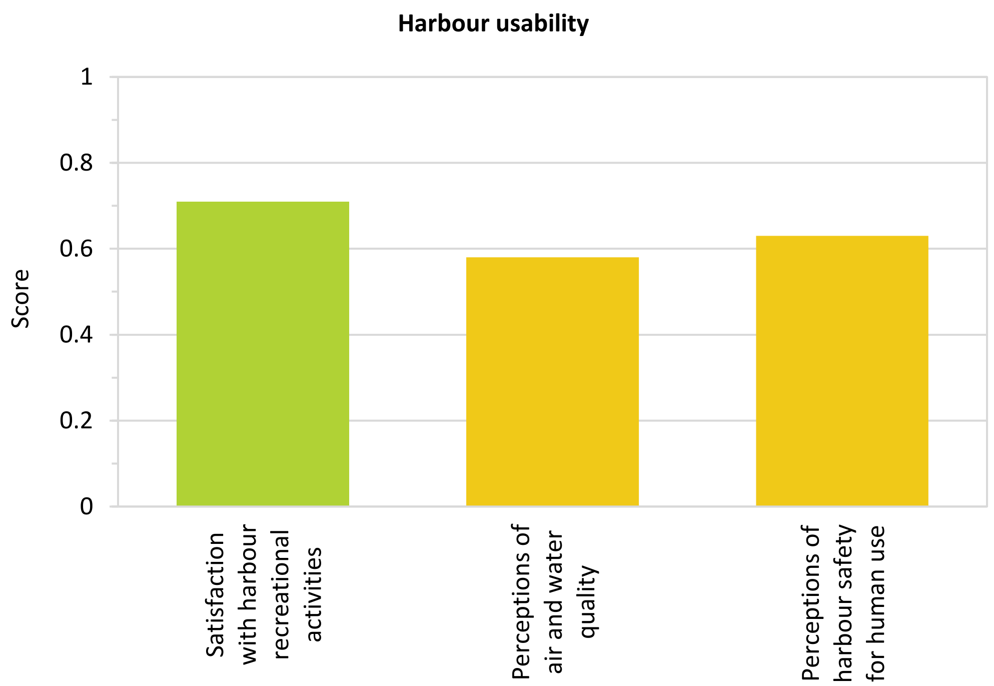


Figure 5.3: Scores for the three indicators of harbour usability in the 2019 Gladstone Harbour Report Card.

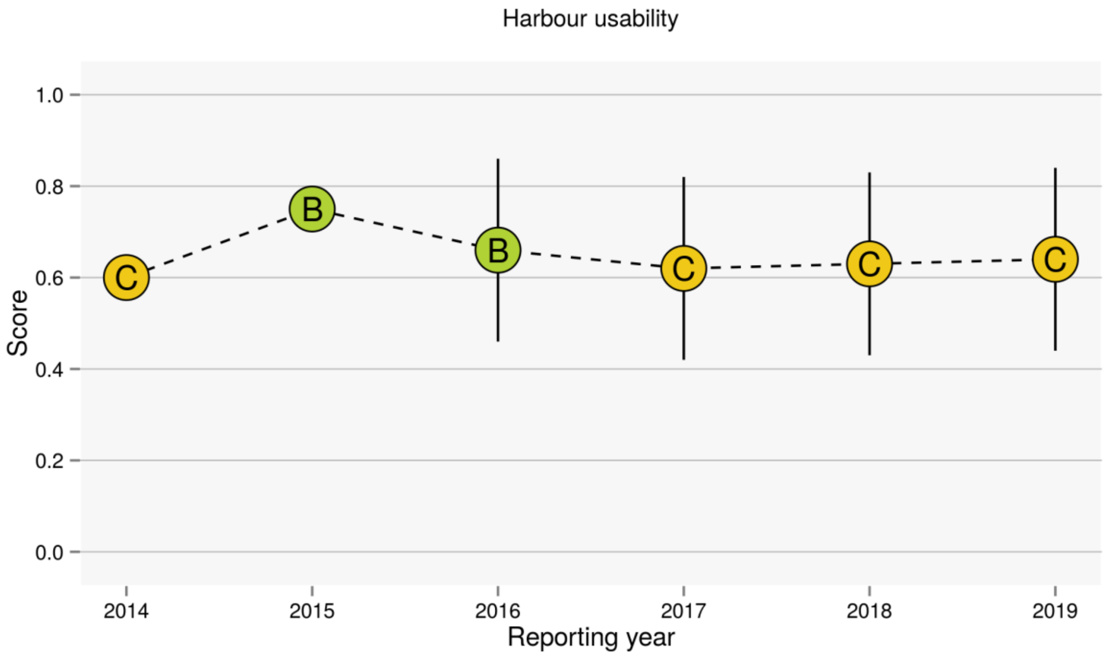


Figure 5.4: The trend of scores received for the harbour usability indicator group since year 2014. Please note an error in the 2014-2015 score which was reported at 0.75 instead of 0.65, hence there has been little real change from 2014-2015 to 2015-2016.

Harbour access

The scores for the four indicators of harbour access ranged from 0.63 (C) for *perceptions of harbour health* to 0.73 (B) for *satisfaction with harbour access* (Figure 5.5). *Satisfaction with boat ramps and public spaces* and *perceptions of barriers to access* both had good scores at 0.65 (B) and 0.66 (B) respectively. All four indicator scores were consistent with the previous year. Specifically, scores for *satisfaction with boat ramps and public spaces* showed a slight decrease while *perceptions of barriers to access* and *satisfaction with access to harbour* increased slightly, and *perceptions of harbour health* remain unchanged from 2018. Of the eleven measures used to report on the *harbour access* indicator group there were seven good scores (B), three satisfactory scores (C) and one poor score (D)—with *marine debris as a problem* scoring 0.48 (D).

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

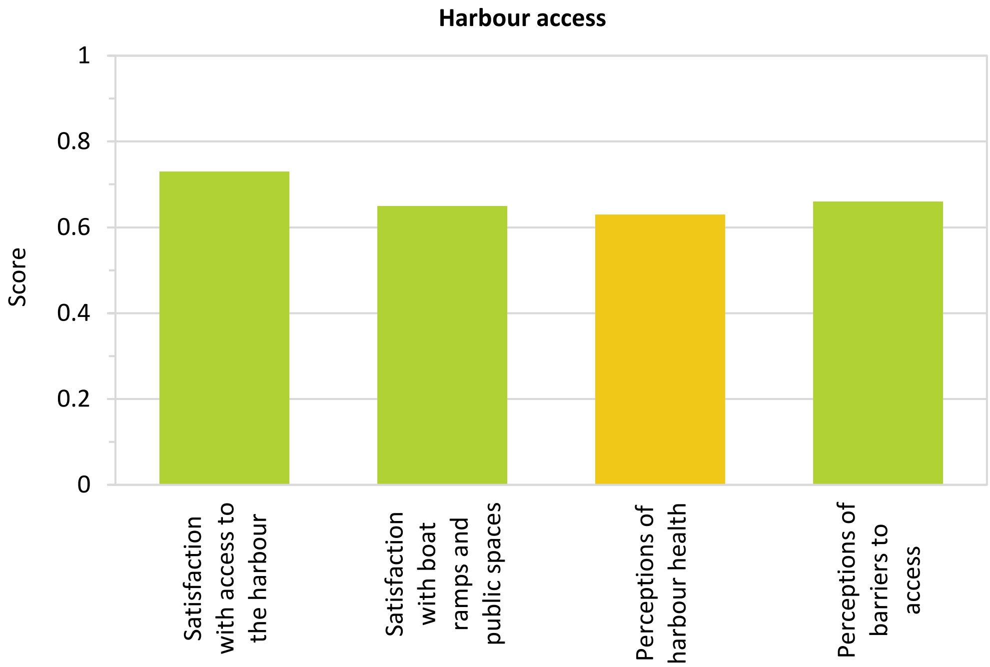


Figure 5.5: Scores for the four indicators of harbour access in the 2018 Gladstone Harbour Report Card.

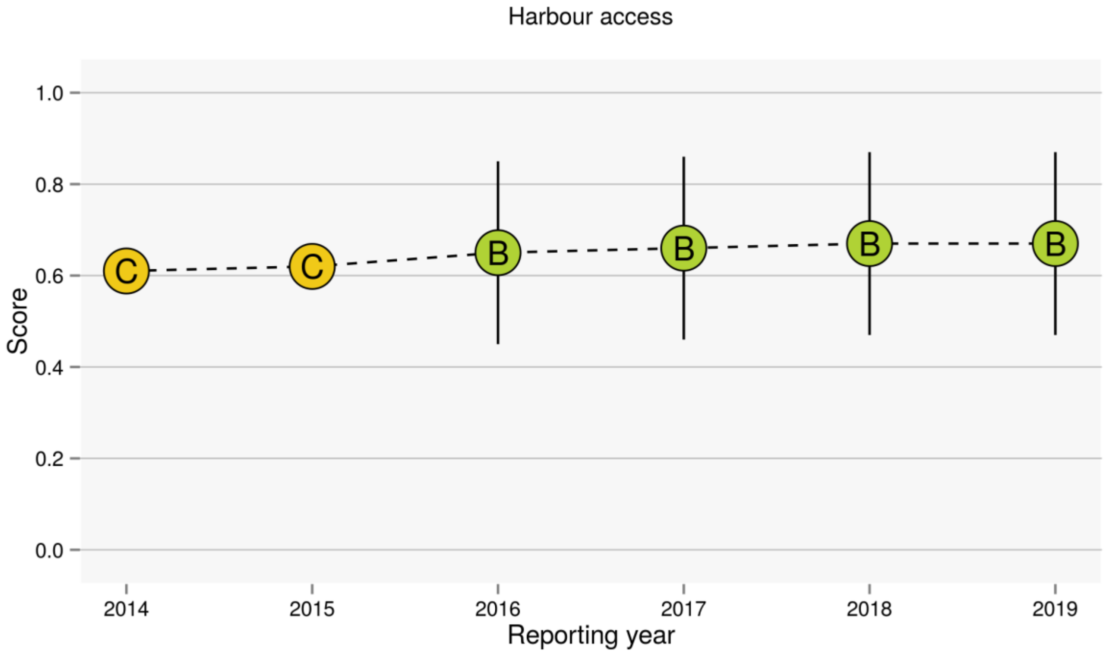


Figure 5.6: The trend of scores received for the harbour access indicator group since year 2014.

Liveability and wellbeing

The *contribution of the harbour to liveability and wellbeing* indicator was 0.70 (B). 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). In 2018, a new measure *aesthetic value* also contributed to the overall score, improving it from 0.66 to 0.70 (B) in 2019. The overall score has increased since monitoring began in 2014 (Figure 5.7).

There were four survey questions used to assess the liveability and wellbeing indicator group—G*ladstone Harbour makes living in Gladstone a better experience*, *I regularly participate in community events in the Gladstone Harbour area,* and two more related to the *aesthetic value* measure. For the first question about 89% of respondents implied they were satisfied, responding with a score of 6 and above, indicating that Gladstone Harbour makes living in Gladstone a better experience. The rate of satisfied respondents has steadily increased since 2014 (90% in 2018, 86% in 2017, 87% in 2016, 70% in 2015). Scores for the second question improved from 0.52 in 2018 to 0.56 (C) in 2019, indicating increased participation with community events in the Gladstone area. About 88% and 85% of respondents respectively implied they were satisfied with the aesthetic value of the harbour area, responding with a score of six or above for the relevant questions: *I enjoy going to the harbour because it is beautiful to look at* and *I enjoy going to the harbour because of its natural beauty*.

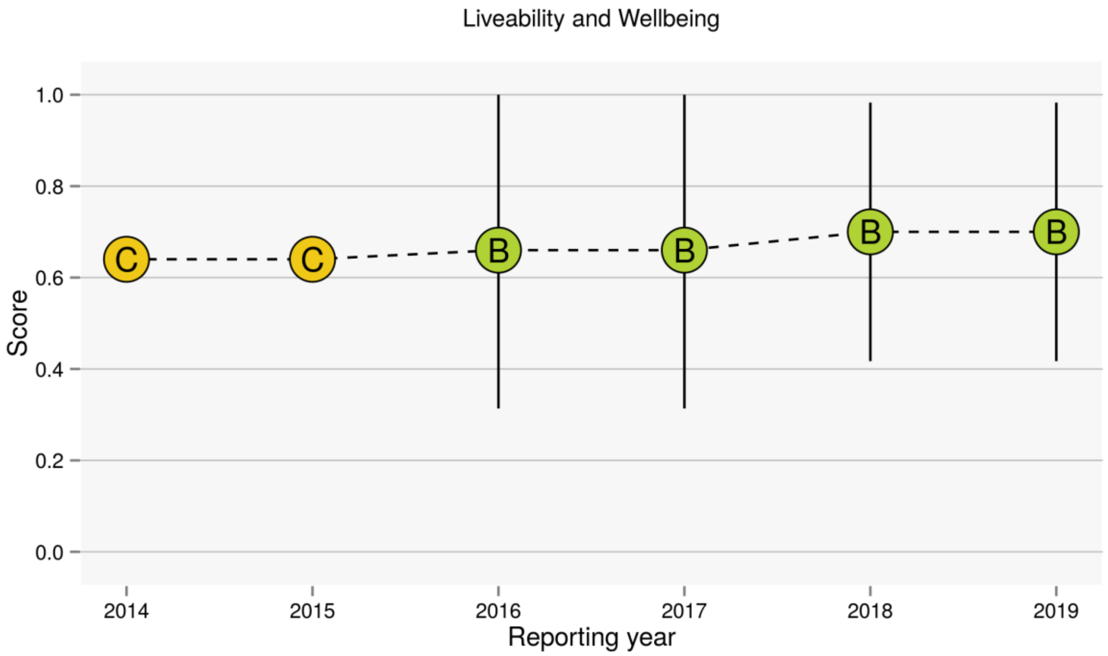


Figure 5.7: The trend of scores received for the liveability and wellbeing indicator group since year 2014. Scores prior to 2018 were based on two measures. The third measure *aesthetic value* was added to the indicator group in 2018.

Word-cloud analysis

First three words

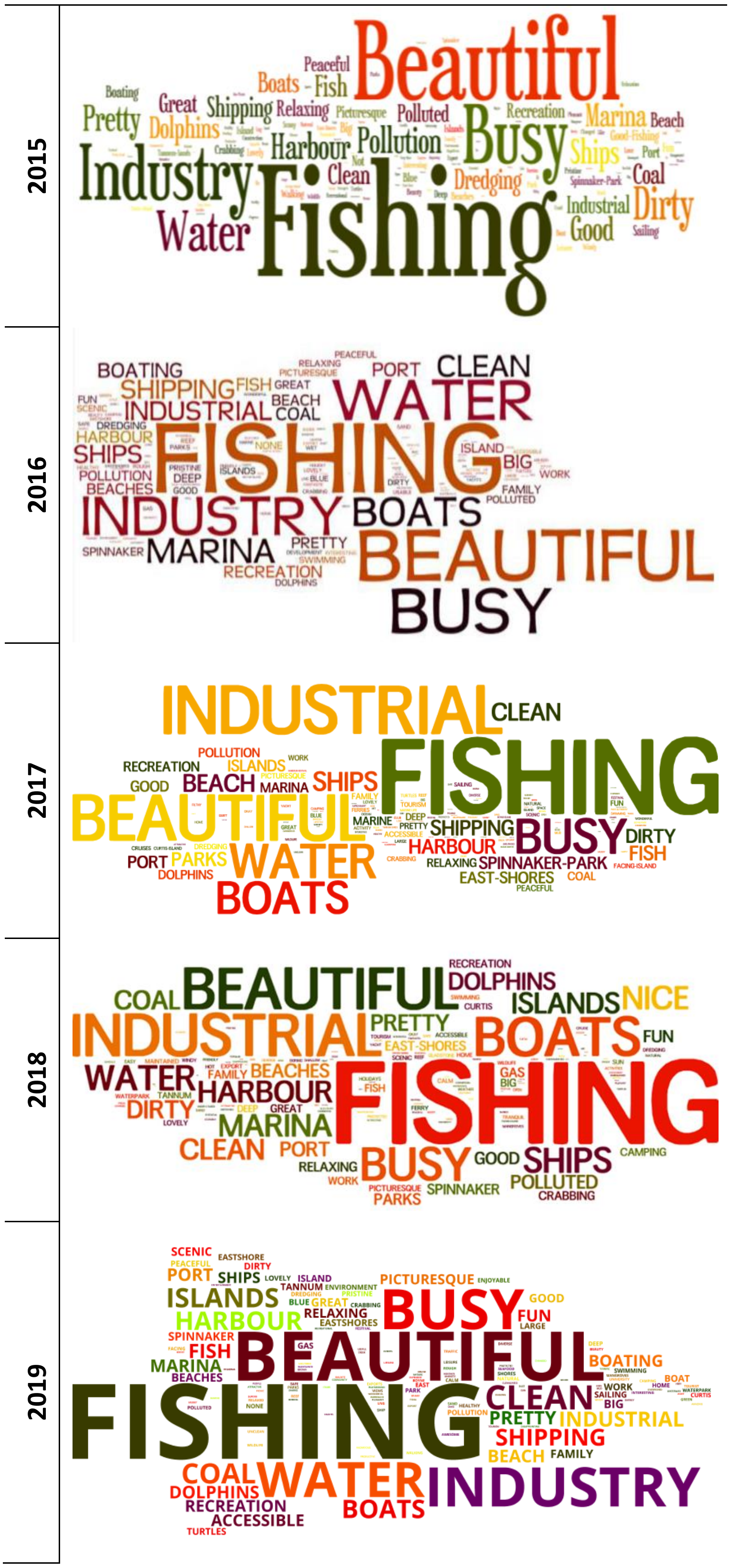


Figure 5.8: Word-cloud analysis of the three words provided by CATI respondents to the question—*when you think of the Gladstone Harbour Area, what are the first three words that come to mind*.

The most frequent three words used to describe the Gladstone harbour area in 2019 remained similar to previous reporting years. The sizes of the words relate to the word frequency when participants responded to the CATI survey.

Overall, the responses indicate that most respondents continue to perceive the harbour area positively as the words ‘fishing’, ‘beautiful’, ‘industry’ and ‘busy’ were prominent in all five years.

The CATI respondents continue to use words such as ‘nice’, ‘great’, ‘pretty’ and ‘clean’ to indicate a positive association with the harbour. These words are more prevalent than words with potentially negative associations such as ‘polluted’, ‘dirty’ and ‘coal’.

5.4. Social indicator conclusions

The overall Social health of the harbour has been gradually increasing since the pilot year, indicating that the Gladstone community continue to enjoy the harbour (Table 5.2). The overall score remained unchanged from 2018 and was similar to that in 2016 and 2017. The Social component has received a good score (B) for the fourth consecutive year (Figure 5.9).

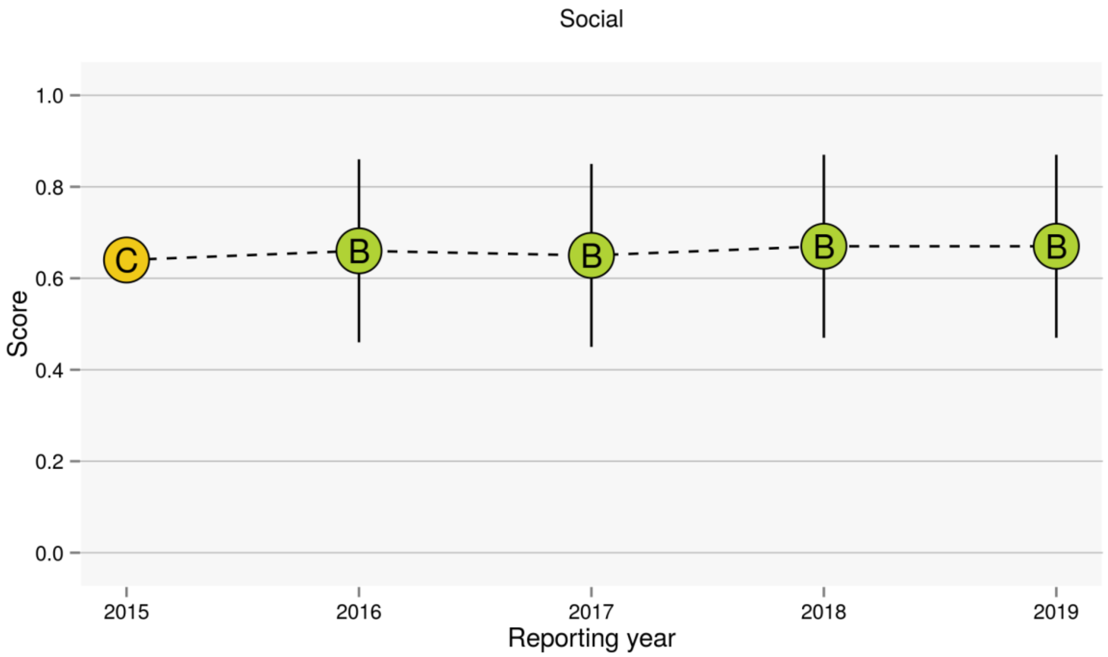


Figure 5.9: Report card scores for the Social component from 2015 to 2019.

Harbour usability

Overall, the harbour usability score improved since 2015.

The harbour usability scores have fluctuated between satisfactory and good scores since monitoring began in 2014. This year, the indicator improved slightly compared to 2018 and maintained its score as satisfactory. In 2019 the *air quality satisfaction* measure had the lowest score amongst the other measures within this indicator. This measure has consistently received a low score since 2014. On the other hand, *satisfaction with the last recreational trip* has received a good score since monitoring began. This measure was also the highest score 0.74 (B) when compared to other measures within this indicator group. The *marine safety incidents* measure remained unchanged while *oil spills* reported for the Gladstone Maritime Region declined for the second year—from 11 in 2017 to 8 in 2019. The 10-point increase in score resulted in a good score for the *oil spills* measure.

Similar to the past two years, 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 four years.

The 2019 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.

Generally, people living in the Gladstone Region feel that the harbour provides them with a positive living experience and quality of life. Many residents continue to participate in community events, such as The Gladstone Harbour Festival, Eco-Fest and Boyne-Tannum Hook Up, that are held in and around the harbour area. Overall, respondents enjoyed going to the harbour because of its natural beauty.

Table 5.2: Social indicator group and indicator scores of reporting years.

	2019	2018	*2017*	*2016*	*2015*	*2014*
Harbour usability	0.64	*0.63*	*0.62*	*0.66*	*0.65* [a]	*0.60*
Satisfaction with harbour recreational activities	0.71	*0.70*	*0.69*	*0.67*	*0.69* [b]	*0.70*
Perceptions of air and water quality	0.58	*0.58*	*0.56*	*0.55*	*0.52*	*0.46*
Perceptions of harbour safety for human use	0.63	*0.61*	*0.60*	*0.76*	*0.72*	*0.38*
Harbour access	0.67	*0.67*	*0.66*	*0.65*	*0.62*	*0.61*
Satisfaction with access to the harbour	0.73	*0.72*	*0.72*	*0.69*	*0.68*	*0.67*
Satisfaction with boat ramps and public spaces	0.65	*0.66*	*0.65*	*0.64*	*0.62*	*0.60*
Perceptions of harbour health	0.63	*0.63*	*0.63*	*0.62*	*0.58*	*0.53*
Perceptions of barriers to access	0.66	*0.65*	*0.65*	*0.65*	*0.61*	*0.64*
Liveability and wellbeing	0.70[C]	*0.70*[C]	*0.66*	*0.66*	*0.64*	*0.64*
Overall score	**0.67**	***0.67***	***0.66***	***0.66***	***0.64***	***0.58***

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

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

[c] Liveability and wellbeing score was determined with an additional measure 'aesthetic value'.

6. 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 2019 the Indigenous cultural heritage scores are those used in the 2018 report card and the overall Cultural component score is aggregated from the 2019 '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'.

6.1. 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 6.1. 'sense of place' was employed as a broad construct and it is assumed to incorporate elements of both place identity and place attachment (Twigger-Ross & Uzzell, 1996). 'Sense of place' may also be useful for exploring community stewardship.

Indigenous cultural heritage

Field data for the Indigenous cultural heritage indicator group were collected through a series of field surveys at Facing Island and Gladstone Central completed in July 2018 (Table 6.2). The Wild Cattle Creek zone was not resurveyed in 2018. However, two sites in The Narrows were assessed. The physical condition related indicators were assessed at site level, whereas the indicators related to the management strategy were assessed at zone level.

Sites are referred to as areas of concentrated group-of-heritage features within the landscape. One or more monitoring stations are established as key locations within sites from which the heritage features heritage elements and non-heritage features are monitored (Terra Rosa, 2018). Overall, 11 sites were revisited in 2017–18 (Table 6.2).

Table 6.1: Indicator groups, indicators and measures used to determine cultural scores for the 2019 Gladstone Harbour Report Card.

Indicator group	Indicators	Measures	Data source	Baseline
'Sense of place'	Place attachment	No place better	CATI survey	10-point scale
		Who am I	CATI survey	10-point scale
	Continuity	How long lived in the area	CATI survey	Proportion of life lived in the area (0–100%)[a]
		Plan to be a resident in the next five years	CATI survey	10-point scale
	Pride in the region	Feel proud living in Gladstone	CATI survey	10-point scale
	Well being	Quality of life	CATI survey	10-point scale
		Input into management	CATI survey	10-point scale
	Appreciation of the harbour	Key part of the community	CATI survey	10-point scale
		Great asset to the region	CATI survey	10-point scale
		Great asset to Queensland	CATI survey	10-point scale
	Values	Variety of marine life	CATI survey	10-point scale
		Opportunities for outdoor recreation	CATI survey	10-point scale
		Attracts visitors to the region	CATI survey	10-point scale
		Enjoy scenery and sights	CATI survey	10-point scale
		Spiritually special places	CATI survey	10-point scale
		Culturally special places	CATI survey	10-point scale
		Historical significance	CATI survey	10-point scale
Indigenous cultural heritage	Physical condition	Intactness of site features	Field survey	10-point scale
		Extent of current disturbance	Field survey	10-point scale
		Management of threats	Field survey	10-point scale
	Management strategies	Recording	Field survey	10-point scale
		Cultural management	Field survey	10-point scale
		Stakeholders	Field survey	10-point scale
		Monitoring	Field survey	10-point scale
		Access	Field survey	10-point scale
		Cultural resources	Field survey	10-point scale

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

Data collection involved recording the health of various heritage aspects relevant to Cultural health (e.g. knapping floor, chopper tools, signage, gravestones and monuments) in relation to pre-defined criteria (Terra Rosa, 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 6.2: 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**

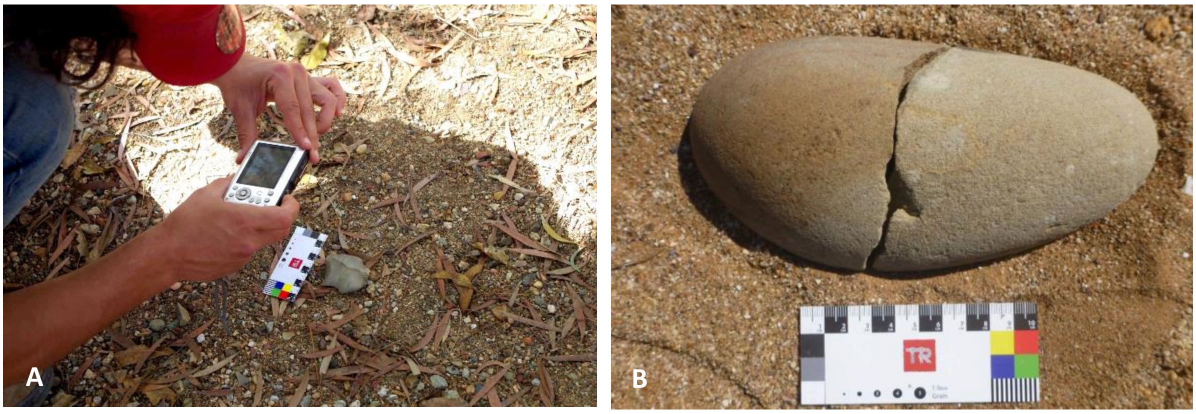


Figure 6.1: A – Photographing site features, B – Grinding stone at Facing Island (Source: Terra Rosa, 2018)

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 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 6.2). 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.

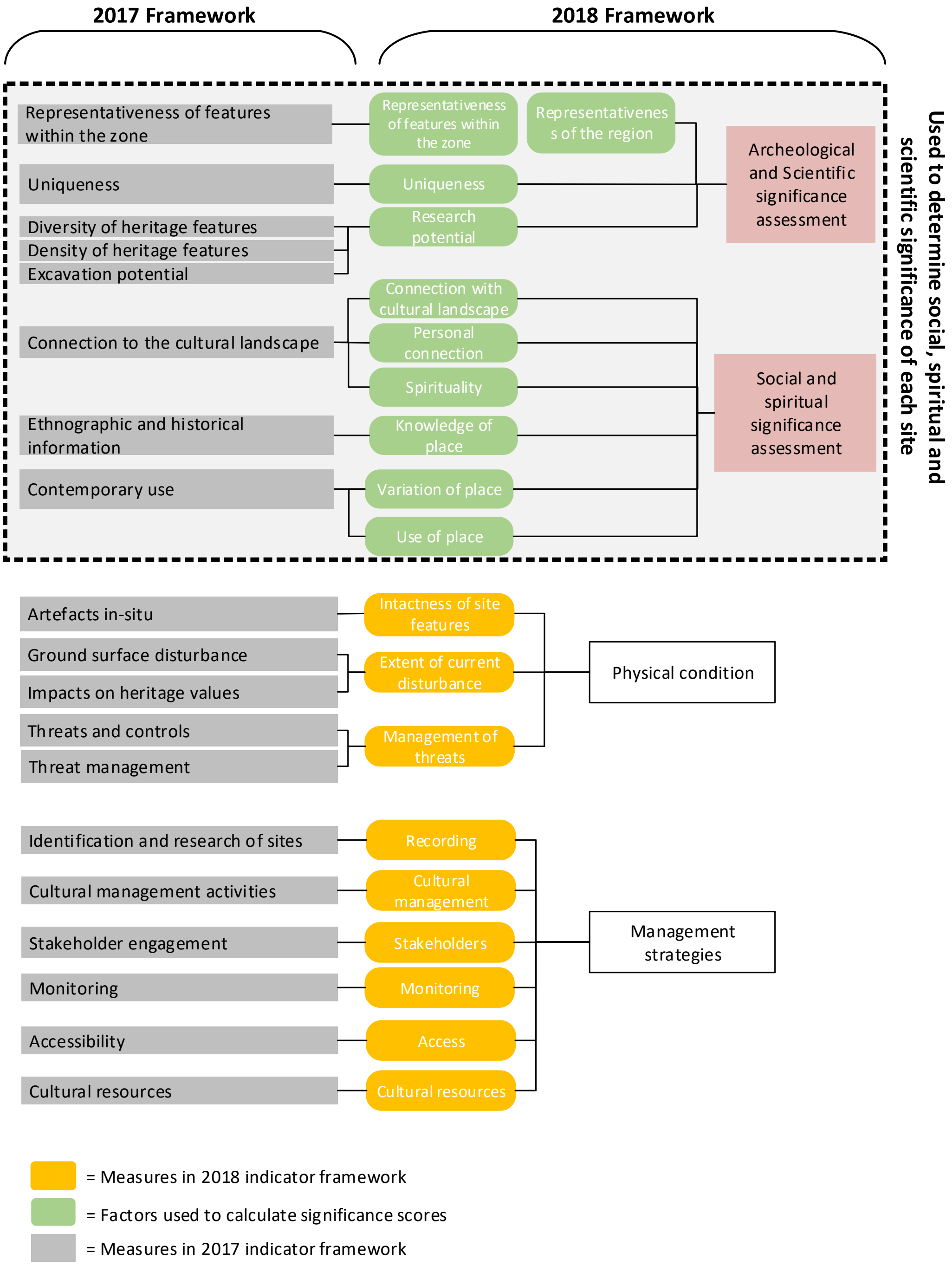


Figure 6.2: 2017 Indigenous cultural health indicators are mapped to the 2018 indicator framework. Two measures which were in the 2017 framework—site registration and developmental pressure measures—are no longer assessed in the 2018 framework.

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.

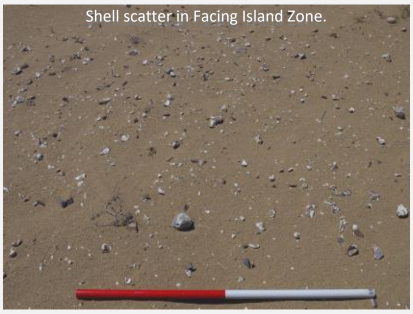
What are heritage elements and heritage features?

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.

6.2. 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 2018 for details of the criteria). GHHP grading thresholds were only applied to aggregated scores.

The indicators under physical condition were weighted on a spatial scale. The processes involved determining the social, spiritual and scientific significance of all sites based on 10 factors (see green boxes in Figure 6.2). 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, 2018).

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

Data aggregation was done using simple averages.

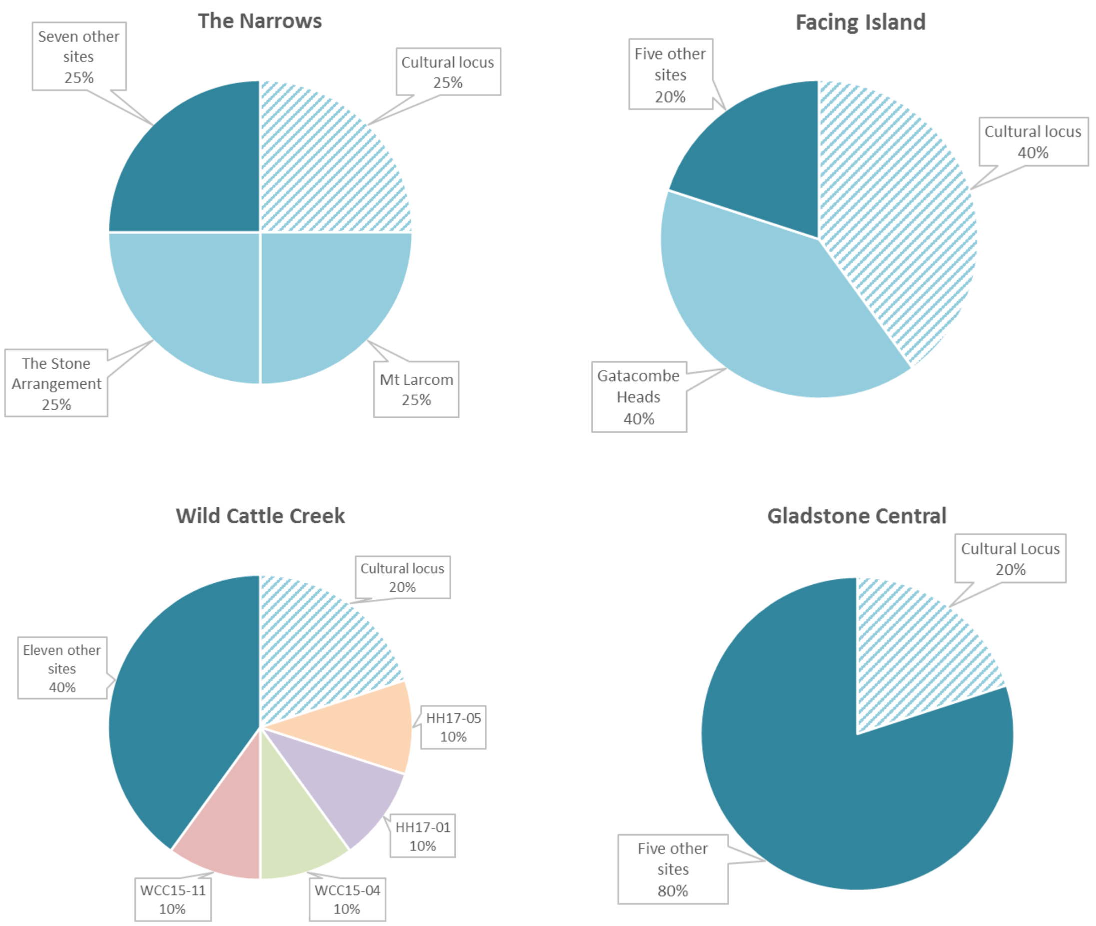


Figure 6.3: Weightings derived from ethnographic consultation for cultural locus and other sites within each zone for Cultural health indicators.

6.3. Results

The overall score for the Cultural component of the Gladstone Harbour Report Card for 2019 was 0.60 (C). This comprised two indicator groups, 'sense of place' assessed on new data for 2019 and Indigenous Cultural health (Figure 6.4) which uses the 2018 report card scores. 'Sense of place' received a score of 0.66 (B) and Indigenous cultural heritage received a score of 0.54 (C).

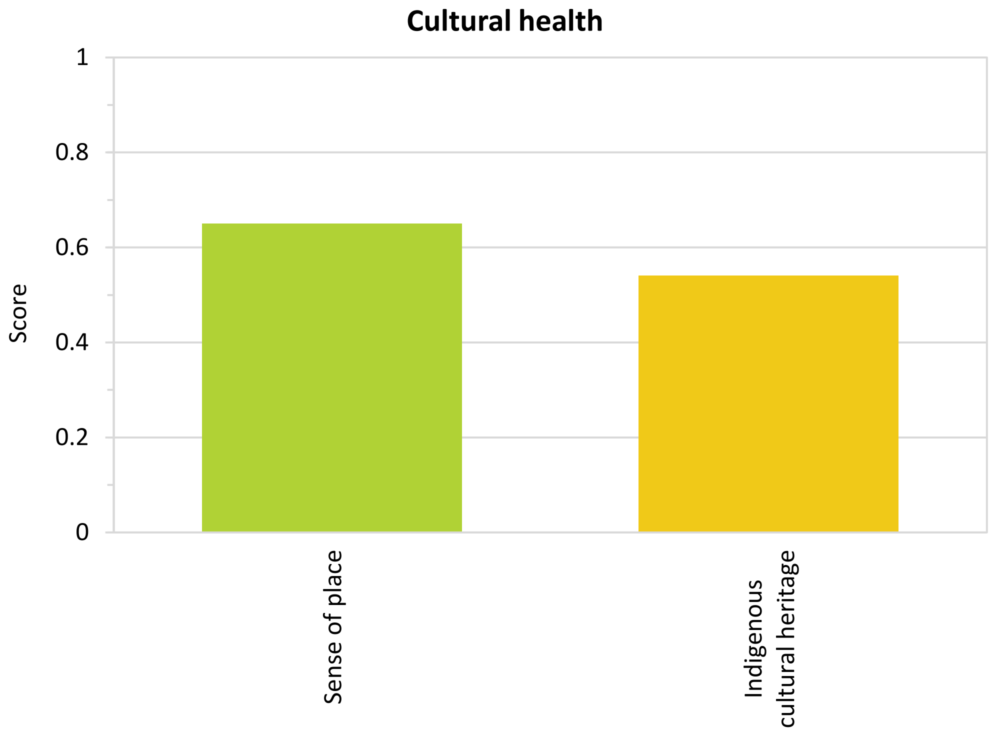


Figure 6.4: Indicator group scores within the Cultural component of the 2019 Gladstone Harbour report card.

'Sense of place'

The 'sense of place' indicator scores ranged from 0.58 (C) for place attachment and continuity to 0.83(B) for appreciation of the harbour (Figure 6.5). All scores were similar to those recorded in 2018.

The highest score of 0.83 (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* – 0.82 (B) and *great asset to Queensland* – 0.81 (B)). The lowest score of 0.53 (C) for continuity was influenced by a low score (*how long lived in the area* – 0.41 (D)) and a high score (*plan to stay the next 5 years* – 0.65 (B)).

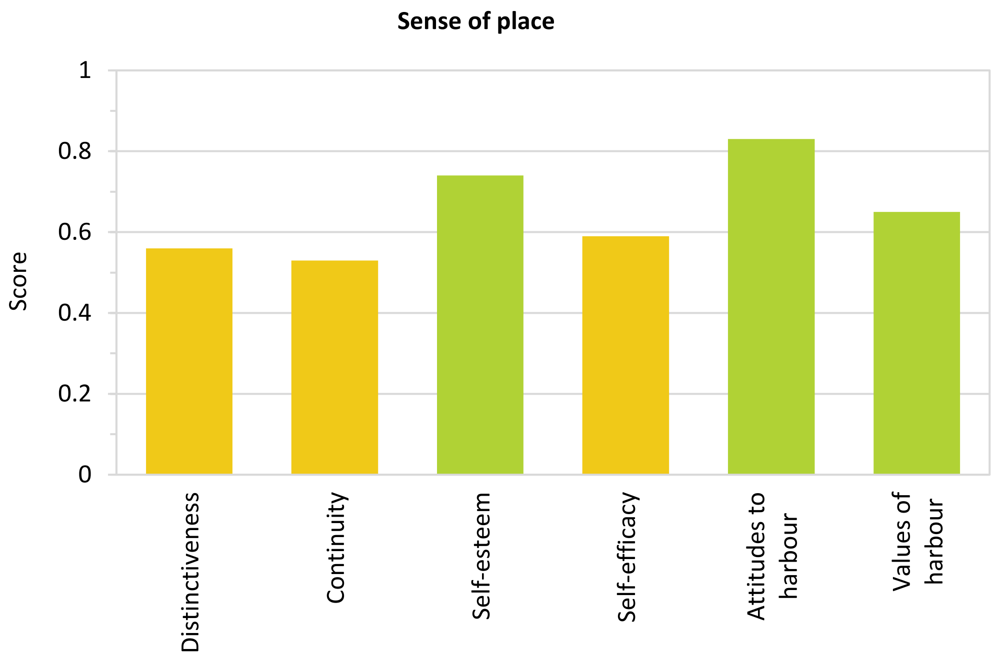


Figure 6.5: Indicator scores for 'sense of place' indicator group used for Cultural health in the 2018 Gladstone Harbour Report Card.

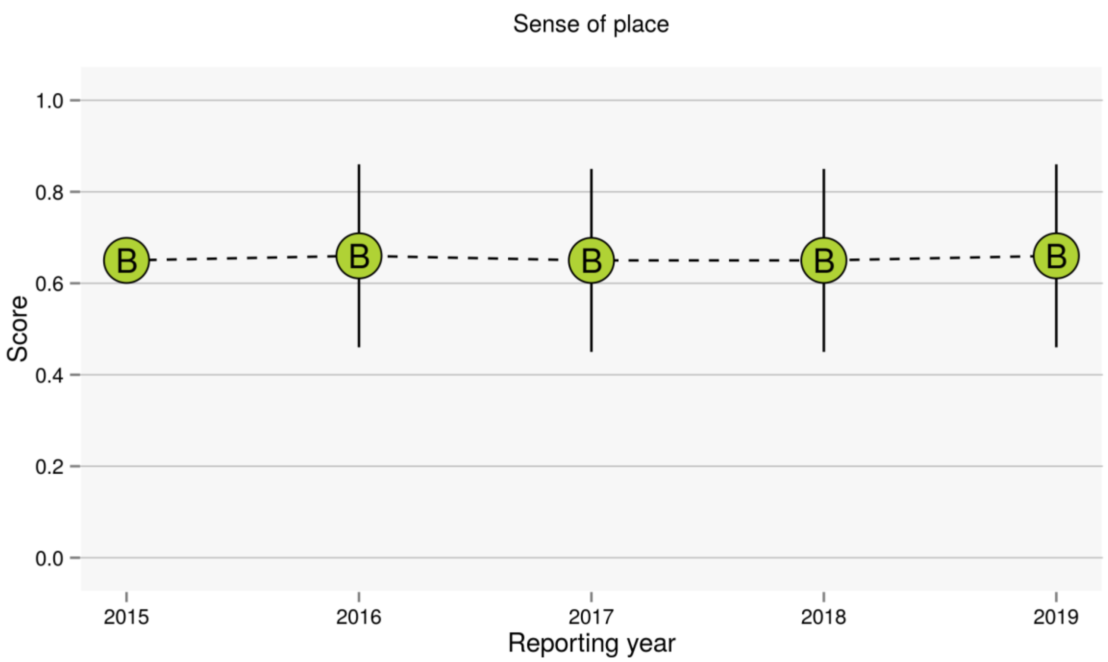


Figure 6.6: Report card scores for the 'sense of place' indicator group from 2015 to 2019.

Indigenous cultural heritage

The overall score for Indigenous cultural heritage was 0.54 (C) and very similar to the 2017 score of 0.55 (C). This score is based on the satisfactory scores received for physical condition (0.56, 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 6.7).

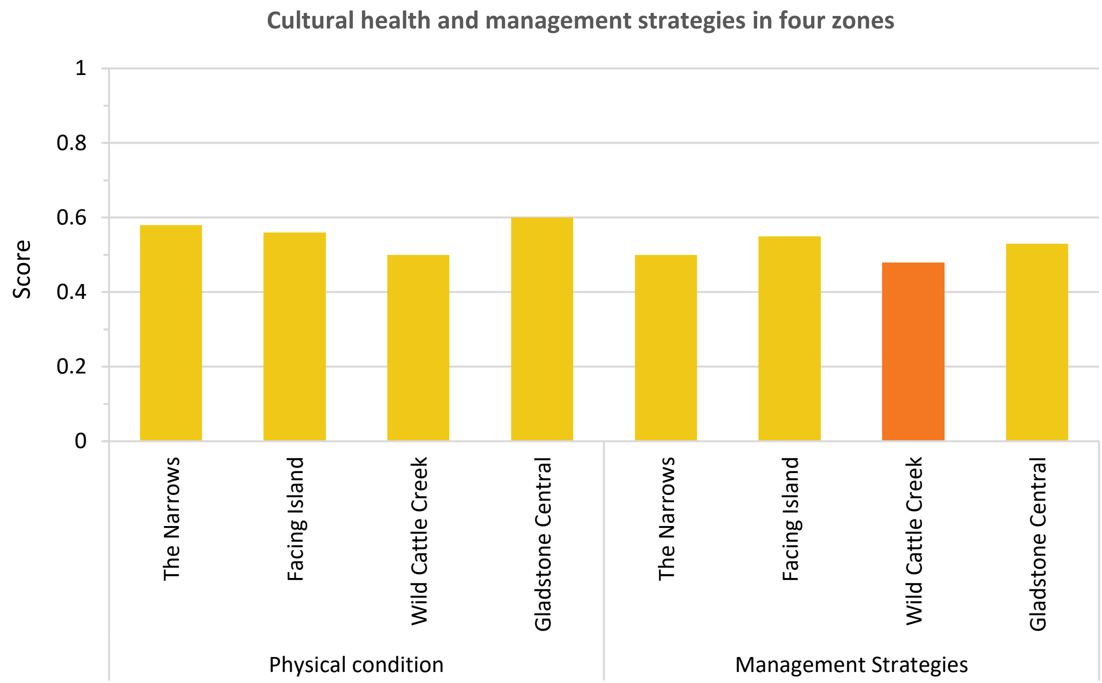


Figure 6.7: Indicator scores for physical condition and management strategies across four reporting zones in the 2018 Gladstone Harbour Report Card.

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

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

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

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

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

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

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

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

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

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

6.4. Cultural indicator conclusions

'Sense of place'

Overall the score for 'sense of place' was 0.66 (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 and 0.65 in 2018) (Table 6.5). This result suggests that the community's expectations of Gladstone Harbour area are mostly being met.

The 2019 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 and was similar to the score received in 2014. This indicator measures the length of time people have lived in the area and whether they planned to stay for the next five years. Low scores for the former indicate that many respondents had not lived in Gladstone all their lives (25% of respondents have lived in Gladstone for 1 to 9 years). However, 51% of respondents indicated that they intended to remain in Gladstone for the next five years, suggesting that the community is becoming less transient and more stable.

The score for appreciation of the harbour remains the highest scoring indicator (0.83) 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 well-being indicator has increased steadily from 2015 to 2019 indicating that residents continue to feel their quality of life is improving. The community input into management measure received a satisfactory score, similar to the previous year.

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

Indicator group	'Sense of place'	2019	*2018*	*2017*	*2016*	*2015*
Indicators	Place attachment	0.58	*0.56*	*0.57*	*0.59*	*0.55*
	Continuity	0.58	*0.53*	*0.54*	*0.59*	*0.57*
	Pride in the region	0.74	*0.74*	*0.72*	*0.74*	*0.72*
	Well-being	0.61	*0.59*	*0.58*	*0.58*	*0.56*
	Appreciation of the harbour	0.83	*0.83*	*0.81*	*0.81*	*0.8*
	Values	0.66	*0.65*	*0.66*	*0.66*	*0.64*
Overall score		**0.66**	***0.65***	***0.65***	***0.66***	***0.65***

Indigenous cultural heritage

The Indigenous cultural heritage indicator framework was revised for the 2018 report card. The overall 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 6.6).

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 6.6: Overall scores for Cultural component.

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

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

7. The Economic component

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

7.1. Data collection

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

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

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

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

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

Overall, the data collection and analytical techniques remained the same for all economic indicators as the 2018 reporting year. To improve the quality of the indicator framework, minor modifications were made by:

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

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

- Adding a new indicator 'water-based recreation' to the economic value (recreation) indicator group in 2018.

Table 7.1: Data sources and baselines employed to derive the economic scores for the 2019 Gladstone Harbour Report Card (Source: De Valck et al., 2019).

Indicator group	Indicator	Measure	Data source	Baseline
Economic performance	Shipping activity	Shipping activity productivity calculated from monthly shipping movements by cargo type (2018–19 financial year)	Gladstone Ports Corporation	10-year average 2009–19
	Tourism expenditure	Gladstone Region's total tourism expenditure output (2017–18 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 2008 to 2018
	Commercial fishing	Productivity of net (fish) fisheries Productivity of trawl (otter) fisheries Productivity of pot (mud crabs) fisheries	**Production (fishing effort)** Queensland Fishing (QFish), Queensland Department of Agriculture and Fisheries **Prices (fish, prawns & crabs)** ABARES – Australian fisheries and aquaculture statistics 2017 (published Dec 2018)	10-year average 2009 to 2019
Economic stimulus	Employment	Gladstone LGA unemployment data (2019 March quarter)	Australian Department of Employment, *Small Area Labour Markets*	Queensland 2019 distribution (March quarter)
	Socio-economic status	Index of Economic Resources derived from 2016 ABS census and updated using the community CATI survey	CATI survey; Australian Bureau of Statistics, 2016 census and ABS (2018)	Australian 2016 distribution
Economic value (Recreation)	Land-based recreation	Land-based recreation satisfaction and economic value	Satisfaction from CATI survey and economic value from Pascoe et al., 2014	10-point scale
	Recreational fishing	Recreational fishing satisfaction and economic value	Satisfaction: CATI survey and 2018 updated economic value (Cannard et al., 2015; Windle et al., 2018)	10-point scale
	Beach recreation	Beach recreation satisfaction and economic value	Satisfaction: CATI survey and 2019 updated economic value	10-point scale
	Water-based recreation	Water-based recreation satisfaction and economic value	Satisfaction from CATI survey and economic value from Windle et al., 2017	10-point scale

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

7.2. Development of indicators and 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).

A 10-year baseline data from 2009 to 2019 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. Similar to the previous year, the tourism indicator was supplemented with expenditure made by passengers and crew members of six (four in previous years) cruise ships docked at Gladstone port in the 2017–18 financial year.

CAPACITY UTILISATION

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

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

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

$$= 50\%$$

DATA ENVELOPMENT ANALYSIS (DEA)

The DEA or frontier analysis is a tool developed in 1978 by Charnes, Cooper and Rhodes as a technique to measure the performance or relative efficiency of organisations such as banks, hospitals and schools. During the analysis, a reference is set, including the best-performing organisations, which is called 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 2009. Production figures come from the three grids, but prices are Queensland state-wide estimates (Figure 3.29 in Section 3.2).

Commercial fishers operating in Queensland's state-managed fisheries are required to complete daily catch and effort logbooks. These logbooks enable fishers to record approximately where, when and how fishing took place, and what was caught. Catch-and-effort data are available from the QFish database maintained by Queensland Department of Agriculture and Fisheries. Those data are recorded from 30 x 30 nautical mile grids and therefore provide only a very general indication of the location of fishing activity. Fishing production data collected from Grid S30 was used as the primary data source for the commercial fishing indicator. This covers most of the Gladstone Harbour and open coastal waters immediately adjacent to the harbour (Figure 3.29). The data for April–June was not included in the analysis for the 2018–19 monitoring year as this information was not available at the time of report preparation.

The total value of commercial fishing was estimated based on catch data by fishing method data from the QFish database and average prices for each species group (fish, prawns and crabs) was derived from the most recent Australian fisheries and aquaculture statistics published by ABARES statistics (Mobsby, 2018).

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 2019 March quarter.

The score for socio-economic status was derived using the IER which is a composite measure of the economic wellbeing of a community. It takes into account 14 variables including income extremes (both high and low) in a population, household ownership, cost of living and other indicators relevant to economic wellbeing in the community. The IER was calculated using 2016 Australian census data. A system of weightings (ABS, 2018) for the variables and estimates for the Gladstone Region were further refined using data collected through the CATI survey. The IER for Gladstone is compared with the IER for other LGAs in Australia to generate a report card score.

Economic value (Recreation)

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

Two components of the recreational values can be assessed:

- The commercial value of the recreation and tourism (estimated based on financial records of commercial tourist operators).
- The non-market value (value associated with residents who use the harbour for 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 439 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).

7.3. Results

The scores for each of the three economic indicator groups ranged from satisfactory to very good yielding an overall score of 0.72 (B) for the Economic component of the 2018 Gladstone Harbour Report Card (Figure 7.2). Of those indicator groups, economic performance received the highest score of 0.90 (A), economic value of recreation received a score of 0.76 (B) and economic stimulus received a score of 0.58 (C).

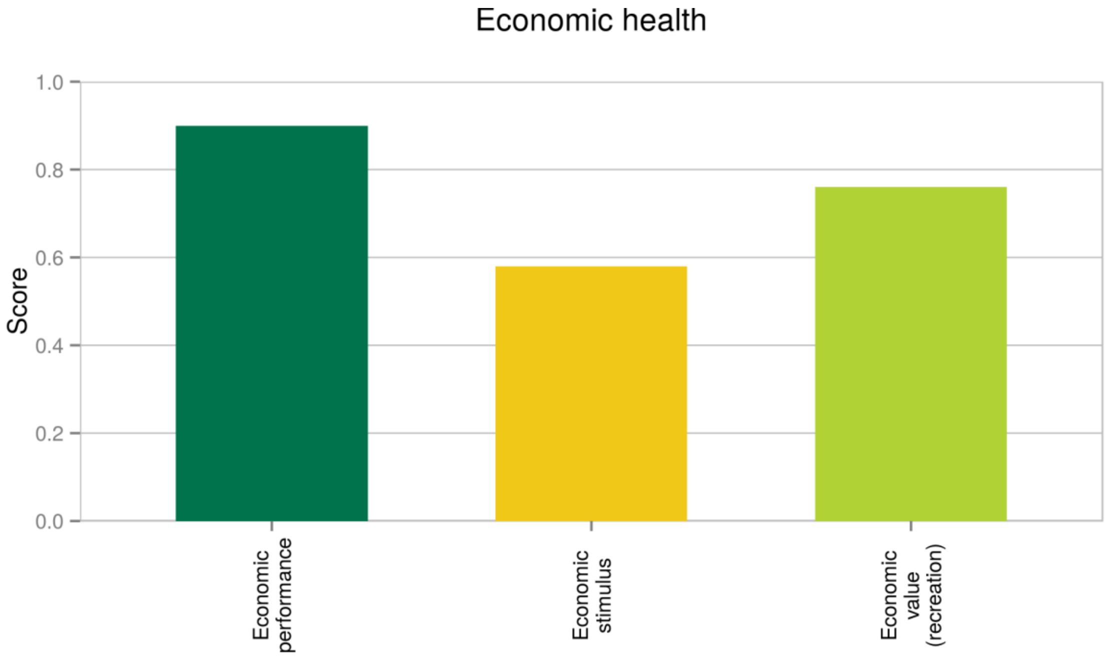


Figure 7.2: The scores for each of the three economic indicator groups in the 2018 Gladstone Harbour Report Card.

Economic performance

The economic performance of Gladstone Harbour remains in very good state (0.90, A) in 2019, a score that was identical to the 2018 score.

Within the economic performance indicator group, shipping activity received the highest score 0.90 (A) (0.90 in 2018) followed by tourism 0.90 (A) (0.90 in 2018). The commercial fishing received the lowest score of 0.36 (D) (0.35 in 2017) (Figure 7.3).

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 7.4).

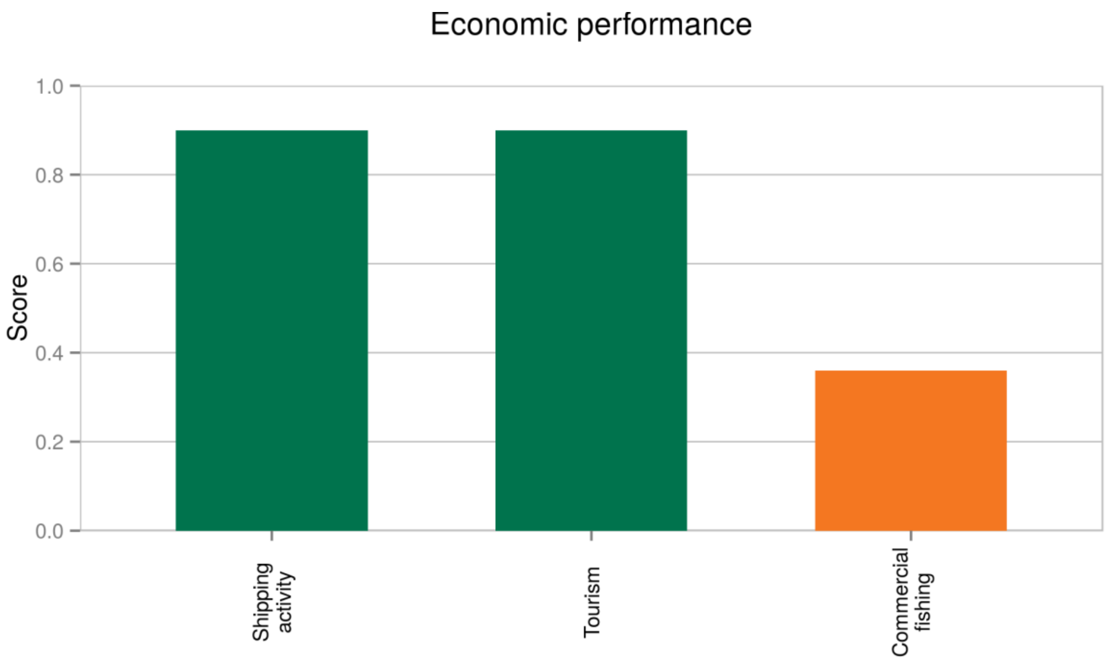


Figure 7.3: Scores for the three indicators of economic performance in the 2018 Gladstone Harbour Report Card.

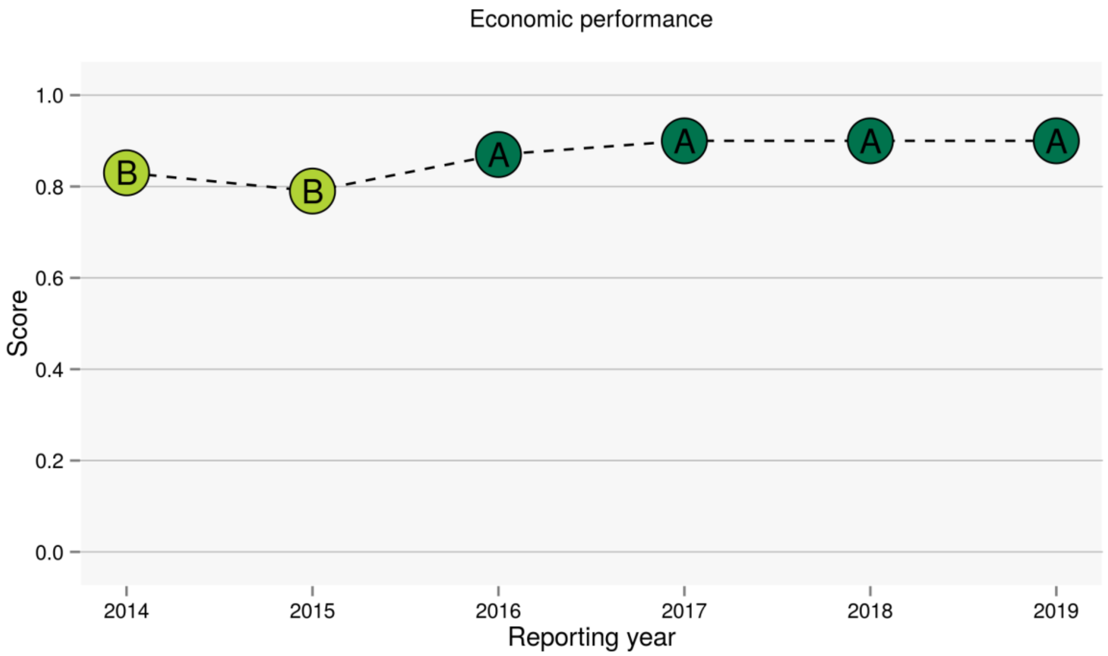


Figure 7.4: Economic performance scores from the 2014 to 2019.

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 2018. The total income generated by the Gladstone Ports Corporation in 2017–18 was $483 million, an increase from $471 million in 2016–17 and $453 million in 2014–15.

Shipping activity continues to be dominated by coal exports but in the last three years there has been more variation in activity compared with LNG and alumina exports which have been more stable (Figure 7.5).

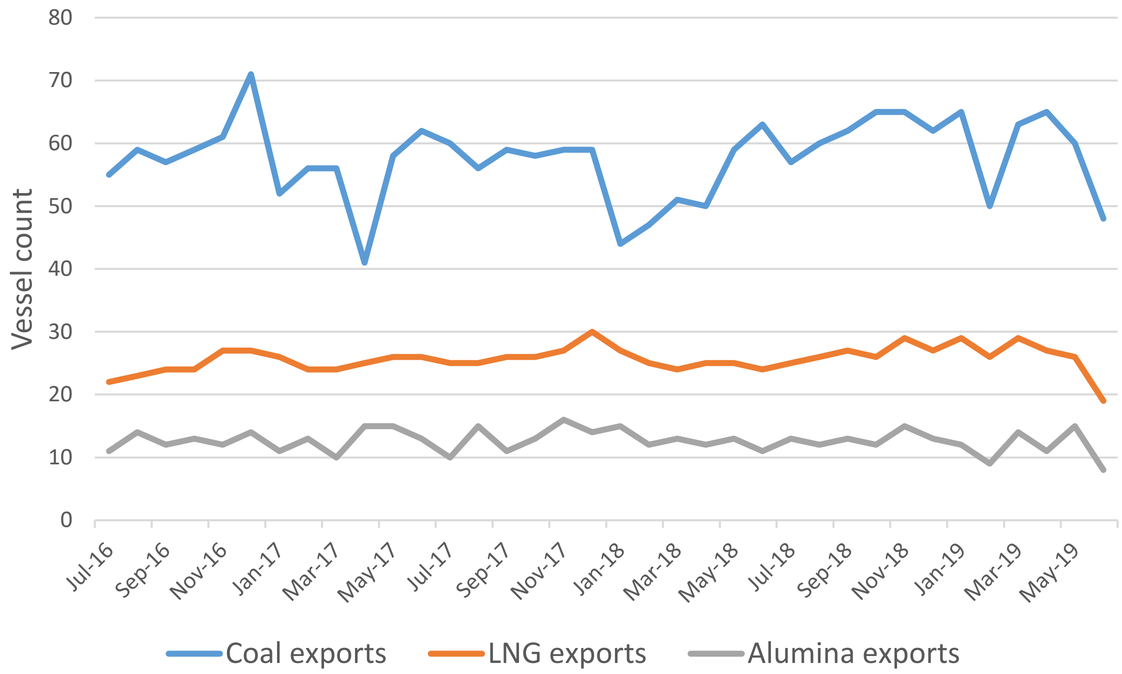


Figure 7.5: Trends in the three main commodity exports from Gladstone Harbour (De Valck et al., 2019).

Overall capacity utilisation remains high even when the now completed Fisherman's Landing expansion is taken into consideration. Hence the high score of 0.90 (A) for the indicator (Figure 7.6).

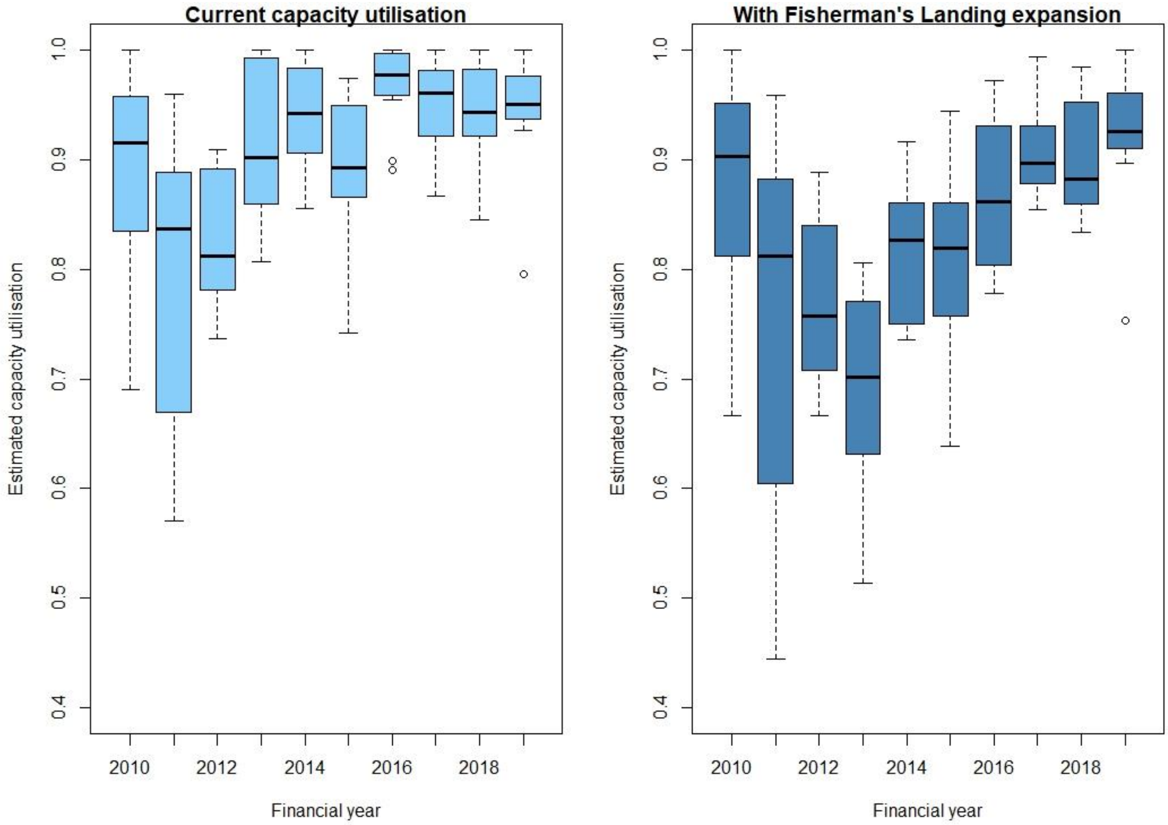


Figure 7.6: Capacity utilisation with the current facilities and with the Fisherman's Landing expansion.

Tourism

The tourism indicator was 0.90 (A) in 2019, an identical score to that recorded in 2018.

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.

The new source of information used this year is Tourism Research Australia's information at the Local Government Area level and selected for Gladstone: https://www.tra.gov.au/Regional/local-government-area-profiles. The latest information available is dated from 2017 and was updated on 29/08/2018 at the time the website was accessed this year (08/07/2019). These data are based on a four-year average from 2014 to 2017, which may explain why this year's value ($308 million) is a bit lower than the one recorded last year ($341 million). This trend may also be explained by the apparent reduction in numbers of visitor nights in 2017-18 (575,358). Compared to 2016-17 (644,239), a 10.7% reduction is observed: https://economy.id.com.au/gladstone/tourism-visitors-nights. These numbers seem to fluctuate substantially, with trends ranging from +31.6 to -21.1% change from one year to another over the past five years.

Commercial fishing

The commercial fishing indicator score was poor 0.36 (D) in 2019 with a similar score to that recorded in 2018. The scores in these two years represent a decline from 0.66 (B) in 2014 when this indicator was first assessed.

This year, the GVP for Gladstone Harbour fisheries was of $0.99 million, a decline from last year when the GVP was $1.64 million. However, the GVP in Gladstone has been declining since 2014. In 2016–17 it was $1.93 million, in 2015–16 it was $2.83 million and in 2013–14 it was $4.68 million (Figure 7.7).

Although the productivity of commercial fisheries in Gladstone has declined since 2014, it has remained relatively strong compared with the neighbouring regions. In 2018–19 the 10-year mean GVP for Gladstone was $3.17 million compared with $1.28 million for Rockhampton/Yeppoon and $1.86 million for the Mackay region (Figure 7.7).

The low score for the commercial fishing indicator was influenced by low poor scores for net fisheries (0.22, E) and trawl fisheries (0.37, D) and a satisfactory score for pot fisheries (0.54, C).

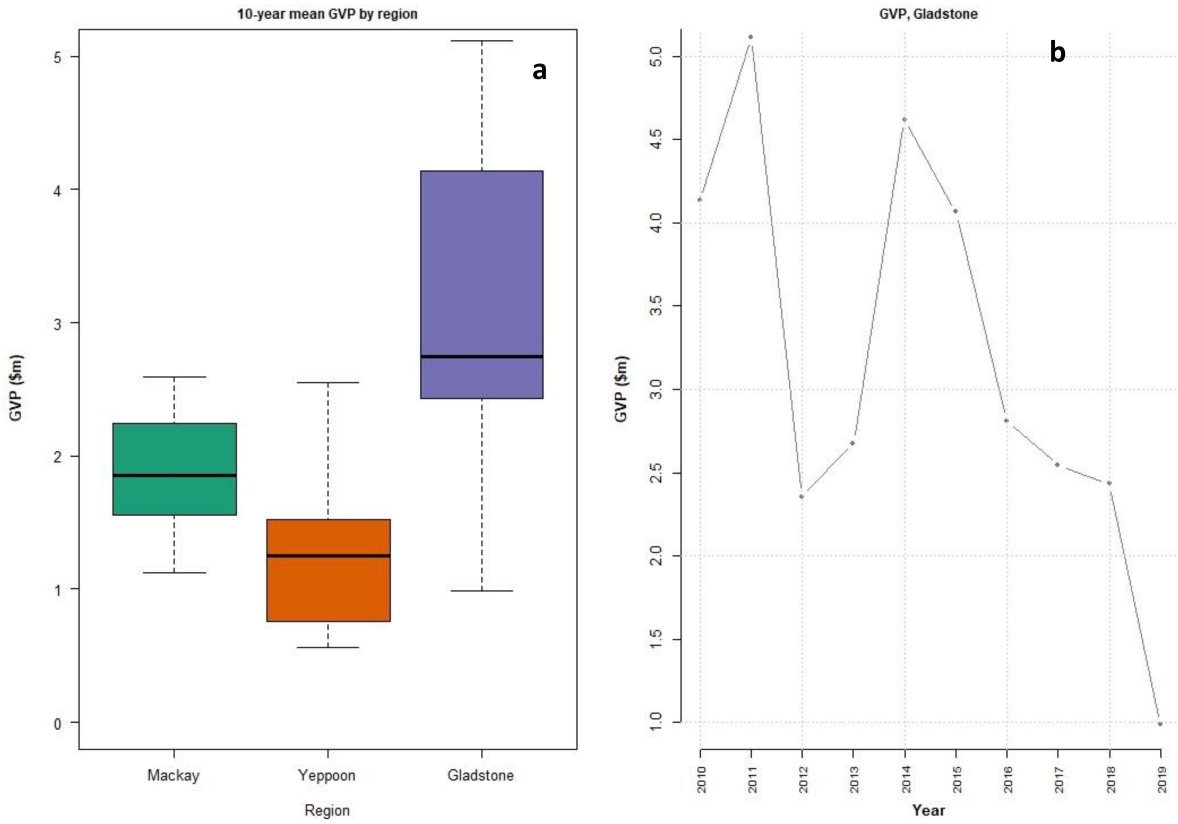


Figure 7.7: The 2009–19 gross value production for: (a) the regions of Mackay, Yeppoon and Gladstone (b) and change in GVP Gladstone, 2009–2019 (De Valck et al., 2019).

Economic stimulus

The score for economic stimulus of 0.58 (C) was aggregated from the scores of two indicators: employment 0.44 (D) and socio-economic status 0.64 (C) (Figure 7.8). While the overall economic stimulus scores steadily declined since the monitoring began in 2014, this year's score was identical to the previous year's score (Figure 7.9).

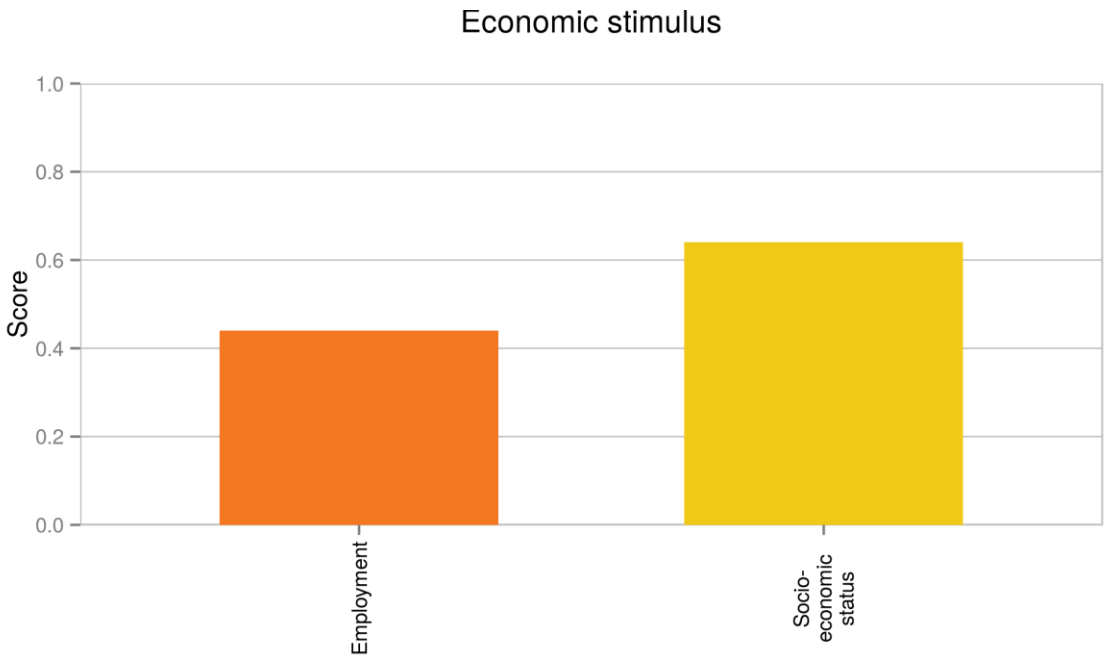


Figure 7.8: Scores for the two indicators of economic stimulus in the 2018 Gladstone Harbour Report Card.

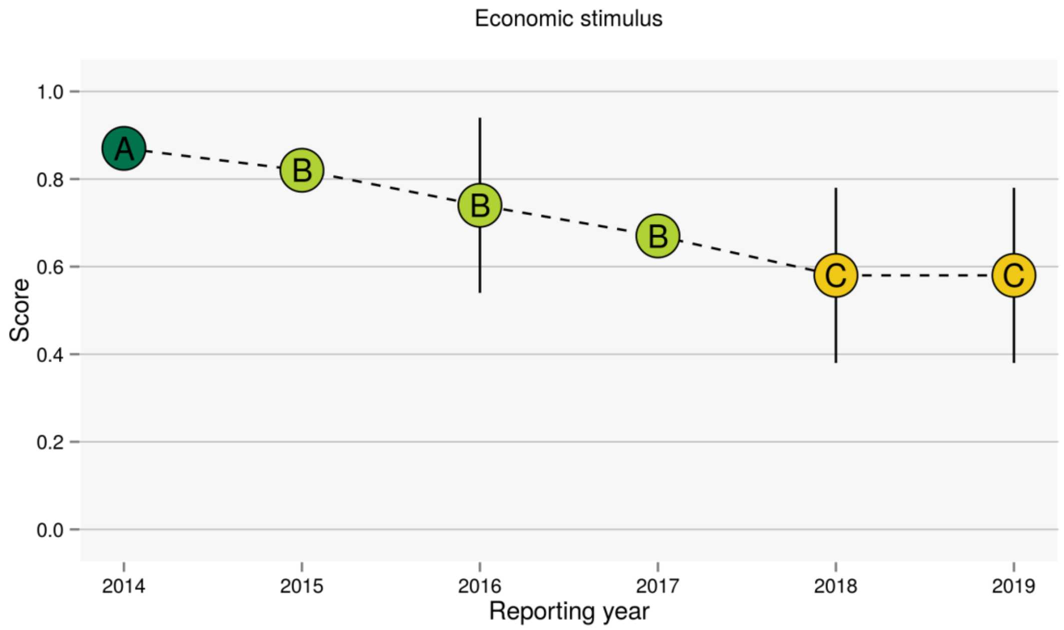


Figure 7.9: Economic performance scores from the 2014 to 2019.

The score for employment in 2019 (0.44) was the same score reported for 2018 as the unemployment rate of 7.3% for the 2019 March quarter was lower than the 2018 rate of 8.0% for the same period but higher than the state average of 6.1%. Over the past 12 months, the relative position of Gladstone remained unchanged compared to other LGAs in Queensland. For comparison, the unemployment rate in Gladstone is similar to that of the neighbouring LGAs of Bundaberg (7.3%) and Rockhampton's (7.4%).

The socio-economic status score for 2019 0.64 (C) was also the same score as recorded in 2018. Although the socio-economic status score has stabilised in the last two years it did decline steadily between 2014, when it was 0.90 (A), and 2018. Overall, the low scores reported for socio-economic status reflect the impact of job losses and increased unemployment in the Gladstone Region. However, calculation of the socio-economic index scores in 2018 and 2019 used census data from the 2016 national census, thereby making the direct comparison of this score somewhat limited as previous scores were based on 2011 census data (Windle et al., 2018).

Economic value (Recreation)

The overall economic value received a score of 0.76 (B) remained the same as previous reporting years (0.74 in 2018, 0.73 in 2017, 0.73 in 2016, 0.72 in 2015) (Figure 7.10). Good scores were received for land-based recreation 0.77, recreational fishing 0.71, beach recreation (0.76) and water-based recreation 0.76 (Figure 7.11).

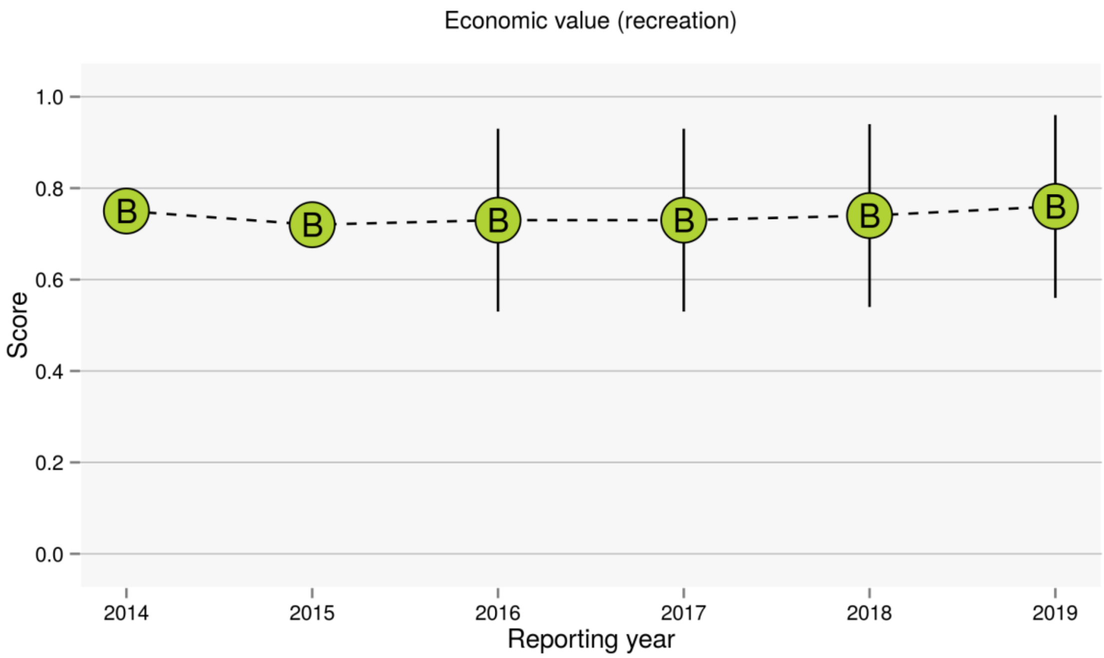


Figure 7.10: Economic value (recreation) scores from 2014. Note that in 2018, the overall score was calculated based on an additional indicator water-based recreation value which was not part of the 2017 assessment.

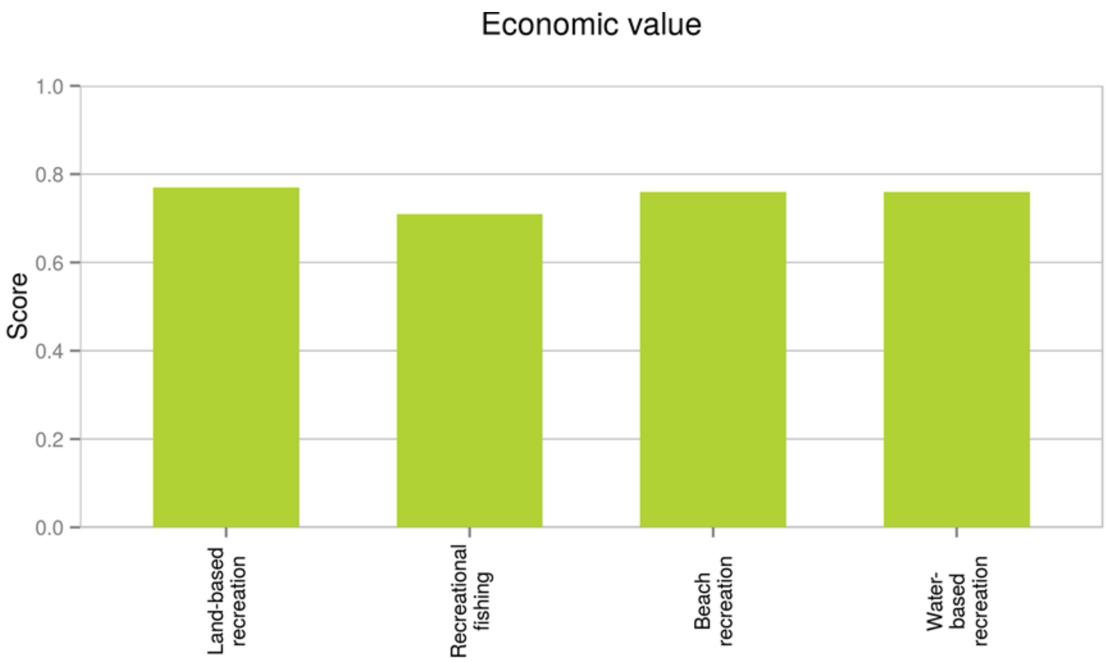


Figure 7.11: Scores for the three indicators of economic value (recreation) in the 2018 Gladstone Harbour Report Card.

The results of the CATI survey indicated that the most popular land-based activities along the shores of Gladstone Harbour were walking, picnicking or barbecuing, and relaxing by the water. The most popular beaches visited by the survey participants were the same as last year, being Tannum Sands followed by Spinnaker Park artificial beach and Boyne Island. Land-based and beach recreational activity were much more prevalent than recreational fishing and other water-based recreation. The average satisfaction ratings for three types of recreational activities by CATI respondents were similar in 2016 and 2017—8.23 for beach recreation, 8.40 for land-based recreation, 7.70 for recreational fishing and 8.29 for water-based recreation.

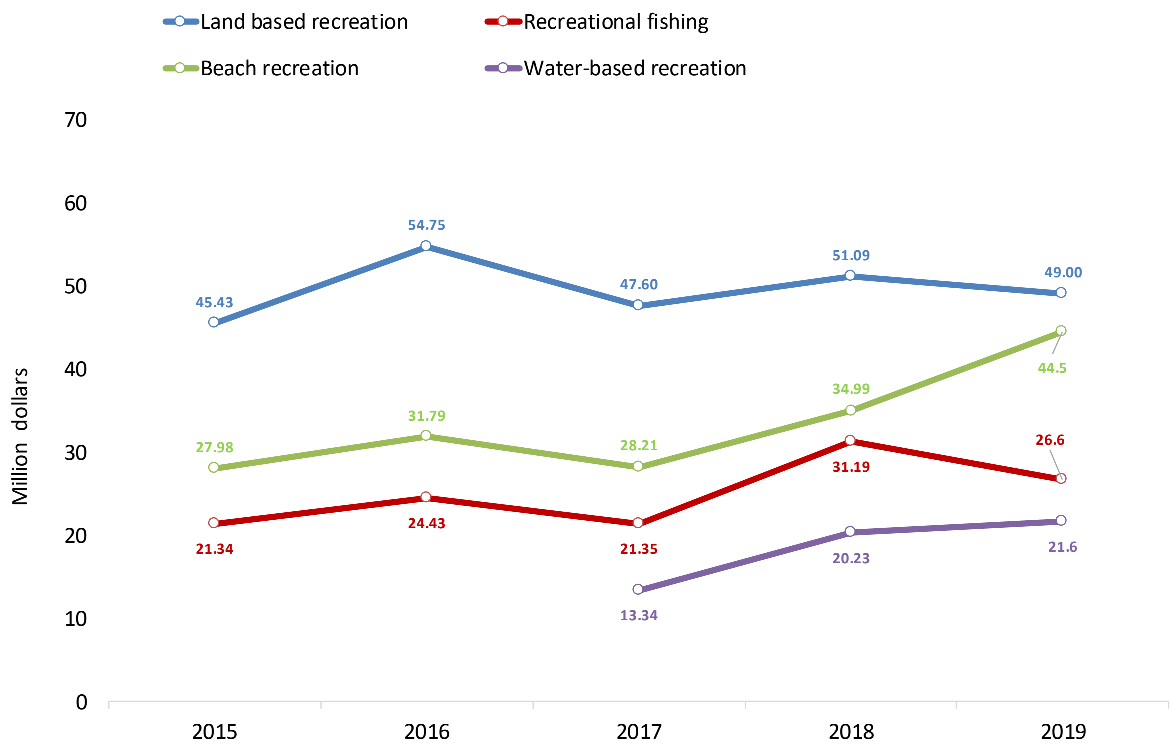


Figure 7.12: The estimated average annual value of recreational trips from 2015–2019.

The highest average annual economic value of $49 million was reported for land-based recreation followed by $44.5 million for beach recreation, $21.6 million for recreational fishing and $21.6 million for water-based recreation. The Overall, the economic value estimates for 2018 were higher than the 2017 values (Figure 7.12).

The land-based recreation trip value decreased by $2.09 million from 2018 a result of a reduced participation frequency from 42.97 to 38.95 trips/year. However, the average satisfaction rating increased from 8.26 in 2018 to 8.40 in 2019. As a result, the score changed from 0.76 in 2018 to 0.77 in 2019.

The recreational fishing trip value decreased from $31.2 million in 2018 to $26.6 million in 2018, a result of reduced participation frequency from 24.49 to 20.73 trips/year. However, the average satisfaction rating on recreational fishing trips increased, from 7.36 in 2018 to 7.70 in 2019, resulting in the report card score increasing from 0.68 in 2018 to 0.71 in 2019.

The beach recreation trip value increased for the second year in a row from $34.99 million in 2018 to $45.5 million in 2019. The average satisfaction with the last beach respondents had visited remained relatively stable, 8.23 compared to 8.22 in 2018. The participation frequency increased slightly from 39.35 to 40.2 trips/year. As a result, the score changed from 0.75 in 2018 to 0.76 in 2019.

The water-based recreation trip value was similar to the previous year, $21.6 million in 2019 compared with $20.2 million in 2018. The average satisfaction rating improved slightly from 8.13 to 8.29 in 2019 and the participation frequency declined slightly from 20.01 trips/year in 2018 to 19.59 in 2019. The overall score was 0.76 similar to the score of 0.75 in 2018.

7.4. 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 7.13). 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 7.2). 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 7.2). The score for economic value (recreation) has remained relatively stable since 2015 and it has received good scores in all years.

Economic performance

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

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

The commercial fishing indicator scores continue to remain low. This result must be interpreted cautiously as there have been some missing data in the QFish database that have affected data for both the current and previous years. The measure for line fishing was also removed from the assessment as it contained multiple data gaps and was a very small fishery. However, the low score is largely driven by lower activity in the net and trawl sectors.

Economic stimulus

Economic stimulus captures the potential stimulus from economic activities that may flow through to the community. The high unemployment rate indicates that the economic stimulus from harbour-based industries on the local economy and job creation is lower than it has been in the past. However, the unemployment rate has stabilised since 2018 and is a similar rate to that recorded in the nearby Bundaberg and Rockhampton LGAs.

The employment and socio-economic indicator scores have also stabilised in 2019 following declines from 2015 (Table 7.2).

Economic value

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

Land-based recreation was the most important recreational activity followed by beach recreation, recreational fishing and water-based recreation and based on total annual values of recreational trips for 2019. This pattern was the same as was observed in 2018.

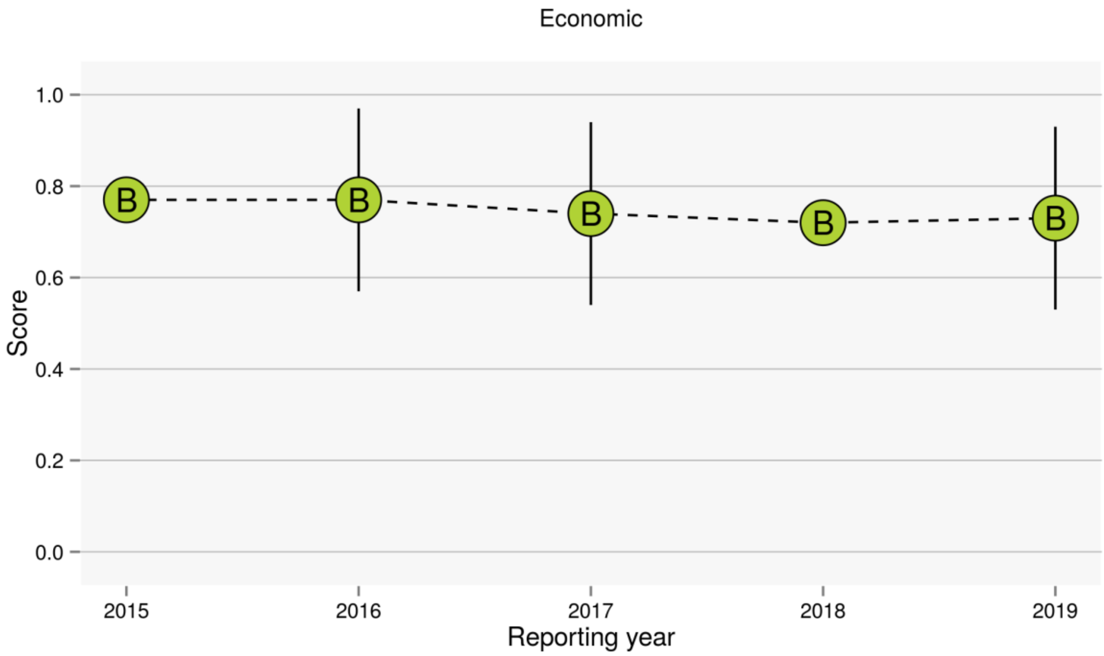


Figure 7.13: Report card scores for the Economic component from 2015 to 2019.

Table 7.2: Economic indicator scores compared for report cards from 2015 to 2019.

		2019	***2018***	***2017***	***2016***	***2015***
Indicator group	**Economic performance**	0.90	*0.90*	*0.90*	*0.87*	*0.79*
Indicators	Shipping activity	0.90	*0.90*	*0.90*	*0.87*	*0.82*
	Tourism	0.90	*0.90*	*0.90*	*0.72*	*0.64*
	Commercial fishing	0.36[d]	*0.35*[d]	*0.35*	*0.43*	*0.63*
Indicator group	**Economic stimulus**	0.58	*0.58*	*0.67*	*0.74*	*0.82*[a]
Indicators	Employment	0.44	*0.44*	*0.53*	*0.62*	*0.64*
	Socio-economic status	0.64[c]	*0.64*[c]	*0.70*	*0.8*	*0.95*[b]
Indicator group	**Economic value (Recreation)**	0.76	*0.74*	*0.73*	*0.73*	*0.72*
Indicators	Land-based recreation	0.77	*0.76*	*0.76*	*0.76*	*0.73*
	Recreational fishing	0.71	*0.68*	*0.65*	*0.66*	*0.71*
	Beach recreation	0.76	*0.75*	*0.74*	*0.75*	*0.7*
	Water-based recreation	0.76	*0.75*	*NA*	*NA*	*NA*
Overall score		**0.73**	***0.72***	***0.74***	***0.75***	***0.77***

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

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

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

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

8. Iconic species of Gladstone Harbour

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

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

Dolphins

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

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

Dugongs

The dugong, *Dugong dugon*, is an EPBC Act-listed marine and migratory species that is also listed as vulnerable in Queensland under the Nature Conservation Act. Dugongs are found throughout the western Indo-Pacific region (eastern Africa to eastern Australia) in tropical and subtropical waters.

Within the Gladstone Harbour area, including Rodds Bay, dugongs are predominantly associated with the *Halophila ovalis* seagrass meadows which are the major component of their diet. Sobtzick et al. (2013) reviewed the status of the dugong population in the Gladstone area as part of the Ecosystem Research and Monitoring Program (ERMP) funded by GPC. This review found that the Port Curtis–Rodds Bay area provides important habitat for a relatively small population of dugongs. The authors indicated that as these areas overlap with areas of human use, the risk to dugongs from human activity may be substantial. The review also found that seagrass meadows within the Gladstone area have regional significance as they provide valuable connecting habitat between dugong populations in southern Queensland (Sobtzick et al., 2013).

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

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

Marine turtles

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

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

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

Migratory shorebirds

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

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

9. Gladstone Harbour drivers and pressures

9.1. Background

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

The Environmental, Social, Cultural and Economic health of Gladstone Harbour could be influenced by major events that operate on scales that extend spatially or temporally beyond the reporting boundaries specified for the four components. For instance, connectivity may be driven by changes in oceanic circulation and wind and rainfall patterns; water chemistry may be influenced by pressures originating from human activities in river catchments. This section summarises some key drivers and pressures that may have influenced the 2018–19 report card scores.

In the reporting year from 1 July 2018 to 30 June 2019, acute climatic events, such as flooding and cyclones, and changes to economic circumstances did not influence the report card scores.

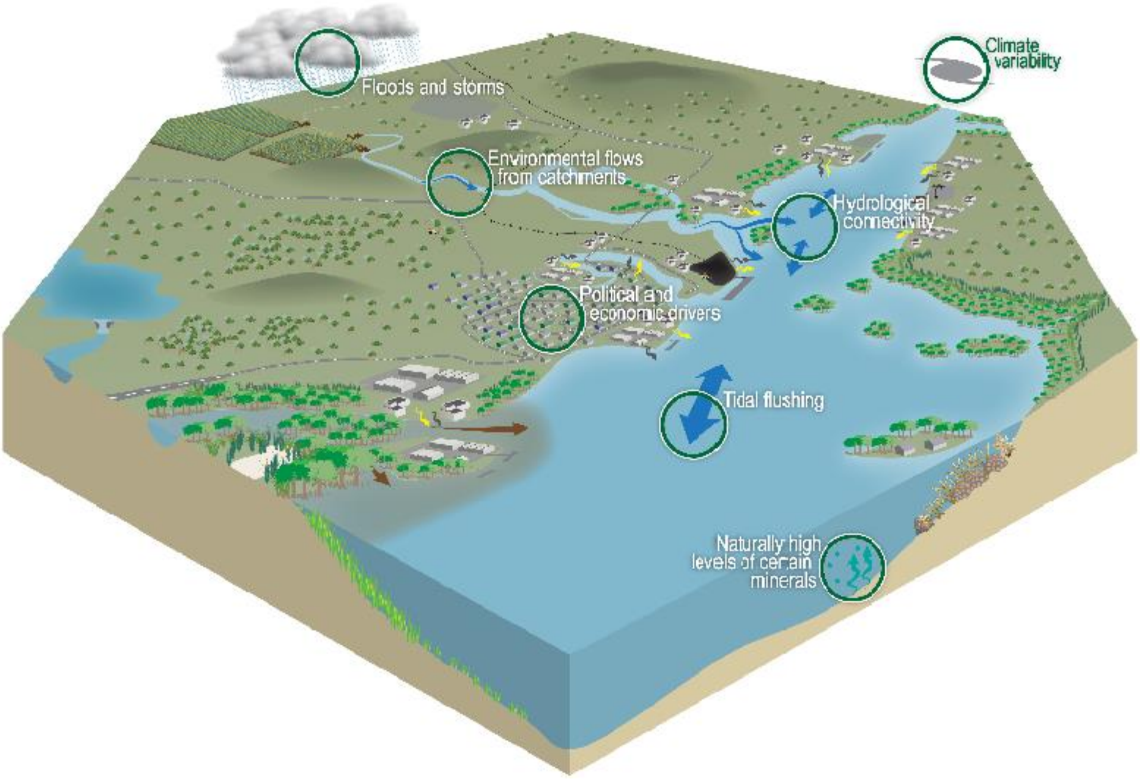


Figure 9.1: Major drivers of environmental change within Gladstone Harbour (Source: McIntosh et al., 2014).

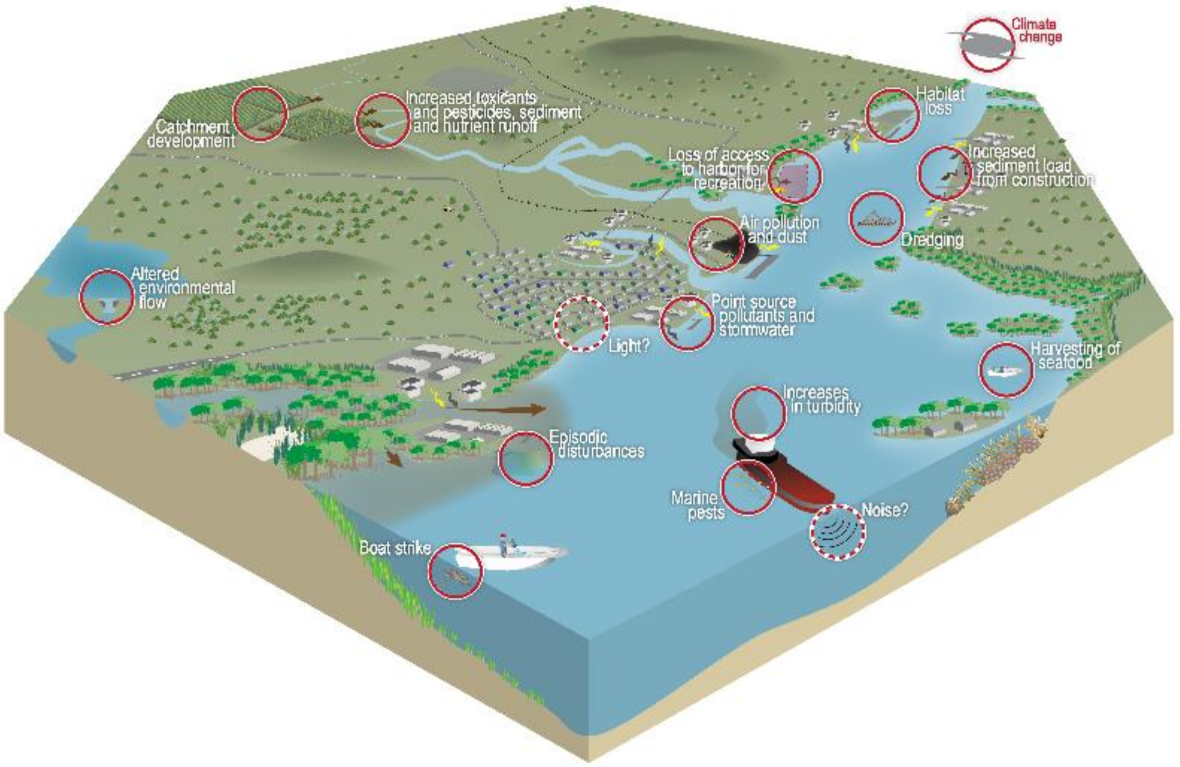


Figure 9.2: Pressures which can drive environmental change within Gladstone Harbour (Source: McIntosh et al., 2014).

9.2. Climate

Gladstone has a subtropical climate with an average maximum of 27.4^{o}C and an average minimum of 18.1^{o}C (Figure 9.3). Rainfall is highly variable; the average annual rainfall recorded at Gladstone (Airport) for the period 1994–2019 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.

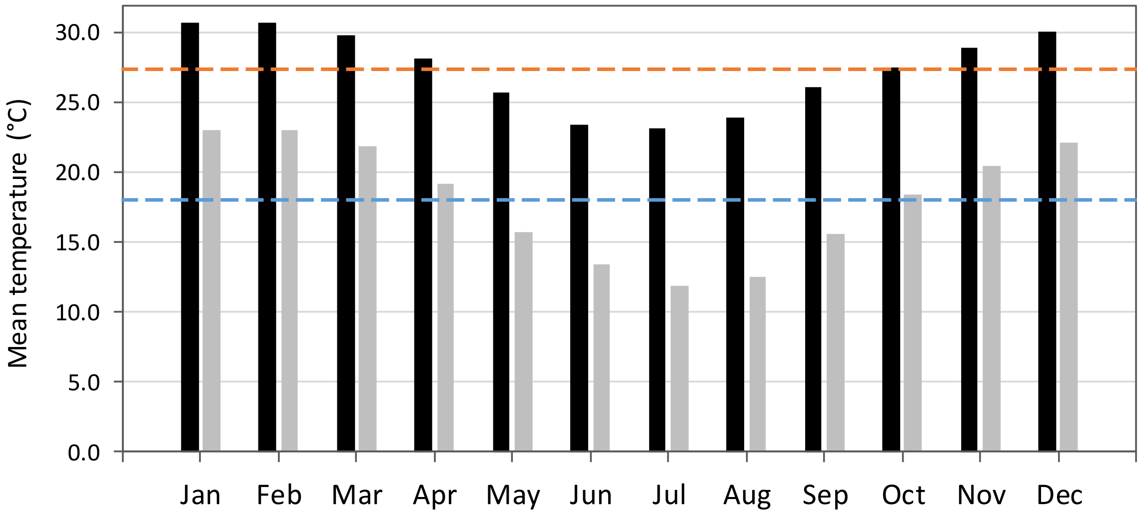


Figure 9.3: Average maximum and minimum monthly temperatures at the Gladstone Airport weather station from 1994–2019. Temperatures shown as follows: average maximum monthly (black bars), average minimum monthly (grey bars), annual maximum average (orange dashed line, 27.4° C), annual minimum average (blue dashed line, 18.1° C). Values were obtained from BOM (http://www.bom.gov.au/climate/data/index.shtml).

2018–19 rainfall

In the 2018–19 reporting year (July 2018 to June 2019), total rainfall recorded at Gladstone Airport was 593 mm—well below the annual average of 875 mm (Figure 9.4). Total monthly rainfall was variable when compared to mean monthly rainfall of the past 25 years (Figure 9.5). For half of the year, total monthly rainfall was relatively comparable to mean monthly rainfall. This occurred during the months of July, October, November, December, March and April. However, total rainfall was considerably lower than the mean monthly rainfall during the remaining months. January, February, May and June had three to four times less rain when compared to the 25-year averages for these months. There was only 0.6 ml of rainfall recorded in September 2018.

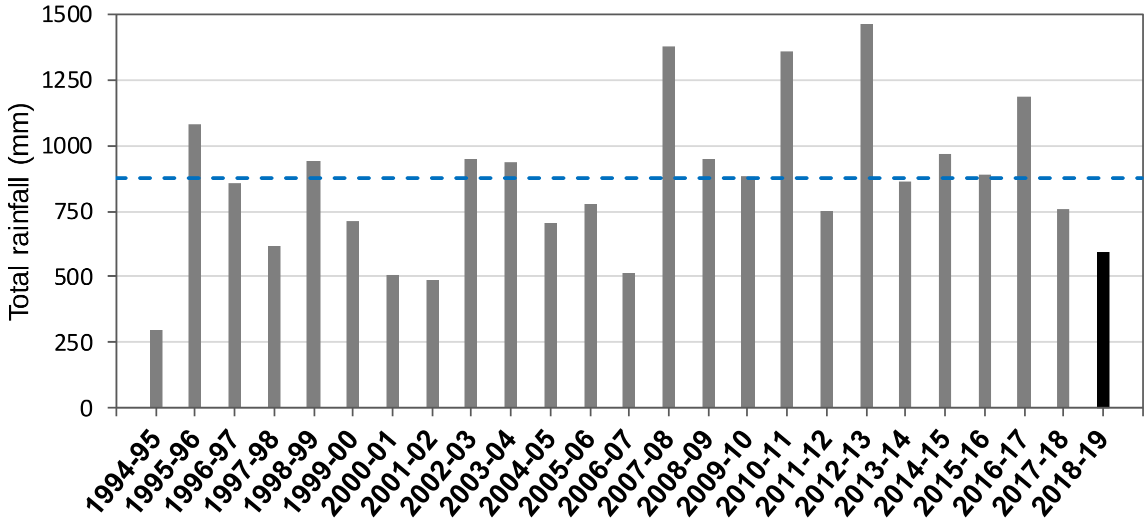


Figure 9.4: Annual rainfall (mm) by reporting year at the Gladstone Airport weather station from 1994–1995 to 2018–2019. Blue dashed line represents the annual mean of total rainfall from 1994–2019 (875 mm). Values were obtained from BOM (http://www.bom.gov.au/climate/data/index.shtml).

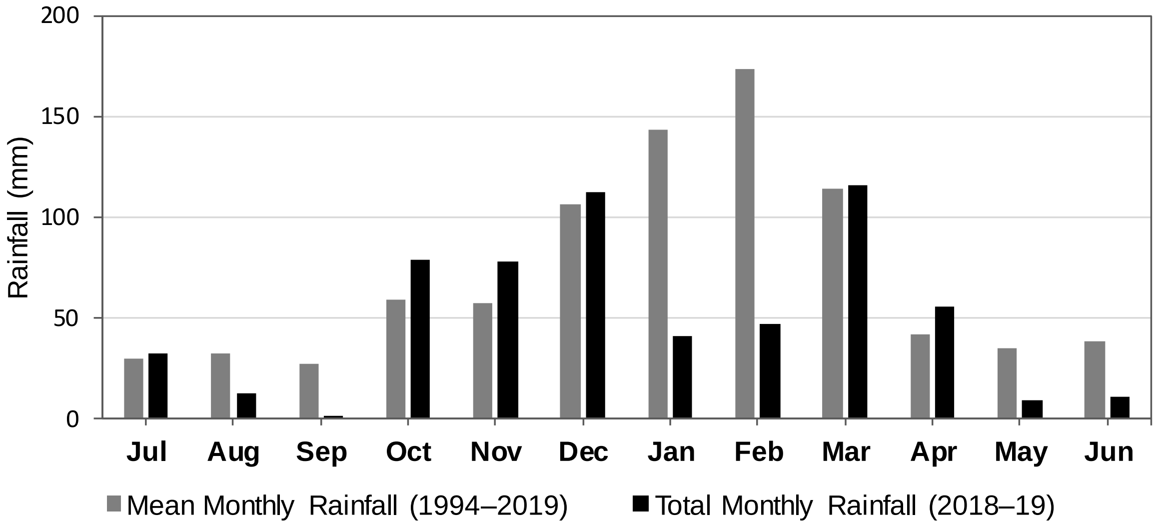


Figure 9.5: Mean monthly rainfall (mm) at the Gladstone Airport weather station (1994–2019) compared to total monthly rainfall for the 2018–19 reporting year. Values were obtained from BOM (http://www.bom.gov.au/climate/data/index.shtml).

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 9.1. 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 2019 show two brief but significant high flow events occurring with the passage of TC Marcia and ex TC Debbie (Figure 9.6). Rainfall associated with TC Marcia caused a peak flow of 91,666 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 2018–19 reporting year, the dry and benign weather conditions resulted in minimal flow from the Calliope. Total monthly water discharge from the Calliope River was considerably lower when compared to median monthly water discharges from October 1938 to June 2019 (Figure 9.7). The highest monthly discharge (July) in the current reporting year was approximately 2.2 times lower than the long-term median of that month. There was also negligible stream discharge in January and June 2019 and no stream discharge in February 2019 from the Calliope River.

Table 9.1: 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 2018–19)			
Annual stream discharge (ML)		December stream discharge (ML)	
Mean	167,265	Mean	21,235
Median	102,113	Median	2,944
Maximum flow (2012–13)	916,693	Maximum flow (1973–74)	401,837

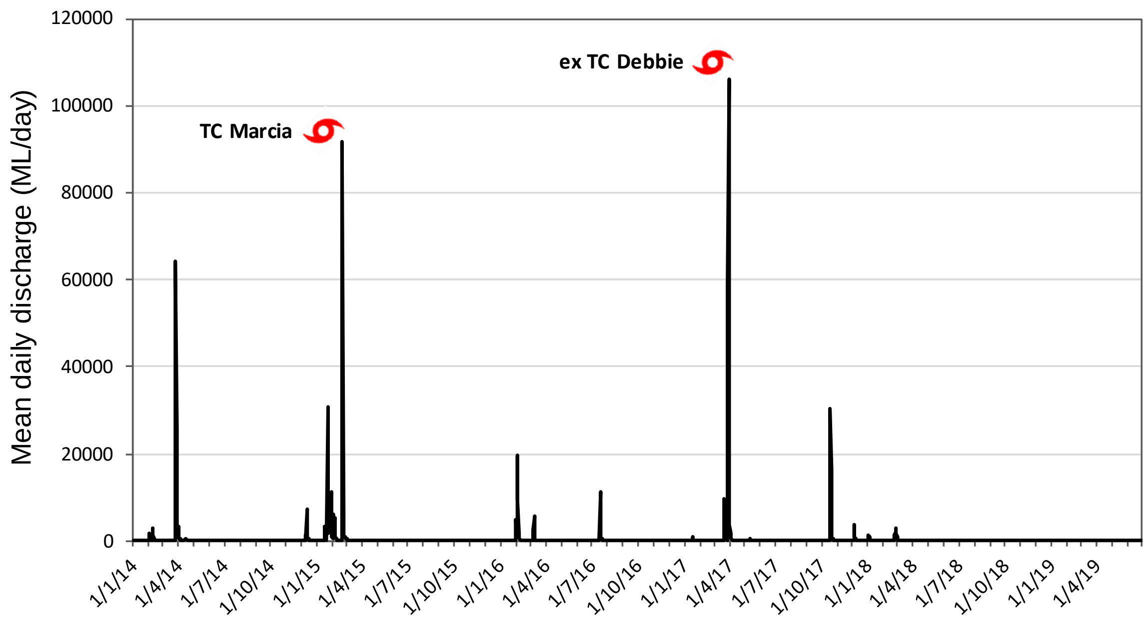


Figure 9.6: Mean daily Calliope River flows recorded at Castlehope between January 2014 and June 2019. Values were obtained from DNRM (https://water-monitoring.information.qld.gov.au/).

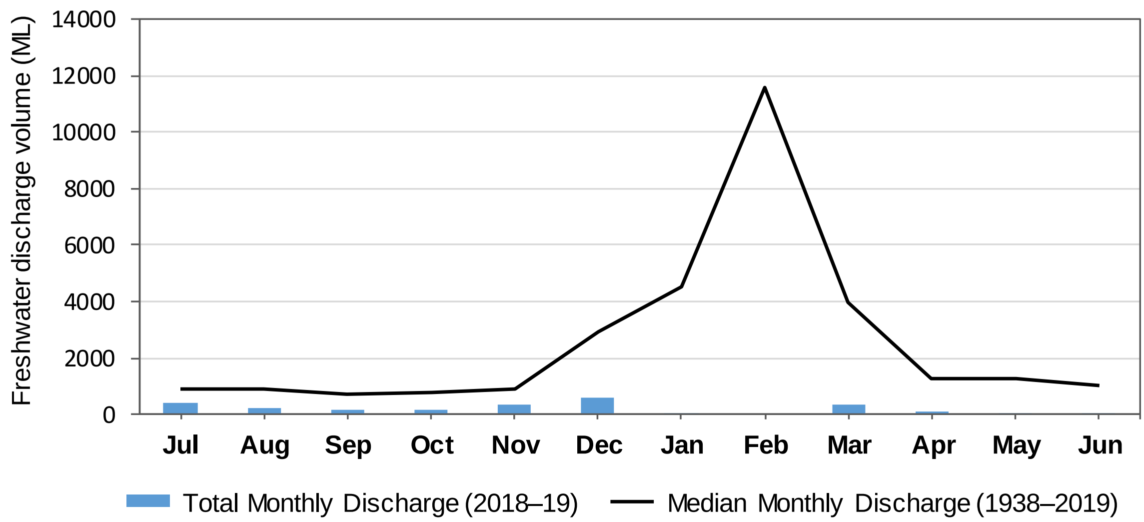


Figure 9.7: Monthly water discharge (July 2018 to June 2019) and median monthly water discharge (October 1938 to June 2019) of the Calliope River at Castlehope. Values were obtained from DNRM (https://water-monitoring.information.qld.gov.au/).

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 (AHD). Since the height of the dam wall was raised in 2002, it has overtopped six times—in 2002, 2010, 2013, 2015, and twice in 2017 (Table 9.2; Figure 9.8).

Table 9.2: Awoonga Dam levels (January 2017 – January 2018) and 2017 overtopping levels compared to the largest overflow recorded in 2013 (Source: Gladstone Area Water Board).

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

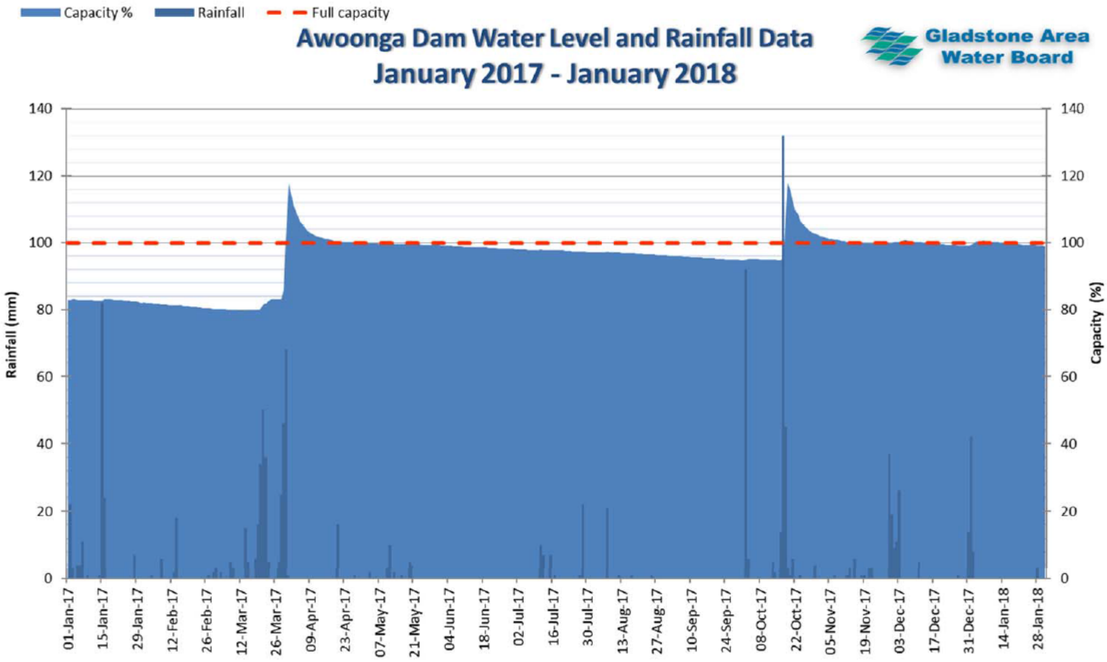


Figure 9.8: Awoonga Dam levels January 2017 to January 2018 (Source: Gladstone Area Water Board).

9.3. Catchment run-off

Gladstone Harbour is bordered by five drainage basins, the Fitzroy (142,545 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 9.9).

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 9.10 and 9.11). 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 AHD was achieved in 2002. In periods of normal flow, it would be expected that coarser sediment particles would settle behind the structure.

Catchment run-off can strongly influence water quality within estuarine systems. It is a major source of sediments, nutrients and pesticides delivered to marine waters (Bartley et al., 2017). Land use within a catchment will influence the type and volume of material exported from that catchment. Suspended sediments are dominated by grazing inputs, while pesticides are sourced from dryland and irrigated cropping and grazing lands (Dougall et al., 2014).

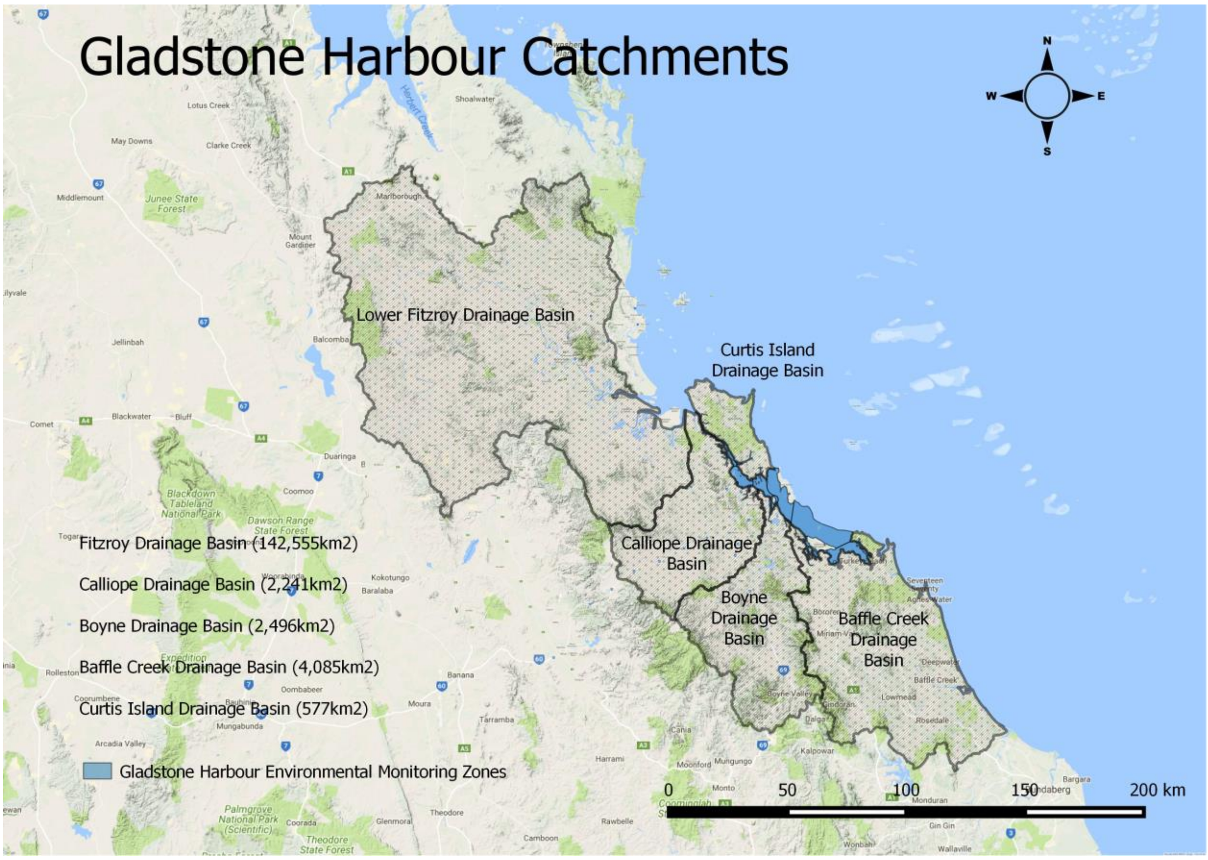


Figure 9.9: Drainage basins surrounding the Gladstone Harbour Environmental Monitoring Zones.

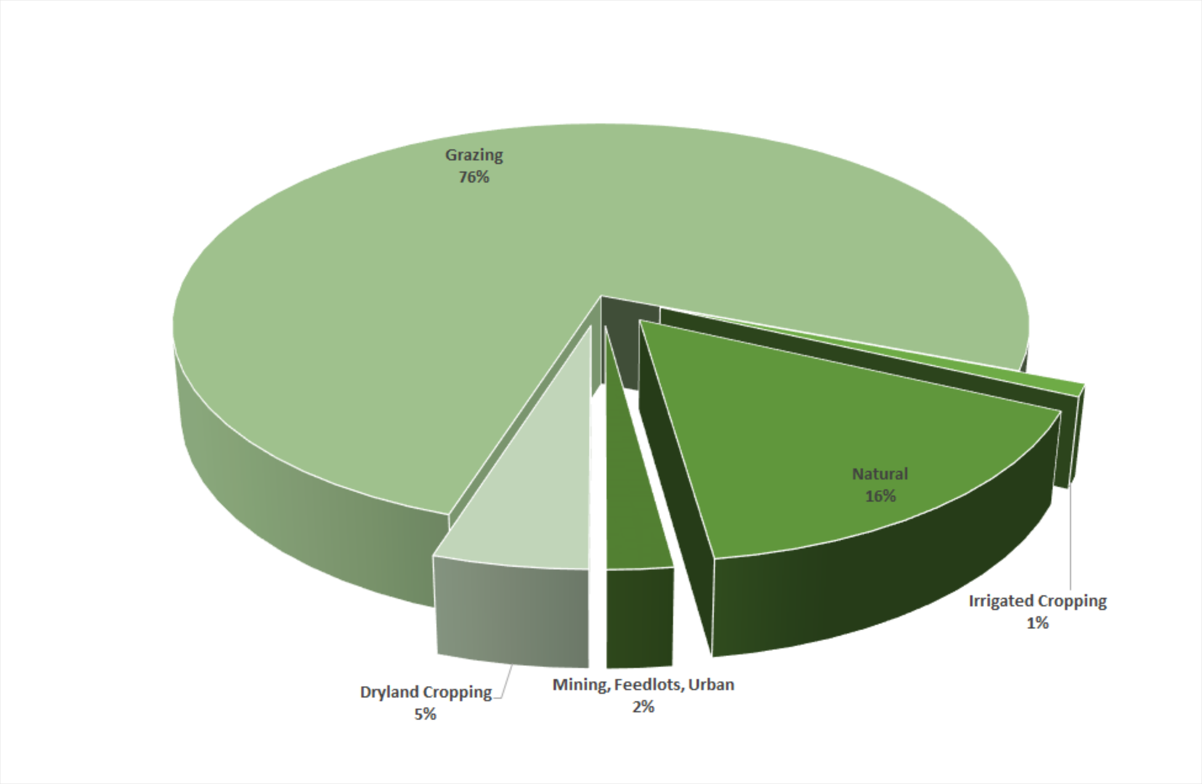


Figure 9.10: Land use in the Boyne catchment (Data source QSpatial, Land use mapping – Fitzroy NRM region 2009, Catchment boundaries, Queensland Wetland*Info*).

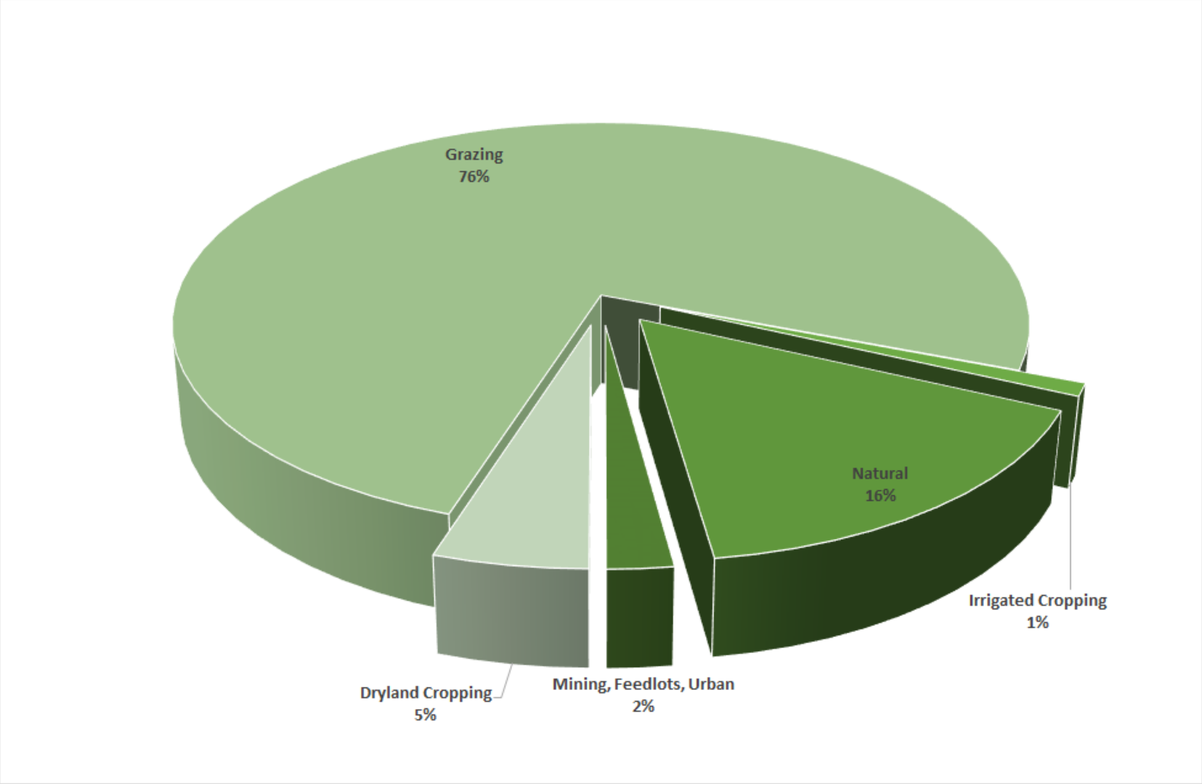


Figure 9.11: Land use in the Calliope catchment (Data source QSpatial, Land use mapping – Fitzroy NRM region 2009, Catchment boundaries, Queensland Wetland*Info*).

Tidal movement and turbidity

Turbidity in Gladstone Harbour is strongly influenced by the large tidal movement. This results in significant resuspension of fine sediments which is directly related to the tidal cycle; larger tides result in increased turbidity (Figure 9.12). 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.

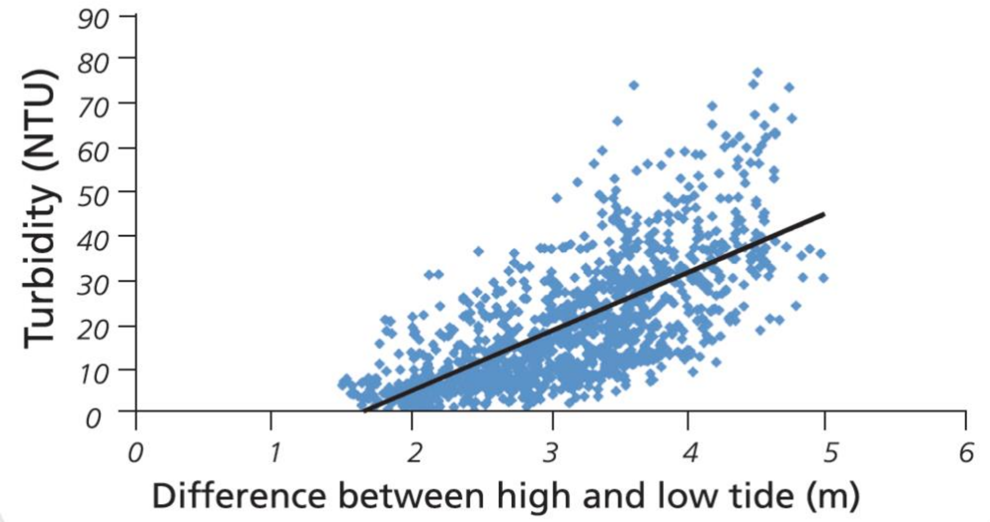


Figure 9.12: The relationship between tidal movement and turbidity in Gladstone Harbour (DEHP 2014 personal communication). NTU: nephelometric turbidity unit.

9.4. Social and economic pressures

Gladstone is an industrial hub of international significance owing to its large-scale production and export facilities. The Gladstone Region's social and economic growth and development patterns have been strongly influenced by the rapid development of the manufacturing, construction and retail trade sectors. This has resulted in a steady increase in Gladstone's population from 2011 (57,890 people) to 62,979 in 2018 Gladstone (.id community downloaded January 2020).

The value of residential building approvals continued to decline in the 2018–19 financial year following a sharp peak in 2012–13 when residential approvals reached $450 million. In the 2018–19 financial year the total value of residential approvals was $21 million down from $31 million in 2017–18. The value of non-residential building approvals has also declined sharply over the same period from a peak of $400.1 million in 2012–13 to $92.3 million in 2018–19. However non-residential building approvals reached a 17-year low in 2017–18 of $18.1 million before recovering strongly to the 2018–19 figure (Figure 9.13).

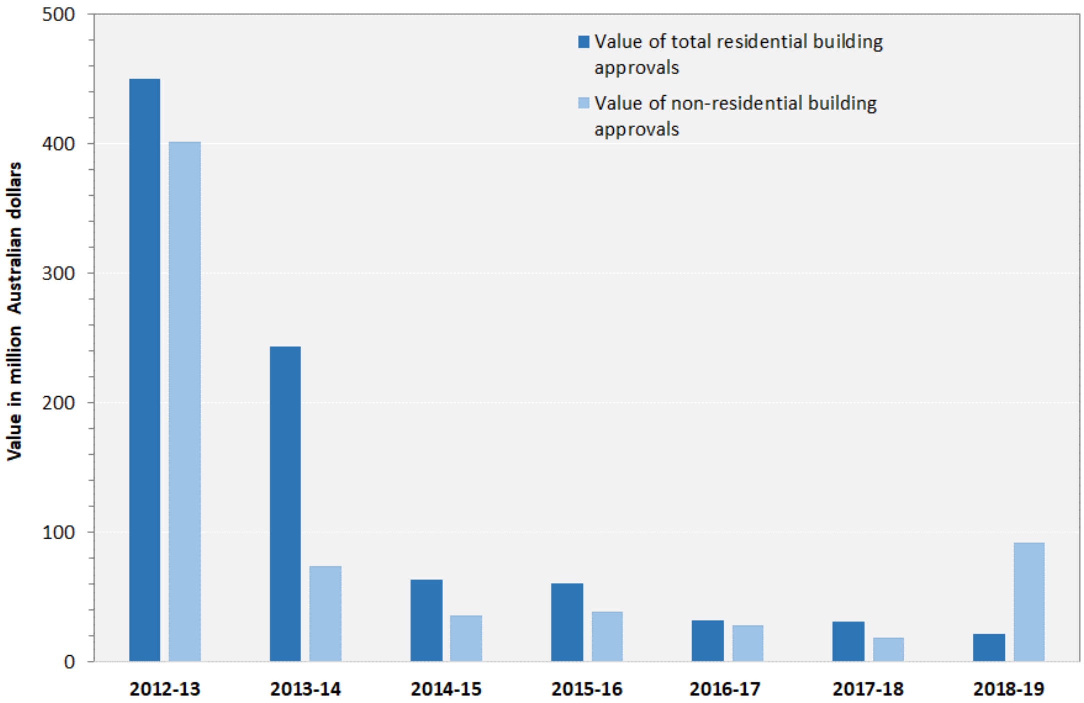


Figure 9.13: The value of residential and non-residential building approvals and approved new dwellings in Gladstone LGA from 2013 2019 (.id community downloaded January 2020).

The number of businesses actively trading in Gladstone also steadily declined from 2014 (4,092) to (3,741) in June 2018. This trend is also reflected in the total employment figures for Gladstone which have declined from 33,081 in the 2013–14 financial year to 29,072 in the 2018–19 financial year (.id community downloaded January 2020).

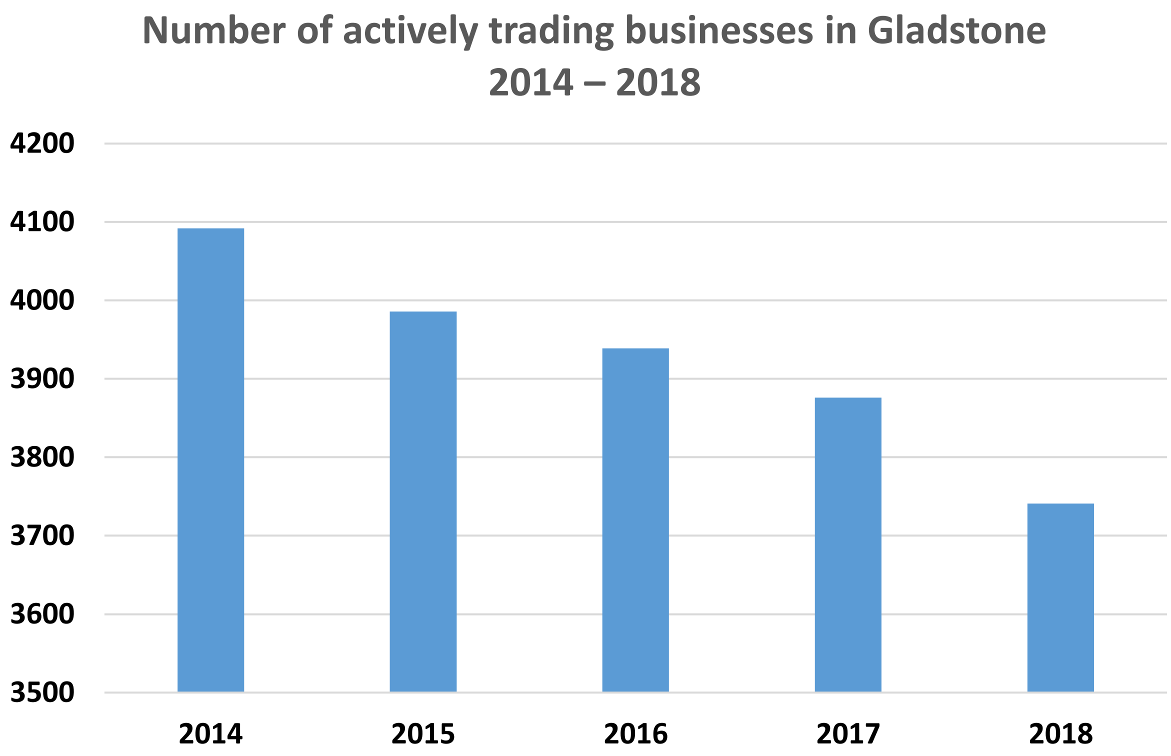


Figure 9.14: The number of actively trading businesses in Gladstone 2014 to 2018 (.id community downloaded January 2020).

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

A new form of tourism emerged in Gladstone with the arrival of the first cruise ship, the Pacific Dawn at Gladstone's Auckland Point Terminal with 2,000 passengers in March 2016 (ABC Capricornia, 2016). In 2018 five cruise ships docked in Gladstone and in 2019 there were 14. It is estimated that each ship generates up to $500,000 for Gladstone's economy (cruisemapper.com downloaded January 2020). Construction work for a new cruise ship terminal at East Shore Precinct was also initiated during the first half of 2018 and is scheduled to be completed in 2020.

10. Guide to the infrastructure supporting the GHHP website

10.1. Data Information Management System

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

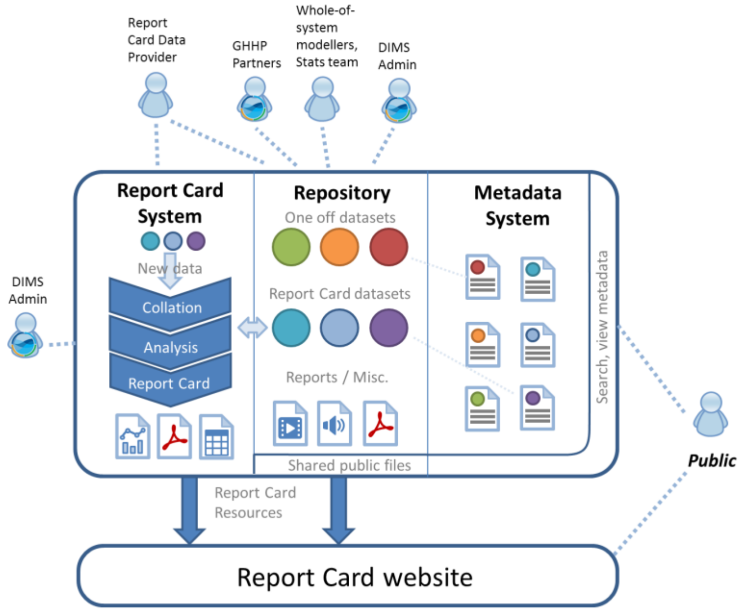


Figure 10.1: Schematic diagram of the links between the report card website and the Data Information Management System (DIMS) to illustrate major components and primary inputs and outputs (Diagram courtesy Australian Institute of Marine Science).

The DIMS server consists of the following four key components.

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

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

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

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

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

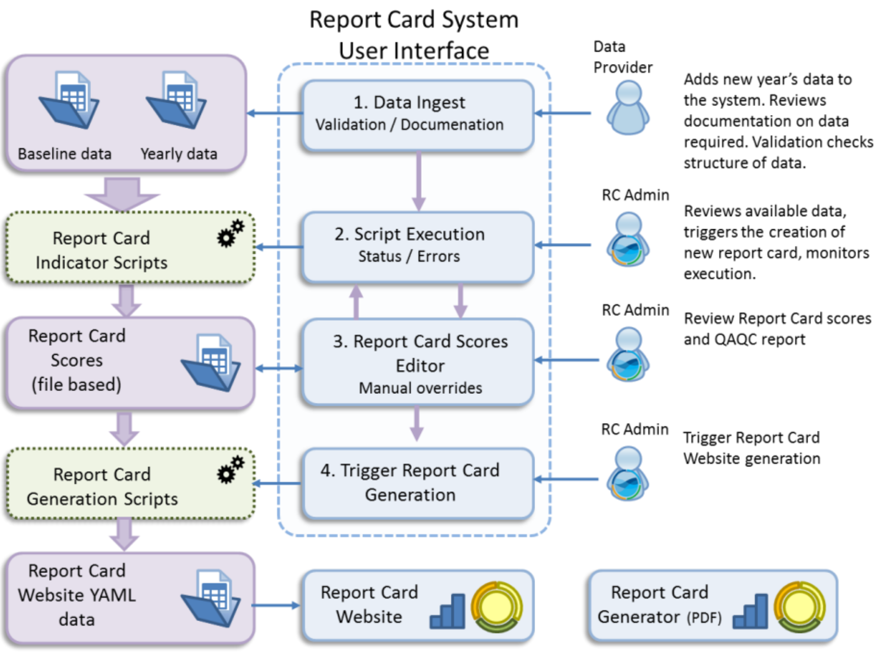


Figure 10.2: Schematic diagram of the report card system showing all data ingestion, script execution and report cards results generation modules (Diagram courtesy Australian Institute of Marine Science).

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

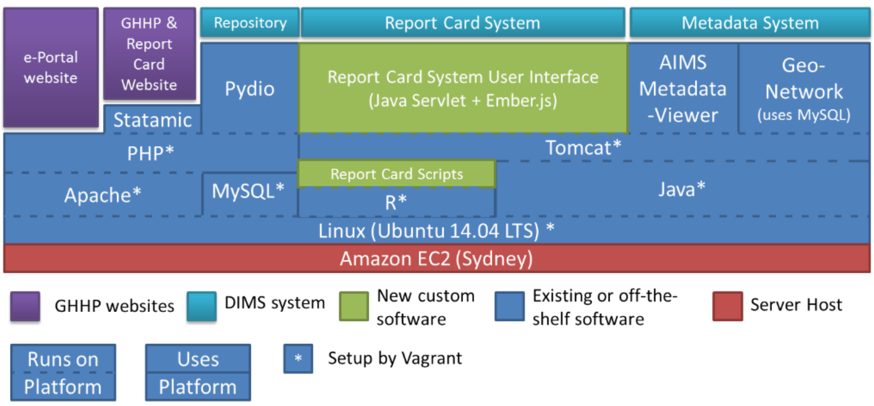


Figure 10.3: Software infrastructure underlying the Data Information Management System (DIMS) operations (Diagram courtesy Australian Institute of Marine Science).

10.2. The Gladstone Harbour Model

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

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

Gladstone Harbour Model Domain

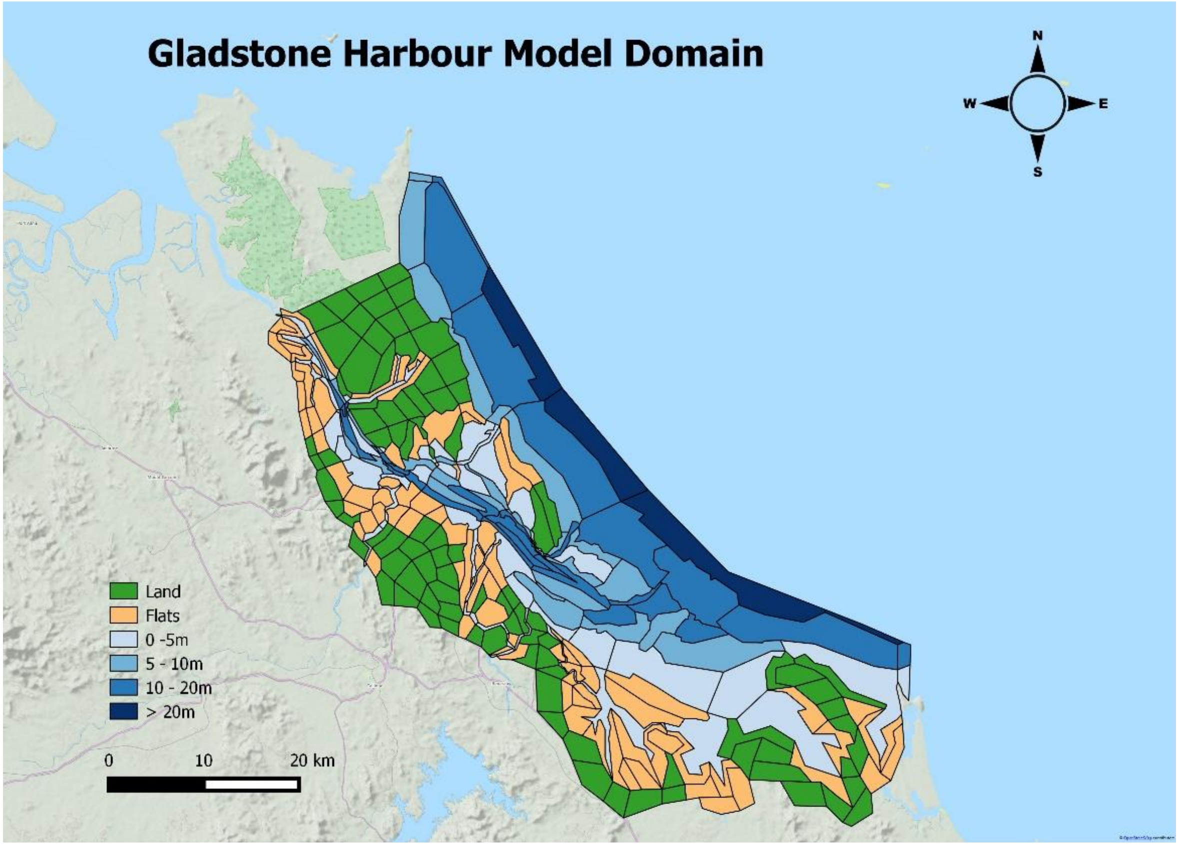


Figure 10.4: The area modelled in the GHHP Atlantis model includes the harbour and surrounding area.

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

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

Physical (Hydrodynamic) and Biogeochemical Model

Hydrodynamic model

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

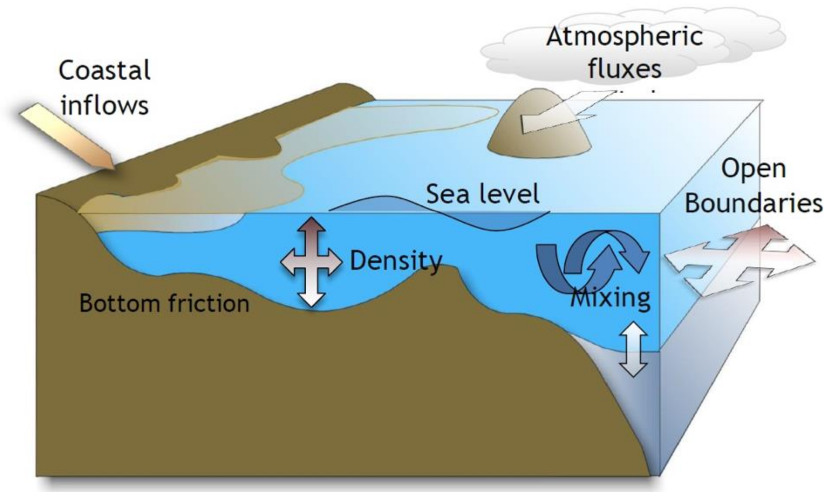


Figure 10.5: Physical processes represented in the hydrodynamic model.

Biogeochemical model

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

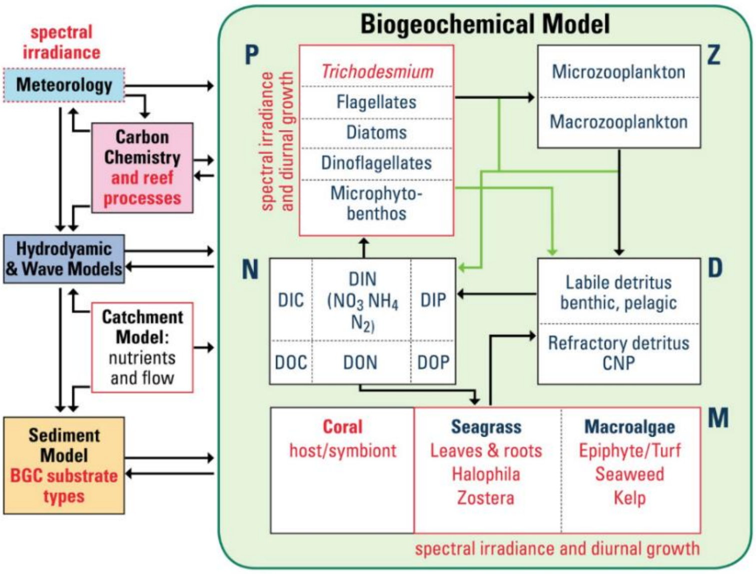


Figure 10.6: Components and processes within the Biogeochemical model.

Ecosystem Elements and Marine Food Webs

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

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

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

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

The Human Elements, Social and Economic, of Gladstone Harbour

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

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

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

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

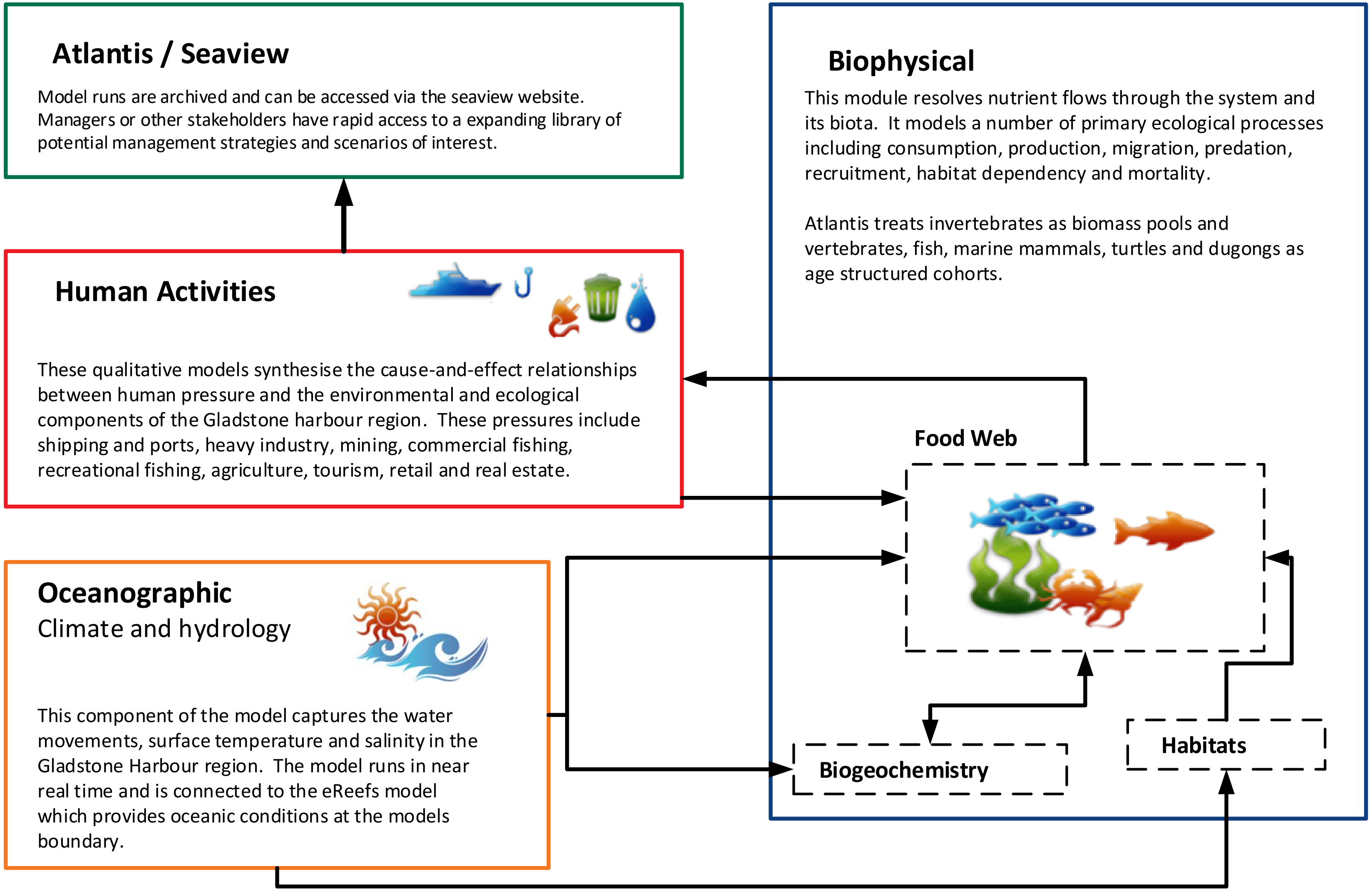
Discussions at these workshops let the researchers draw qualitative models of how the system is linked together and how it responds to change. These qualitative models where then converted into quantitative model components for use in the systems model.

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

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

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

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



Initial results

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

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

Further information

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

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

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12. Glossary

Terms and acronyms	Definition
ABS	Australian Bureau of Statistics
AHD	Australian height datum
AIMS	Australian Institute of Marine Science
Asset	A particular feature of value to the GHHP for monitoring and reporting, e.g. seagrass meadows or swimmable beaches
Baseline	A point of reference from which to measure change
BBN	Bayesian belief network
CATI	computer-assisted telephone interviewing
Component	The 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
DEHP	Department of Environment and Heritage Protection
DIMS	Data Information Management System
Ecosystem health	An ecosystem that is stable and sustainable, maintaining its organisation and autonomy over time and its resilience to stress. Ecosystem health can be assessed using measures of resilience, vigour and organisation. Source: http://www.biodiversity.govt.nz/picture/doing/nzbs/glossary.html
Environmental indicators	Metrics derived from observation used to identify indirect drivers of environmental problems (e.g. population growth), direct pressures on the environment (e.g. overfishing), environmental condition (e.g. contaminant concentrations), broader impacts of environmental condition (e.g. health outcomes) or effectiveness of policy responses (de Sherbinin et al., 2013)
ERMP	Ecosystem Research and Monitoring Program
FHRP	Fish Health Research Program
GHHP	Gladstone Healthy Harbour Partnership
GHM	Gladstone Harbour Model
GPC	Gladstone Ports Corporation
Guidelines and criteria	Science-based numerical concentration limits or descriptive statements recommended to support a designated water use. Guidelines are not legally enforceable.
GVP	Gross value of production

HAI	Health Assessment Index
HAT	Highest astronomical tide
HEV	High ecological value
ICHD	Indigenous Cultural Heritage Database
Indicator	Numerical values that provide insight into the state of the environment, or human health etc. The environment is highly complex and indicators provide a simple, practical way to track changes in the state of the environment over time.
IER	Index of economic resources
ISP	GHHP Independent Science Panel
LAT	lowest astronomical tide
LGA	local government area
Liveability	In this report, liveability is used to refer to a sense of place, quality of housing, provision of health services, recreation facilities, attraction of the urban environment and availability of services.
LNG	Liquid natural gas
MC	GHHP Management Committee
MD	Moderately disturbed
Metadata	'data about data', the series of descriptors used to identify a particular dataset (e.g. author, date of creation, format of the data, location of the data points)
MMP	Marine Monitoring Program
Model/modelling	The creation of conceptual, graphical or mathematical models to describe, visualise or test abstract concepts and processes. Models help explain complex real-world interactions and add to our ability to understand how human actions impact on ecosystems. Models can be used to analyse scenarios to support decision making.
NMI	National Measurement Institute
NTU	Nephelometric turbidity units
PAH	Polycyclic aromatic hydrocarbons
PCIMP	Port Curtis Integrated Monitoring Program
Physico-chemical	Physical and chemical forces that influence the environment and the biodiversity and people within e.g. temperature, salinity
Point source	A single, identifiable localised source of a release e.g. a stormwater outlet
PSU	Practical Salinity Units

QA/QC	Quality assurance/quality control – the processes used to ensure the quality of a product (QA), and then to assess whether the product or services meet quality standards then correct where necessary to meet those standards (QC). Raw data may contain errors or be in formats unsuitable for further analysis, so appropriate QC needs to be applied to assess and correct data.
QFish	Queensland Fishing
Raw data (also 'primary data')	Data that have not been processed or otherwise manipulated apart from QA/QC to ensure accuracy
RC	Report card
Reference condition	Recorded indicator values are compared against values from sites not impacted by human disturbance or alteration, or, which represent a control site considered to be 'healthy' (Connolly et al., 2013)
Standards	Legal limits permitted for a specific water body
TC	Tropical cyclone
TCM	Travel cost method
TropWATER	Centre for Tropical Water & Aquatic Ecosystem Research (James Cook University)
VFC	Visual Fish Condition
WICET	Wiggins Island Coal Export Terminal

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

Project name and institution	Reports and publications
ISP001 Mapping and synthesis of data and monitoring in Gladstone Harbour Australian Institute of Marine Science	Llewellyn, L., Wakeford, M., & McIntosh, E. (2013). *Mapping and synthesis of data and monitoring in Gladstone Harbour*. A report to the Independent Science Panel of the Gladstone Healthy Harbour Partnership, August 2013. Australian Institute of Marine Science, Townsville. Download the final report for this project. View the GHHP ePortal
ISP002 Review of the use of report cards for monitoring ecosystem and waterway health	Connolly, R.M., Bunn, S., Campbell, M., Escher, B., Hunter, J., Maxwell, P., Page, T., Richmond, S., Rissik, D., Roiko, A., Smart, J., & Teasdale, P. (2013). *Review of the use of report cards for monitoring ecosystem and waterway health*. Report to: Gladstone Healthy Harbour Partnership, November 2013. Queensland, Australia. Download the final report for this project.
ISP003 Models and indicators of key ecological assets in Gladstone Harbour CSIRO Wealth from Oceans Flagship	Dambacher, J.M., Hodge, K.B., Babcock, R.C., Fulton, E.A., Apte, S.C., Plagányi, É.E., Warne, M., & Marshall, N.A. (2013). *Models and indicators of key ecological assets in Gladstone Harbour*. A report prepared for the Gladstone Healthy Harbour Partnership. CSIRO Wealth from Oceans Flagship, Hobart. Dambacher, J.M., Hodge, K.B., Babcock, R.C., Fulton, E.A., Apte, S.C., Plagányi, É.E., Warne, M., & Marshall, N.A. (2013). *Précis for models and indicators of key ecological assets in Gladstone Harbour*. A report prepared for the Gladstone Healthy Harbour Partnership. CSIRO Wealth from Oceans Flagship, Hobart. Download the final report for this project.
ISP004 Guidance for the selection of social, cultural and economic indicators for the development of the Gladstone Healthy Harbour Report Card Central Queensland University	Greer, L., & Kabir, Z. (2013). *Guidance for the selection of social, cultural and economic indicators for the development of the GHHP Report Card*. Report to the Gladstone Healthy Harbour Partnership, School of Human Health and Social Science. Central Queensland University Australia, Rockhampton. Download the final report for this project.
ISP005 Piloting of social, cultural and economic data for the Gladstone Healthy Harbour Report Card CSIRO	Reports and publications Pascoe, S., Cannard, T., Marshall, N., Windle, J., Flint, N., Kabir, Z., & Tobin, R. (2014). *Piloting of social, cultural and economic indicators for the Gladstone Healthy Harbour Partnership Report Card*. Draft report prepared for the GHHP by CSIRO, Oceans and Atmosphere Flagship. Cannard, 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.

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ISP006 Development of a Gladstone Harbour Model to support the Gladstone Healthy Harbour Report Card CSIRO Wealth from Oceans Flagship	Fulton, E.A. & van Putten, I. (2014) Project ISP006: Milestone Report December 2014. CSIRO, Australia. Baird M., Margvelashvili N. (2015) *Receiving Water Quality & Sediment Scenarios:* Final Report. CSIRO, Australia. Fulton EA, Hutton T, van Putten IE, Lozano-Montes H and Gorton R (2017) Gladstone Atlantis Model – Implementation and Initial Results. Report to the Gladstone Healthy Harbour Partnership. CSIRO, Australia. Download the final report for this project. FultonEA, HuttonT, van Putten IE, Lozano-Montes Hand GortonR(2017) Gladstone Atlantis Model–Implementation and Initial Results. Report to the Gladstone Healthy Harbour Partnership. CSIRO, Australia. Download the final report for this project.

ISP007 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 GHHP Gladstone Harbour Report Card. CSIRO Wealth from Oceans Flagship, Hobart, University of Queensland. Download the final report for this project. Condie, S., Herzfeld, M., Andrewartha, J., Gorton, B., & Hock, K. (2017). Connectivity Indicators for the 2016 GHHP Gladstone Harbour Report Card. CSIRO Wealth from Oceans Flagship, Hobart, University of Queensland. Download the final report for this project Gorton, R., Condie, S. & Andrewartha, J. (2017) 2016-17 Connectivity Indicators for the GHHP Gladstone Harbour Report Card. CSIRO Oceans and Atmosphere, Hobart. Download the final report for this project.
ISP008 Provision of statistical support during the development of the Gladstone Harbour Report Card Queensland University of Technology	Johnson, S., Logan, M., Fox, D. & Mengersen, K. (2015). ISP008 Final Report (revised) Provision of statistical support during the development of the Gladstone Harbour Report Card. Queensland University of Technology, Brisbane.
ISP008-2015 Provision of statistical support during the development of the Gladstone Harbour Report Card Australian Institute of Marine Science	Logan, M. (2015) *Provision of final environmental grades and scores for the 2015 Gladstone Harbour Report Card.* Report prepared by the Australian Institute of Marine Science for Gladstone Healthy Harbour Partnership. December 3, 2015. Download the final report for this project.
ISP009 Development of a Data Information Management System for the Gladstone Harbour Report Card monitoring data	AIMS. (2014). *Design and architecture of the Data Information Management System (DIMS) for the GHHP Report Card monitoring data*. Project ISP009. Australian Institute of Marine Science, Townsville.
ISP010 Statistical assessment of the fish indicators and score for the pilot report card	Venables, W.N. (2015). *GHHP Barramundi Recruitment Index Project Final Report*. Gladstone Healthy Harbour Partnership, Gladstone. Download the final report for this project.

Bill Venables, CSIRO Research Fellow	
ISP011 Seagrass indicators for the Gladstone Harbour Report Card Centre for Tropical Water & Aquatic Ecosystem Research	Bryant, C.V., Jarvis, J.C., York, P.H., & Rasheed, M.A. (2014). *Gladstone Healthy Harbour Partnership Pilot Report Card: ISP011 Seagrass Draft Report – October 2014*. Research Publication 14/53. Centre for Tropical Water & Aquatic Ecosystem, James Cook University. Download the final report for this project. Carter, A.C., Jarvis, J.C., Bryant, C.V., & Rasheed, M.A. (2015). *Gladstone Healthy Harbour Partnership 2015 Report Card ISP011: Seagrass final report*. Centre for Tropical Water & Aquatic Ecosystem Research Publication 15/29, James Cook University, Cairns. Download the final report for this project. Carter, A.C., Bryant, C.V., Davies, J.D. & Rasheed, M.A. (2016). *Gladstone Healthy Harbour Partnership 2016 Report Card ISP011: Seagrass final report*. Centre for Tropical Water & Aquatic Ecosystem Research Publication 15/29, James Cook University, Cairns. Download the final report for this project. Carter AB, Wells JN & Rasheed MA (2017). 'Gladstone Healthy Harbour Partnership 2017 Report Card, ISP011: Seagrass'. Centre for Tropical Water & Aquatic Ecosystem Research Publication 17/29, James Cook University, Cairns. Download the final report for this project. Bryant CV, Carter AB, Chartrand KM, Wells JN & Rasheed MA (2018) *Gladstone Healthy Harbour Partnership 2018 Report Card, ISP011: Seagrass.* Centre for Tropical Water & Aquatic Ecosystem Research Publication 18/22, James Cook University, Cairns. Download the final report for this project. Carter AB, Chartrand KM, Wells JN & Rasheed MA (2019) Gladstone Healthy Harbour Partnership 2019 Report Card, ISP011: Seagrass. Centre for Tropical Water & Aquatic Ecosystem Research Publication 19/15, James Cook University. Download the final report for this project.
ISP012 Cultural indicators pilot project 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.

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

Zone	Physicochemical													
	Level of Protection	Turbidity		pH range		Nutrients			Metals					
		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	140	7	15
2. Graham Creek	MD	8	13	7.2–8.2	7.4–8.3	170	20	1	24	1.3	4.4	140	7	15
3. Western Basin	MD	8	13	7.2–8.2	7.4–8.3	170	18	1	24	1.3	4.4	140	7	15
4. Boat Creek	MD	14	25	7.2–8.2	7.4–8.3	190	22	2	24	1.3	4.4	140	7	15
5. Inner Harbour	MD	8	13	7.2–8.2	7.4–8.3	160	21	1	24	1.3	4.4	140	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	140	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	140	7	15
8.Mid Harbour	MD	4	9	7.2–8.2	7.4–8.3	135	14	1	24	1.3	4.4	140	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	140	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	140	7	15
11. Outer Harbour	MD	3	7	8.0–8.2		130	13	1	24	1.3	4.4	140	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	140	7	15
13. Rodds Bay	HEV	4	5	7.2–8.2	7.4–8.3	160	13	1	24	1.3	4.4	140	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.

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: A single manganese (Mn) guideline for MD systems (140 µg/L, 95% species protection with corals present) is applied to all harbour zones.

Other Metals: The 95% species protection value from the ANZECC/ARMCANZ (2000) 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