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Gladstone Healthy Harbour Partnership

TECHNICAL REPORT

GLADSTONE HARBOUR REPORT CARD 2021

Authorship statement

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

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Gladstone Healthy Harbour Partnership partners

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Management Committee representatives

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Executive summary

Context

The 2021 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 environmental monitoring undertaken in the period 1 July 2020 to 30 June 2021 and environmental, social, cultural and economic monitoring undertaken in 2018 and 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 2021 Gladstone Harbour Report Card for each component of harbour health.

Overall component grades

The overall component scores and grades for the 2021 report card were: Environmental 0.68 (B), Social 0.67 (B), Cultural 0.60 (C), and Economic 0.73 (B). As the scores and grades for the Social, Cultural and Economic components have been stable since their inception, no new monitoring for these components was undertaken in the 2019–20 report card year. Scores and grades from the 2018 and 2019 report cards have been used for these components and further monitoring is scheduled to take place in 2021–22 for Social, Cultural ('sense of place') and Economic. Cultural heritage is scheduled to be monitored again in 2022–23. Except for mangroves, all Environmental indicators were assessed in 2020 and the Environmental score is based on new data and the 2019 mangrove data. Mangrove monitoring will be conducted again in 2023–24.

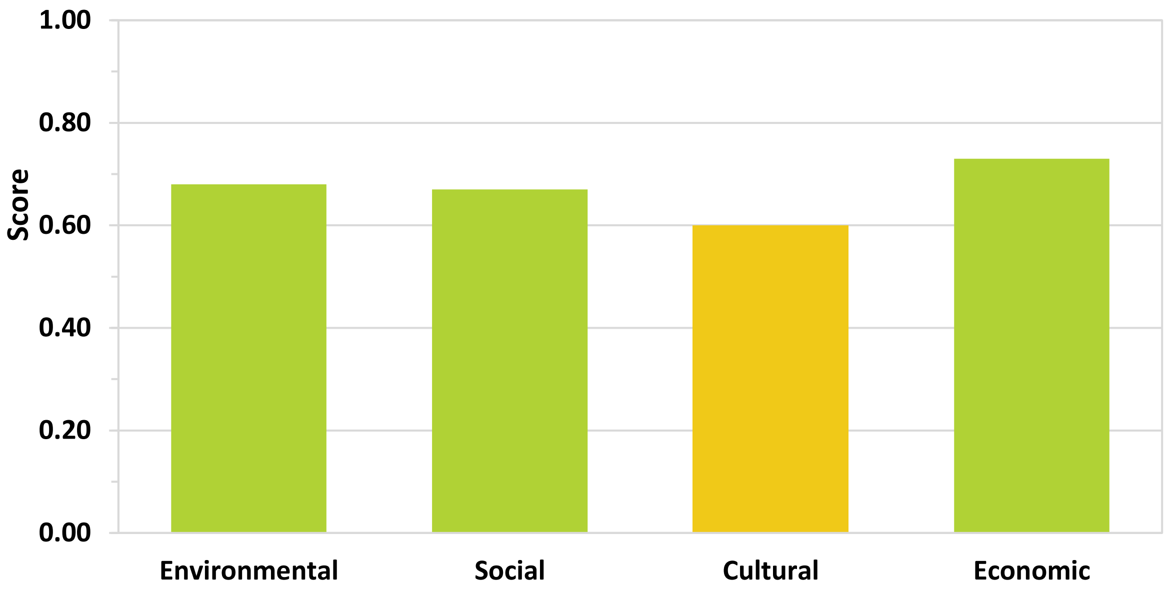


Figure 2: Overall scores for each of the four components of Gladstone Harbour Health in 2021.

Environmental health

The overall grade for the Environmental component was a B (0.68) which was similar to the 2020 Grade (B, 0.66). The water and sediment quality indicator group received a score of 0.93 (A), habitats a score of 0.48 (D) and fish and crabs a score of 0.62 (C) (Table 1). Water and sediment quality scores were similar to the previous year. The habitats score was also similar to the 2020 score of 0.50, however the 0.02 variation in the score was sufficient to change the grade from a C to a D. The overall score for fish and crabs improved from 0.56 in 2020 as a result of an improved fish Health Assessment Index grade. In 2021, the fish Health Assessment Index grade was A (0.90) compared to a B (0.67) in 2020.

Table 1: Environmental indicator group scores for the 13 harbour zones and the overall harbour scores in 2021.

Zone	Indicator groups		
	Water and sediment quality	Habitats (seagrass, corals and mangroves)	Fish and crabs
1. The Narrows	0.88	0.74	0.66
2. Graham Creek	0.94	0.64	0.68
3. Western Basin	0.97	0.63	0.88
4. Boat Creek	0.88	0.46	0.59
5. Inner Harbour	0.94	0.57	0.61
6. Calliope Estuary	0.94	0.58	0.65
7. Auckland Inlet	0.89	0.65	0.48
8. Mid Harbour	0.93	0.40	0.80
9. South Trees Inlet	0.94	0.79	0.64
10. Boyne Estuary	0.93	0.26	0.68
11. Outer Harbour	0.98	0.39	0.82
12. Colosseum Inlet	0.96	0.72	0.69
13. Rodds Bay	0.97	0.67	0.63
Harbour score	**0.93**	**0.48**	**0.62**

Water and sediment quality

Water quality received a score of 0.91 (A)—a continued improvement from the 2017 result (0.76, B) and the highest recorded in a Gladstone Harbour Report Card. The sediment quality indicator also received a very good score (0.96, A) which was near identical to previous years (Table 3). Since the first report card in 2015, water quality has been rated as good or very good and sediment quality has consistently been rated as very good.

Water quality

Water quality was relatively uniform across the harbour. Eleven of the thirteen zones received a very good score, with the remaining two zones receiving a good score (Table 2). Compared to the previous year, scores for the physicochemical group were comparable, showing very good scores in all thirteen zones. The nutrient harbour score (0.79, B) increased for the third consecutive year since the 2018 score of 0.47 (D) due to higher scores for total nitrogen and chlorophyll-*a*. Dissolved metal scores of 0.96 – 1.00 (A) were uniformly very good for the seventh consecutive year.

Table 2: Water quality indicator scores for the 2021 Gladstone Harbour Report Card. Scores from 2020 and 2019 are shown for comparison.

Water quality	Physico-chemical score	Nutrients score	Dissolved metals score	2021	*2020*	*2019*
1. The Narrows	0.85	0.66	1.00	0.84	*0.85*	*0.74*
2. Graham Creek	1.00	0.76	1.00	0.92	*0.91*	*0.79*
3. Western Basin	0.97	0.87	1.00	0.95	*0.89*	*0.77*
4. Boat Creek	0.85	0.69	0.97	0.84	*0.85*	*0.68*
5. Inner Harbour	1.00	0.82	1.00	0.94	*0.85*	*0.82*
6. Calliope Estuary	0.95	0.86	1.00	0.94	*0.94*	*0.80*
7. Auckland Inlet	0.87	0.71	0.99	0.85	*0.82*	*0.77*
8. Mid Harbour	0.92	0.80	1.00	0.91	*0.87*	*0.86*
9. South Trees Inlet	0.99	0.77	0.98	0.91	*0.87*	*0.83*
10. Boyne Estuary	0.94	0.71	0.96	0.87	*0.90*	*0.88*
11. Outer Harbour	1.00	0.91	1.00	0.97	*0.96*	*0.93*
12. Colosseum Inlet	0.99	0.79	1.00	0.93	*0.89*	*0.88*
13. Rodds Bay	1.00	0.87	1.00	0.96	*0.89*	*0.83*
Harbour score	**0.95**	**0.79**	**0.99**	**0.91**	***0.89***	***0.81***

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).

Table 3: Sediment quality indicator scores for the 2021 Gladstone Harbour Report Card. Scores from 2020 and 2019 are shown for comparison.

Zone	Metals and metalloid score	2021	*2020*	*2019*
1. The Narrows	0.92	0.92	*0.91*	*0.92*
2. Graham Creek	0.95	0.95	*0.90*	*0.91*
3. Western Basin	0.99	0.99	*0.98*	*0.98*
4. Boat Creek	0.92	0.92	*0.89*	*0.92*
5. Inner Harbour	0.94	0.94	*0.93*	*0.92*
6. Calliope Estuary	0.95	0.95	*0.95*	*0.96*
7. Auckland Inlet	0.93	0.93	*0.95*	*0.94*
8. Mid Harbour	0.96	0.96	*0.97*	*0.94*
9. South Trees Inlet	0.97	0.97	*0.96*	*0.96*
10. Boyne Estuary	0.99	0.99	*1.00*	*0.99*
11. Outer Harbour	0.98	0.98	*0.99*	*0.97*
12. Colosseum Inlet	1.00	1.00	*0.97*	*0.96*
13. Rodds Bay	0.98	0.98	*0.96*	*0.98*
Harbour score	**0.96**	**0.96**	***0.95***	***0.95***

Habitats

The overall score for habitats was poor (0.48, D), a similar score to the previous year of 0.50 (C). The seagrass and coral scores were similar to the previous year, although the seagrass score has improved substantially over the past three years from 0.40 (D) in 2018 to 0.72 (B) in 2021. The coral score remained very poor 0.14 (D) and the overall score for mangroves was based on monitoring completed in 2019 and therefore the score was identical this year (0.57, C).

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 2021 was 0.72 (B) indicating a good overall condition (Table 4). This is the second year of good condition and third consecutive year of marked improvement from previous report cards in which overall seagrass condition was poor. At the zone level, overall condition scores were satisfactory or above for five of the six zones. Thirteen of the 14 monitored meadows were also in satisfactory, good or very good condition. In contrast, Meadow 43 was in poor condition for the fourth consecutive year. Results suggest the continued good seagrass condition was largely a result of environmental factors characterized by below average rainfall and river flow.

Table 4: Seagrass indicator scores for the 2021 Gladstone Harbour Report Card. Scores from 2020 and 2019 are shown for comparison. Scores may differ slightly to those reported by Smith et al. (2021b) due to bootstrapping used to calculate GHHP report card scores (see Logan et al., 2016).

Zone	Meadow	Biomass	Area	Species composition	Overall meadow	2021	*2020**	*2019*
1. The Narrows	21	0.84	0.99	0.93	0.84	0.84	*0.80*	*0.71*
3. Western Basin	4	1.00	0.97	0.91	0.94	0.75	*0.81*	*0.69*
	5	0.86	0.82	0.82	0.82			
	6	0.88	0.94	0.62	0.75			
	7	0.63	0.74	1.00	0.63			
	8	0.86	0.69	0.57	0.63			
	52–57	0.71	0.95	1.00	0.71			
5. Inner Harbour	58	0.59	0.91	0.60	0.59	0.59	*0.70*	*0.21*
8. Mid Harbour	43	0.33	0.87	0.50	0.33	0.48	*0.44*	*0.52*
	48	0.64	0.72	0.97	0.64			
9. South Trees Inlet	60	0.97	1.00	1.00	0.97	0.97	*0.99*	*0.89*
13. Rodds Bay	94	0.84	0.87	0.99	0.84	0.70	*0.87*	*0.49*
	96	0.75	1.00	0.97	0.75			
	104	0.51	0.86	0.83	0.51			
Harbour score						0.72	*0.77*	*0.59*

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

Corals

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

In 2021, corals were in very poor condition for the fourth consecutive year and received an overall score of 0.14 (E). This was a result of a low cover of living coral, high macroalgal cover, low abundance of juvenile corals, and a poor overall score for change in hard coral cover (Table 5). Score changes at the sub-indicator level were minor between 2020 and 2021—coral cover received a similar score, juvenile density marginally improved and macroalgae cover and change in hard coral cover declined. 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 2021 Gladstone Harbour Report Card. Scores from 2020 and 2019 are shown for comparison.

Zone	Coral cover	Macroalgal cover	Juvenile density	Change in hard coral cover	2021	*2020**	*2019*
8. Mid Harbour	0.07	0.00	0.15	0.43	0.16	*0.20*	*0.19*
11. Outer Harbour	0.07	0.00	0.15	0.26	0.12	*0.14*	*0.17*
Harbour score	**0.07**	**0.00**	**0.15**	**0.34**	**0.14**	***0.17***	***0.18***

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

Mangroves

Scores for the mangrove indicator have remained stable since it was included in the report card in 2018. As a result, this indicator will only be monitored every five years and no new monitoring was conducted in 2020. The 2019 mangrove scores as presented below are used to calculate the overall scores for the habitats indicator group and the overall Environmental score.

In 2019 three sub-indicators were used to assess mangrove health: extent, canopy condition and shoreline condition. Mangrove extent, the proportion of mangroves in a tidal wetland, and canopy condition, were determined from satellite imagery. Shoreline condition, which assesses the proportion of dead mangroves within the shoreline trees, was determined from aerial photography.

The overall score for mangroves in Gladstone Harbour was 0.57 (C) marginally lower than the score of 0.60 (C) in 2018 (Table 6). This may have been a result of the drier conditions which prevailed during the 2018–19 reporting year.

Table 6: Overall mangrove zone and harbour scores for the 2020 and 2019 reporting years. Scores from 2018 are shown for comparison.

Zone	Mangrove extent	Mangrove canopy condition	Shoreline condition	2019 to 2021	*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 0.62 (C) Bream recruitment received a score of 0.62 (C) consistent with the score of 0.64 (C) received in the previous year. The mud crab indicator maintained a poor score 0.48 (D), the fourth consecutive year in which a poor score was recorded. The fish health indicator (Fish health assessment index and fish visual condition) received a good score of 0. 82 (B), an increase from the previous year's score of 0.69 (B).

Fish health

The harbour score for fish health was 0.82 (B) which was the average of the harbour scores for the two fish health sub-indicators:

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

Both sub-indicators assessed the health of fish species commonly caught in Gladstone Harbour. However, there were some differences in the species assessed because of the different fishing methods used. The score for visual fish condition was 0.74 (B), while the overall score for the fish health assessment index was 0.90 (A) an improvement from 2020 when this indicator gave a B (0.67) (Table 7). The health assessment index was calculated by scoring and summing visual inspection scores for external and internal measures. The scores for visual fish condition (Table 8) are derived from two metrics: an external visual assessment of fish health, which includes assessing the skin, eyes and fins, as well as recording the incidence of parasites, deformities and fish body condition determined from the length weight relationship. Measures of fish body condition are widely used to assess the health of individuals or groups of fish.

Table 7: Overall fish health assessment index (HAI) species and harbour scores from 2019 to 2021.

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

ND – No data or insufficient data to determine a score

Table 8: Overall visual fish condition (VFC) species and harbour scores from 2019 to 2021.

Visual fish condition (VFC)	FVA	FBC	VFC 2021	VFC 2020	*VFC 2019*
Yellow-finned bream	0.95	0.47	0.71	0.71	*0.61*
Pikey bream	0.98	0.48	0.73	0.74	*0.81*
Barred javelin	0.94	0.54	0.74	ND	*0.99*
Dusky flathead	0.97	0.54	0.76	ND	*0.52*
Mangrove jack	0.96	0.55	0.75	ND	*0.56*
Harbour score			**0.74**	**0.72**	***0.69***

FVA – Fish visual assessment; FBC – Fish body condition; ND – No Data

Fish recruitment

Fish recruitment was assessed for two species: yellow-finned bream *Acanthopagrus australis* and pikey bream *Acanthopagrus pacificus*. The overall score for 2021 was 0.62 (C) similar to the score recorded in 2020 (0.64, C). The final scores (Table 9) were measured against a 2012 to 2020 baseline. The 2021 score for fish recruitment indicates a season with higher recruitment rate (increased catch rate) relative to the mean reference level determined over the baseline period. The total number of bream caught in the 2021 reporting year was 626, 329 yellow-finned bream and 297 pikey bream. Pikey bream tended to dominate in the northern sites while yellow-finned bream tended to dominate in the southern sites.

Table 9: Bream recruitment scores for 12 harbour zones and the overall harbour score from 2016 to 2021.

Zone	2021	2020	*2019*	*2018*	*2017*
1. The Narrows	0.54	0.63	*0.18*	*0.58*	*0.75*
2. Graham Creek	0.84	0.92	*0.17*	*0.77*	*0.58*
3. Western Basin	0.94	0.98	*0.13*	*0.79*	*0.78*
4. Boat Creek	0.35	0.38	*0.32*	*0.61*	*0.47*
5. Inner Harbour	0.61	0.63	*0.16*	*0.67*	*0.64*
6. Calliope Estuary	0.68	0.66	*0.28*	*0.70*	*0.79*
7. Auckland Inlet	0.63	0.80	*0.53*	*0.87*	*0.91*
8. Mid Harbour	0.78	0.62	*0.12*	*0.58*	*0.71*
9. South Trees Inlet	0.47	0.39	*0.25*	*0.69*	*0.71*
10. Boyne Estuary	0.53	0.51	*0.32*	*0.52*	*0.74*
11. Outer Harbour	Not surveyed				
12. Colosseum Inlet	0.56	0.63	*0.39*	*0.61*	*0.71*
13. Rodds Bay	0.51	0.52	*0.33*	*0.59*	*0.74*
Harbour score	**0.62**	**0.64**	***0.27***	***0.66***	***0.71***

Mud crabs

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

The overall mud crab score in 2021 was 0.48 (D) and was similar to previous years, which ranged from 0.39 to 0.49 (D) since 2018 (Table 10). This was a result of mostly very poor scores for sex ratio (0.00–0.57), abundance scores ranging from very poor to very good (0.00–1.00) and mostly very good scores for prevalence of rust lesions ranging from 0.47 to 1.00. Three zones received a satisfactory overall score and three zones received a poor overall score. As only two mud crabs were caught in Auckland Creek, a score was not calculated for this zone for the fourth consecutive year.

Table 10: Mud crab indicator scores for the 2021 Gladstone Harbour Report Card. Scores from 2020 and 2019 are shown for comparison.

Zone	Sex Ratio	Abundance (CPUE)	Prevalence of rust lesions	2021	*2020*	*2019*
1. The Narrows	0.00	1.00	0.92	0.64	*0.60*	*0.63*
2. Graham Creek	0.00	0.27	0.89	0.39	*0.34*	*0.45*
4. Boat Creek	0.03	0.83	0.94	0.60	*0.71*	*0.48*
5. Inner Harbour	0.07	0.63	0.47	0.39	*0.39*	*0.48*
6. Calliope Estuary	0.14	0.26	1.00	0.47	*0.19*	*0.43*
7. Auckland Inlet	NC	0.00	NC	NC	*NC*	*NC*
13. Rodds Bay	0.57	0.16	0.96	0.56	*0.22*	*0.36*
Harbour score	**0.14**	**0.45**	**0.86**	**0.48**	***0.39***	***0.47***

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

Social health

The scores for the Social component have remained stable since it was included in the pilot report card in 2014. As a result, this component will only be monitored every third year and no new monitoring was conducted in 2021. Social health will be assessed again in 2021–22 for the 2022 report card. The 2019 Social component scores are used for the 2021 report card.

The overall score for Social health in 2019 was 0.67 (B), which was similar to previous years. 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 recorded previously 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 to 2021 reporting years. Scores from 2018 and 2017 are shown for comparison.

Indicator groups	Social indicators	2019 to 2021	2019 to 2021	*2018*	*2017*
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**	***0.67***	***0.66***

Cultural health

The Cultural component score is comprised of two indicator groups, 'sense of place' and Indigenous cultural heritage. 'Sense of place' was last monitored in 2019 and these results are used in the 2021 report card. The 'sense of place' score has remained stable over the life of the report card. Hence monitoring of this indicator group will be conducted triennially from 2019 with the next scheduled reporting of this indicator group to occur in the 2021–22 reporting year. The score for Indigenous cultural heritage ranged from 0.53 to 0.55 in the 3 years it has been monitored between 2016 and 2018. Owing to the stability of this indicator group, from 2018 onwards monitoring is scheduled to occur every five years with the next round of monitoring due in the 2022–23 reporting year. Results from the 2018 surveys will be used to calculate the overall score for the Cultural component until then.

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) and Indigenous cultural heritage 0.54 (C).

The overall 'sense of place' score was similar to previous years (Table 12). 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 stable since it was included in the report card in 2016. The overall Indigenous cultural heritage score of 0.54 (C) was based on site surveys conducted in 2016, 2017 and 2018 (Table 13).

Table 12: Scores for the 'sense of place' indicator group, 2016 to 2021. Scores from 2018 to 2016 are shown for comparison.

Indicator group	Indicators	2019 to 2021	2019 to 2021	*2018*	*2017*	*2016*
'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 to 2021 report cards.

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

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

Economic health

The Economic component was last assessed in 2019 and had an overall score of 0.72 (B), with scores ranging from 0.72 to 0.77 between the 2015 and 2019 report cards. As the scores for the Economic component and its indicator groups have been stable over this 5-year period, from 2019 onwards this component will be monitored every three years with the next round of monitoring due to occur for the 2022 report card.

The 2021 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 when last assessed in 2019.

Table 14: Scores for the economic indicator groups from 2016 to 2021. The 2018 to 2016 scores are shown for comparison.

Indicator group	Indicators	2019 to 2021	2019 to 2021	*2018*	*2017*	*2016*
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	0.76	*0.74*	*0.73*	*0.73*
	Recreational fishing	0.71				
	Beach recreation	0.76				
	Water-based recreation	0.76				
Overall score		**0.72**	**0.72**	***0.72***	***0.74***	***0.75***

1. Introduction

1.1 The Gladstone Healthy Harbour Partnership

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 in 2013.

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

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

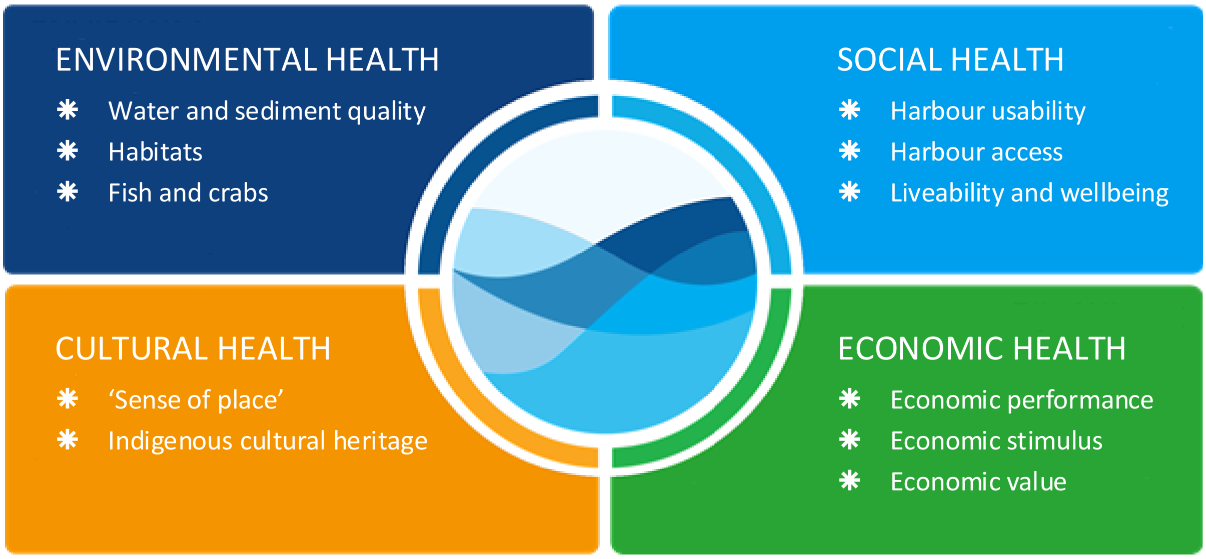


Figure 1.1: The four components of harbour health.

1.2. Reporting periods

The reporting period for the 2021 Gladstone Harbour Report Card was 1 July 2020 to 30 June 2021. This allows the significant environmental changes that occur in the wetter summer months to be captured in the annual data. However, mangrove data collected in the 2018–19 reporting year was used to complete the Environmental component. No new data for the Social, Cultural and Economic components was collected during the 2020–21 report card year. All grades and scores for these components are those used in the 2019 report card.

2. From indicators to report card grades

2.1. Structure and indicators

The hierarchy of score aggregation used to calculate the final grade for each component of harbour health can include up to five levels of aggregation: components, indicator groups, indicators, sub-indicators and measures (Table 2.1). This structure derives the final scores from raw data collected through field sampling, community surveys and publicly available sources.

Table 2.1: The five levels of aggregation employed to determine the grades and scores in the 2021 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.

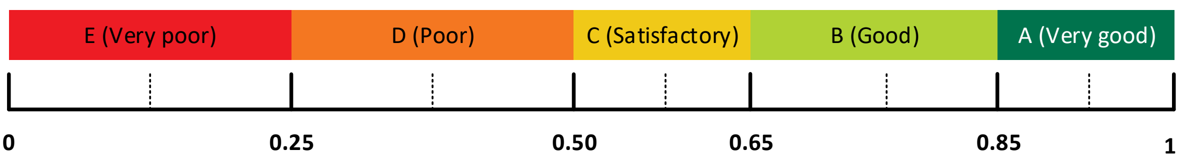


Figure 2.1: Grade ranges used in the 2021 Gladstone Harbour Report Card.

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 2019–20 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 2019–20 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).

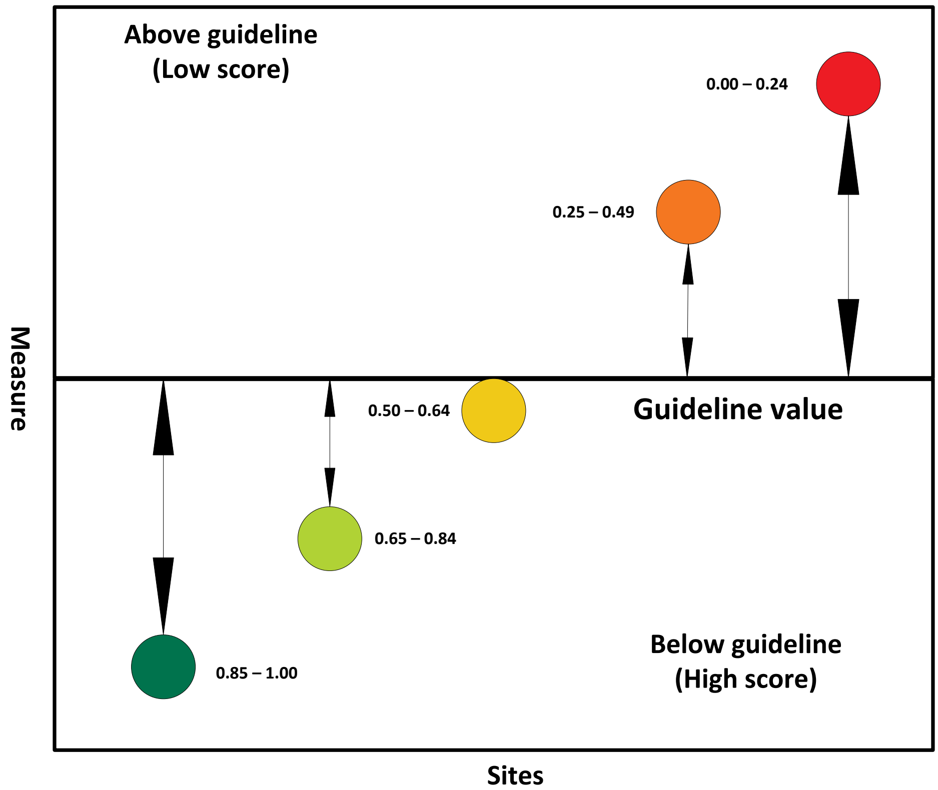


Figure 2.2: Water and sediment quality measures are scored relative to zone and measure specific guideline values.

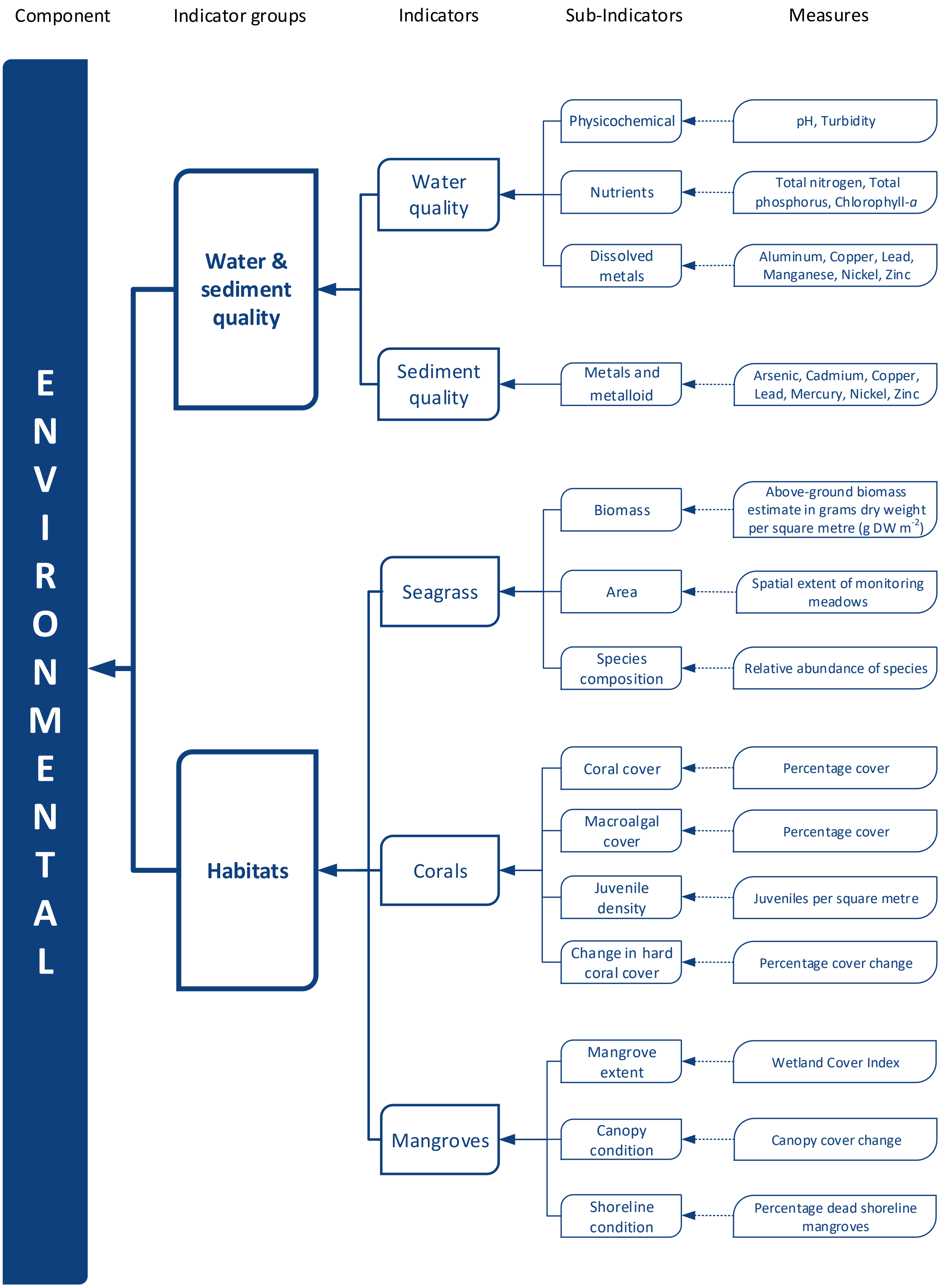


Figure 2.3a: The levels of aggregation used to determine the environmental scores and grades in the 2021 Gladstone Harbour Report Card. There are 3 environmental indicator groups, 8 indicators, 19 sub-indicators and 47 measures.

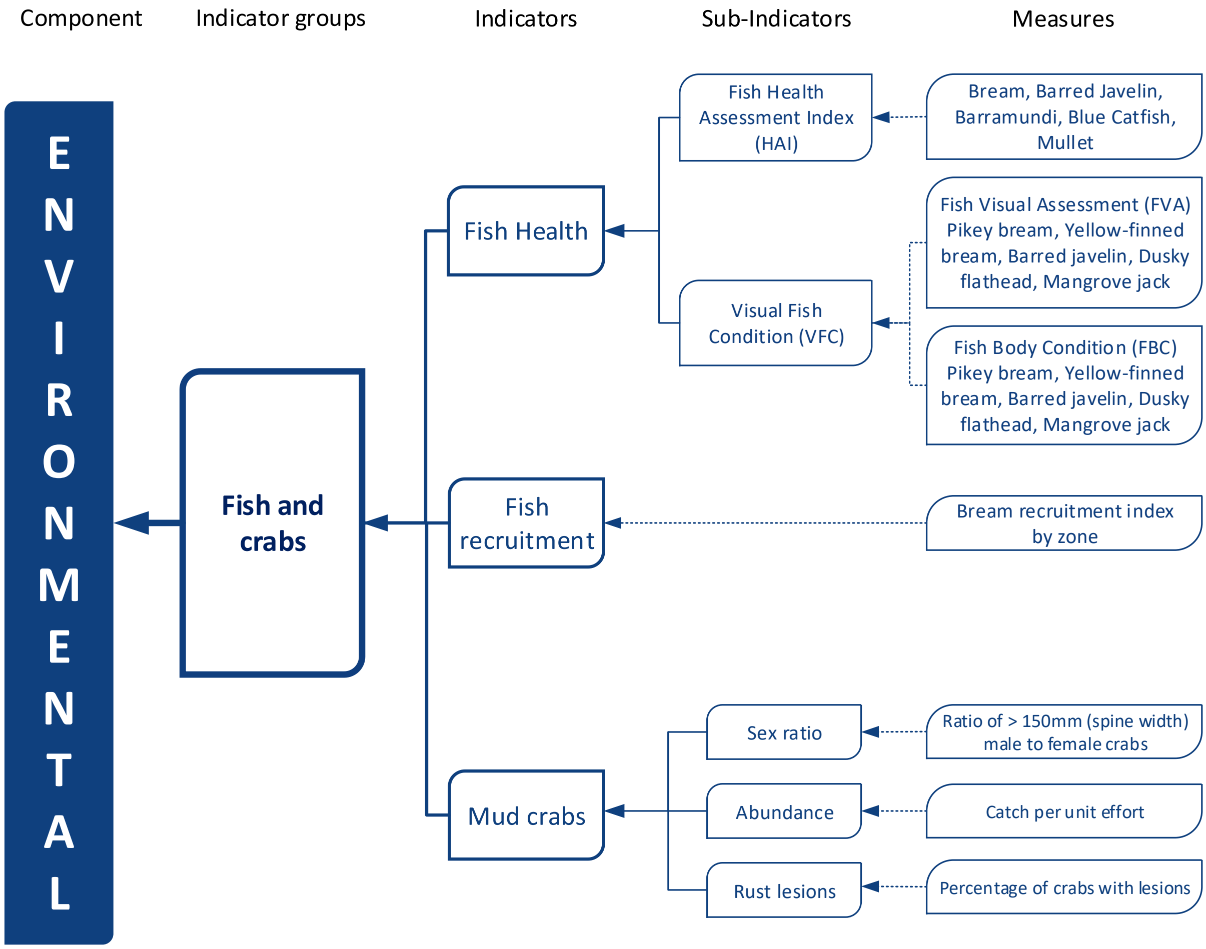


Figure 2.3b: The levels of aggregation used to determine the environmental scores and grades in the 2021 Gladstone Harbour Report Card. There are 3 environmental indicator groups, 8 indicators, 19 sub-indicators and 47 measures.

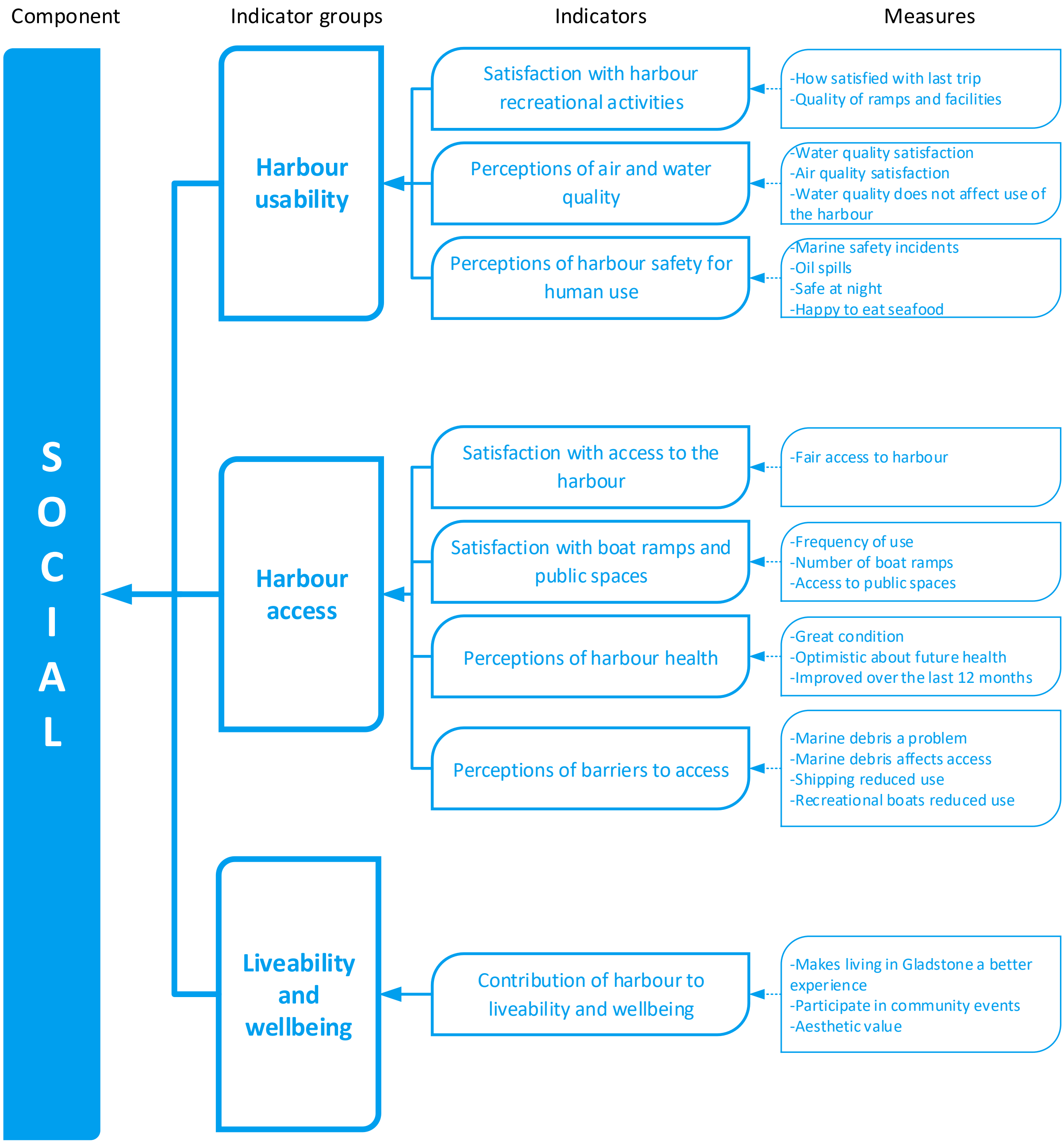


Figure 2.4: The levels of aggregation used to determine the social scores and grades in the 2021 Gladstone Harbour Report Card. There are 3 social indicator groups, 8 indicators and 23 measures.

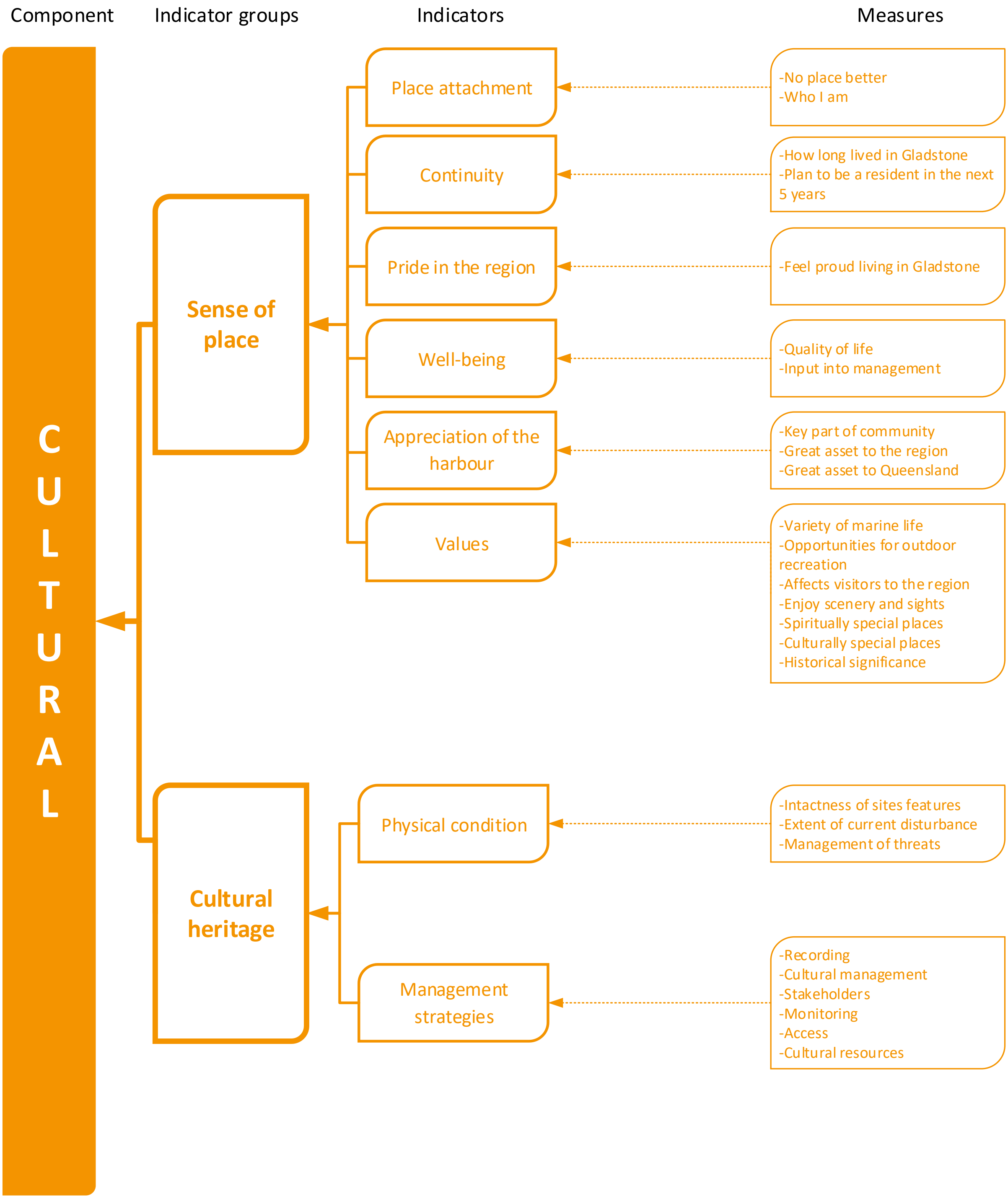


Figure 2.5: The levels of aggregation used to determine the cultural grades and scores in the 2021 Gladstone Harbour Report Card. There are 2 cultural indicator groups, 8 indicators and 26 measures.

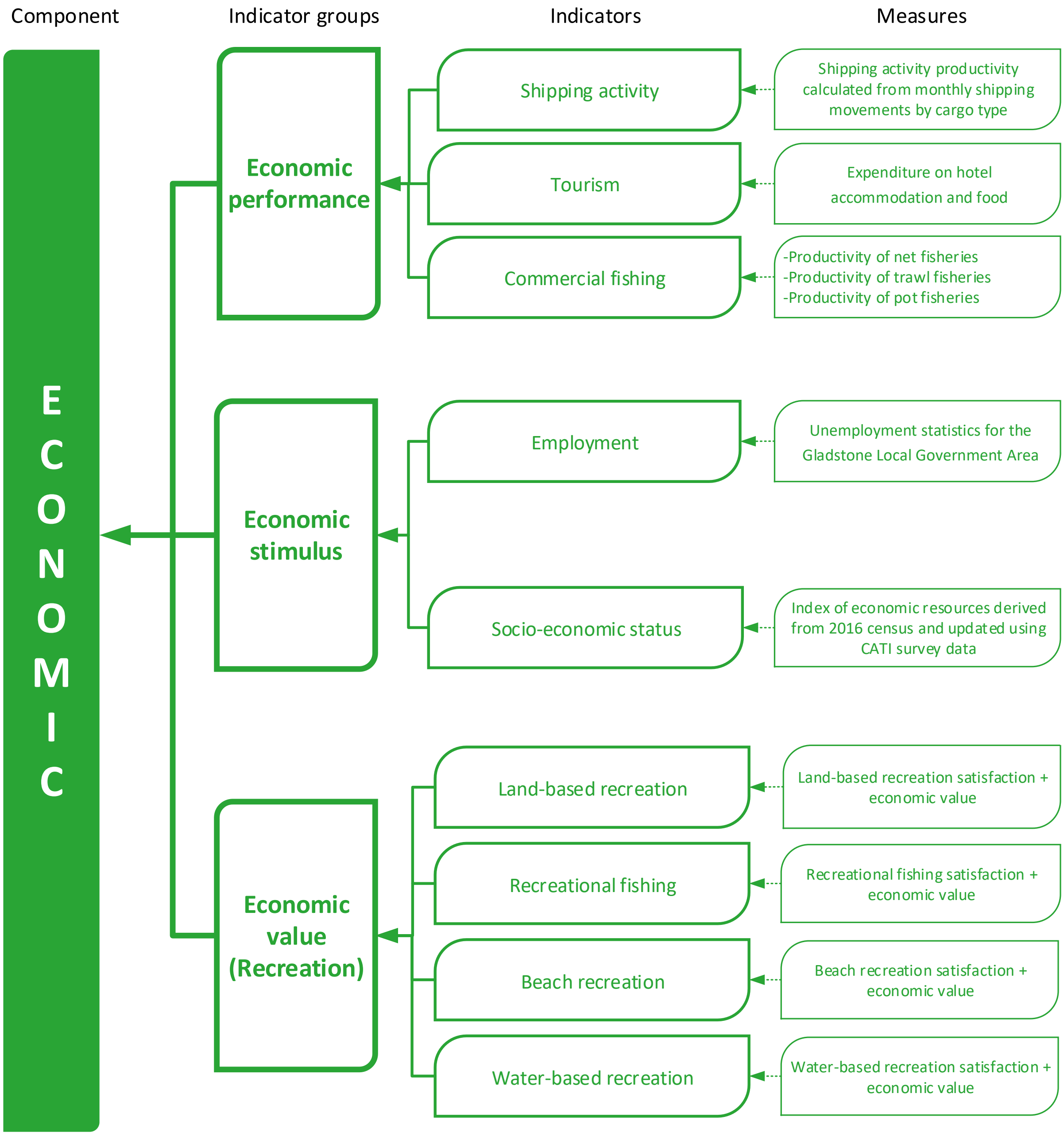


Figure 2.6: The levels of aggregation used to determine the economic scores and grades in the 2021 Gladstone Harbour Report Card. CATI = Computer-Assisted Telephone Interviewing. There are 3 economic indicator groups, 9 indicators and 11 measures.

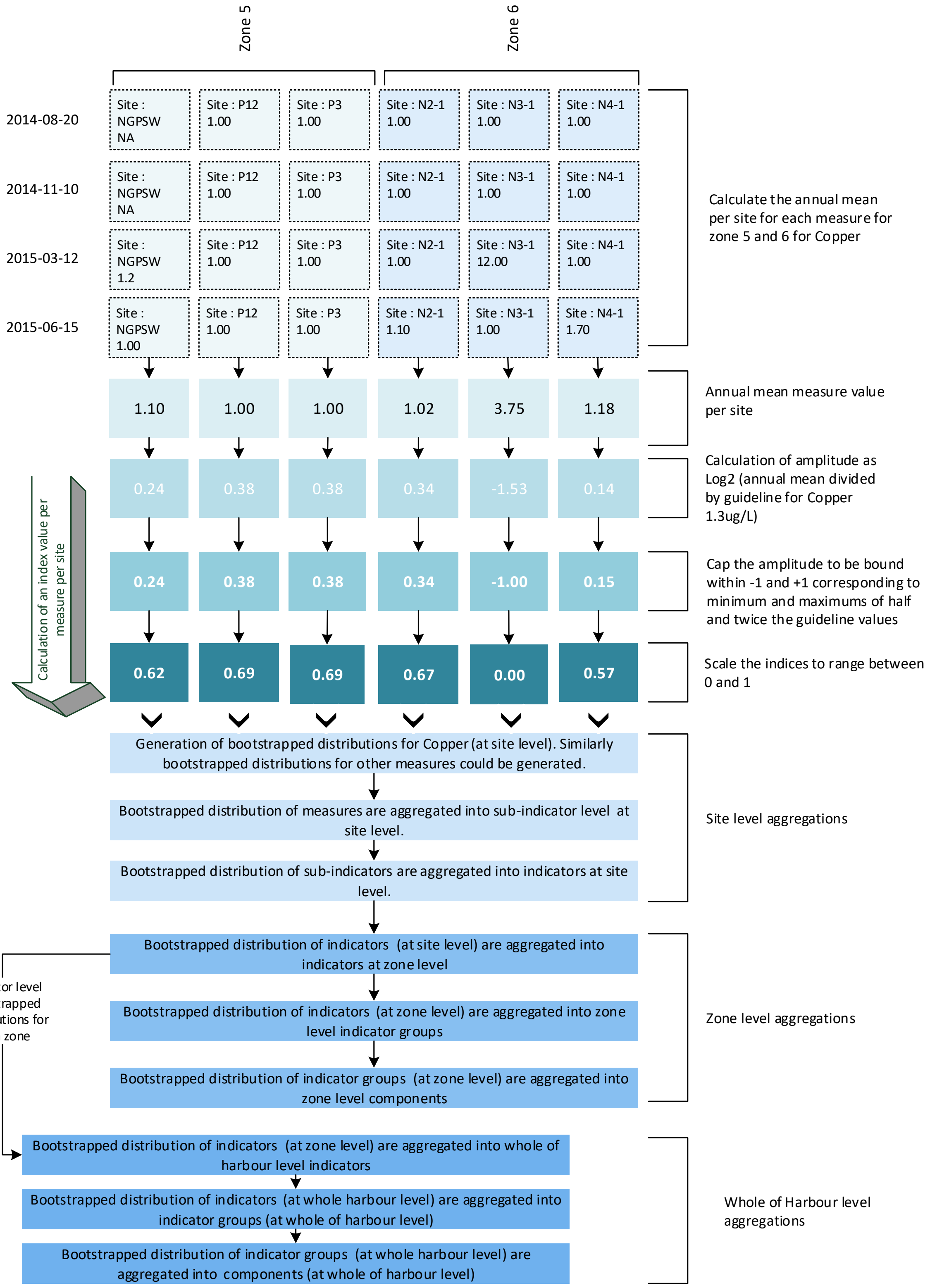


Figure 2.7: Aggregation of report card scores—a worked example using the water quality measure for copper in zones 5 and 6.

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 component received a high confidence rating in 2021. The Social and Economic components received high confidence ratings in 2021 while the Cultural component remained at a moderate rating.

The Environmental component received a high confidence rating for the first time in 2019 and retains that rating for the 2021 report card. The high confidence rating was achieved as the Environmental component has been completed and additional years of data indicate the robustness of the methods used to determine the grades. Six of the eight indicators received high confidence ratings, while water and quality and fish health received moderate ratings (Table 2.2). These were identical to the ratings received in 2019 and 2020.

Table 2.2: Confidence ratings for individual environmental indicators in 2021.

Indicator	Confidence	Reason
Water quality	Moderate	Only 'far-field' sites were reported on, and these were sampled only four times a year.
Sediment quality	High	Appropriate methodology and sampling frequency, minimal laboratory issues since the pilot report card in 2014.
Seagrass	High	Consistent methods used over seven years of monitoring. Minor changes to scoring methods in 2018.
Corals	High	Consistent methods used over seven years of monitoring. Minor changes to scoring methods in 2018.
Mangroves*	High	Two years of monitoring, high quality data and consistent with other mangrove monitoring programs in Queensland. The 2019 results were used in the 2020 and 2021 report cards.
Fish health	Moderate	Four years of monitoring (2018–2021) 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	Six years of monitoring with consistent methods and data analysis. Minor change to sampling frequency in 2021.
Mud crabs	High	Five years of monitoring with an appropriate methodology. The benchmarks are based on local populations. Minor changes to scoring methods in 2020.

* The mangrove data used to calculate the overall 2021 Environmental score were collected in 2019.

The confidence ratings for the Social, Cultural and Economic components remain unchanged from 2019 as the 2019 results are used for the 2021 report card.

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 or 2020 and the 2018 scores and grades have been used. The methodology to assess Indigenous Cultural Heritage in a report card framework is still relatively new and further refinements may be required. The methodology to assess 'sense of place' is well established but based on a single survey only and there is no corroborating data. The development of ways to corroborate the 'sense of place' data and continued development of the Indigenous Cultural Heritage indicator will lead to improved confidence for this component.

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

3. 2021 Environmental Monitoring

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

3.1. Water and sediment quality

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

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

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

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

For the same reason, GHHP applied a draft manganese guideline value for marine waters of 140 µg/L for the water quality assessment in all zones from 2014–2019, which was the appropriate guideline for moderately disturbed systems with corals present (COAG Standing Council on Environment and Water, 2013). The draft guideline value of 140 µg/L was recommended by the ISP as it was derived using the species sensitivity distribution method and was based on the most relevant information available at the time. However, the draft manganese guideline value has yet to be finalised and additional chronic studies with corals are to occur in 2022. Given that there is no longer a strong rationale to maintain the original draft guideline value (140 µg/L), the ISP recommended to change the GHHP manganese guideline value to the ANZG (2018) value of 80 µg/L—which is based on ANZECC/ARMCANZ (2000)—until the new guideline value is peer reviewed and adopted. For this reason, the ISP applied the guideline of 80 µg/L across all zones for manganese in marine waters.

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 wasapplied to nickel (Ni). Water quality guideline values were selected for moderately disturbed systems.

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

- *Australian and New Zealand Standards for water quality and sediment sampling* (AS/NZS 5667.1:1998, 5667.4:1998, 5667.6:1998, 5667.12:1998)
- *American Public Health Association (APHA) Standard Methods for the Examination of Water and Wastewater* (APHA, 2005)
- *Australian and New Zealand Water Quality Guidelines* (ANZECC, 1992, 1998; ANZECC/ARMCANZ, 2000; ANZG, 2018)
- *Queensland Water Quality Guidelines* (DEHP, 2009)
- *Department of Environment and Science Monitoring and Sampling Manual* (DES, 2018)
- *Revision of the ANZECC/ARMCANZ Sediment Quality Guidelines* (Simpson et al., 2013)

3.1.1. Water and sediment quality data collection

Water quality

Under a data-sharing agreement, Port Curtis Integrated Monitoring Program (PCIMP) provided GHHP with water quality data for calculating scores for the 2021 report card. Those data were based on samples collected from 51 sites across the 13 harbour zones in August and November 2020 and March and June 2021 (Figures 8.1–8.27). Methods in this section were provided by PCIMP (PCIMP, 2019).

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

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

All analysing laboratories have been accredited by the National Association of Testing Authorities, Australia. This is to ensure compliance with relevant international and Australian standards and competency in providing consistently reliable testing, calibration, measurement, and inspection data. Dissolved metal samples were sent to the National Measurement Institute and nutrient samples were sent to the Queensland Health Laboratories apart from chlorophyll-*a* samples, which were sent to Australian Laboratory Services. Field blanks, travel blanks and duplicate samples were dispatched to the same respective laboratories based on sample type.

Table 3.1: Water quality sub-indicators and measures in the 2021 Gladstone Harbour Report Card.

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

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

Sediment quality

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

Sediment samples were collected from the same 51 harbour monitoring sites used for water quality sampling in May 2021. Grab samples were collected for sediment quality measures using a stainless steel Ponar grab sampler (0.008 m^3 volume). These samples were deposited into a collection tub that had been triple rinsed with seawater and then photographed. All sediment quality measurements used the top 100 mm of the sample, which were deposited into laboratory-provided sample containers using pre acid-washed polypropylene trowels.

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

Sediment nutrients were not included as there are no relevant national or international guidelines. They may be included in future report cards should relevant guidelines become available. Polycyclic aromatic hydrocarbons have not been included since the first report card owing to the extremely low concentrations recorded in 2015.

Table 3.2: Sediment quality measures in the 2021 Gladstone Harbour Report Card.

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

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

What water and sediment quality measures were not included?

In October 2021, the ISP discussed QA/QC issues with the raw dataset for 2021 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 potentially perverse results (e.g., zones with the lowest WQOs tended to have the lowest scores).
4. There would be an element of double counting if NOx and orthophosphate were included, as these are already measured under total nitrogen and total phosphorous respectively.

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

3.1.2. *Water and sediment quality measures*

A total of 18 water and sediment quality measures were assessed and reported in the 2021 Gladstone Harbour Report Card. These measures were recommended by the GHHP ISP as indicative of the factors relevant to the harbour and its condition. The importance of each measure to overall harbour health is described in the sections below.

Physicochemical indicators

pH

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

Turbidity

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

Nutrients

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

Total nitrogen

Total nitrogen 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.

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).

Mercury

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

Nickel

Nickel 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.

3.1.3. Water and sediment quality results

3.1.3.1 Water quality

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

The overall score for water quality in the 2021 report card was 0.91 (A). This was the second time since monitoring began in 2015 that the water quality indicator received a very good score. Eleven zones received very good scores (0.85–0.97, A) and two zones received good scores (0.84, B) (Table 3.3).

Table 3.3: Water quality indicator scores for the 2021 Gladstone Harbour Report Card. Scores from 2020 and 2019 are shown for comparison.

Water quality	Physico-chemical score	Nutrients score	Dissolved metals score	2021	*2020*	*2019*
1. The Narrows	0.85	0.66	1.00	0.84	*0.85*	*0.74*
2. Graham Creek	1.00	0.76	1.00	0.92	*0.91*	*0.79*
3. Western Basin	0.97	0.87	1.00	0.95	*0.89*	*0.77*
4. Boat Creek	0.85	0.69	0.97	0.84	*0.85*	*0.68*
5. Inner Harbour	1.00	0.82	1.00	0.94	*0.85*	*0.82*
6. Calliope Estuary	0.95	0.86	1.00	0.94	*0.94*	*0.80*
7. Auckland Inlet	0.87	0.71	0.99	0.85	*0.82*	*0.77*
8. Mid Harbour	0.92	0.80	1.00	0.91	*0.87*	*0.86*
9. South Trees Inlet	0.99	0.77	0.98	0.91	*0.87*	*0.83*
10. Boyne Estuary	0.94	0.71	0.96	0.87	*0.90*	*0.88*
11. Outer Harbour	1.00	0.91	1.00	0.97	*0.96*	*0.93*
12. Colosseum Inlet	0.99	0.79	1.00	0.93	*0.89*	*0.88*
13. Rodds Bay	1.00	0.87	1.00	0.96	*0.89*	*0.83*
Harbour score	**0.95**	**0.79**	**0.99**	**0.91**	***0.89***	***0.81***

The physico-chemical scores for pH were uniformly very good (1.00) in all zones (Table 3.4). The scores for turbidity ranged from good to very good, with the majority of zones being ranked very good. Only four zones (The Narrows, Boat Creek, Auckland Inlet and the Mid Harbour) had good scores, with The Narrows and Auckland Inlet receiving the lowest scores (0.69, B). The harbour score for the physico-chemical sub-indicator (0.95, A) was the highest observed since 2015.

Like previous report cards, nutrients received the lowest score of 0.79 (B) amongst the water quality sub-indicators. However, nutrient scores improved for the third consecutive year at the majority of zones and, overall, were the highest since GHHP reporting began. Nine of the 13 monitoring zones had good scores ranging from 0.69 to 0.82 (Table 3.3). The remaining four zones had very good scores ranging from 0.86 to 0.91. The Outer Harbour has the highest nutrient score (0.91, A) while The Narrows had the lowest nutrient score (0.66, C). At the measure level, total phosphorous received the highest scores, total nitrogen received the lowest scores, and chlorophyll-a scores were more variable ranging from 0.48 (D) to 0.99 (A) (Table 3.4). For the first time since monitoring began in 2015, all three nutrient measures showed a good or very good score at the harbour level.

All zones had consistently very good scores (0.96–1.00) for dissolved metals (Table 3.3). The same was true at the measure level as four of the six metals received very good scores across the 13 zones (Table 3.4). The exceptions—copper at Western Basin (0.79, B) and manganese at Boat Creek (0.84, B)—showed good scores, with the remaining twelve zones for the two measures showing consistently very good scores.

Table 3.4: Scores for water quality measures for each of the 13 zones in the 2021 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	0.69	0.68	0.83	0.48	1.00	1.00	1.00	1.00	1.00	1.00
2. Graham Creek	1.00	1.00	0.73	1.00	0.55	1.00	1.00	1.00	1.00	1.00	1.00
3. Western Basin	1.00	0.94	0.71	1.00	0.92	1.00	1.00	1.00	1.00	1.00	1.00
4. Boat Creek	1.00	0.69	0.50	0.59	0.97	1.00	1.00	1.00	0.84	1.00	1.00
5. Inner Harbour	1.00	1.00	0.75	1.00	0.71	1.00	1.00	1.00	1.00	1.00	1.00
6. Calliope Estuary	1.00	0.89	0.67	0.94	0.97	1.00	1.00	1.00	1.00	1.00	1.00
7. Auckland Inlet	1.00	0.74	0.55	0.73	0.85	1.00	1.00	1.00	0.93	1.00	1.00
8. Mid Harbour	1.00	0.84	0.66	1.00	0.74	0.98	1.00	1.00	1.00	1.00	1.00
9. South Trees Inlet	1.00	0.97	0.73	0.99	0.59	1.00	0.85	1.00	1.00	1.00	1.00
10. Boyne Estuary	1.00	0.88	0.40	1.00	0.73	1.00	0.79	1.00	1.00	1.00	1.00
11. Outer Harbour	1.00	1.00	0.74	1.00	0.99	1.00	1.00	1.00	1.00	1.00	1.00
12. Colosseum Inlet	1.00	0.97	0.56	1.00	0.82	1.00	1.00	1.00	1.00	1.00	1.00
13. Rodds Bay	1.00	1.00	0.76	1.00	0.85	1.00	1.00	1.00	1.00	1.00	1.00
Harbour score	**1.00**	**0.89**	**0.65**	**0.93**	**0.78**	**1.00**	**0.97**	**1.00**	**0.98**	**1.00**	**1.00**

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

3.1.3.2. Sediment quality

The overall sediment quality scores were derived from one sub-indicator—metals and metalloid. Six metals (cadmium, copper, lead, mercury, nickel and zinc) and the metalloid arsenic were assessed. The harbour score for sediment quality was 0.96 (A)— nearly identical to the 2017 to 2020 scores of 0.95 (A).

Zone scores for sediment quality were all very good, ranging from 0.92 (A) in The Narrows to 1.00 (A) in Colosseum Inlet (Table 3.5). This was a result of low concentrations of all measures (arsenic, cadmium, copper, lead, mercury, nickel and zinc) (Table 3.6). While zone scores were uniformly very good for most measures, there were a number of good or satisfactory scores for sediment arsenic and nickel.

Table 3.5: Sediment quality sub-indicator scores for each of the 13 zones in the 2021 Gladstone Harbour Report Card. Overall zone and harbour scores in 2019 and 2020 are shown for comparison.

Zone	Metals and metalloid score	2021	*2020*	*2019*
1. The Narrows	0.92	0.92	*0.91*	*0.92*
2. Graham Creek	0.95	0.95	*0.90*	*0.91*
3. Western Basin	0.99	0.99	*0.98*	*0.98*
4. Boat Creek	0.92	0.92	*0.89*	*0.92*
5. Inner Harbour	0.94	0.94	*0.93*	*0.92*
6. Calliope Estuary	0.95	0.95	*0.95*	*0.96*
7. Auckland Inlet	0.93	0.93	*0.95*	*0.94*
8. Mid Harbour	0.96	0.96	*0.97*	*0.94*
9. South Trees Inlet	0.97	0.97	*0.96*	*0.96*
10. Boyne Estuary	0.99	0.99	*1.00*	*0.99*
11. Outer Harbour	0.98	0.98	*0.99*	*0.97*
12. Colosseum Inlet	1.00	1.00	*0.97*	*0.96*
13. Rodds Bay	0.98	0.98	*0.96*	*0.98*
Harbour score	**0.96**	**0.96**	***0.95***	***0.95***

Table 3.6: Scores for sediment quality measures for each of the 13 zones in the 2021 Gladstone Harbour Report Card.

Zone	Metals and metalloid						
	Arsenic	Cadmium	Copper	Lead	Mercury	Nickel	Zinc
1. The Narrows	0.79	1.00	1.00	1.00	1.00	0.63	1.00
2. Graham Creek	0.85	1.00	1.00	1.00	1.00	0.81	1.00
3. Western Basin	0.97	1.00	1.00	1.00	1.00	0.93	1.00
4. Boat Creek	0.78	1.00	1.00	1.00	1.00	0.66	1.00
5. Inner Harbour	0.60	1.00	1.00	1.00	1.00	1.00	1.00
6. Calliope Estuary	0.94	1.00	1.00	1.00	1.00	0.73	1.00
7. Auckland Inlet	0.77	1.00	0.98	1.00	1.00	0.78	1.00
8. Mid Harbour	0.78	1.00	0.98	1.00	1.00	0.95	1.00
9. South Trees Inlet	0.87	1.00	1.00	1.00	1.00	0.92	1.00
10. Boyne Estuary	0.93	1.00	1.00	1.00	1.00	1.00	1.00
11. Outer Harbour	0.88	1.00	1.00	1.00	1.00	1.00	1.00
12. Colosseum Inlet	1.00	1.00	1.00	1.00	1.00	1.00	1.00
13. Rodds Bay	0.89	1.00	1.00	1.00	1.00	1.00	1.00
Harbour score	**0.85**	**1.00**	**1.00**	**1.00**	**1.00**	**0.88**	**1.00**

3.1.4. Water and sediment quality conclusions

Scores for the water quality indicator have remained high since the first full report card in 2015, receiving a good grade (B) from 2015 to 2019 and a very good grade (A) in 2020 and 2021 (Figure 3.1). In 2021, water quality was relatively uniform across the harbour, with all zones but two receiving very good scores overall. Compared to the previous year, scores for the physicochemical group were relatively consistent, showing marginally higher scores for turbidity. Dissolved metals scores were consistently very good for the seventh consecutive year. Conversely, nutrient scores improved at twelve of the 13 monitoring zones compared to 2020. The overall nutrient score was the highest received in the GHHP program. Paired with overall very good physico-chemical and dissolved metal scores, improvements in nutrient scores resulted in the highest overall water quality score (0.91, A) observed since GHHP reporting began.

While nutrient scores have shown incremental improvements since 2018, the nutrient sub-indicator maintained the lowest score of the three sub-indicators for the seventh consecutive year. Although nutrient sources are difficult to define, catchment run-off is a major source of nutrients in estuarine waters such as Gladstone Harbour (Hale & Box, 2014). The level of nutrients entering the harbour can also be influenced by land use (agricultural, industrial, urban, etc.), discharge from portside industries and climatic condition, with the nutrient load expected to increase with wet season run-off. As nutrients can bind to fine sediments, the resuspension of sediments associated with tidal movements or wave action can also lead to increased nutrient levels within Gladstone Harbour.

Good to very good nutrient and turbidity scores may have resulted from the lower-than-average rainfall and minimal discharge from the Boyne and Calliope rivers (Figures 5.3 to 5.8). River flow from the Calliope continues to be very low, with below-average flow evidenced since 2018 (Smith et al., 2021b).

From 2017 to 2019, Boat Creek received the lowest nutrient, physico-chemical (turbidity) and overall zone score. Boat Creek also received generally lower scores when compared with other zones in 2020 and 2021. In contrast, Outer Harbour received the highest nutrient, physico-chemical (turbidity) and overall zone score for the fifth consecutive year. These results indicate that the more ocean-influenced zones (such as Outer Harbour) have lower nutrient concentrations relevant to respective WQOs and improved water clarity compared to other zones. The small and shallow nature of several of the estuarine zones, which are more prone to the resuspension of sediments owing to wind and tidal movement, likely influences the higher nutrient concentrations and turbidity values exhibited at zones such as Boat Creek.

For additional information on the water and sediment quality indicators of Gladstone Harbour, please refer to the 2017 and 2018 reports (Schultz et al., 2019; Hansler et al., 2020). These technical reports provide greater detail on potential factors affecting water quality, data quality assurance and quality control and other comparison techniques used to elucidate trends in the water and sediment quality of Gladstone Harbour.

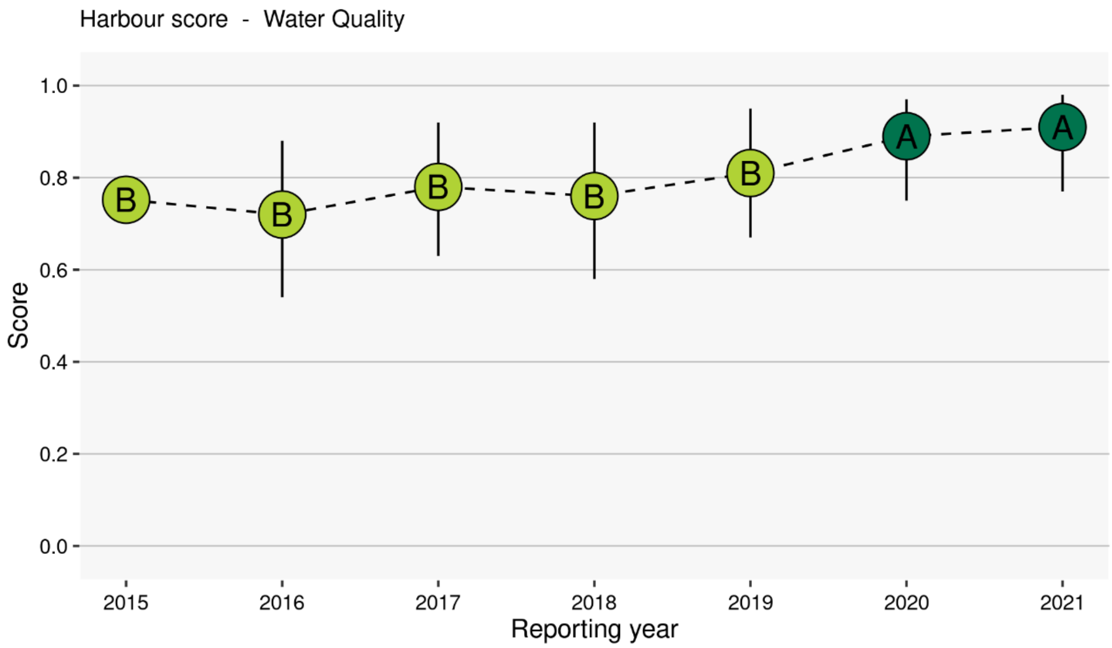


Figure 3.1: Trends in the harbour score for water quality, 2015–2021 (Error bars show 95% bootstrap confidence intervals).

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

As in previous years, zone scores for arsenic and nickel were occasionally good or satisfactory. The lowest score for an individual measure was for arsenic, which received the only good score. Angel et al. (2012) showed that particulate arsenic concentrations exceeded the ANZECC/ARMCANZ ISQG[1]-low trigger value in two samples from The Narrows and one sample near Quoin Island. They noted that

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

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.

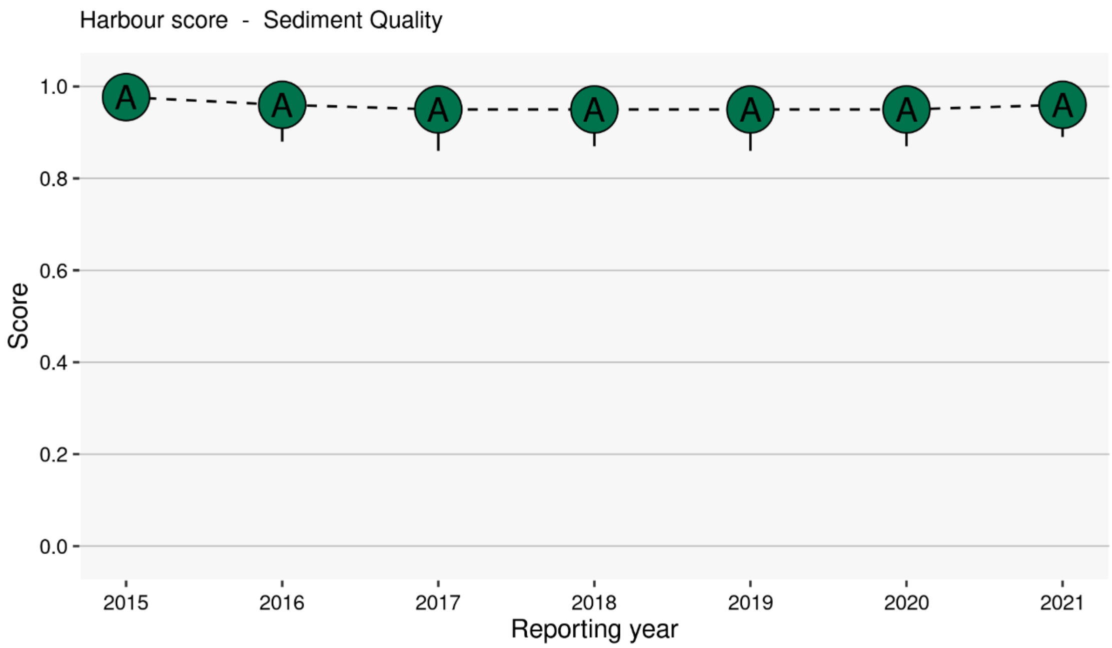


Figure 3.2: Trends in the harbour score for sediment quality, 2015–2021 (Error bars show 95% bootstrap confidence intervals).

3.2. Habitats

3.2.1. Seagrass

What is seagrass?

Seagrasses are the only flowering plants that can live entirely submerged in seawater. These unique, aquatic plants grow in sediment on the seafloor with erect, elongate 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:

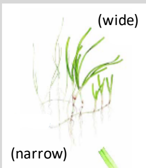
Zostera muelleri ssp. *capricorni*
Halophila ovalis
Halophila decipiens
Halophila spinulosa
Halodule uninervis (wide and narrow leaf)

Zostera muelleri ssp. *capricorni*

Halophila ovalis

Halophila decipiens

Halophila spinulosa



Halodule uninervis

Seagrass meadows are one of the most important habitat types 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 3.3). 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 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 (Smith et al., 2021a; Smith et al., 2021b), which was funded by the Gladstone Ports Corporation Ltd. Nearly two decades of monitoring and research has provided insight into potential causes and trends with regard to changes in the seagrass meadows of Gladstone Harbour.

3.2.2. Seagrass data collection

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

The annual seagrass monitoring program started in 2004 and currently assesses 14 representative intertidal and shallow subtidal seagrass meadows in Gladstone Harbour and Rodds Bay (Figures 8.2, 8.6, 8.10, 8.16, 8.18 and 8.26). 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 3.3: Seagrasses at low tide.

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

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

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

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

Resistance to disturbance: Larger bodied, persistent species generally have a higher physiological resistance to disturbance, while small-bodied colonising species can recover more rapidly following disturbances.

- **Biomass** – 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 ($gDWm^{-2}$) for each of the replicate quadrats at a site.

Area

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

Table 3.7: Mapping precision and mapping methodology for seagrass meadows for seagrass surveys conducted in November 2020 (Source: Smith et al., 2021b).

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

3.2.3. Development of seagrass indicators and scoring

Seagrass scores for the Gladstone Harbour Report Card were 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-indicator's biomass, area and species composition (Table 3.8). 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 grade range (Carter et al., 2015).

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

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

Table 3.8: Threshold values between grades A to E varied for the seagrass meadow types for each of the three seagrass sub-indicators (biomass, area and species composition). Each grade was determined by the percentage difference from a baseline of the 10-year mean (Source: Smith et al., 2021b).

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
Biomass	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
Area	Stable	>10% above	10% above–10% below	10–30% below	30–50% below	>50% below
Area	Variable	>20% above	20% above–20% below	20–50% below	50–80% below	>80% below
Area	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
Species composition	Stable; Mixed species	>20% above	20% above–20% below	20–50% below	50–80% below	>80% below
Species composition	Variable; Mixed species	>20% above	20% above–40% below	40–70% below	70–90% below	>90% below

3.2.4. Seagrass results

The overall score in the 2021 reporting year was 0.72 (B), indicating a good overall condition for seagrass. This is the second year of good condition and third consecutive year showing marked improvement from the overall poor condition observed from 2015 to 2018. At the zone level, overall condition scores were satisfactory or above for five of the six zones. Only the Mid Harbour was in poor condition, however, improved compared to the previous year. Overall, 13 of the 14 monitored meadows were in satisfactory, good or very good condition (Table 3.9).

Table 3.9: Seagrass scores for the 2021 Gladstone Harbour Report Card. Scores from 2020 and 2019 are shown for comparison. Note, 2021 scores may differ slightly to those reported by Smith et al. (2021b) due to bootstrapping used to calculate GHHP report card scores (see Logan et al., 2016).

Zone	Meadow	Biomass	Area	Species composition	Overall meadow	2021	*2020**	*2019*
1. The Narrows	21	0.84	0.99	0.93	0.84	0.84	*0.80*	*0.71*
3. Western Basin	4	1.00	0.97	0.91	0.94	0.75	*0.81*	*0.69*
	5	0.86	0.82	0.82	0.82			
	6	0.88	0.94	0.62	0.75			
	7	0.63	0.74	1.00	0.63			
	8	0.86	0.69	0.57	0.63			
	52–57	0.71	0.95	1.00	0.71			
5. Inner Harbour	58	0.59	0.91	0.60	0.59	0.59	*0.70*	*0.21*
8. Mid Harbour	43	0.33	0.87	0.50	0.33	0.48	*0.44*	*0.52*
	48	0.64	0.72	0.97	0.64			
9. South Trees Inlet	60	0.97	1.00	1.00	0.97	0.97	*0.99*	*0.89*
13. Rodds Bay	94	0.84	0.87	0.99	0.84	0.70	*0.87*	*0.49*
	96	0.75	1.00	0.97	0.75			
	104	0.51	0.86	0.83	0.51			
Harbour score						0.72	*0.77*	*0.59*

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

Zone 1 – The Narrows

The Narrows has one monitored meadow at Black Swan Island, an intertidal meadow with variable biomass. The overall score for this meadow was good (0.84, B) for the third consecutive year since the poor condition in 2018. All three sub-indicators showed good to very good scores—demonstrating the highest meadow biomass since 2010 (~6.9 $gDWm^{-2}$), the highest meadow area score in the monitoring program (0.99, A) and a high presence of the historically dominant species, *Z. muelleri*.

Zone 3 – Western Basin

Western Basin contains six monitored seagrass meadows, five of which are intertidal and one subtidal (Meadow 7). In 2021 this zone was in good condition (0.75, B) for the third consecutive year. All seagrass meadows received were in satisfactory or better condition—with two meadows scored as satisfactory, three meadows scored as good, and one meadow scored as very good.

Results were somewhat mixed among the various meadows, though showed a general trend of marginally lower meadow scores than in 2020. Meadow 4 was in very good condition (0.94, A) for the second year and the only meadow to show a higher meadow score than the previous year. The remaining five meadows had marginally lower meadow scores than the previous year; however, meadow scores were driven by different sub-indicator scores at each meadow. For instance, the lowest of the three sub-indicators was species composition at three meadows, biomass at two meadows and area at one meadow (Meadow 7). Meadow 7 has also been the most variable meadow since GHHP monitoring began in 2015, which is typical of a subtidal meadow dominated by *Halophila* species.

Zone 5 – Inner Harbour

Inner Harbour has one monitored meadow in the south-east corner of the zone near South Trees Inlet. The Inner Harbour was in satisfactory condition (0.59, C). This was a lower condition score than in 2020 when Meadow 58 was in good condition. The decrease in zone/meadow score was driven by lower biomass and species composition scores than the previous year. In 2021 biomass and species composition scores were satisfactory, 0.59 and 0.60 (C) respectively. Although meadow area was also lower than in 2020 it still received a very good score (0.91, A) for the second consecutive year.

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 remained poor (0.48, D) for the second consecutive year. This was largely driven by Pelican Banks, which received a poor score (0.33, D) or lower for the sixth consecutive year. While seagrass area remained very good and has improved markedly since 2017, biomass has remained poor or very poor since 2016. Species composition at Pelican Banks was satisfactory but has shown a similar declining trend to that observed for biomass. In contrast, Meadow 48 was in satisfactory condition (0.64, C), showing satisfactory biomass, good area and very good species composition scores. This was the first time since 2011 that the meadow was composed of the dominant species *H. uninervis*.

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 (0.97, A), with all three sub-indicators in very good condition for the fourth consecutive year. This marks the fifth year of improved seagrass condition from the overall poor condition (0.48, D) in 2016. Record meadow area was recorded in 2021, with the meadow covering ~12.7 ha. Biomass scored very good (0.97, A) for the fourth consecutive year. Moreover, the persistent and traditionally continuous species *Z. muelleri* covered 100% of the meadow for the first time in six years.

Zone 13 – Rodds Bay

There are three intertidal monitoring meadows in Rodds Bay—Meadows 94, 96 and 104. The overall condition of this zone was good (0.70, B) in 2021. This was a decrease from the previous year when Rodds Bay received the best overall condition score of the past decade. All three meadows showed a decreased score compared to the previous year. Similarly, there was a general pattern in scores among sub-indicators. Area and species composition remained very good (0.86–1.00, A) at all three meadows, excluding species composition at Meadow 104 which received a good score (0.83, B). Likewise, biomass had the lowest of the three sub-indicator scores with Meadows 94 and 96 scored as good (0.84 & 0.75, B) and Meadow 104 scored as satisfactory (0.51, C).

3.2.5. Seagrass conclusions

The overall condition of monitored seagrass meadows in Gladstone Harbour was good in 2021 for the second consecutive year. This is first time seagrass has maintained a good condition for consecutive years since widespread losses due to flooding in 2009 and 2010. As in 2020, nine meadows were at pre-2010 conditions or better (Table 3.10). Although biomass was lower at some meadows as compared to the previous year—thus contributing to the lower harbour score than in 2020—the vast majority of sub-indicators were above baseline levels (Table 3.9). Only Meadow 43 received a poor score or lower for one of its sub-indicators (biomass). Overall, 13 of the 14 monitored meadows were in satisfactory, good or very good condition.

Environmental conditions such as rainfall and Calliope River discharge are key influences on the seagrass meadow condition of Gladstone Harbour (McCormack et al., 2013). For the past three reporting years there has been below average rainfall and river flow (Figures 5.3 to 5.8; GHHP, 2019; GHHP, 2020). Flow from the Calliope River from 2018 to 2020 was below average, and outflow was very low during the 2020 wet season (Smith et al., 2021a). Dry, benign weather conditions cause an increase in benthic light, which has created ideal conditions for seagrass growth in Gladstone Harbour. Reduced daytime tidal exposure this reporting year likely provided further protection from extreme desiccation and thermal stress for the region's intertidal seagrasses (e.g., Unsworth et al. 2012 as cited in Smith et al., 2021b). There has been a general trend in improvement in seagrass meadows along Queensland's east cost between Cairns and Port Curtis since widespread losses in 2009 and 2010 (e.g., York et al. 2016; Reason et al. 2017; McKenna et al. 2017; Bryant et al. 2019 as cited in Smith et al., 2021b). However, recovery has varied by location, local climate events and the severity of the initial seagrass losses. In context with the state, Gladstone Harbour zones had one of the better outcomes for seagrass condition in the 2021 reporting year (Smith et al., 2021b).

Port activities such as dredging may change benthic light conditions which can result in seagrass declines (Smith et al., 2021b). In the preceding year, capital dredging and maintenance dredging works were completed in the harbour and removed approximately 800,000 m^3 and 256,000 m^3 of seabed material respectively. Capital dredging occurred in the Clinton Channel and maintenance dredging throughout the length of the shipping channel, with both types of operations managed accordingly to ensure benthic light requirements of seagrasses were not negatively impacted. While there were minor declines in biomass at some meadows in the Western Basin and Inner Harbour (adjacent zones to capital dredging works), the closest meadow (Meadow 4) remained in very good condition suggesting there was no impact on seagrass from capital dredging works. Moreover, minor declines in biomass were observed in harbour and the reference meadows in Rodds Bay, which suggests the changes were due to regional conditions rather than port operations.

The exception to recovery in Gladstone Harbour was the Mid Harbour, which showed a poor condition for the second consecutive year. The poor condition results from significant losses in biomass since 2010 and declining species composition since 2015 at Pelican Banks (Meadow 43), which has been in poor or very poor condition for six years in a row. As there are no obvious differences in environmental factors or anthropogenic activity, the poor condition at Pelican Banks may have resulted from megafaunal grazing pressure. In addition to the current monitoring program, dugong and turtle feeding trails have been regularly observed at Pelican Banks (e.g., Rasheed et al. 2017; Hamann et al., 2016; Limpus et al., 2017 as cited in Smith et al., 2021b; Carter et al., 2020). Moreover, recent research using herbivore exclusion cages has found the impact of dugongs and green turtles on seagrass biomass was greater at Pelican Banks than other Gladstone Harbour monitoring meadows (e.g., Scott et al. 2021 as cited in Smith et al., 2021a & Smith et al., 2021b). It is unclear why high grazing pressure has continued as biomass decreases; however, it is the most likely process preventing the recovery of seagrass biomass at Pelican Banks. Given this meadow's importance as a key seagrass resource in Gladstone Harbour, recovery remains key to overall marine environmental health in the region.

Seagrass meadows in Gladstone Harbour started 2021 with a high level of resilience to external pressures, both natural and anthropogenic. Meadows in the harbour are likely to have preserved and replenished their seedbanks, further strengthening their resilience and recovery capacities. Continuing high levels of resilience mean seagrasses should be well placed to cope with forecast La Niña weather patterns and anthropogenic pressures in the 2022 reporting year.

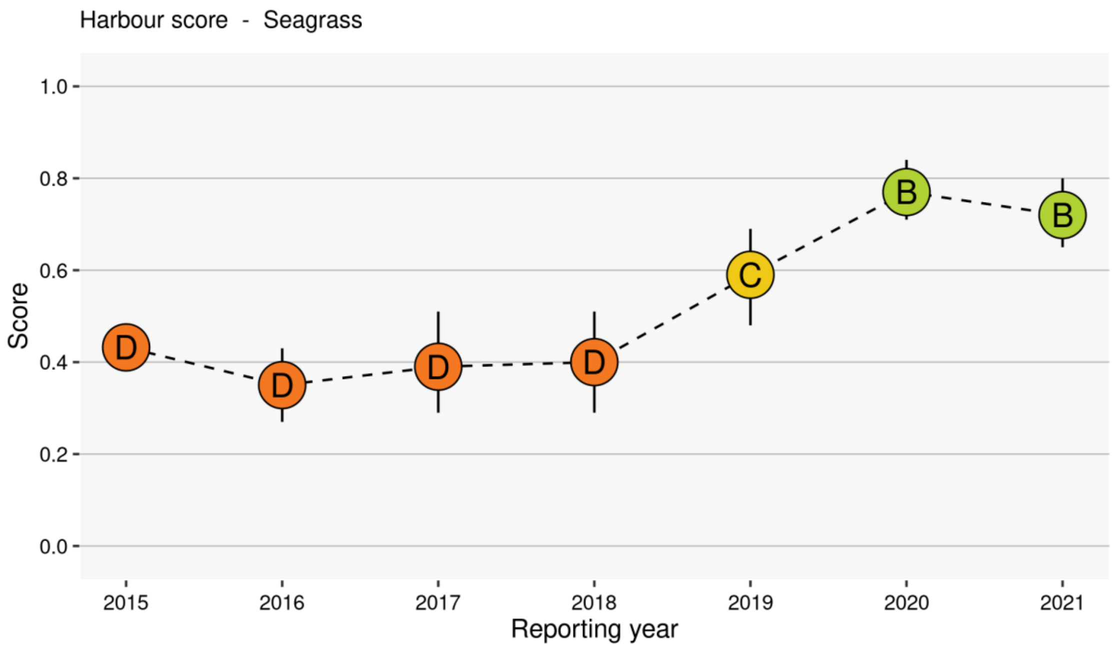


Figure 3.4: Trends in the harbour score for seagrass, 2015 – 2021 (Error bars show 95% bootstrap confidence intervals). Note, 2020 score corrected for an error in biomass calculation and differs from the score previously reported on. Refer to [2020 Seagrass Report] or [2020 Technical Report] for further detail.

Table 3.10: Grades for individual seagrass monitoring meadows from annual (November) surveys, 2002–2020 (Source: Carter et al., 2019). Note, report card and monitoring years differ (e.g., 2021 Report Card = 2020 monitoring). Grades for 2019 and 2020 monitoring were added separately for comparison.

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

3.2.6. Corals

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

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

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

Four sub-indicators of coral health were measured to calculate the coral score for the 2021 Gladstone Harbour Report Card:

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

3.2.7. Coral data collection

Establishment of long-term monitoring sites

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

Four permanently marked survey sites (transects) were established in the Mid Harbour at Rat Island, Farmers Reef, Facing Island and Manning Reef and two permanent sites were established in the Outer Harbour at Seal Rocks North and Seal Rocks South (Figures 8.16 and 8.22).

Coral monitoring

Coral monitoring was conducted on 4–5 May 2021 and included the following three methodologies:

1. Photo point intercept transects

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

2. Juvenile corals

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

3. Disturbances

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

3.2.8. Development of coral sub-indicators and scoring

Each of the four coral sub-indicators was scored against a baseline based on expert opinion and data from the Marine Monitoring Program (MMP) for inshore reefs. The baseline for each of the four sub-indicators represented the threshold between report card grades of C (satisfactory condition) and D (poor condition). The highest possible score of 1.00 was set to represent coral reefs in as good condition as could be expected in the local environment (Table 3.11 and Figure 3.5). The lowest score of 0.00 was set to represent the worst condition that could be expected in the local environment (Table 3.11 and Figure 3.5). Although it is possible for the observed results to be outside those limits, the scores were capped at 0.00 and 1.00 to allow scaling to the GHHP range of grades.

Combined cover of hard and soft coral

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

A detailed description of the development of the critical values and thresholds for coral cover are presented in Thompson et al. (2015). The values and thresholds used for the combined coral cover are based on two prior assessments of coral cover on nearshore reefs. A broad-scale survey of nearshore reefs between Cape Tribulation and the Keppel Islands conducted in 2004 using the same sampling methods as the Gladstone Harbour surveys returned a mean hard coral cover of 33% and 5% cover for soft corals (Sweatman et al., 2007). This 38% mean was observed after severe loss of corals owing to thermal bleaching in 1998 and 2002 and is considered too low for a threshold that would indicate a good condition (Thompson et al., 2015). A summary of coral surveys from over 100 sites between Cape Flattery and the Keppel Islands in 1996 prior to the bleaching events found a mean coral cover of hard corals of approximately 48% when the results were corrected to be consistent with MMP methods (Thompson et al., 2015). Allowing for some soft coral cover and rounding to an even percentage a 50% threshold for coral cover was proposed for the MMP and adopted for use in the Gladstone Harbour report card. Correcting for the differences in the grading schemes between the Reef Report Card and the Gladstone Harbour Report Card a 40% threshold is applied (Table 3.11). This figure is consistent with surveys conducted in Gladstone Harbour (Mid Harbour) prior to 2009 where a mean hard coral cover of 39% was reported (BMT WBM, 2013). Although the BMT WBM (2013) report did not provide a mean estimate for soft coral cover, Figure 3.7 of that report indicates soft coral cover in the middle harbour ranged between ~4% and 40%.

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

Macroalgal cover

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

Critical values for macroalgal cover were developed through the MMP and fitted to the Gladstone Harbour Report Card grading scheme (Figure 2.1). A baseline of 14% macroalgal cover was set at the D/C threshold (the point where the grade changes from passing to failing) for coral communities in Gladstone Harbour (Table 3.11).

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

Juvenile coral density

Recovery of coral reefs from disturbances such as flooding, cyclones, thermal bleaching or outbreaks of crown-of-thorns starfish is dependent on the recruitment of new coral colonies and regeneration of existing colonies. The number of juvenile colonies at a reef can be negatively affected by poor water quality particularly where there is elevated concentrations of nutrients and agrichemicals and high turbidity (van Dam et al., 2011; Erftemeijer et al., 2012 cited in Thompson et al., 2015). High rates of sediment deposition (Rogers, 1990) and a high cover of macroalgae (Foster et al., 2008; Mumby & Steneck, 2008) will also negatively impact the number of juvenile colonies observed. Hence juvenile coral density can provide an indication of a reef's potential for recovery from disturbance given the current conditions.

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

Thresholds for juvenile coral density were set based on data on the densities of juvenile colonies recorded over four years of the MMP (2005–2009). That monitoring determined the mean density of juvenile corals for inshore reefs at sites 2 m below lowest astronomical tide to be about 7.7 juvenile corals per m^2 of available substrate. For this study, the limits were set at 0 and 13 juvenile colonies per m^2 respectively (Table 3.11).

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

Change in hard coral cover

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

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

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

Table 3.11: Coral sub-indicator thresholds for the Gladstone Harbour Report Card.

Sub-Indicator	Baseline (aligned with the report card C/D threshold of 0.50)	Upper bound (score = 1.00)	Lower bound (score = 0.00)
Combined cover of hard and soft corals	40%	90%†	0%
Macroalgal cover	14%	5%	20%
Juvenile coral density	4.6 m^{-2}	13 m^{-2}	0 m^{-2}
Change in hard coral cover	Lower 95% confidence interval	Twice the upper 95% confidence interval	Twice the lower 95% confidence interval

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

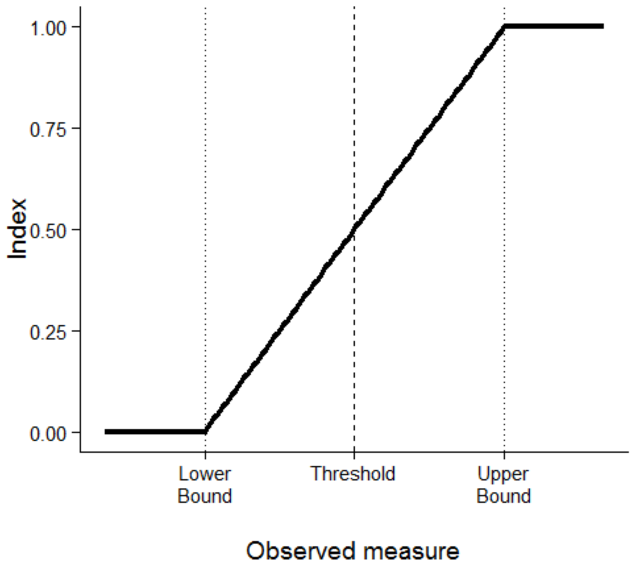


Figure 3.5: Generic scoring of the coral sub-indicators based on the threshold and bounds outlined in Table 3.11.

Aggregation of sub-indicator scores

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

3.2.9. Coral results

The overall grade for the 2021 report card was an E (0.14) for the fourth consecutive year. 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. Score changes at the sub-indicator level were minor between 2020 and 2021—coral cover (0.07, E) received a similar score, juvenile density (0.15, E) marginally improved and macroalgae cover (0.00, E) and change in hard coral cover (0.34, D) declined. There were no grade changes in at the sub-indicator level between the current and previous year. Both the Mid Harbour and the Outer Harbour demonstrated very poor coral condition for the third consecutive year, receiving scores of 0.16 and 0.12 (E) respectively (Table 3.12). In comparison with 2020 scores, the overall score of the Mid Harbour was marginally higher while the Outer Harbour slightly declined.

Coral cover (%) was very low at all reefs and substantially lower than the 40% threshold required to receive a grade of C (Table 3.13). In 2021, mean coral cover increased marginally at Manning Reef and Rat Island but declined elsewhere. Scuba surveys indicated that the bio-eroding sponge *Cliona orientalis* continues to impact the coral community across the Harbour and in particular colonies of *Turbinaria* at Seal Rocks South and *Porites* at Facing Island. Although minor fluctuations in scores have occurred since GHHP monitoring began in 2015, both zones had very poor coral cover scores for the seventh consecutive year (Table 3.14). 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).

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

The size for juvenile corals can indicate their age as corals spawn annually. Juvenile coral colonies in the 0–2 cm range can broadly be considered a result of the previous spawning event. Juvenile coral colonies in the 2–5 cm range are estimated to be between one and two years old. For the third consecutive year, juvenile density was in very poor condition (0.15, E) at the harbour level (Table 3.12). Scores for juvenile coral density were predominantly very poor at the reef level, with only Farmers Reef receiving a poor score (0.30, D)—an identical result to 2020. Of note was the continued and overall lack of the fast-growing, branching corals of the family Acroporidae across the harbour. Though the limited presence of *Acropora* juveniles within the harbour remains a promising sign.

The overall change in hard coral cover score remained poor (0.34, D) and showed a decrease when compared to the overall scores in 2019 and 2020 (0.41 and 0.40, D). Compared to the previous year, reef scores in the Mid Harbour were similar while the Outer Harbour showed lower scores, mostly due to a decline in hard coral cover at Seal Rocks North. Note, the presence of bleached corals at Outer Harbour reefs in 2020 meant that changes in hard coral cover between 2019 and 2020 did not inform on the sub-indicator scores at those reefs. This also impacted the 2021 change in hard coral cover sub-indicator as the score is calculated over a three-year period. It is equally important to note that the scores acute pressures have not been observed (e.g., flood, cyclone) over the past three years and thus, coral cover should be in a state of recovery.

Table 3.12: Coral indicator scores for the 2021 Gladstone Harbour Report Card. Scores from 2020 and 2019 are shown for comparison.

Zone	Coral cover	Macroalgal cover	Juvenile density	Change in hard coral cover	2021	*2020**	*2019*
8. Mid Harbour	0.07	0.00	0.15	0.43	0.16	*0.20*	*0.19*
11. Outer Harbour	0.07	0.00	0.15	0.26	0.12	*0.14*	*0.17*
Harbour score	**0.07**	**0.00**	**0.15**	**0.34**	**0.14**	***0.17***	***0.18***

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

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

Zone/Reef	Coral cover		Macroalgal cover		Juvenile density		Change in hard coral cover	
	Value (%)	Score	Value (%)	Score	Value (m^{-2})	Score	Value (%)	Score
				8. Mid Harbour				
Facing Island	8.25	0.10	63.25	0.00	0.18	0.02	-0.88	0.33
Farmers Reef	2.13	0.03	32.25	0.00	2.77	0.30	-3.64	0.46
Manning Reef	1.38	0.02	55.75	0.00	1.62	0.18	0.12	0.38
Rat Island	12.13	0.15	31.75	0.00	0.93	0.10	0.74	0.54
				11. Outer Harbour				
Seal Rocks North	1.00	0.01	73.29	0.00	0.94	0.10	-0.89	0.19
Seal Rocks South	9.63	0.12	46.00	0.00	1.86	0.20	-0.38	0.33

3.2.10. Coral conclusions

The overall score for corals remained very poor (0.14, E) in 2021 (Figure 3.6; Table 3.12). Although coral cover was broadly consistent to previous years and juvenile density showed a slight improvement since 2020, these scores were offset by decreased macroalgae and change in hard coral cover scores (Table 3.14). As such, the overall coral score continued to decline from the peak score recorded in 2017 (0.28, D).

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. Recovery since the severe impacts of flooding in 2013 has been limited thus far in Gladstone Harbour coral communities.

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

Results strongly suggest a continued shift from coral to macroalgal dominance within Gladstone Harbour. In combination, the continued poor or very poor scores for each sub-indicator corroborate studies that demonstrate density-dependant feedback mechanisms which promote macroalgal dominance where conditions maintain the proliferation of macroalgae (e.g., Mumby et al., 2007, Mumby et al., 2013, cited in Thompson et al., 2021). The persistent high cover of macroalgae may be affecting coral recruitment processes by occupying available space for juvenile settlement. Results from the MMP have recorded a general pattern of high macroalgal cover and low juvenile coral densities on several reefs. The poor to very poor scores for change in hard coral cover are also likely to be influenced by coral-macroalgae interactions. Macroalgae genera such as *Sargassum* and *Asparagopsis* and in particular *Lobophora* and *Dictyota* have direct negative impacts on living corals (e.g., Lirman, 2001; Vega Thurber et al., 2012, Morrow et al., 2017, cited in Thompson et al., 2021). In addition to macroalgae, the widespread presence of the bio-eroding sponge *Cliona orientalis* continues to be the most significant contributor to coral mortality within the harbour (Table 3.15). Similarly coral bleaching, in response to high water temperature in early 2020, is likely to have contributed to the current very poor condition. Ongoing monitoring since 2015 demonstrates a clear lack of recovery since the severe loss of coral noted in 2015.

In the broader context of inshore reefs on the Great Barrier Reef, the coral communities in Gladstone Harbour score poorly compared with other reefs monitored by the MMP. As might be expected, the Gladstone Harbour reefs are regionally most similar to those in the Fitzroy Region, in particular Pelican Island. Pelican Island is proximal to the mouth of the Fitzroy River and was severely impacted by flooding in 2011. Like reefs in Gladstone Harbour, recovery of coral communities at Pelican Island has been negligible with high cover of red and brown macroalgae persisting to 2020. Reefs monitored by

GHHP also group closely with Daydream and Double Cone islands from the Whitsundays region, which were severely impacted by cyclone Debbie in 2017. Communities at Pelican, Daydream and Double Cone islands and Gladstone Harbour reefs shared characteristics such as low coral cover, high macroalgae cover or a combination of the two.

Corals in Gladstone Harbour were in very poor condition and demonstrated limited recovery potential in 2021. As such recovery will be largely dependent on connectivity with populations of living corals beyond the harbour. While surveys in recent years revealed some encouraging signs—juvenile diversity was greater than the living adult genera within the harbour and the continued presence of *Acropora* juveniles—settlement and growth rates of coral larva are likely to be low if the high macroalgal cover and its associated negative pressures persist.

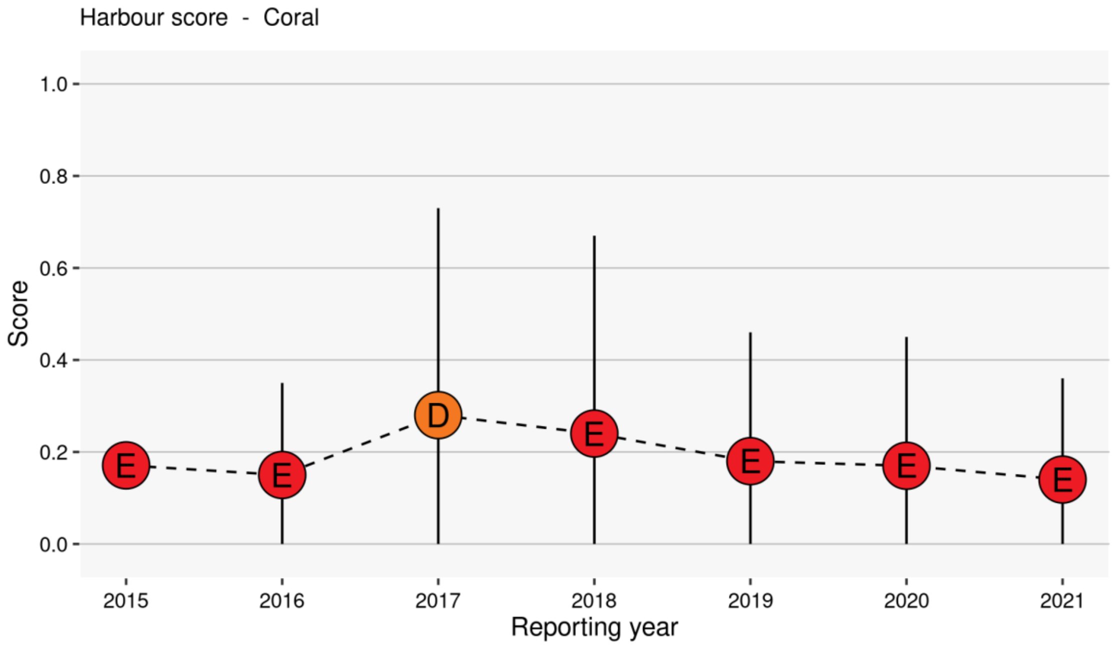


Figure 3.6: Trends in the harbour score for coral, 2015 – 2021 (Error bars show 95% bootstrap confidence intervals). Note, 2020 score corrected for an error in change in hard cord cover calculation and differs from the score previously reported on. Refer to 2020 Coral Report or 2020 Technical Report for further detail.

Table 3.14: A comparison of coral sub-indicator scores for the Mid Harbour and Outer Harbour for surveys conducted from 2015 to 2021.

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

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

Table 3.15: Causes of coral mortality at time of survey. Survey area of 200 m^2 at each reef. Data from 2019–2020 included for comparison. No data are included for Manning Reef as no ongoing mortality was recorded. Bio-eroding sponge is primarily *Cliona orientalis*.

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

3.3. Fish and crabs

3.3.1 Fish health

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

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

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

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

In 2021 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 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 Australian Bass Tournaments (ABT) and by recreational fishers (e.g., Gladstone Sportfishing Club), a large portion of the harbour can be assessed at a lower cost than more traditional methods.

The VFC scores are based on two separate metrics, the first is an external assessment of fish health the fish visual assessment (FVA). 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 health assessment index (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.

3.3.2 Fish health data collection

Fish mobility

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

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

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

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

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 bottom dwellers such as dusky flathead and those that feed higher in the water column. As these species occupy a variety of trophic level and habitats, they may be differentially affected by any fish health issues. For example, demersal or benthic species are in closer contact with pollutants accumulated in sediments and as a result are more likely than pelagic species to present with abnormalities (Cowled, 2016). The target species are:

- Yellow-finned bream *Acanthopagrus australis*
- Pikey bream *Acanthopagrus berda*
- Barred javelin *Pomadasys kaakan*
- Dusky flathead *Platycephalus fuscus*

- Mangrove jack *Lutjanus argentimaculatus*
- Barramundi *Lates calcarifer*

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

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

Data was collected over the course of the 2020–21 reporting year (01/07/2020 – 30/06/2021) 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 in the 2021 reporting year:

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

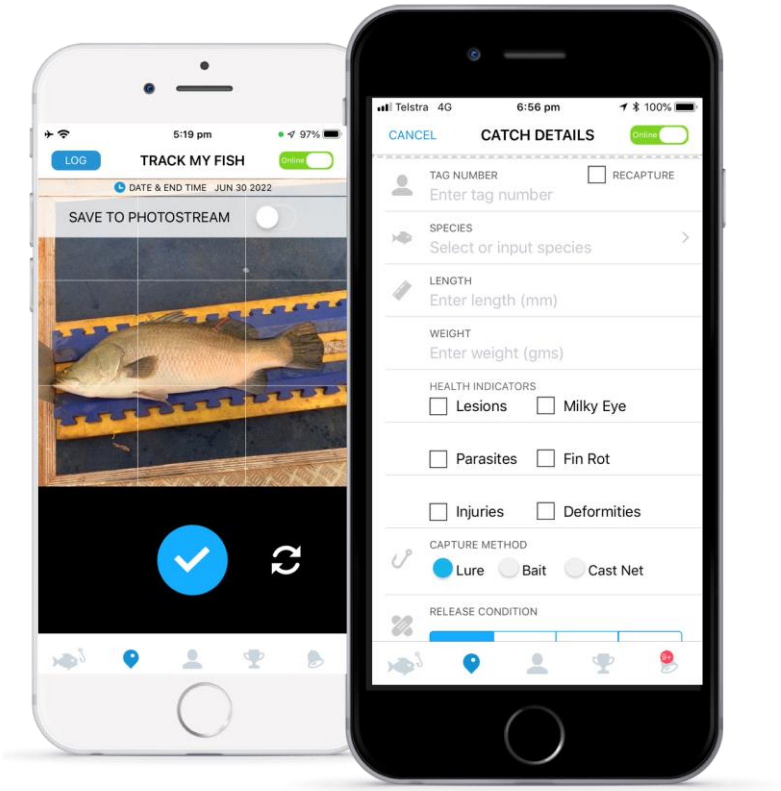


Figure 3.8: Data for the visual fish condition index was collected by fishers using the Trackmyfish app.

Over the course of the study period, 1 July 2020 to 30 June 2021, a total of 1,666 images of the six target species were captured using the Trackmyfish app (Figure 3.9). Human and visual assessments were made for each condition with close to 100% agreement between the two.

Data for fish body condition were collected in Gladstone Harbour at the ABT Bream Competition conducted on 26 and 27 September 2020 and at the Boyne Tanum Hook-up conducted in Gladstone Harbour between 20 April and 5 May 2021. Data on yellow-finned bream and pikey bream were collected at the ABT Bream Competition (n = 61 fishes) and data on five target species were collected at the Boyne Tanum Hook-up (n = 1068 fishes). A total of 1,139 fishes were assessed and the results for 967 fish were used to calculate the report card scores.

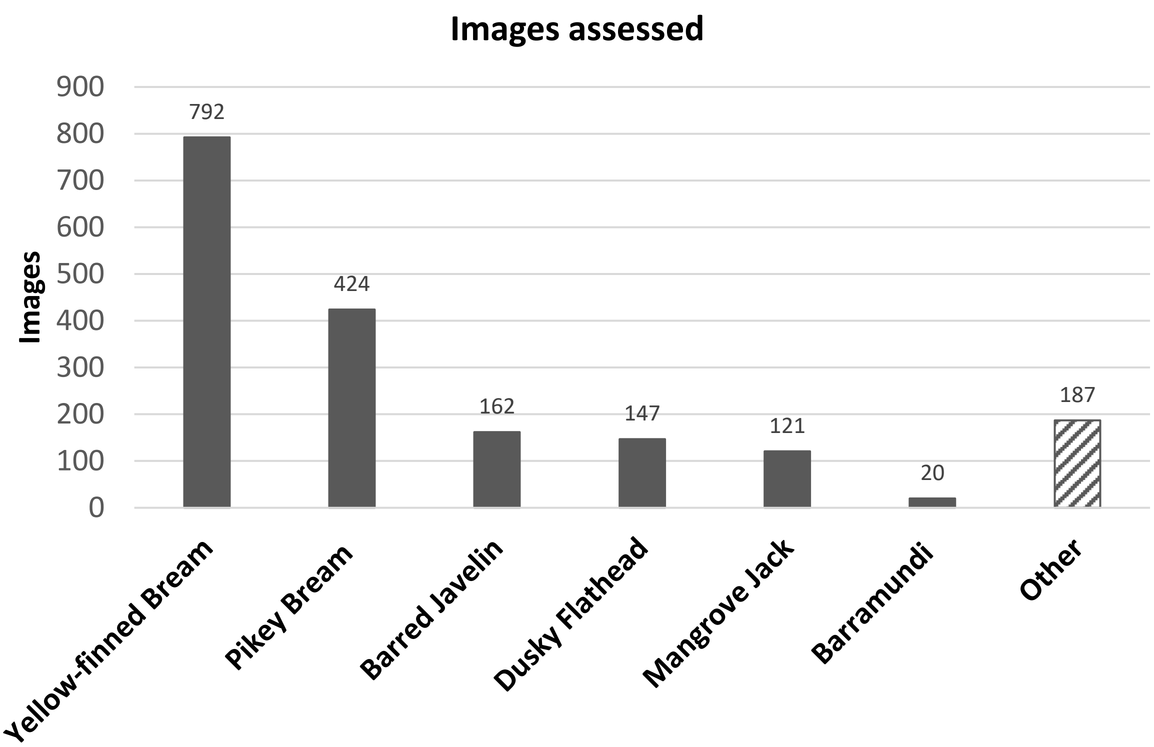


Figure 3.9: Number of images of each of the six target species captured using the Trackmyfish App over the 2021 reporting year.

Health assessment index

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

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

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

Sampling was conducted during the 2020–21 reporting year in Gladstone Harbour in Spring 2020 and Autumn 2021. The surveys in Gladstone Harbour were designed to produce an even catch effort across the northern, central and southern areas of the harbour with a focus on inshore and estuarine sites, this included 11 environmental monitoring zones.

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

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

A total of 126 fishes from 17 species were caught across Gladstone Harbour and the Baffle Creek reference site. Barred javelin (n = 31) and blue catfish (n = 32) were caught in the highest numbers and barred javelin were caught in the most zones. A total of 80 fishes from 4 of the 5 target species were caught, no bream were caught and only four diamond scale mullet were caught in the harbour. With the absence of bream and the low mullet numbers the report card scores were calculated based on three species: barred javelin, blue catfish and barramundi.

3.3.3. Development of fish health indicators and scoring

Visual fish condition

The fish visual assessment is based on the HAI developed by Adams et al. (1993). However, unlike the HAI in which the fish is euthanised and 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 3.16).

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 3.16: Scoring for five variable conditions used in the fish visual assessment in 2021.

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

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

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

Values of W have been calculated from the logarithmic (base 10) equivalent:

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

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

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

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

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

The final score for the species in the current year is calculated as the average score for the species (where n is the number of fish being assessed) in the current year as shown in Table 3.

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

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

Health assessment index

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

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

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

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

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

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

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

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

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

Table 3.16: Scoring for nine variable conditions used in the health assessment index in 2021 (Source: Wesche et al., 2013).

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

3.3.4. Fish health results

The overall score for fish health in 2021 was 0.82 (B), comprised of a score of 0.74 for visual fish condition and a score of 0.90 for the health assessment index. For both studies the overall harbour score is applied to each of the 13 environmental monitoring zones and indicates good fish health across the harbour.

Visual fish condition

The overall score for fish visual condition was 0.74 (B) comprised of an overall harbour score for fish visual assessment of 0.97 (A) and a score of 0.50 for fish body condition. All species assessed for fish visual assessment received a very good score ranging from 0.94 to 0.98. Fish body condition was calculated for all target species except for barramundi, these scores ranged from 0.47 for yellow-finned bream to 0.55 for mangrove jack (Table 3.17).

Table 3.17: The visual fish condition score calculated from the mean of the fish visual assessment and fish body condition for five species of fish caught in Gladstone Harbour in the 2020–21 reporting year.

Fish Species	Fish visual assessment	Fish body condition	Visual fish condition
Yellow-finned bream	0.95	0.47	0.71
Pikey bream	0.98	0.48	0.73
Barred javelin	0.94	0.54	0.74
Dusky flathead	0.97	0.54	0.76
Mangrove jack	0.96	0.55	0.75
Harbour score			**0.74**

From the total sample (all fishes) the detection of visible pathologies was low, with no incidence of eye health issues detected and only one fish (0.06%) with visible parasites and six fishes (0.4%) with visible deformities detected (Table 3.18). For all species, the most detected condition was fins (54% of the total sample) ranging from 17% detection in dusky flathead to 66% in yellow-finned bream. However, the severity of the condition was low with 98% of all fishes in which the condition was detected recording a low or moderate score (Table 3.19). Skin was the next most recorded condition, although the detection rate (1% of all fish) and the severity were low (Table 3.20).

Table 3.18: Number of visual fish health incidences detected and species scores for six species of fish in the 2020–21 reporting year.

Species	N	Fins	Skin	Eyes	Parasites	Deformities
Yellow-finned bream	792	520 (66%)	9 (1%)	0	1 (0.1%)	3 (0.4%)
Pikey bream	424	185 (44%)	7 (2%)	0	0	3
Barred javelin	162	83 (51%)	2 (1%)	0	0	0
Dusky flathead	147	25 (17%)	2 (1%)	0	0	0
Mangrove jack	121	84 (69%)	4 (3%)	0	0	0
Barramundi*	20	8 (40%)	0	0	0	0
Total	1666	905 (54%)	24 (1%)	0	1 (0.06%)	6 (0.4%)

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

Table 3.19: Fin condition recorded for six species of fish in in the 2020–21 reporting year.

Condition (Score) / Species	No active erosion (0)	Light active erosion (10)	Moderate active erosion with some haemorrhage (20)	Severe active erosion with some haemorrhage (30)	N
Yellow-finned bream	272 (34%)	507 (64%)	12 (1.5%)	1 (0.5%)	792
Pikey bream	239 (56%)	181 (42%)	3 (1.5%)	1 (0.5%)	424
Barred javelin	77 (48%)	76 (47%)	9 (5%)	0	162
Dusky flathead	122 (83%)	23 (16%)	2 (1%)	0	147
Mangrove jack	37 (31%)	84 (69%)	0	0	121
Barramundi*	12 (60%)	8 (40%)	0	0	20
Total	759 (45%)	879 (53%)	26 (1.5%)	2 (0.5%)	1666

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

Table 3.20: Skin condition recorded for six species of fish in in the 2020–21 reporting year.

Condition (Score) / Species	Normal no aberrations (0)	Mild skin aberrations (10)	Moderate skin aberrations (20)	Severe skin aberrations (30)	N
Yellow-finned bream	783 (99%)	9 (1%)	0	0	792
Pikey bream	417 (98%)	6 (1.5%)	1 (0.5%)	0	424
Barred javelin	160 (99%)	2 (1%)	0	0	162
Dusky flathead	145 (99%)	2 (1%)	0	0	147
Mangrove jack	117 (97%)	4 (3%)	0	0	121
Barramundi*	20 (100%)	0	0	0	20
	1642 (98.6%)	23 (1.39%)	1 (0.01%)	0	1666

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

Fish body condition

Fish body condition was calculated for five species of fishes caught in Gladstone Harbour at the ABT Bream Tournament (September 2020) and the Boyne Tanum Hook-up (May 2021) (Table 3.21). Weight (g) and length (mm) was recorded for 967 fishes from five species (Table 3.21) and the relative condition factors was calculated for each species by comparing this data to the historic mean. This mean was derived from historic data recorded during the Boyne Tanum Hook-up from 2003 to 2021; data was available for all years except 2009, 2011 and 2020.

The overall score for fish body condition was 0.50 (C), three species of fish barred javelin (0.54), dusky flathead (0.54), and mangrove jack (0.55) were in satisfactory condition and the two bream species yellow-finned bream (0.47) and pikey bream (0.48) were in poor condition.

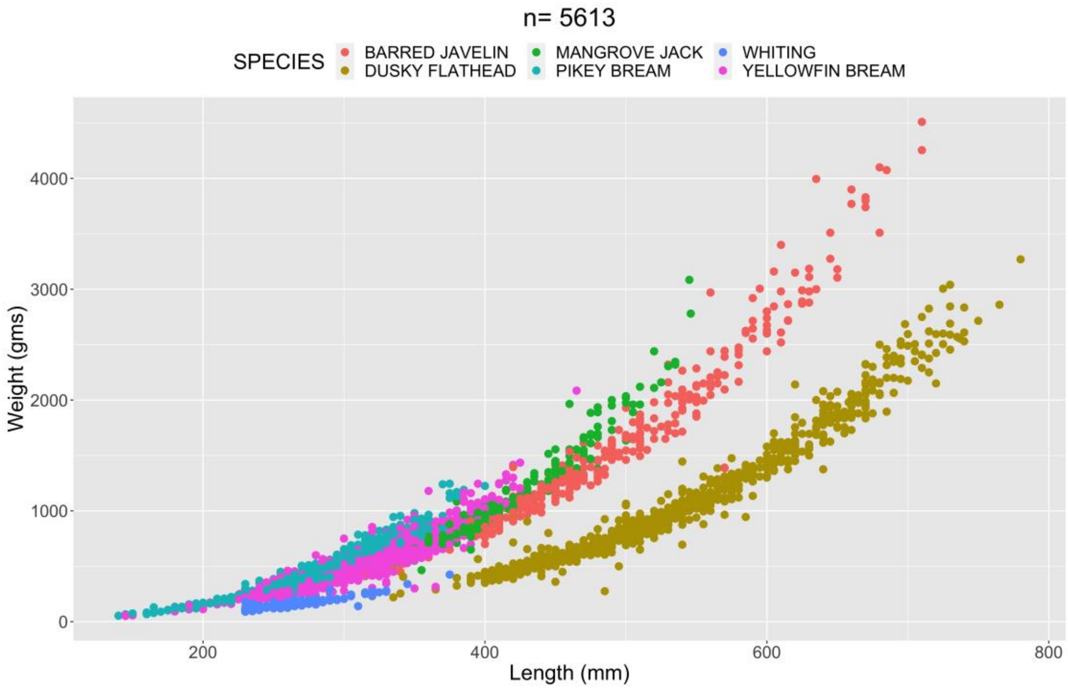


Figure 3.10: Length weight relationship for five fish species from the Boyne-Tannum Hook-Up from 2003 – 2021 (Source Sawynok et al., 2021).

Table 3.21: Relative condition factor calculated for 5 species in 2021.

Species	(N)	Relative condition factor		
		Min	Max	Mean
Yellow-finned bream	639	0.607	1.638	1.004
Pikey bream	69	0.357	1.305	1.005
Barred javelin	92	0.889	1.150	1.004
Dusky flathead	93	0.867	1.182	1.000
Mangrove jack	74	0.718	1.615	1.003

Health assessment index

The overall health assessment index score was 0.90 (A). Three of the five monitored fish species received a very good score and the two remaining species, blue catfish (0.81) and mullet (0.81), received good scores (Table 3.22).

The overall HAI score was the average scores for nine measures (Table 3.23). Overall scores for external pathologies; skin, eyes and fins were low. For example, the highest average score for skin was 2.14 for mullet. The highest scores (poorest health) in all species were for liver ranging from 5.63 in bream to 15.00 in mullet.

Table 3.22: Overall health assessment index scores for five fish species and the overall score for Gladstone Harbour in 2021.

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

Table 3.23: Average measures and health assessment index (HAI) total scores for fish caught in Gladstone Harbour in the 2020–21 reporting year. Organ scores ranged from 0 to 30 and HAI scores ranged from 0 to a possible maximum of 270.

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

Overall

The overall score for fish health in 2021 was the aggregation of the two fish health projects (Table 3.24). As no individual zone scores are calculated for fish health, this score also constitutes the fish health score for all 13 environmental monitoring zones.

Table 3.24: Overall fish health scores for Gladstone Harbour in 2021.

Visual fish condition	**Fish health assessment index**	**Overall fish health 2021**
0.74	0.90	**0.82**

3.3.5. *Fish health conclusions*

Visual fish condition

In 2021 the overall score for visual fish condition was 0.74, although this score is similar to the 2020 score of 0.72, these results are not directly comparable, as the 2020 scores were based on two fish species, rather than the five species used to calculate this year's score. However, the score is comparable to the 2019 score of 0.69 suggesting that over the three years of monitoring visual fish health in Gladstone Harbour has been stable.

All species of fish received very good scores for fish visual assessment (0.94 for barred javelin to 0.98 for pikey bream) and the scores for fish body condition ranged from satisfactory (0.55 for mangrove jack) to poor (0.47 for yellow-finned bream). Poor body condition scores were recorded in only two species yellow-finned bream and pikey bream which indicated condition below the long-term average.

Health assessment index

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

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

3.3.6. Fish recruitment

Fish recruitment is one of the three key dynamic functions that affects a fish population, the other two are growth rate and mortality. The fish recruitment index is based on the total catch of juveniles of two bream species and is defined as the annual production of juvenile fish entering the mature fish population in Gladstone Harbour (Sawynok 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 2020–21 reporting year and data from this survey are reported here.

What fish were used as indicators of harbour health ?

Yellow-finned bream

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

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

Pikey bream

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

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

Yellow-finned bream
(Acanthopagrus australis)

Pikey bream
(Acanthopagrus berda)

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

3.3.7. *Fish recruitment data collection*

Data for the two bream species were collected monthly from 26 sites across 12 harbour zones between December 2020 and February 2021 (Figure 3.11). This was a reduction of one month from surveys conducted in previous years (2016 to 2020). The Outer Harbour was excluded from the surveys as there were no suitable bream habitats (Table 3.25). Where possible, within each zone, a minimum of two sites were selected to cover the upper tidal limit and another selected within the daily tidal range. Each survey was completed within two weeks, following the largest spring tides as recruitment of fish into nursery habitats is influenced by these large tides. A species fork length up to 100 mm defined juvenile or year 0 recruits (Sawynok & Sawynok, 2021).

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, 2021) (Figure 3.12).

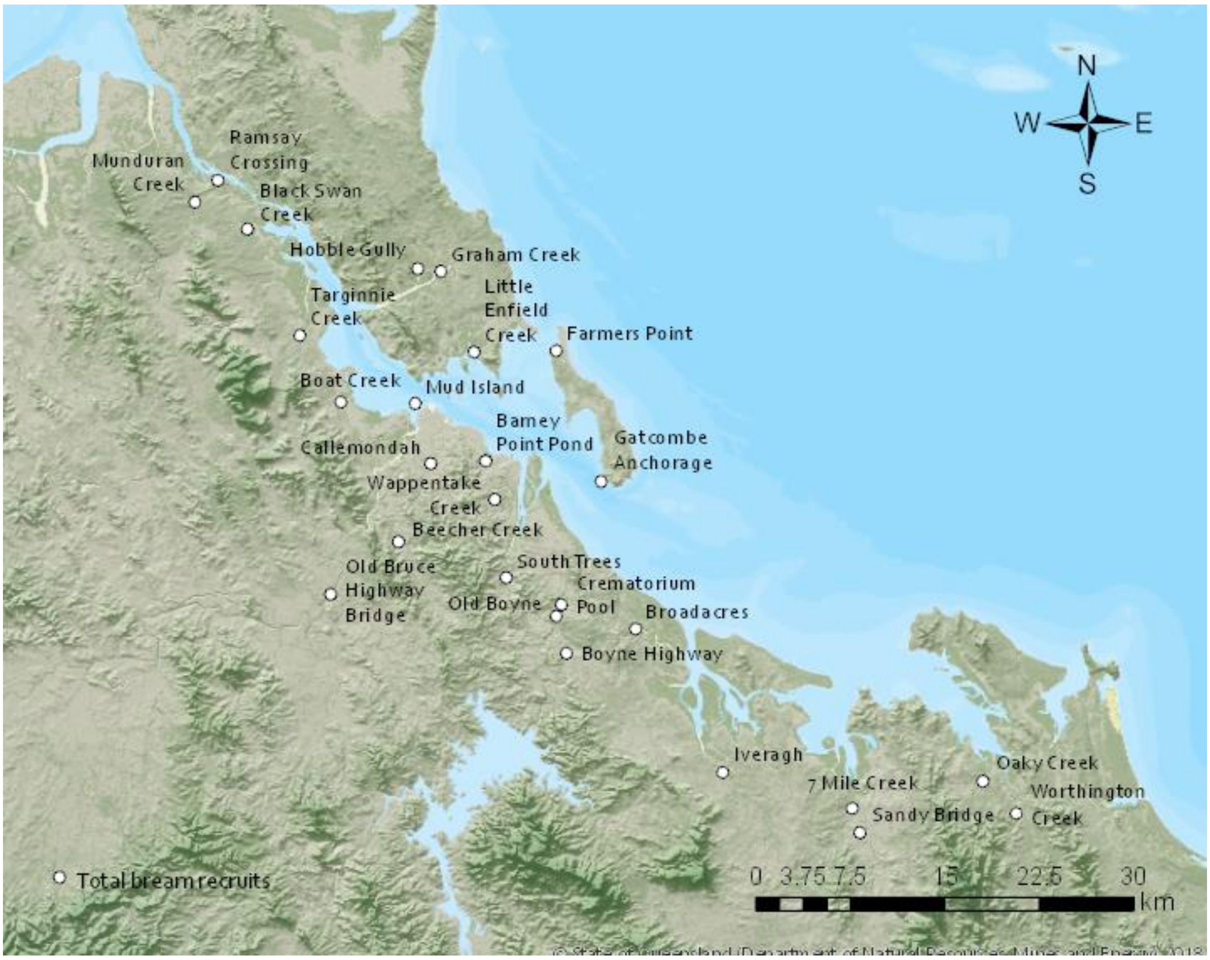


Figure 3.11: Bream nursery habitats surveyed around Gladstone Harbour between December 2020 and February 2021.

Gladstone Healthy Harbour Partnership

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

Table 3.25: Number of sites surveyed and number of juvenile bream caught and released in each GHHP monitoring zone in 2020-21.

Harbour zone	Sites	Yellow-finned bream	Pikey bream
Zone 1. The Narrows	Ramsay Crossing	1	1
	Munduran Creek	17	1
	Black Swan Creek	4	21
	Targinnie Creek	32	8
Zone 2. Graham Creek	Graham Creek	0	28
	Hobble Gully	5	83
Zone 3. Western Basin	Wiggins Island	21	8
Zone 4. Boat Creek	Boat Creek	1	0
Zone 5. Inner Harbour	Little Enfield Creek	4	33
	Barney Point Pond	0	0
Zone 6. Calliope Estuary	Beecher Creek	7	5
	Old Bruce Highway Bridge	47	11
Zone 7. Auckland Inlet	Callemondah	9	28
Zone 8. Mid Harbour	Farmers Point	6	0
	Gatcombe Anchorage	2	18
Zone 9. South Trees Inlet	Wappentake Creek	2	1
	South Trees	5	7
	Crematorium Pool	23	11
Zone 10. Boyne Estuary	Old Boyne	23	4
	Boyne Highway	23	0
Zone 11. Outer Harbour	*Not surveyed*		
Zone 12. Colosseum Inlet	Broadacres	8	8
	Iveragh	21	0
Zone 13. Rodds Bay	Oaky Creek	19	3
	7 Mile Creek	26	17
	Worthington Creek	10	1
	Sandy Bridge	13	0
Total	**26 sites**	**329**	**626**

3.3.8. Development of fish recruitment indicators and scoring

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

The final statistical model comprises:

- A response variable: Total yellow-finned and pikey bream juvenile catch count per visit, together with an offset term of log (number of casts), giving an effective response of catch per cast.
- Random effect terms: Sampling site (allowing for productivity differences between sites not explained by the fixed effects), year (as the main effect), year by site interaction (to better account for the variability in spatio-temporal scale).

- Log link: Allows all difference or changes to be assessed on a proportional or relative scale rather than an absolute one.
- Fixed temporal effects: Month term allowing for systematically different catch rates within the survey year.
- Fixed environmental effects: Presence and absence of rocks, water depth at a site.

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

3.3.9. Fish recruitment results

Overall, the fish recruitment score for 2021 was 0.62 (C), indicating a satisfactory condition. Of the 12 zones monitored one zone (Western Basin) had a very good score, three zones had good scores, six zones had satisfactory scores and two zones (Boat Creek and South Trees Inlet) had poor scores. Four zones had higher scores than those recorded in the previous year and eight zones had lower scores (Table 3.26) and the overall score was similar to that recorded in 2020 (Figure 3.13).

The total number of bream caught in the 2021 reporting year was 626 comprised of 329 yellow-finned bream and 297 pikey bream. Owing to the reduction of sampling effort, 1560 casts in 2021 compared to 2080 in previous years these results are not directly comparable with past results.

Table 3.26: Fish recruitment scores for all harbour zones and overall harbour score for fish recruitment from 2017 to 2021.

Zone	2021	2020	*2019*	*2018*	*2017*
1. The Narrows	0.54	0.63	*0.18*	*0.58*	*0.75*
2. Graham Creek	0.84	0.92	*0.17*	*0.77*	*0.58*
3. Western Basin	0.94	0.98	*0.13*	*0.79*	*0.78*
4. Boat Creek	0.35	0.38	*0.32*	*0.61*	*0.47*
5. Inner Harbour	0.61	0.63	*0.16*	*0.67*	*0.64*
6. Calliope Estuary	0.68	0.66	*0.28*	*0.70*	*0.79*
7. Auckland Inlet	0.63	0.80	*0.53*	*0.87*	*0.91*
8. Mid Harbour	0.78	0.62	*0.12*	*0.58*	*0.71*
9. South Trees Inlet	0.47	0.39	*0.25*	*0.69*	*0.71*
10. Boyne Estuary	0.53	0.51	*0.32*	*0.52*	*0.74*
11. Outer Harbour	Not surveyed				
12. Colosseum Inlet	0.56	0.63	*0.39*	*0.61*	*0.71*
13. Rodds Bay	0.51	0.52	*0.33*	*0.59*	*0.74*
Harbour score	**0.62**	**0.64**	***0.27***	***0.66***	***0.71***

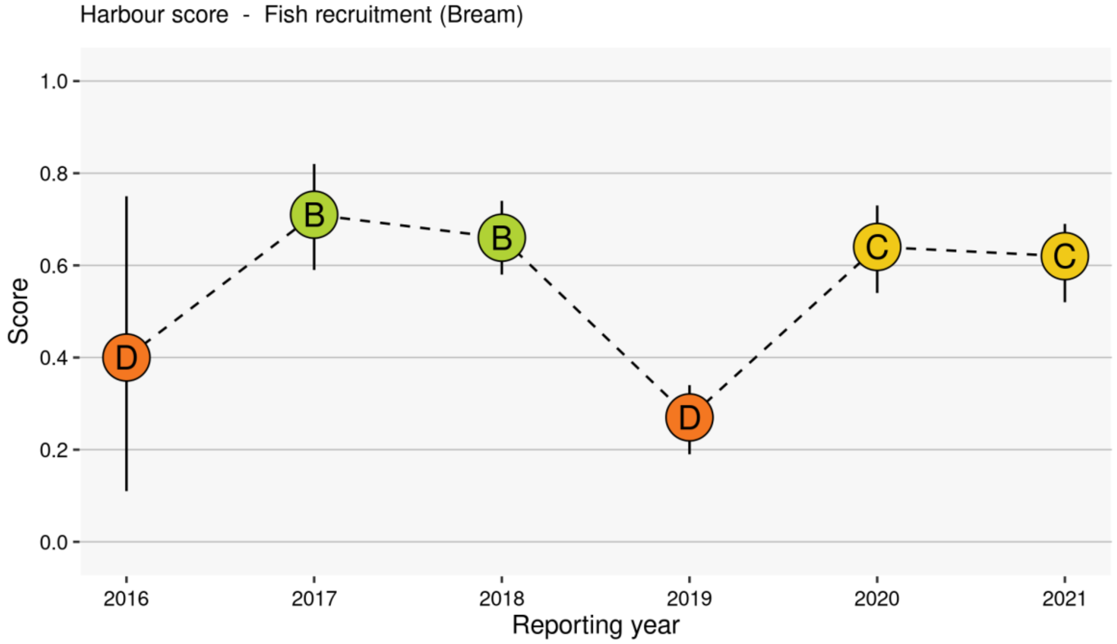


Figure 3.13: Trends in the harbour score for fish recruitment, 2016 – 2021 (Error bars show 95% bootstrap confidence intervals).

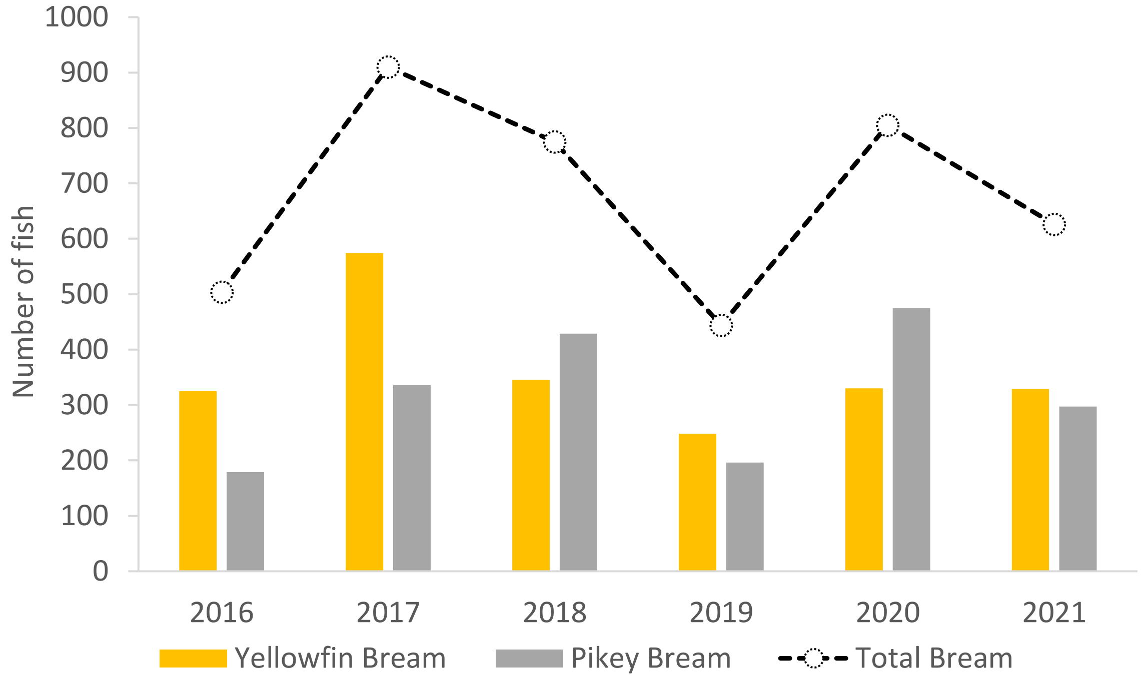


Figure 3.14: Yellow-finned and pikey bream recruits from 2016 to 2021 fish recruitment surveys.

3.3.10. Fish recruitment conclusions

In the 2020–21 report card year the number of surveys conducted was reduced from 104 (26 sites x 4 sampling rounds) to 78 (26 sites x 3 sampling rounds) with surveys in December, January and February and none in March as in previous years. The reduction in the number of surveys appears to have had little effect on the overall result. The previous four years have shown that by March the catch rate of bream is declining, with the March catch rate being 0.21 fish per cast (2020) to 0.08 fish per cast (2019) less than the December to February catch rate.

Rainfall of 143.6mm in December was likely to have boosted the prawn catch which was highest in the past 6 years. However, the total rainfall of 5.6mm in Gladstone for January and February resulted in very dry and poor conditions at most sites. This would likely have limited the opportunity for recruits to access some sites and reduce fish dispersal at others.

Persistent strong winds at the time of surveys had a marked effect at Ramsay Crossing where the results were the poorest of any year and were not reflective of the potential recruitment in that area. There were just two recruits recorded at the site compared with 75 from surveys conducted there in the previous year.

This year saw a large fluctuation in the number of goldlined rabbitfish *Siganus lineatus*. From 2015-16 to 2018-19 the total number of fish recorded from December to March was 75-163. This rose to 634 in 2019-20 and fell again to 39 in 2020-21. This suggest that 2019-20 was a strong recruitment year however the drivers of recruitment for this species are unknown.

3.3.11. Mud crabs

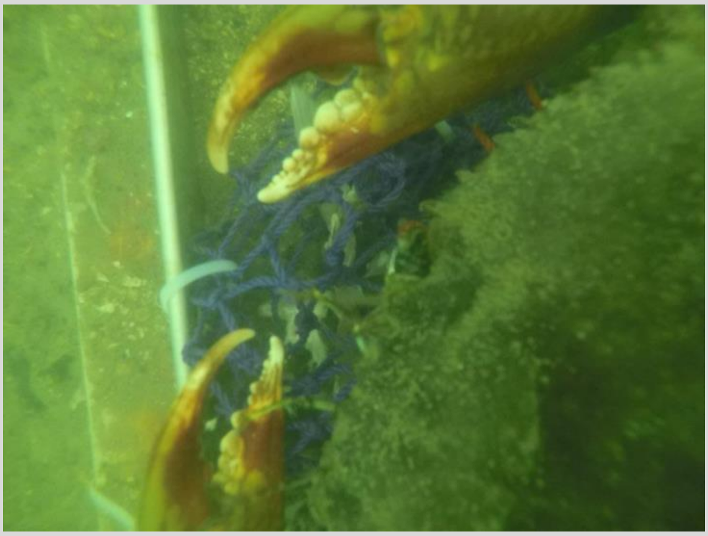


Figure 3.15: Mud crab feeding at a Baited Retrievable Underwater Video during the pilot study in 2017 (Photo courtesy of CQU).

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 suitable indicators of mud crab health and a methodology for determining report card scores (Figure 3.15).

3.3.12. Mud crab data collection

Monitoring site selection

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

From the nine sites assessed, seven were selected for future report card monitoring (Table 3.27). Two sites were excluded from future monitoring. Rodds Bay site A was excluded owing to insufficient mud crab habitat to accommodate the number of pots required and South Trees Inlet owing to a very low catch rate in the initial survey.

Table 3.27: GHHP zones assessed as permanent report card mud crab monitoring sites in 2017. From the nine sites assessed seven were included in the report card and recommended for ongoing mud crab monitoring.

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

Mud crab monitoring

Two rounds of mud crab monitoring were conducted in 2021—a summer (warm, wet season) survey from 6–9 February and a winter (cool, dry season) survey from 3–6 June.

Twenty heavy-duty, four-entry collapsible crab pots were set at a minimum of 100 m apart at each site. The exception was Boat Creek where fewer pots could be placed within the confines of this small zone. Sampling dates and times were determined by tidal cycles. The baited crab pots were set at least three hours before the low tide, and collected at least two hours after the low tide, resulting in soak times of approximately five hours per pot. All pots were placed so that they would be submerged for the duration of deployment to prevent mortality of any fish or other bycatch. Pots were placed as close as possible to mangrove habitats within this limit.

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

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

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

3.3.13. Development of mud crab indicators and scoring

A literature search for potential mud crab indicators identified nine classes of potential mud crab indicators (Table 3.28). This included the three sub-indicators identified by the ISP for consideration: abundance, size distribution and visual health (McIntosh et al., 2014). Other potential indicators were identified in the literature or were those used in other mud crab surveys in the Gladstone area.

Table 3.28: Potential mud crab indicators were identified and ranked based on their suitability for calculating report card scores.

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

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

1. Sex ratio: based on legal size limit

   $$\frac{\text{(number of male mud crabs >150 mm carapace width)}}{\text{(number of female mud crabs >150 mm carapace width)}}$$

2. Abundance: catch per unit effort (CPUE)

   $$\frac{\text{(total number of mud crabs caught)}}{\text{(number of pots set)}}$$

3. Visual health: prevalence of rust lesions

   $$\frac{\text{(number of mud crabs with lesions)}}{\text{(number of mud crabs assessed for lesions)}}$$

The report card scores were calculated using a methodology similar to that used in the South East Queensland Report Card (Fox, 2013) and the Fitzroy Basin Report Card (Flint et al., 2017b). The indices for sex ratio, abundance and visual health were calculated and compared to a benchmark and a worst-case scenario (Table 3.29). Calculated index values lower than the worst-case scenario scored 0; values higher than the benchmark value scored 1. This resulted in a range of scores between 0 and 1. Benchmarks and worse-case scenarios were selected based on existing data and data collected during the 2017 report card monitoring.

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

Table 3.29: Calculation of mud crab scores for the 2021 report card.

Measure	Benchmark	Worst-case scenario	Method
Sex ratio	Male to female sex ratio of 2:1 from an unfished Central Queensland population at Eurimbula Creek (Flint et al., 2019) **(2)**	25th percentile of Long-Term Monitoring Program data **(0.25)**	1–((x-B)/(WCS-B)) Where: x=recorded CPUE B=benchmark (2) WCS=worst-case scenario (0.25)
Abundance (CPUE)	Moving average of 75th percentile of the combined 2017, 2018, 2019, 2020 & 2021 scores **(1.8)**	Catch rate of < 1 crab per allowable 4 pots **(0.25)**	1–((x-B)/(WCS-B)) Where: x=recorded CPUE B=benchmark (1.95) WCS=worst-case scenario (0.25)
Prevalence of rust lesions	25th percentile of the 2017 data (4%) **(0.04)**	Prevalence recorded by Dennis et al. (2016) in Gladstone Harbour of 37%, rounded down to 35% **(0.35)**	1–((x–B)/(WCS–B)) Where: x=recorded prevalence B=benchmark (0.04) WCS=worst-case scenario (0.35)

The sex ratio measure assessed fishing pressure, as only male crabs can be retained. A minimally disturbed benchmark requires data from an unfished population, where an undisturbed male to female crab ratio can be determined. The 2017 benchmark was set at 3:1 based on unfished populations in Micronesia (Alberts-Hubatsch et al., 2016). In 2018, the sex ratio benchmark was updated to 2:1 using data from unfished populations in northern NSW and an unfished section of Moreton Bay (Butcher, 2004, Pillans et al., 2005). In 2018–19, a GHHP-funded CQU study investigated the sex ratio from a more local population in Eurimbula Creek (an un-crabbed estuary in Central Queensland). Findings from this study corroborate the previously reported sex ratio benchmark of 2:1 (Flint et al., 2019). As the Long-Term Monitoring Program data are the longest time series available, the worst-case scenario was set from this data at the 25th percentile (0.25).

Abundance was indirectly measured as catch per unit effort (CPUE)—total catch divided by the number of pots within each of the seven monitoring zones. The benchmark for abundance (measured as CPUE) was set as the 75th percentile of the past three years. An accumulating average of the 75th percentile will be used for up to 10 years to account for natural variability. Using the accumulating average from 2017–2021, the benchmark for 2021 was 1.8 crabs/pot. The worst-case value was set at 0.25, equivalent to one crab from four pots. The maximum number of pots that a recreational crabber is allowed is four and a catch of less than one mud crab from four pots is undesirable.

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

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

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

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

3.3.14. Mud crab results

The overall mud crab score for the 2021 report card was 0.48 (D). This was a result of very poor to satisfactory scores for sex ratio (0.00–0.57), abundance scores ranging from very poor to very good (0.00–1.00) and poor to very good scores for prevalence of rust lesions (0.47–1.00) (Table 3.30). The condition of mud crab populations in the harbour was graded poor for the fourth consecutive year. Note the overall harbour score has been influenced by the change in scoring methods for 2020 and 2021 report cards, however, the change scores are only marginal.

The zone with the highest overall scores were The Narrows (0.64, C) and Boat Creek (0.60, C), which had good or better scores for abundance and very good scores for prevalence of rust lesions. The Narrows has been the highest scoring zone for four of the five years of monitoring and has consistently received the highest possible score for abundance (1.00, A). For the first time since monitoring began, Rodds Bay received a satisfactory score (0.56, C). While driven by a satisfactory sex ratio score (0.57, C), it is important to note this score was derived from a relatively small sample of crabs.

The remaining three zones—Calliope Estuary (0.47, D), Graham Creek (0.39, D) and Inner Harbour (0.39, D)—received poor scores (Table 3.30). An overall score for Auckland Creek was not calculated for the fourth consecutive year, as less than five crabs were caught in this zone over the two sampling periods.

Table 3.30: Mud crab indicator scores for the 2021 Gladstone Harbour Report Card. Scores from 2020 and 2019 are shown for comparison.

Zone	Sex Ratio	Abundance (CPUE)	Prevalence of rust lesions	2021	*2020*	*2019*
1. The Narrows	0.00	1.00	0.92	0.64	*0.60*	*0.63*
2. Graham Creek	0.00	0.27	0.89	0.39	*0.34*	*0.45*
4. Boat Creek	0.03	0.83	0.94	0.60	*0.71*	*0.48*
5. Inner Harbour	0.07	0.63	0.47	0.39	*0.39*	*0.48*
6. Calliope Estuary	0.14	0.26	1.00	0.47	*0.19*	*0.43*
7. Auckland Inlet	NC	0.00	NC	NC	*NC*	*NC*
13. Rodds Bay	0.57	0.16	0.96	0.56	*0.22*	*0.36*
Harbour score	**0.14**	**0.45**	**0.86**	**0.48**	***0.39***	***0.47***

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

Sex ratio (based on legal size limit)

In 2021, five zones received very poor scores ranging from 0.00 to 0.14 (E) (Table 3.31). A score for Auckland Creek could not be calculated due to an insufficient catch (n < 5) while Boat Creek received a satisfactory score (0.57, C). Although the highest sex ratio score received by an individual zone since 2018, it is important to note this score was based on a relatively small number of crabs (n = 19).

In 2021 a total of 229 legal-sized mud crabs (carapace width >150 mm) were caught, of which 43 were male—about 4 females for every one male crab. When the two sampling periods were combined, five of the six zones where a score could be calculated had more than two females to every one male crab. The exception to this was Rodds, which had an average of 0.8 females to every one male crab. Overall, the harbour score for sex ratio (0.14, E) was higher than previous years.

Table 3.31: Sex ratio of legal-sized mud crabs (carapace width >150 mm) in February and June 2021 by zone. Note, figures for sex ratio represent actual male-to-female crab ratios and not GHHP scores.

Zone name	**February 2021**			**June 2021**		
	Males	Females	Sex ratio	Males	Females	Sex ratio
Narrows	5	48	0.10	4	59	0.07
Grahams Creek	2	7	0.29	0	6	0.00
Boat Creek	4	2	2.00	4	24	0.17
Inner Harbour	2	13	0.15	6	8	0.75
Calliope Estuary	0	2	0.00	5	8	0.63
Auckland Inlet	1	1	1.00	/	/	NC
Rodds Bay	1	1	1.00	9	7	1.29
Harbour average			**0.65**			**0.48**

NC: Not calculated

Abundance: catch per unit effort (CPUE)

For the fourth consecutive year the highest catch rate was recorded in The Narrows where there was an average of 3.9 mud crabs per pot (Table 3.32). The Narrows received the highest possible score (1.00, A), Boat Creek received a good score (0.83, B) and the Inner Harbour received a satisfactory score (0.63, C) for abundance. Abundance scores at the remaining four zones were poor or very poor, with scores ranging from 0.00 at Auckland Inlet to 0.27 at Graham Creek. Overall, the harbour score for abundance increased from 0.38 (D) in 2020 to 0.45 (D) in 2021, although the grade remained the same.

Table 3.32: Catch per unit effort (CPUE) for pots set in seven harbour zones during the February and June 2021 mud crab surveys.

Zone name	February 2021			June 2021		
	Pots	Crabs caught	CPUE	Pots	Crabs caught	CPUE
1. The Narrows	20	74	3.70	20	83	4.15
2. Graham Creek	20	18	0.90	20	9	0.45
4. Boat Creek	20	13	0.65	16	39	2.44
5. Inner Harbour	20	25	1.25	20	24	1.20
6. Calliope Estuary	20	5	0.25	20	21	1.05
7. Auckland Inlet	20	2	0	20	0	0.00
13. Rodds Bay	20	2	0.10	19*	17	0.89
Harbour average			**0.99**			**1.45**

* One pot went missing from Rodds Bay, so only 19 were retrieved.

Visual health: prevalence of rust lesions

A very low incidence of rust lesions was recorded at five of the harbour zones: The Narrows, Graham Creek, Boat Creek, Calliope Estuary and Rodds Bay. Scores for these five zone ranged from 0.89 to 1.00 (A). In contrast the Inner Harbour received a poor score (0.47, D). The score for prevalence of rust lesions was not calculated in Auckland Inlet owing to the insufficient number of crabs caught (Table 3.33). Overall, the 2021 score for this sub-indicator was similar to those previously recorded from 2017 to 2019 (0.86 – 0.98, A) and higher than that reported in 2020 (0.73, B). When comparing sampling events, fewer crabs with rust lesions were encountered in the June sample.

Table 3.33: Number and percentage of mud crabs with external lesions (rust spot) in February and June 2021 by zone.

Zone name	February 2021		June 2021	
	# with lesions	% with lesions	# with lesions	% with lesions
1. The Narrows	9	12.16	1	1.20
2. Graham Creek	1	5.56	1	11.10
4. Boat Creek	1	7.69	2	5.13
5. Inner Harbour	7	28.00	3	12.50
6. Calliope Estuary	0	0.00	0	0.00
7. Auckland Inlet	1	50.00	/	NC
13. Rodds Bay	0	0.00	1	5.88
Harbour average		**14.77**		**5.97**

NC: Not calculated

3.3.15. Mud crab conclusions

The mud crab sub-indicators have been selected to represent a range of pressures on mud crabs in Gladstone Harbour. These pressures include commercial and recreational fishing and environmental condition. The mud crab sub-indicators were designed to reveal change over time and elucidate trends in mud crab health. Confidence in the mud crab indicator will improve as the dataset grows annually. The overall score 0.48 (D) was similar to the previous three years, which ranged from 0.39 to 0.49 (D) (Figure 3.16). This result was driven by an overall very poor sex ratio, poor abundance and very good prevalence of rust lesions scores (Table 3.30).

In Queensland it is illegal to take female crabs, hence changes in the ratio of male to female crabs can indicate changes in fishing pressures. In 2021, the majority of zones where sex ratio could be calculated scored very poorly—a similar pattern to previous years. When the two sampling periods were combined, there were more than two females to every one male crab within five of the six measured zones. This pattern suggests that fishers are observing regulations for the release of female crabs, which may be skewing the sex ratio towards a female-dominated population. Presently, the timing and population effect of the female spawning migration is not well understood and the possibility that this may be influencing the observed scores cannot be ruled out. In addition to changes in population dynamics, sex ratio may impact ecosystem processes owing to differences in behaviour between male and female crabs. For example, only male crabs dig burrows, a behaviour which may aid the process of bioturbation (disturbance of sedimentary deposits by living organisms) in mangrove ecosystems. Research is required to understand how a changed sex ratio impacts the health of mud crab populations.

In the current year, abundance received a poor overall score for the fourth consecutive year. Caution is required in interpreting the abundance scores as CPUE data can be highly variable. As in previous years the abundance scores ranged from very good to very poor at the zone level. Mud crab populations can be influenced by a range of anthropogenic and natural impacts. Natural factors include differences in crab distribution, growth or survival related to habitat, reproductive cycles, and environmental conditions such as temperature and water motion (Knuckey, 1999; Alberts-Hubatsch et al., 2016). Sampling factors including capture technique, sampling area and time may also influence mud crab catches. When these factors are controlled, abundance can indicate changes to external pressures such as extraction (fishing), habitat availability and recruitment limitation. The reliability of the abundance sub-indicator is expected to improve over time as more data are collected using consistent sampling methods.

The prevalence of rust lesions was scored with moderately high confidence in the benchmark and worst-case scenario as they are based on research data from Gladstone Harbour (Andersen & Norton, 2001; Dennis et al., 2016) and data collected during the 2017 GHHP monitoring year. Five of the six zones where this measure could be calculated received very good scores (Table 3.30). These scores indicate a very low prevalence of rust spot lesions across the harbour. The average incidence of rust spot lesions across the seven monitored zones was 10.3% for the combined February and June survey periods, considerably lower than the 37% incidence recorded in 2012 (Dennis et al., 2016) or less than half of the 22% recorded in the late 1990s by Andersen et al. (2000).

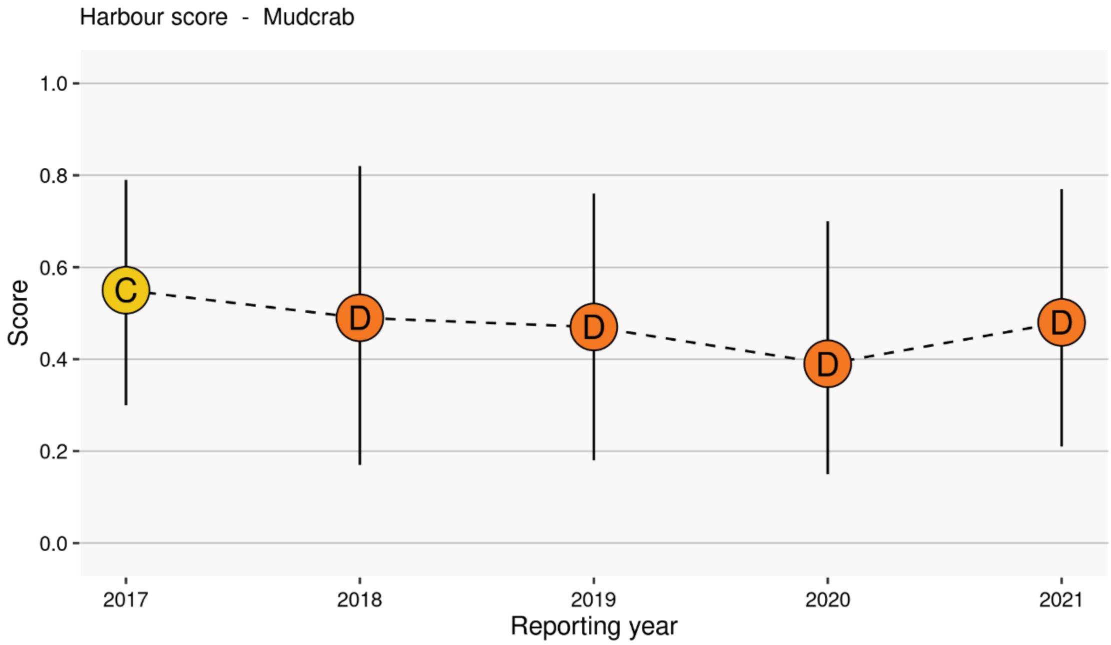


Figure 3.16: Trends in the harbour score for mud crabs, 2017 – 2020 (Error bars show 95% bootstrap confidence intervals).

3.4. Environmental component and indicator groups results

The overall Environmental component score for the 2021 report card was 0.68 (B). This was derived by aggregating the three environmental indicator groups (water and sediment quality, habitats and fish and crabs) using the bootstrapping methodology (Logan, 2016).

The indicator group scores were derived by aggregating the water and sediment quality indicator scores for water and sediment quality, aggregating the seagrass, corals and mangrove indicators for habitats and aggregating the two fish health indicators, fish recruitment and mud crabs for fish and crabs. The overall scores for the three indicator groups were: water and sediment quality 0.93 (A), habitats 0.48 (D), and fish and crabs 0.62 (C) (Table 3.34).

The zone scores for the habitat indicator group only include the habitat indicators present in each zone. While mangroves are present in all zones, coral is present in two zones and seagrass is present in six zones. The health of other important habitat types, such as benthic habitat which occurs in all zones, was not measured. Sampling for fish health was conducted in the north, central and southern areas of the harbour and a single fish health score was applied to all zones. Fish recruitment surveys were conducted in all zones except the Outer Harbour. Mud crab monitoring was conducted in six zones. Water and sediment quality sampling was conducted in all zones. No new mangrove monitoring was conducted in 2021 and the mangroves scores are based on the survey work conducted in 2019.

Table 3.34: 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	0.88	0.74*	0.66~
2. Graham Creek	0.94	0.64	0.68~
3. Western Basin	0.97	0.63*	0.88
4. Boat Creek	0.88	0.46	0.59~
5. Inner Harbour	0.94	0.57*	0.61
6. Calliope Estuary	0.94	0.58	0.65~
7. Auckland Inlet	0.89	0.65	0.48
8. Mid Harbour	0.93	0.40*#	0.80
9. South Trees Inlet	0.94	0.79*	0.64
10. Boyne Estuary	0.93	0.26	0.68
11. Outer Harbour	0.98	0.39#	0.82
12. Colosseum Inlet	0.96	0.72	0.69
13. Rodds Bay	0.97	0.67*	0.63~
Harbour score	**0.93**	**0.48**	**0.62**

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

The first report card in 2015 contained four environmental indicators, water quality, sediment quality, seagrass and coral. Since then, four additional environmental indicators have been added to the program. These are fish recruitment in 2016, mud crabs in 2017, mangroves in 2018 and fish health in 2019. From 2020, owing to budget constraints, several environmental indicators will only be monitored every three or five years. Hence mangroves were not assessed in the 2020 and 2021 report cards and the 2019 results were used to calculate the habitat score.

While the annual environmental grade is not strictly comparable in the period between 2015 and 2018 owing to the continued addition of indicators. The period between 2019 and 2021 shown an increase in the overall grade from a C to a B (Figure 3.17). This is attributable to improvements in water quality scores for nutrients and turbidity, seagrass and the fish and crabs indicator group. While the improvement in water quality may be associated with the dry conditions that have persisted in the 2019-20 and 2020-21 reporting years owing to reduced terrestrial runoff, the interactions between rainfall, river flows and the fish and crabs indicator group require further investigation.

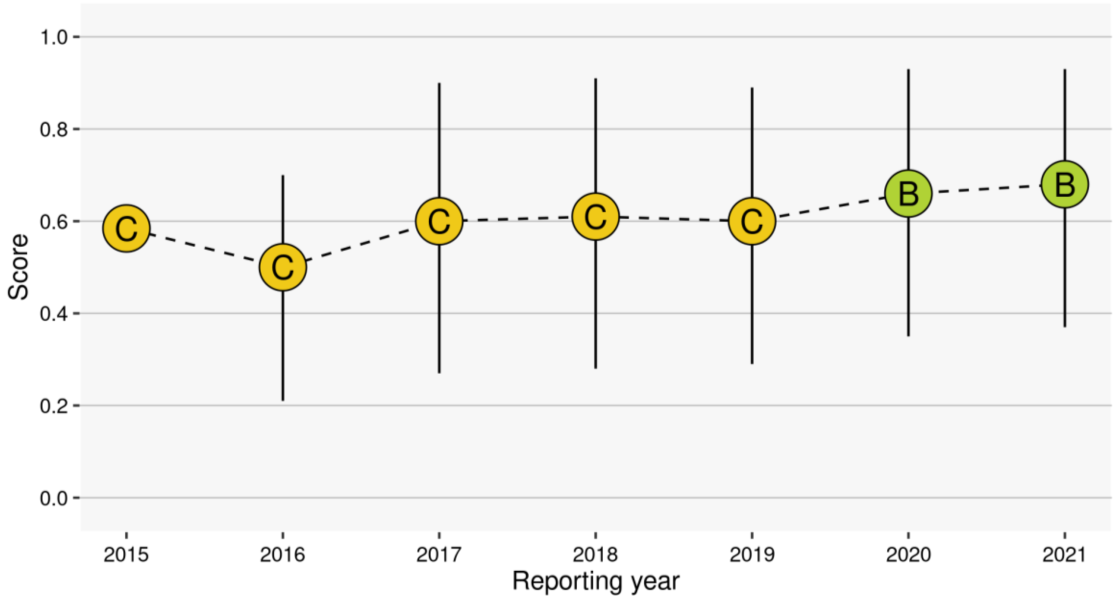


Figure 3.17: Trends in the overall Environmental score, 2015 – 2021 (Error bars show 95% bootstrap confidence intervals).

4. Other data used in the Calculation of 2021 Report Card scores

Report card monitoring between 2014 and 2021 has revealed that while some environmental indicators are sensitive to short-term environmental changes in response to climate variables such as rainfall (e.g. seagrass and fish recruitment) other environmental indicators such as mangroves are more stable owing to the greater buffering capacity of these long-lived species.

The Social, Cultural and Economic indicators have all proven to be particularly stable over the six-year period between 2014 and 2019.

From 2020, there was a move to less frequent monitoring where indicators or components show little annual variation but will show long-term trends. From 2020, monitoring of the social, cultural, economic components and the mangroves indicator will move to a frequency of between 2 and 5 years. Where an indicator has shown little variation e.g., water quality and coral, but there is strong public interest, annual monitoring will be retained.

Report card scores for indicators monitored at a frequency of greater than one-year will be calculated with the data collected in previous years. In the 2021 report card the results for the Social, Cultural and Economic components and the mangrove indicator are those presented in the 2019 and 2020 report cards. These results are presented in sections 4.1 to 4.4.

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

4.1. Environmental 2019

4.1.1. Mangroves

Mangroves were last monitored in 2019 (Duke & Mackenzie, 2019) and had an overall score of 0.57, a small change from 2018 when the score was 0.60 (Figure 4.1). As variation in mangrove scores is likely to be small from year to year in response to changes to climatic conditions such as wet or dry years and/or changes in sea level, mangrove monitoring will move to a 5-year cycle with the next scheduled monitoring to occur in 2024. While it is acknowledged that mangrove condition could change rapidly in response to unpredictable catastrophic events such as cyclones or major marine spills the probability of such events is small. Hence the results from monitoring conducted in 2019 will be used to calculate the overall Environmental score in 2021 and in subsequent report cards until the next round of mangrove monitoring is conducted. A full description of the mangrove indicator including all methods and results can be found in the 2019 Technical Report and 2019 Mangrove project report.

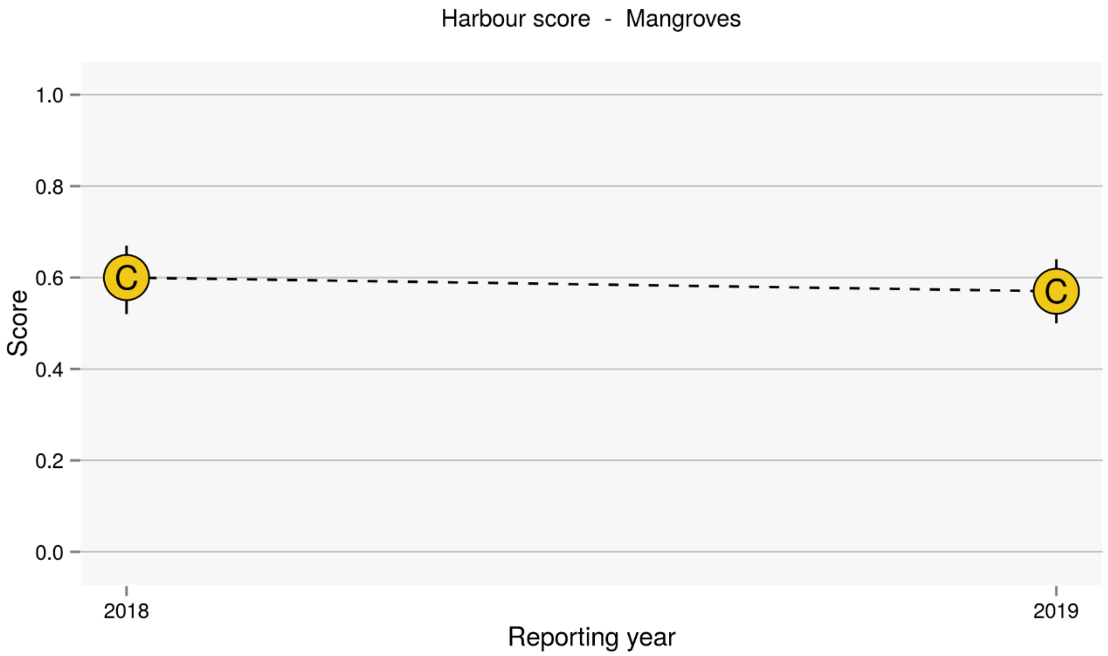


Figure 4.1: Change in overall mangrove score between 2018 and 2019 (Error bars show 95% bootstrap confidence intervals).

4.1.2. Overall mangrove results

The overall score for mangroves in Gladstone Harbour in 2019 was 0.57 (C). Three zones were in good condition and eight zones were considered satisfactory (Table 4.1). 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 4.1: Overall mangrove zone and harbour scores for the 2019 reporting year. The 2018 scores are shown for comparison.

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

4.2. Social 2019

The Social component was last assessed in 2019 and had an overall score of 0.67, the same as the previous year's score and similar to the scores received since the first report card in 2015 (Figure 4.2). As the scores for this indicator have been stable over this 5-year period, from 2019 onwards the Social component will be monitored every three years. Hence for the 2021 report card the Social score from 2019 will be used. However, it is not clear what impact COVID-19 would have had on the overall Social score in 2021. Full descriptions of the Social component and indicator groups including all methods and results can be found in the 2019 Technical Report and 2019 Social, Cultural and Economic project report.

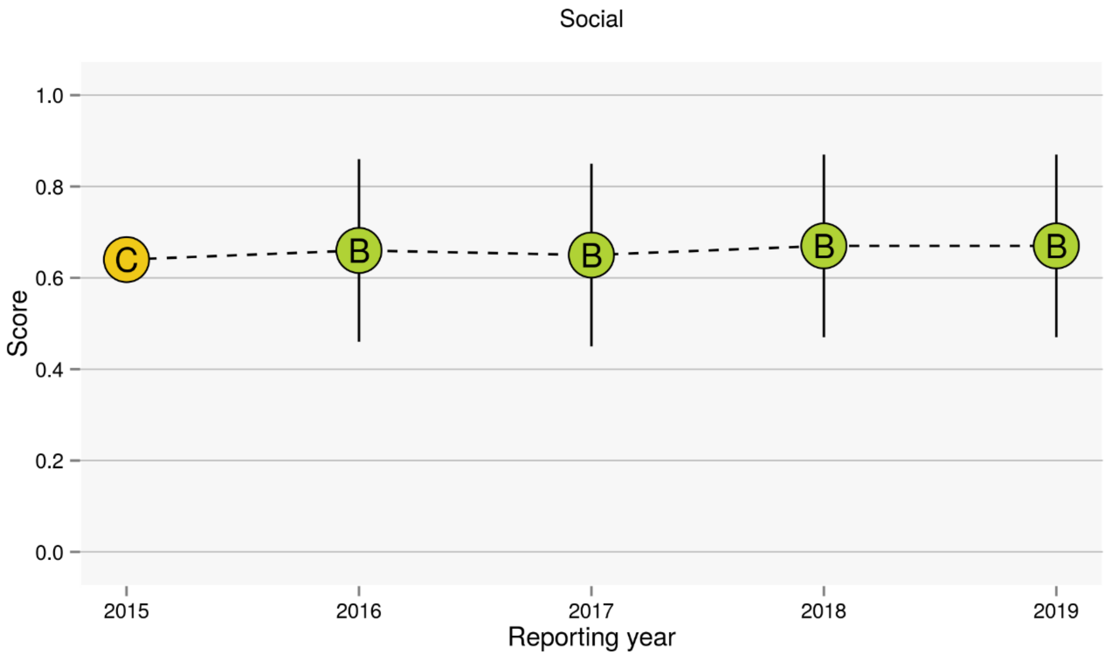


Figure 4.2: Change in the overall Social score between 2015 and 2019. Error bars were not calculated for the 2015 score as this score was calculated prior to the use of the DIMS in 2016 (Error bars show 95% bootstrap confidence intervals).

4.2.1. Overall Social results

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. 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 4.3).

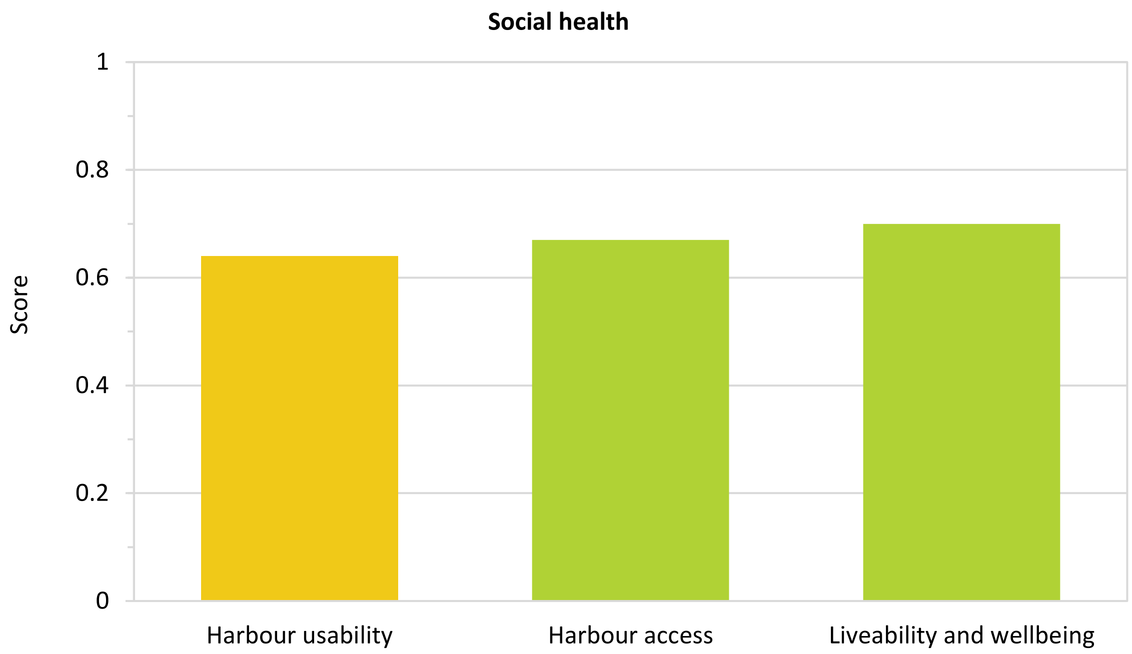


Figure 4.3: Indicator group scores within the Social component of harbour health in the 2019 Gladstone Harbour Report Card.

4.3. Cultural 2019

The Cultural component score is comprised of two indicator groups: 'sense of place' and Indigenous cultural heritage. 'Sense of place' captures community views on place identity and place attachment through the CATI survey, while Indigenous cultural heritage which assesses the physical condition of cultural heritage sites and management strategies to protect these sites. 'Sense of place' was last monitored in 2019 and these results are used in the 2021 report card. Like the Social indicator groups, the 'sense of place' score has remained stable over the life of the GHHP program (Figure 4.4). Hence monitoring of this indicator group will be conducted triennially from 2019 with the next scheduled reporting of this indicator group to occur in the 2022 report card. However, as with the Social component, the impacts of the COVID-19 pandemic on the 'sense of place' indicator group are not known.

The score for Indigenous cultural heritage ranged from 0.53 to 0.55 in the three years it has been monitored between 2016 and 2018 (Figure 4.5). Owing to the stability of this indicator group from 2018 onwards monitoring is scheduled to occur every 5 years with the next round of monitoring due for the 2023 report card. Results from the 2018 surveys will be used to calculate the overall score for the Cultural component until then. Full description of the Cultural component and indicator groups including all methods and results can be found in the 2019 Technical Report, 2019 Social, Cultural and Economic and the 2018 Indigenous cultural heritage project reports.

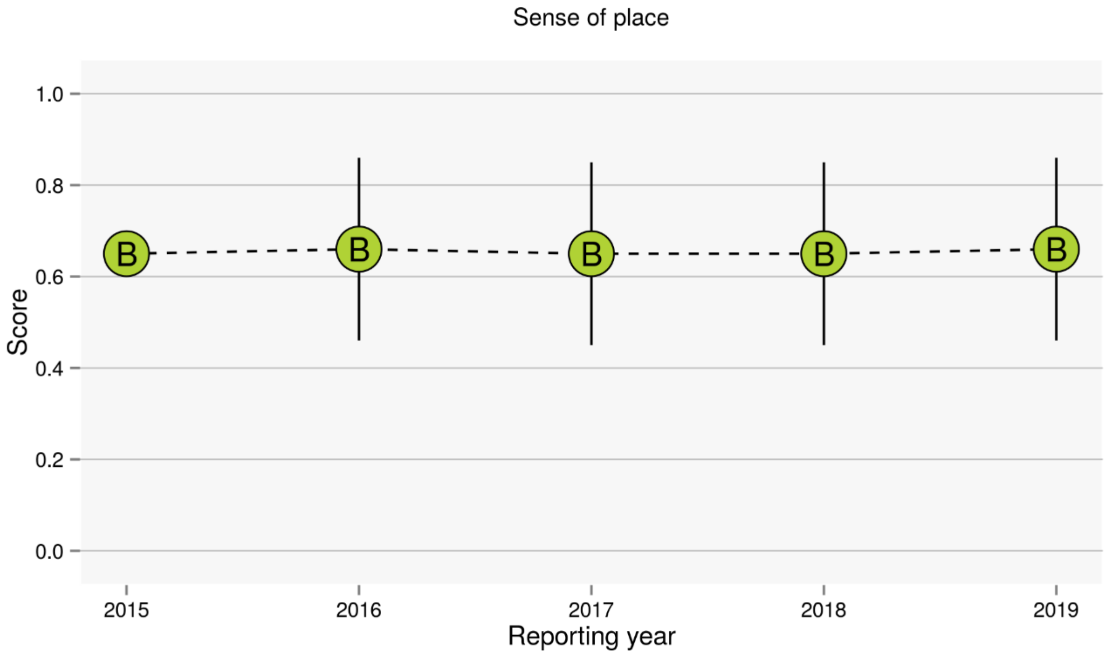


Figure 4.4: Changes in the 'sense of place' score from 2015 to 2019 (Error bars show 95% bootstrap confidence intervals).

Figure 4.5: Changes in the overall Indigenous cultural heritage score from 2016 to 2018.

4.3.1. Overall Cultural 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 with new data for 2019 and Indigenous Cultural heritage which used 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).

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 4.6). All scores were similar to those recorded in the previous year.

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)).

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 Wild Cattle Creek, which received a poor score of 0.48 (D) for management strategies (Figure 4.7).

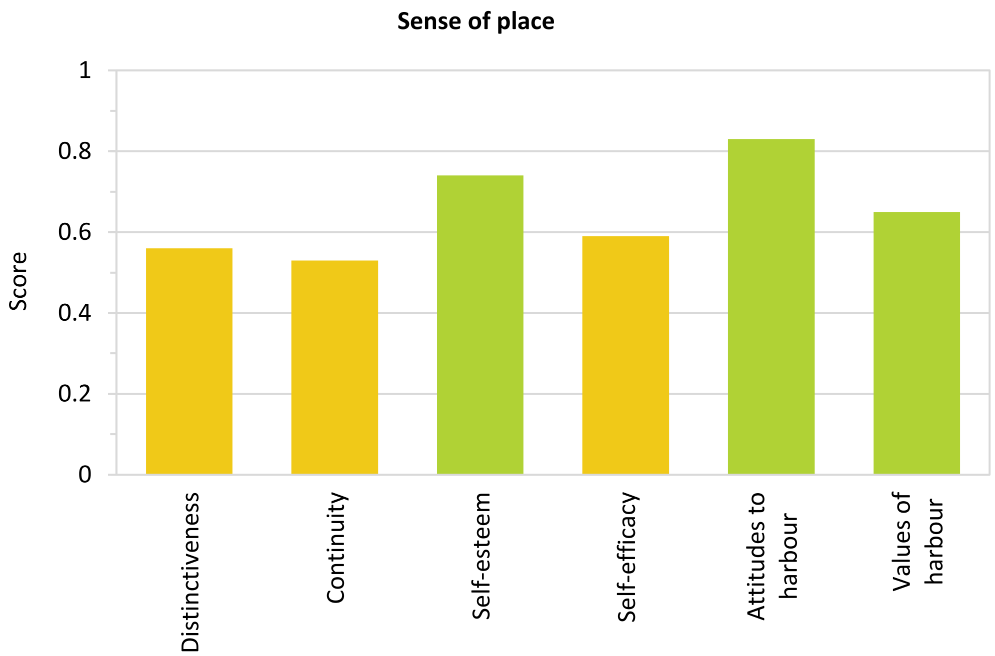


Figure 4.6: Indicator scores for 'sense of place' indicator group used for Cultural health in the 2018 Gladstone Harbour Report Card.

Figure 4.7: 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.* Within the cultural management strategies indicators, *cultural management* and *cultural resources* measures received very poor scores across all zones.

4.4 Economic 2019

The Economic component was last assessed in 2019 and had an overall score of 0.72 (B), with scores ranging from 0.72 to 0.77 between the 2015 and 2019 report cards (Figure 4.8). As the scores for the Economic component and its indicator groups have been stable over this 5-year period, from 2019 onwards the Economic component will be monitored every three years with the next round of monitoring due to occur for the 2022 report card. The 2019 report card scores for the Economic component will be used in the 2021 report card. It is not clear what impact the COVID-19 pandemic would have had on the overall Economic score. Full descriptions of the Economic component and indicator groups including all methods and results can be found in the 2019 Technical Report and 2019 Social, Cultural and Economic project report.

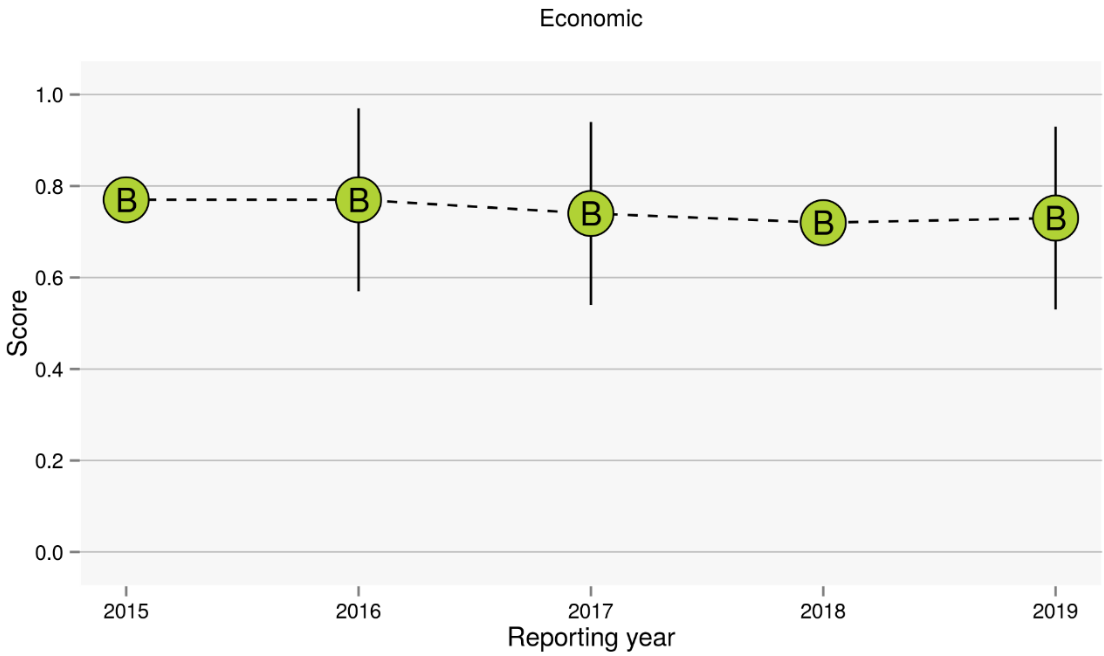


Figure 4.8: Changes to the overall Economic component score between 2015 and 2019 (Error bars show 95% bootstrap confidence intervals).

4.4.1 Overall Economic 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 2019 Gladstone Harbour Report Card (Figure 4.9). 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).

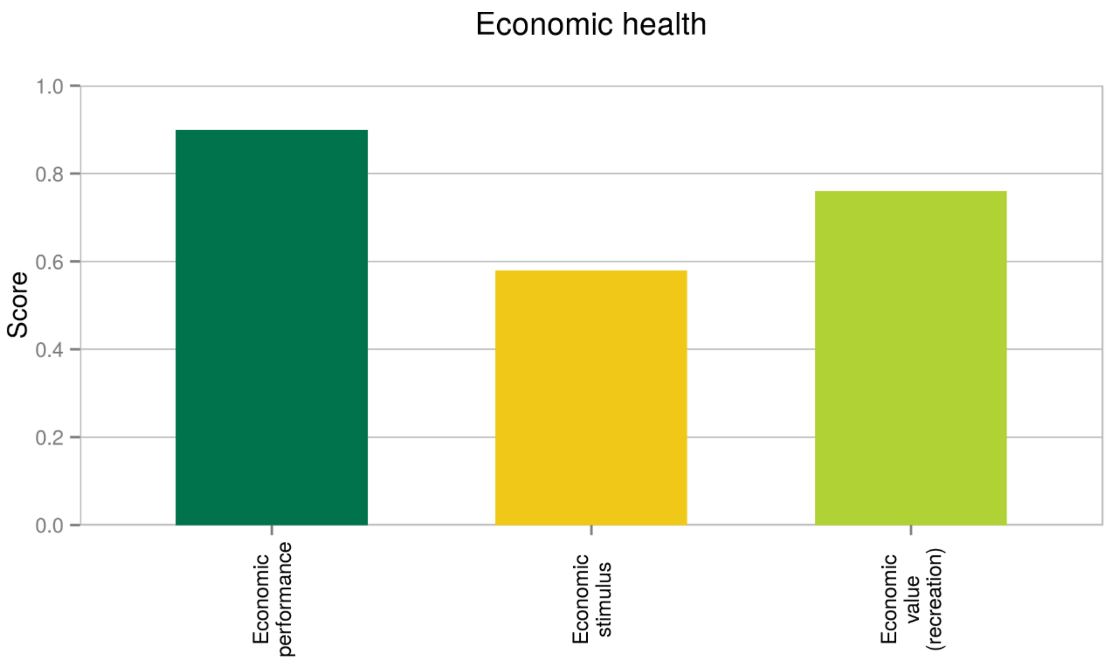


Figure 4.9: The scores for each of the three economic indicator groups in the 2019 Gladstone Harbour Report Card.

5. Gladstone Harbour drivers and pressures

5.1. 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 5.1). 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 5.2).

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 2019–20 report card scores.

In the reporting year from 1 July 2019 to 30 June 2020, acute climatic events, such as flooding, and cyclones did not influence the report card scores. Social, Cultural and Economic indicators were not assessed, and the 2019 results were used in the report card. A review of the social, cultural and economic pressures effecting Gladstone Harbour in 2019 is contained in the 2019 Technical Report.

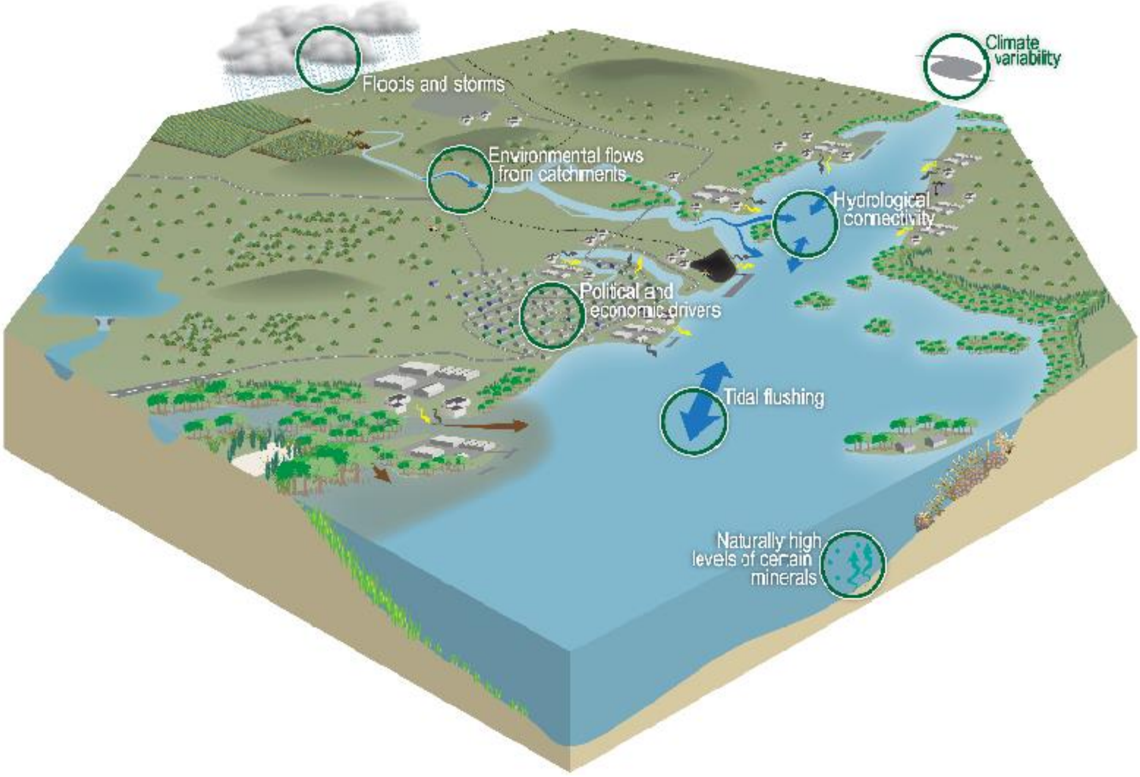


Figure 5.1: Major drivers of environmental change within Gladstone Harbour (Source: McIntosh et al., 2014).

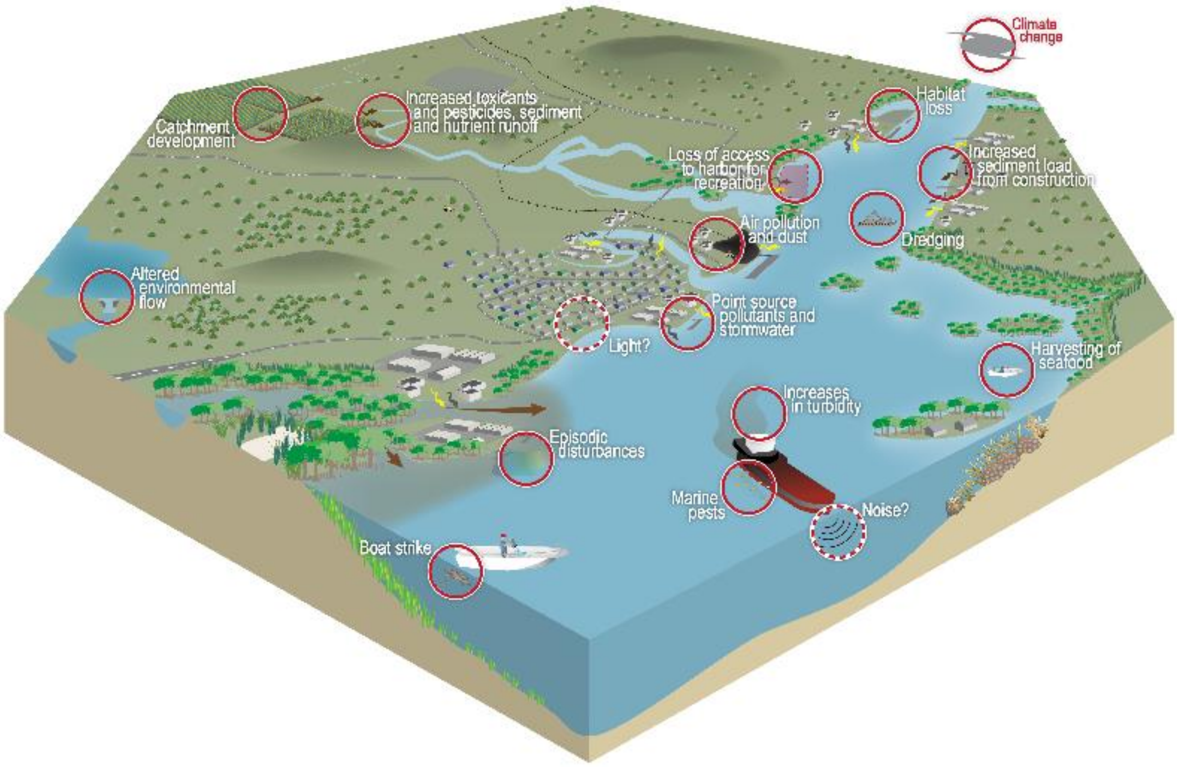


Figure 5.2: Pressures which can drive environmental change within Gladstone Harbour (Source: McIntosh et al., 2014).

5.2. Climate

Gladstone has a subtropical climate with an average maximum of 27.4ºC and an average minimum of 18.1ºC (Figure 5.3). Rainfall is highly variable; the average annual rainfall recorded at Gladstone (Airport) for the period 1994–2020 was 875 mm. The maximum and minimum annual rainfall totals recorded at this site were 1,542 mm in 2010 and 308 mm in 2001 respectively. Consistent with a subtropical climate, the summer months are wetter than winter months.

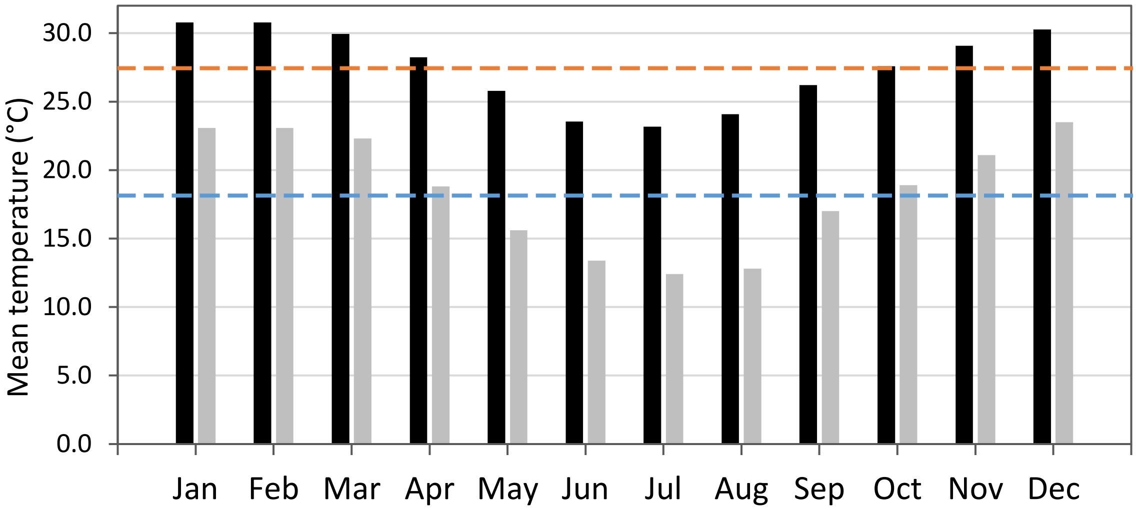


Figure 5.3: Average maximum and minimum monthly temperatures at the Gladstone Airport weather station from 1994–2021. Temperatures shown as follows: average maximum monthly for 2021 (black bars), average minimum monthly for 2020 (grey bars), annual maximum average (orange dashed line, 27.4º C), annual minimum average (blue dashed line, 18.1º C). Values were obtained from BOM (http://www.bom.gov.au/climate/data/index.shtml).

2019–20 rainfall

In the 2020–21 reporting year (July 2020 to June 2021), total rainfall recorded at Gladstone Airport was 625 mm—well below the annual average of 853 mm (Figure 5.4). Total monthly rainfall was variable when compared to mean monthly rainfall of the past 26 years (Figure 5.5). Across the reporting year rainfall was below average with seven months recording dryer than average conditions. The driest period was January and February in which the total rainfall was just 64 mm for the two-month period well below the average for these two months of 319 mm. The driest month was May (6.6 mm), and the wettest month was March (134 mm).

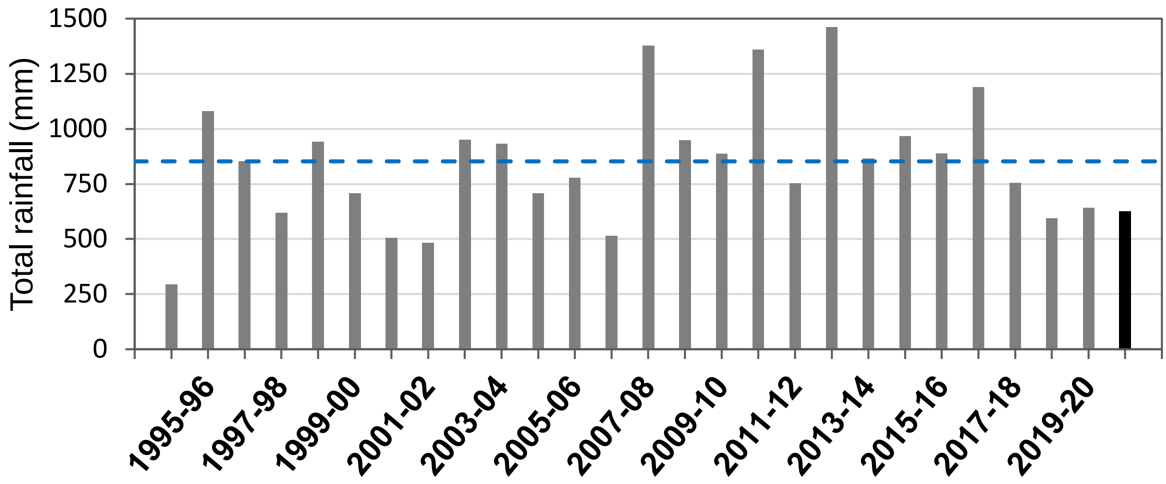


Figure 5.4: Annual rainfall (mm) by reporting year at the Gladstone Airport weather station from 1994–1995 to 2020–2021. Blue dashed line represents the annual mean of total rainfall from 1994–2021 (856 mm). Values were obtained from BOM (http://www.bom.gov.au/climate/data/index.shtml).

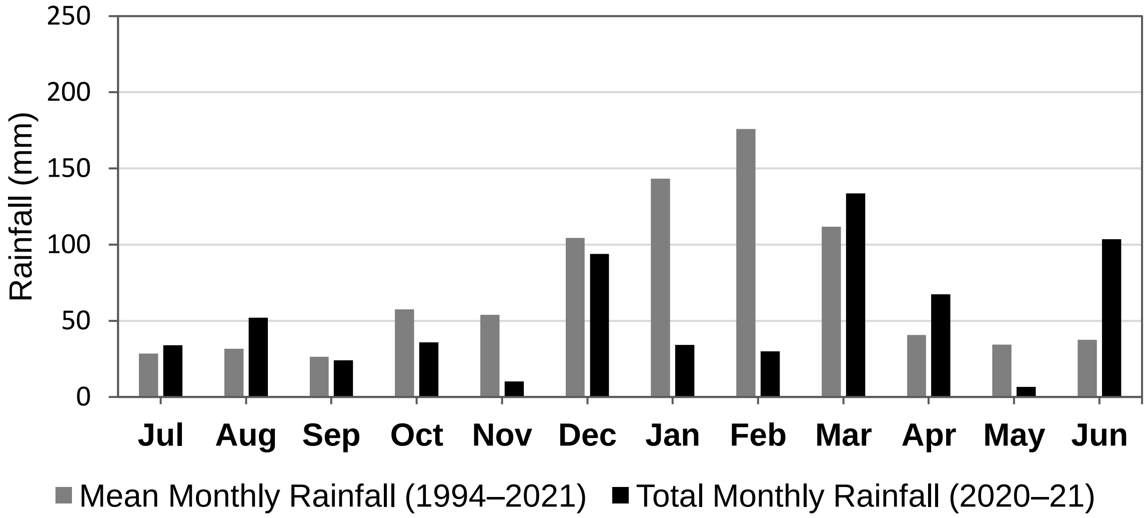


Figure 5.5: Mean monthly rainfall (mm) at the Gladstone Airport weather station (1994–2021) compared to total monthly rainfall for the 2020–21 reporting year. Values were obtained from BOM (http://www.bom.gov.au/climate/data/index.shtml).

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 5.1. 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 2021 show two brief but significant high flow events occurring with the passage of TC Marcia and ex TC Debbie (Figure 5.6). 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 2020–21 reporting year, the mostly dry conditions resulted in minimal flow from the Calliope in most months. For most months total monthly water discharge from the Calliope River was considerably lower compared to the monthly median discharge (1938 – 2019), but discharges were considerably above the long-term medium in October, March and April. There was also negligible stream discharge in July through to September, November to February and May through June.

Table 5.1: Streamflow summary for the Boyne River (1984–85 to 2011–12) and the Calliope River (1938–39 to 2018–19). Values were obtained from DNRM (https://water-monitoring.information.qld.gov.au/).

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

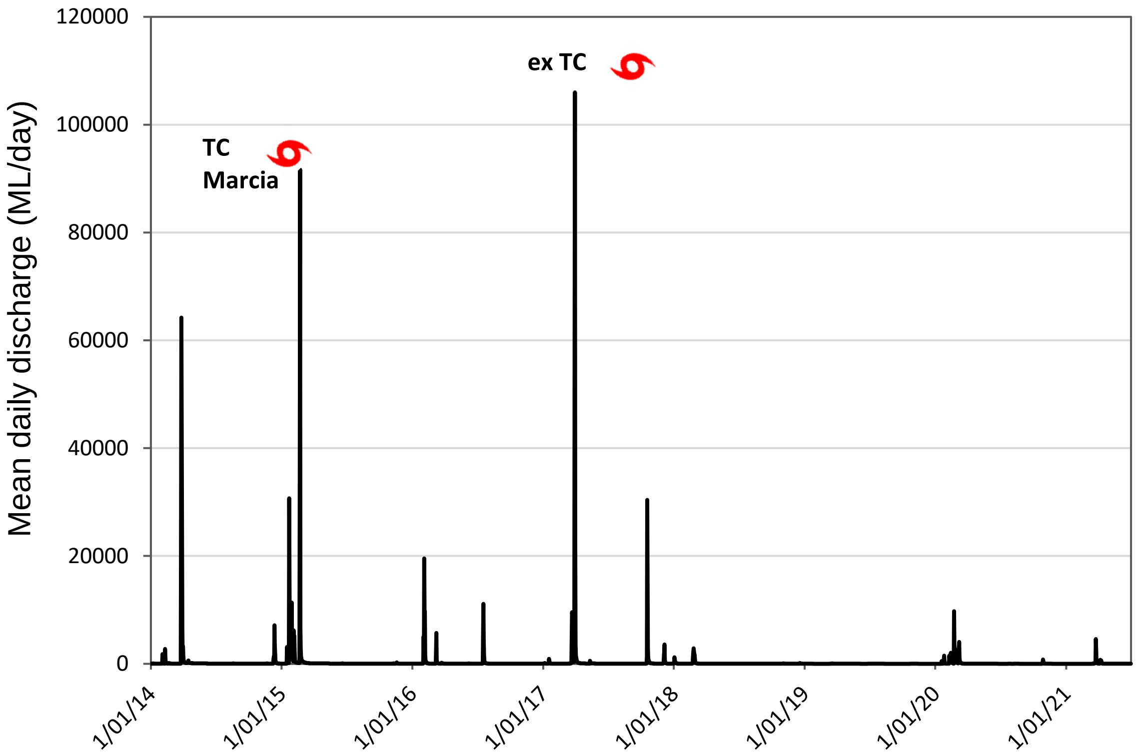


Figure 5.6: Mean daily Calliope River flows recorded at Castlehope between January 2014 and June 2021. Values were obtained from DNRM (https://water-monitoring.information.qld.gov.au/).

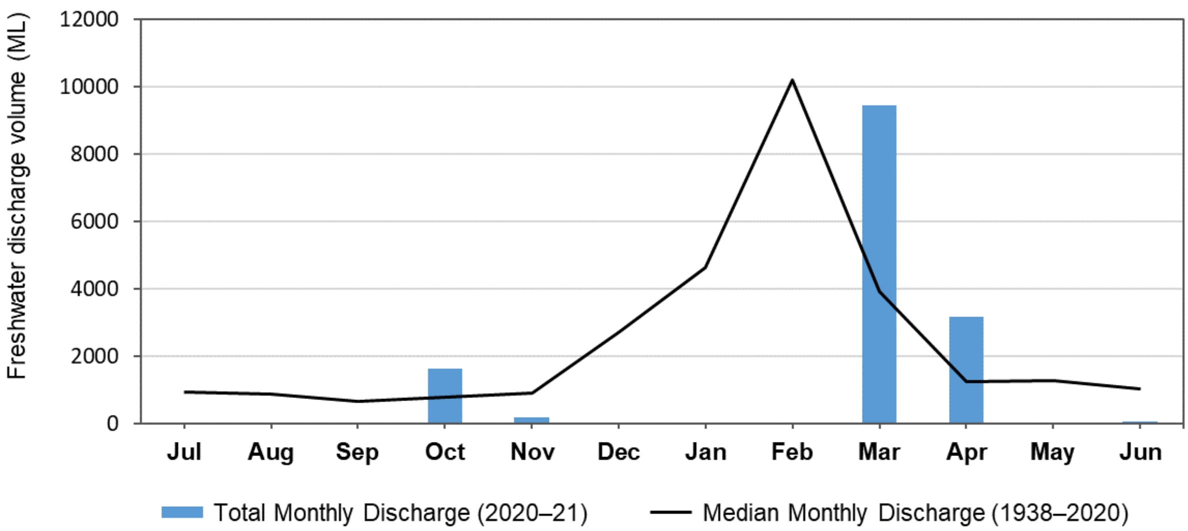


Figure 5.7: Monthly water discharge (July 2019 to June 2020) and median monthly water discharge (October 1938 to June 2020) of the Calliope River at Castlehope. Values were obtained from DNRM (https://water-monitoring.information.qld.gov.au/).

The main water storage for Gladstone is the Awoonga Dam located on the Boyne River approximately 25 km south-west of Gladstone. The dam has a storage capacity of 250,000 ML and is overtopped when the storage level exceeds 40 m Australian Height Datum (Table 5.2). Since the height of the dam wall was raised in 2002, it has overtopped eight times—in 2002, 2010, 2013, 2015, 2017 and 2018. No overtopping occurred in the 2020–21 report card year (Figure 5.8).

Table 5.2: Highest Awoonga Dam levels and last overtopping (Source: Gladstone Area Water Board).

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

AHD – Australian Height Datum

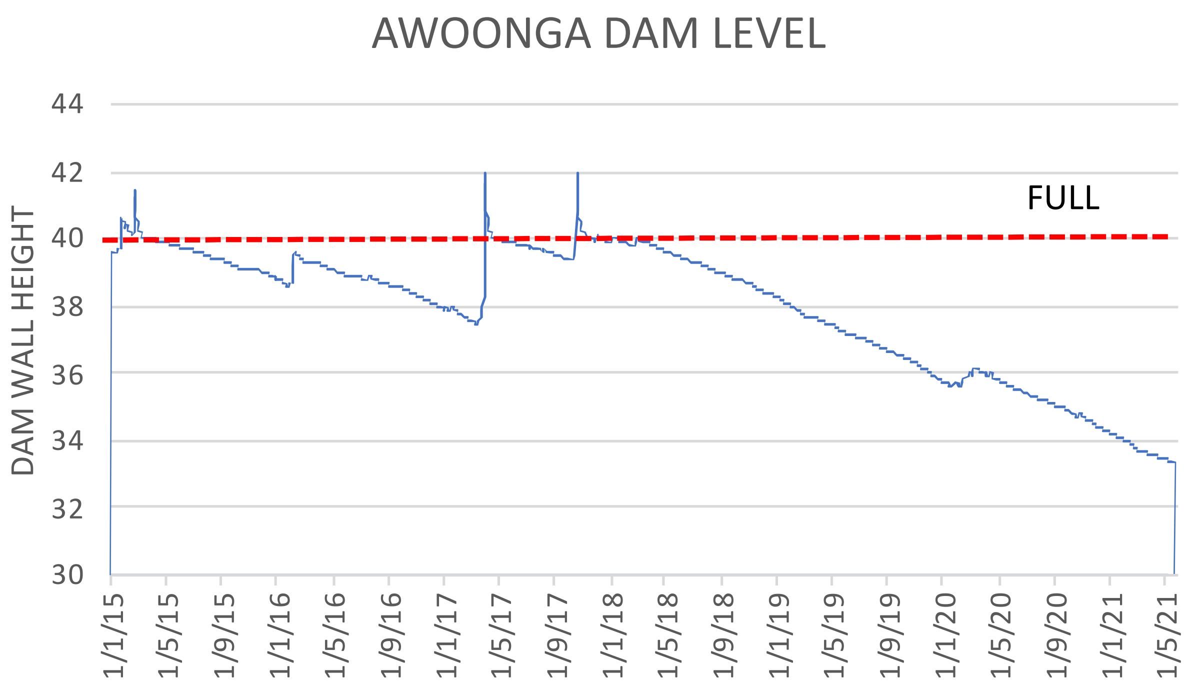


Figure 5.8: Awoonga Dam levels January 2015 to May 2021 (Source: Sawynok et al., 2021).

5.3. 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 5.9).

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 5.10 and 5.11). Much of the flow from the Boyne River into Port Curtis is restricted by Awoonga Dam, constructed in phases beginning in the 1960s. The current spillway height of 40 m Australian height datum was achieved in 2002. In periods of normal flow, it would be expected that coarser sediment particles would settle behind the structure.

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

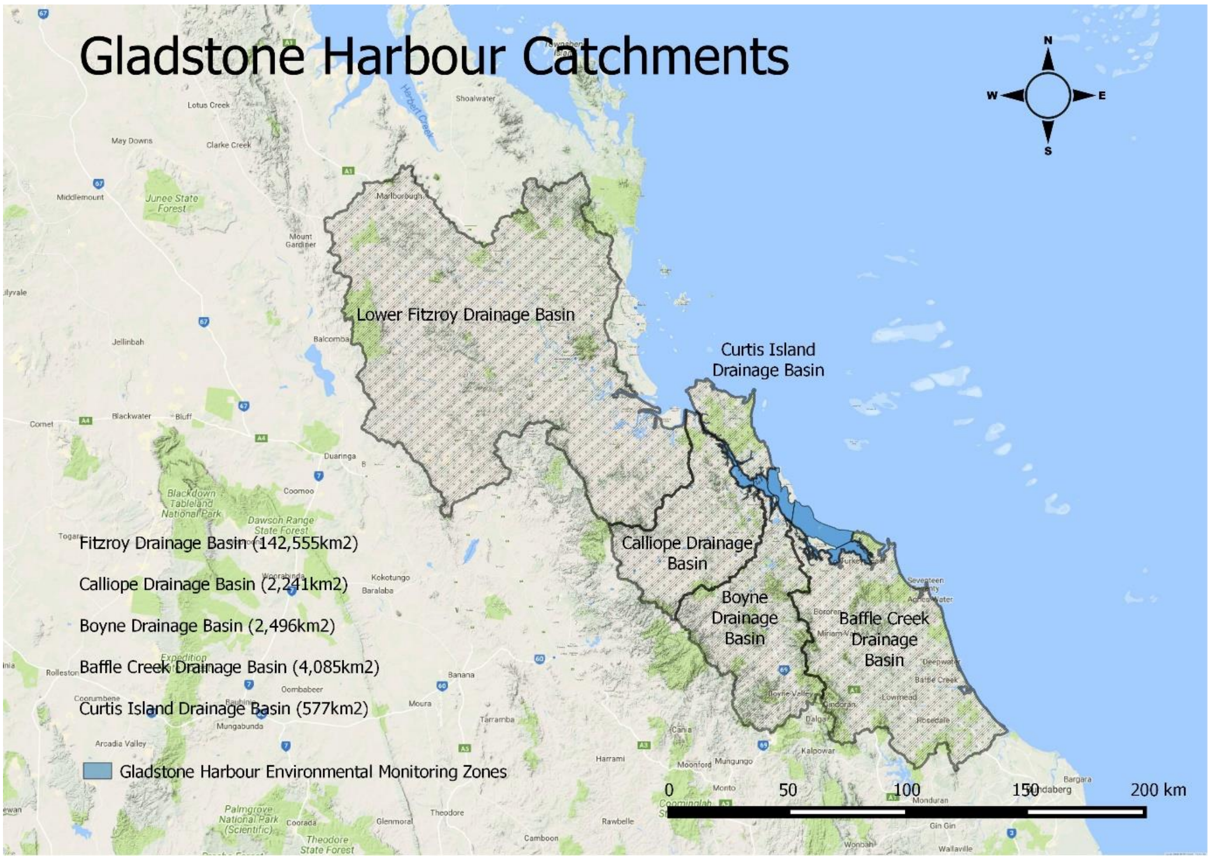


Figure 5.9: Drainage basins surrounding the Gladstone Harbour environmental monitoring zones.

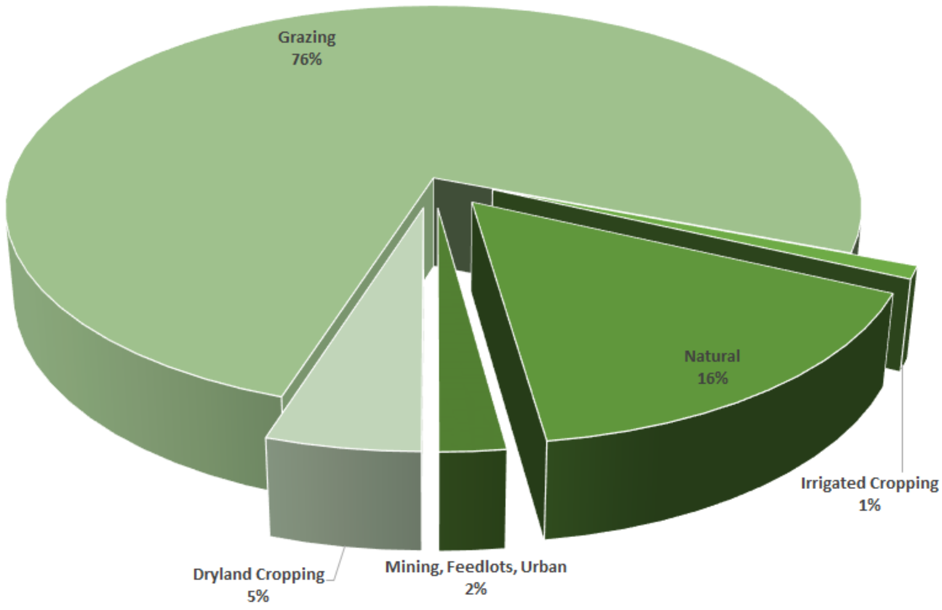


Figure 5.10: Land use in the Boyne catchment (Data source QSpatial, Land use mapping – Fitzroy NRM region 2009, Catchment boundaries, Queensland Wetland*Info*).

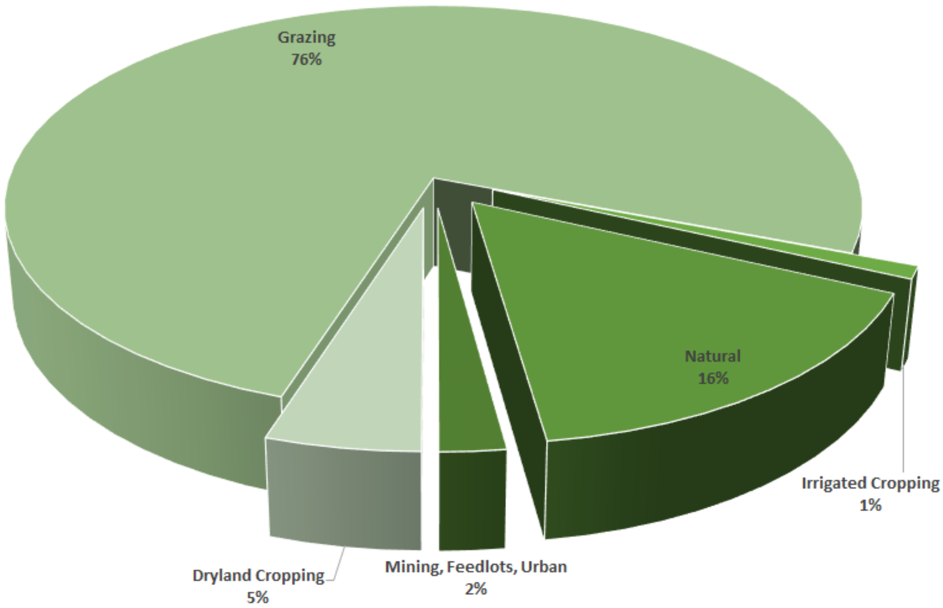


Figure 5.11: Land use in the Calliope catchment (Data source QSpatial, Land use mapping – Fitzroy NRM region 2009, Catchment boundaries, Queensland Wetland*Info*).

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 5.12). 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.

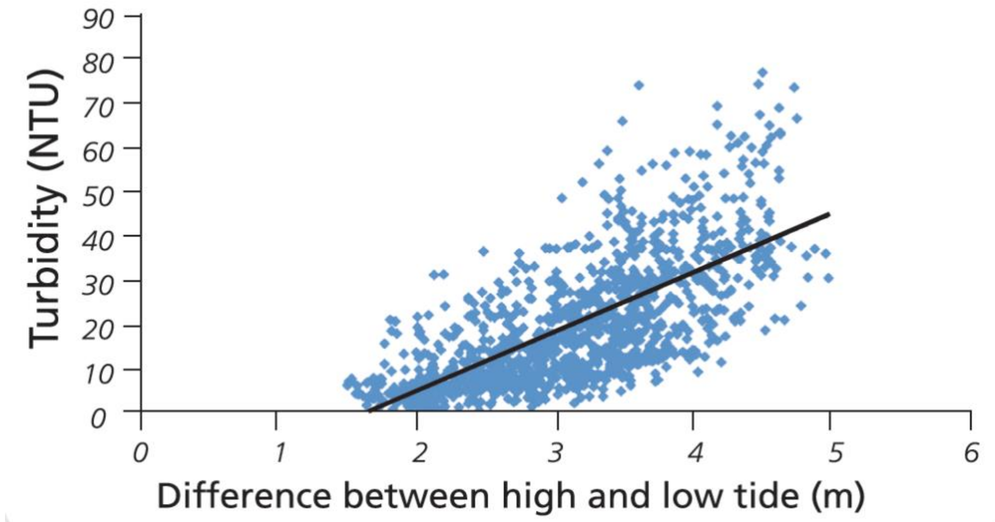


Figure 5.12: The relationship between tidal movement and turbidity in Gladstone Harbour (DEHP 2014, personal communication). NTU: nephelometric turbidity unit.

6. Guide to the infrastructure supporting the report card

6.1. Data Information Management System

The GHHP Data Information Management System (DIMS) is an essential infrastructure developed by Australian Institute of Marine Science which allows a range of users to store, calculate and visualise report card raw data and results (Figure 6.1). Given the large social, cultural, economic and environment monitoring datasets used to inform a report card, this system helps to manage the data systematically and consistently with a reliable backup system. The DIMS is also an information source for the website that can collate and analyse different data types and produce graphical outputs and tables.

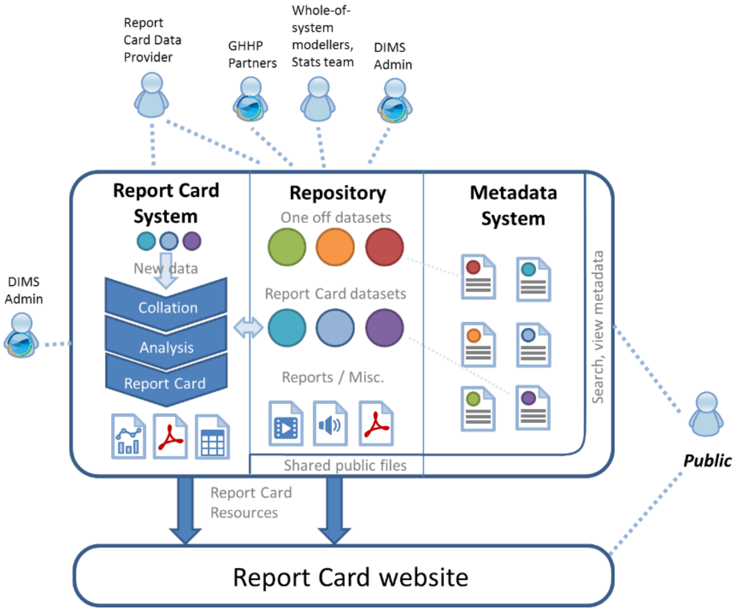


Figure 6.1: Schematic diagram of the links between the report card website and the Data Information Management System (DIMS) to illustrate major components and primary inputs and outputs (Diagram courtesy Australian Institute of Marine Science).

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 6.2).
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.

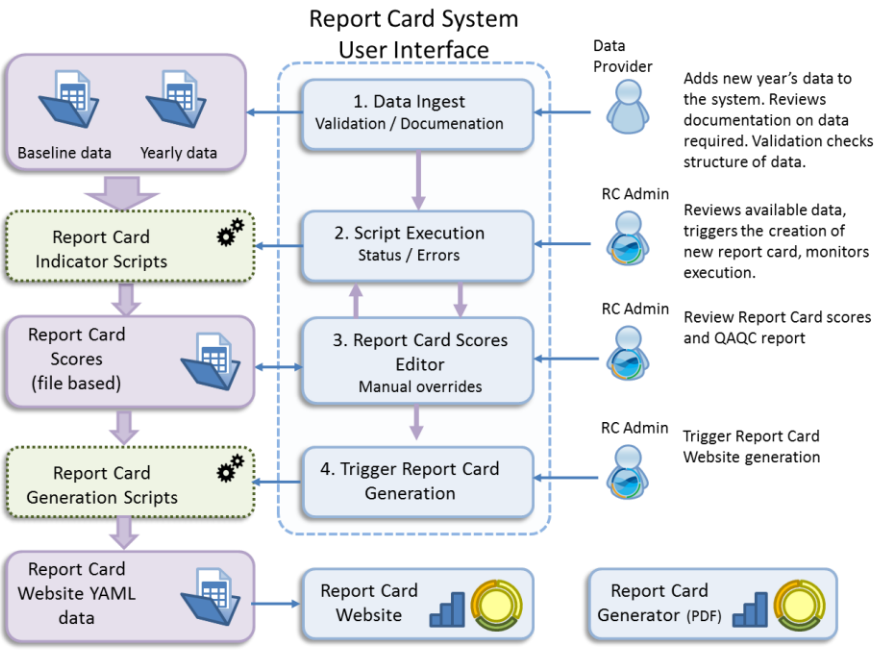


Figure 6.2: Schematic diagram of the report card system showing all data ingestion, script execution and report cards results generation modules (Diagram courtesy Australian Institute of Marine Science).

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 6.3). This approach makes the system highly portable and not dependent on Australian Institute of Marine Science systems. A core advantage of using the Amazon system for backup is its ability to scale-up the server capacity as the needs of the DIMS services expand over time.

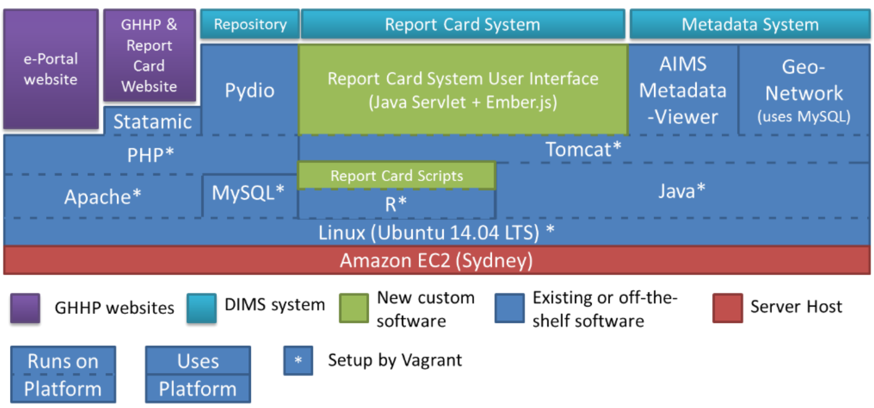


Figure 6.3: Software infrastructure underlying the Data Information Management System (DIMS) operations (Diagram courtesy Australian Institute of Marine Science).

7. Geographical scope

7.1. 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 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 developed the current 13 zones (Figure 7.1). These zones were also used to define regionally specific water quality objectives for the Capricorn Coast (DEHP, 2014).

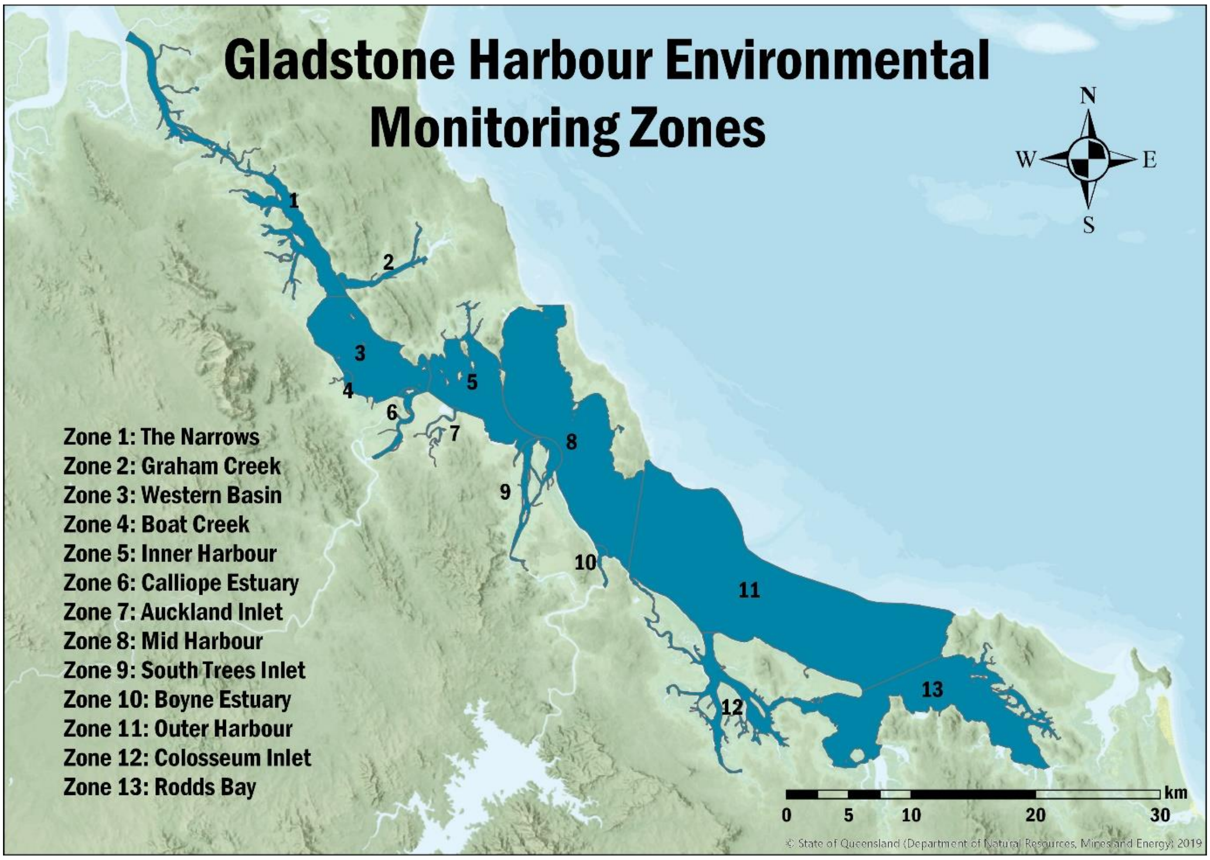


Figure 7.1: The 13 Gladstone Harbour zones for which environmental parameters were measured for the 2019 Gladstone Harbour Report Card.

Figure 7.2: 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 7.3: The Narrows photographed from the south with Keppel Bay in the distance.

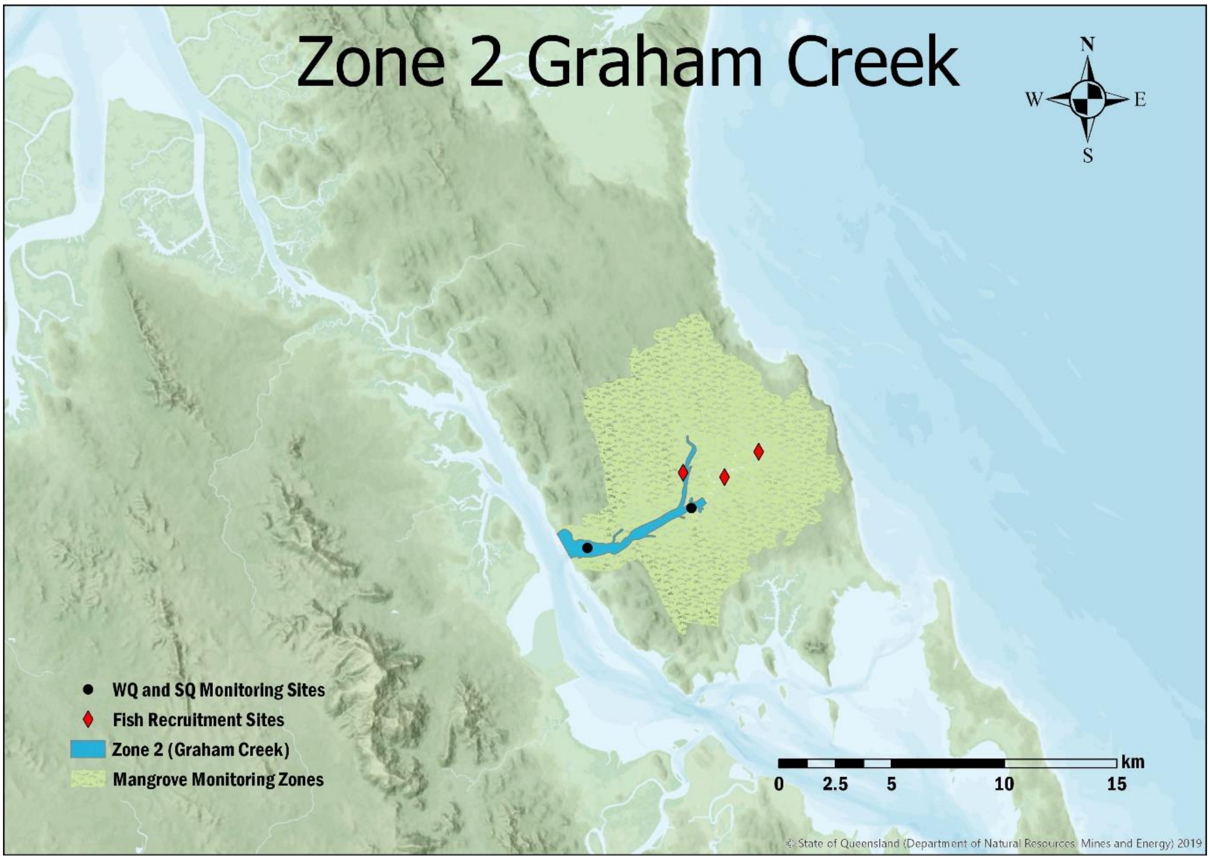


Figure 7.4: Habitat types and sampling sites in Graham Creek.

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 7.5: 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.

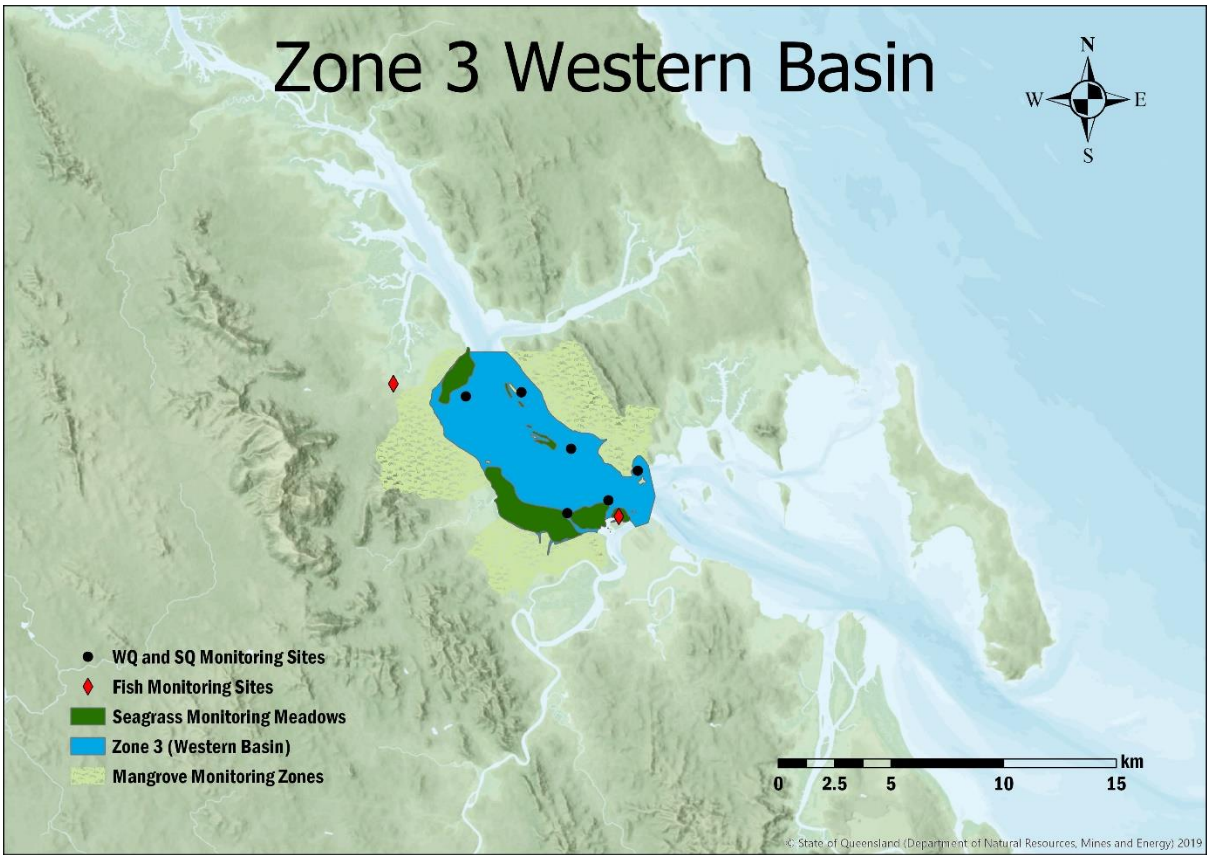


Figure 7.6: Habitat types and sampling sites in the Western Basin.

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

Zone area: 39.19 km^2
Fish health monitoring

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

Figure 7.7: The south-western corner of Curtis Island, showing two liquid natural gas plants in the foreground and the Western Basin in the distance.

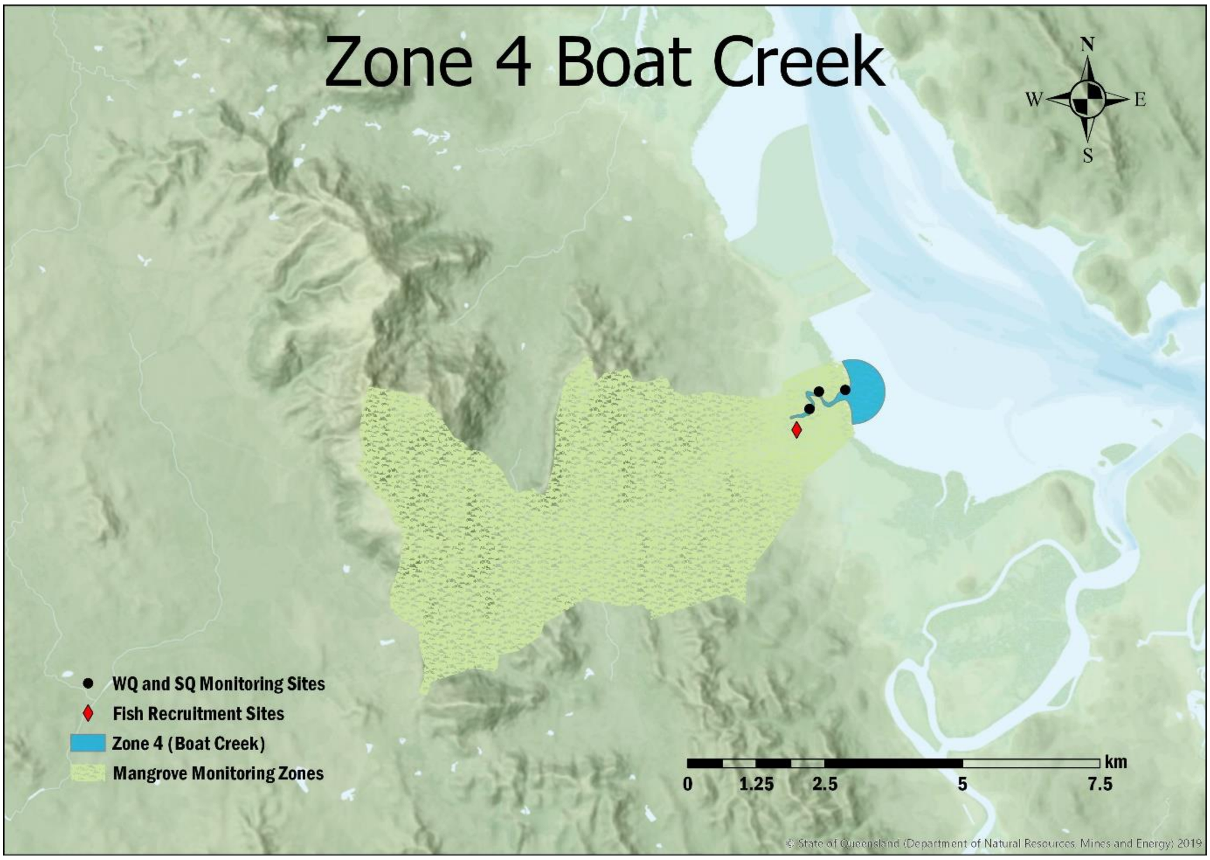


Figure 7.8: Habitat types and sampling sites in Boat Creek.

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 7.9: Inlet to Boat Creek photographed from the Western Basin.

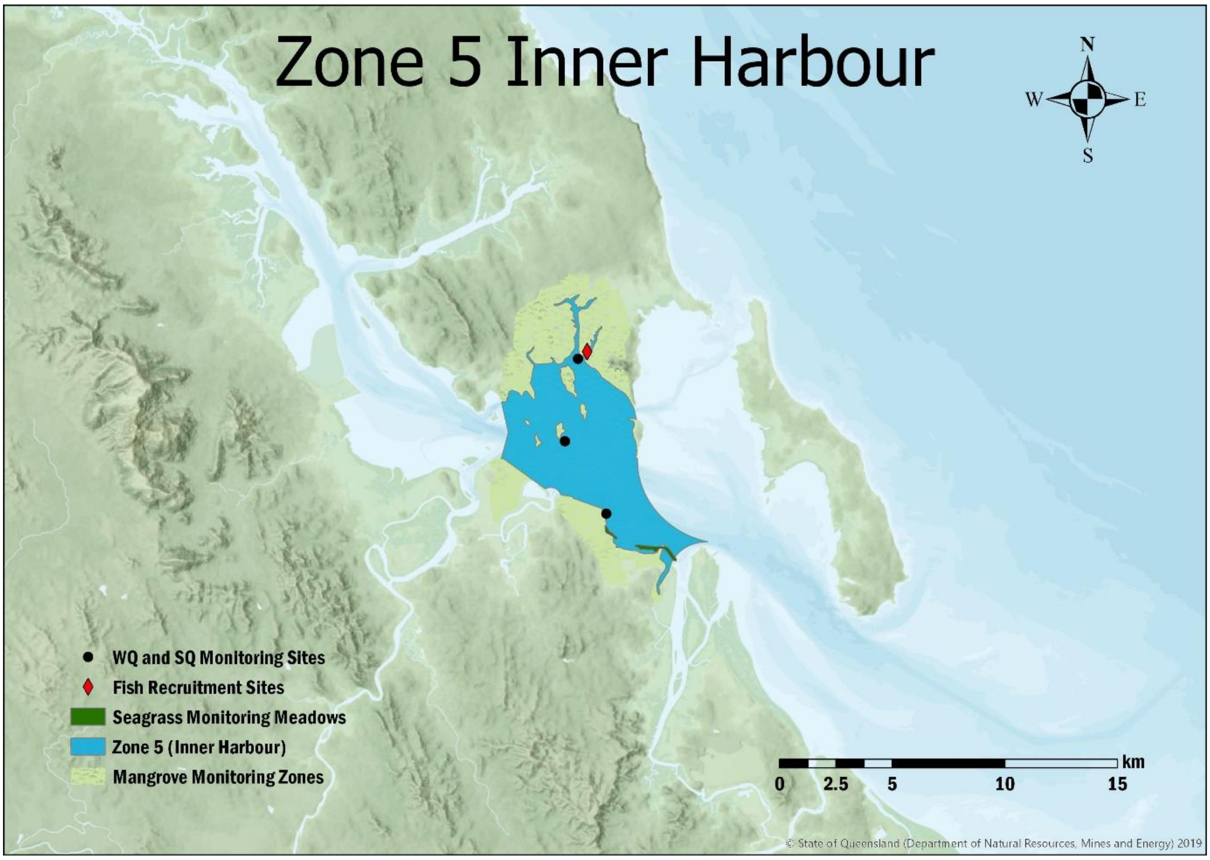


Figure 7.10: Habitat types and sampling sites in the Inner Harbour.

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.

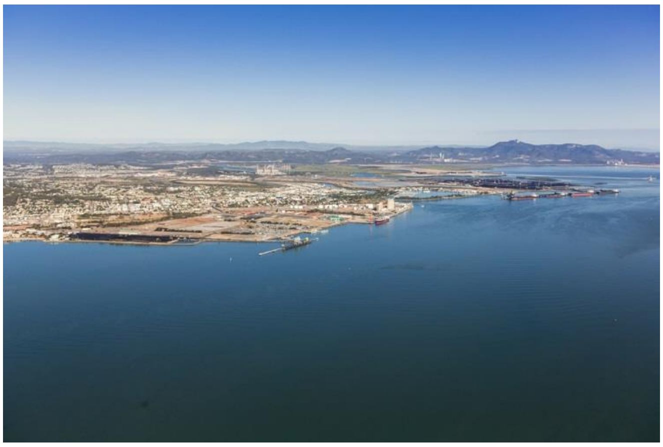


Figure 7.11: The Inner Harbour photographed from the north-east, with Auckland Point wharves and the City of Gladstone on the left and the RG Tanna coal loading facility on the right.

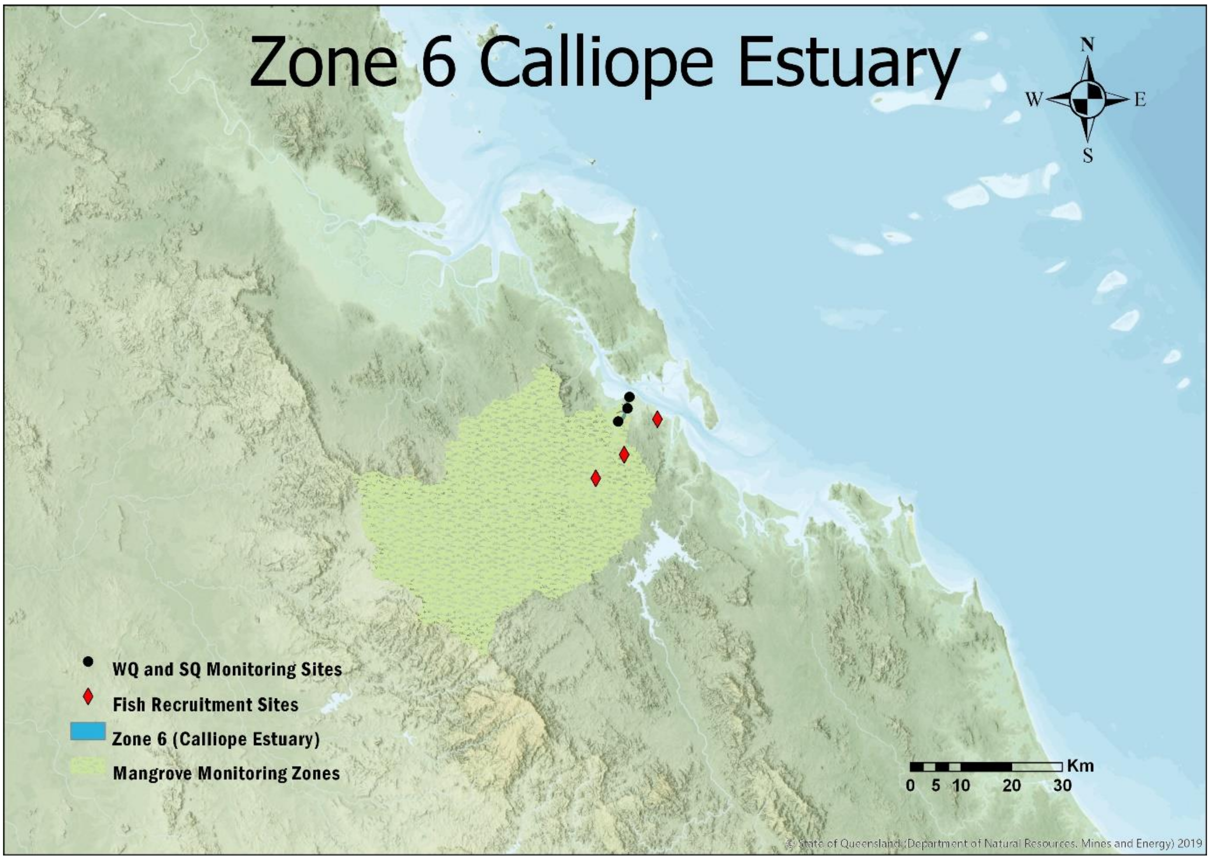


Figure 7.12: Habitat types and sampling sites in Calliope Estuary.

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

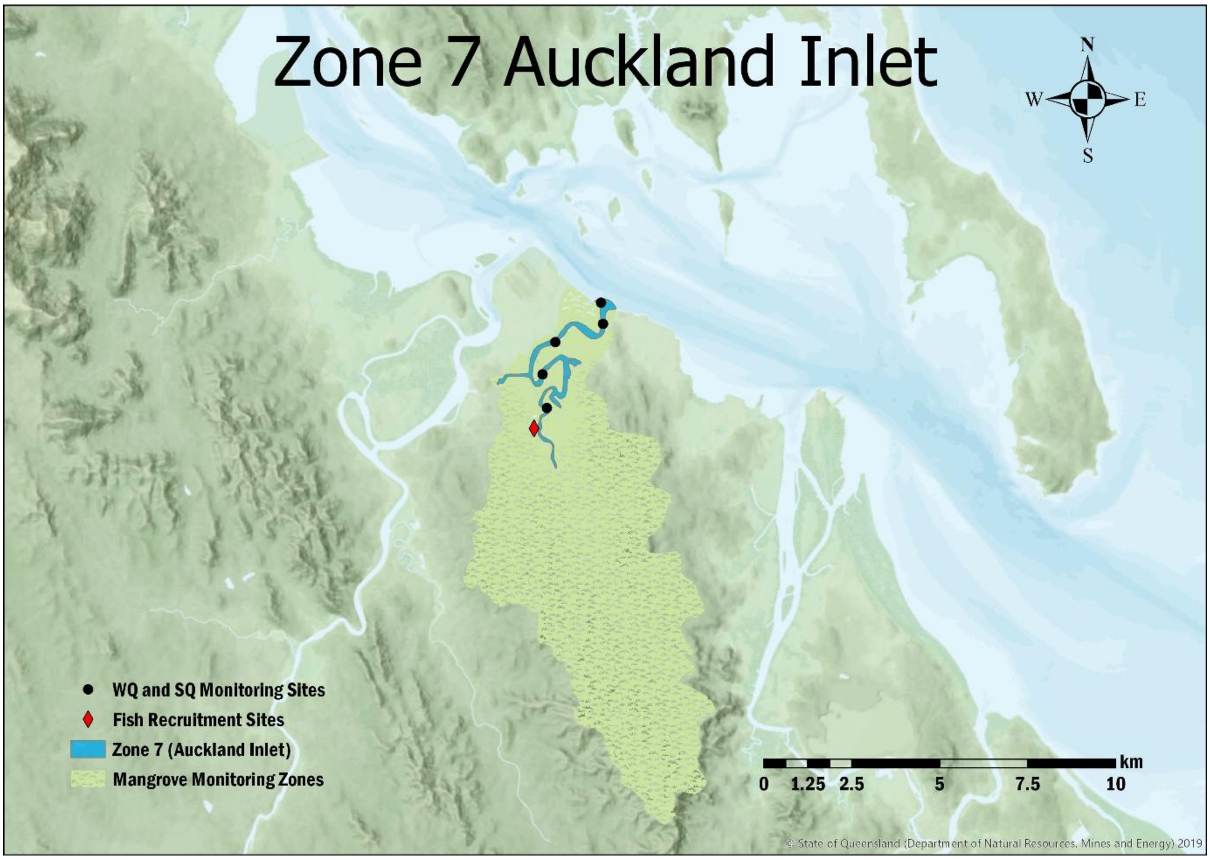


Figure 7.14: Habitat types and sampling sites in Auckland Inlet.

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

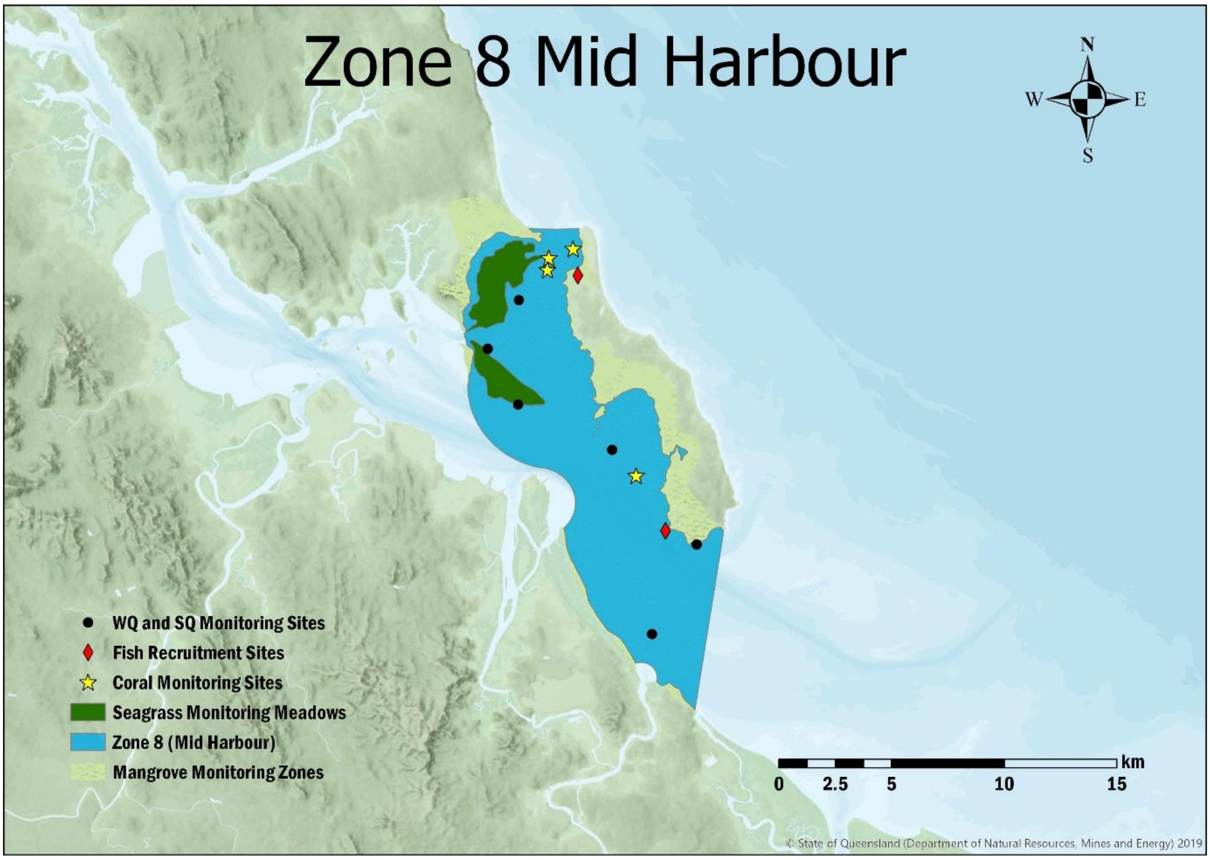


Figure 7.16: Habitat types and sampling sites in the Mid Harbour.

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.

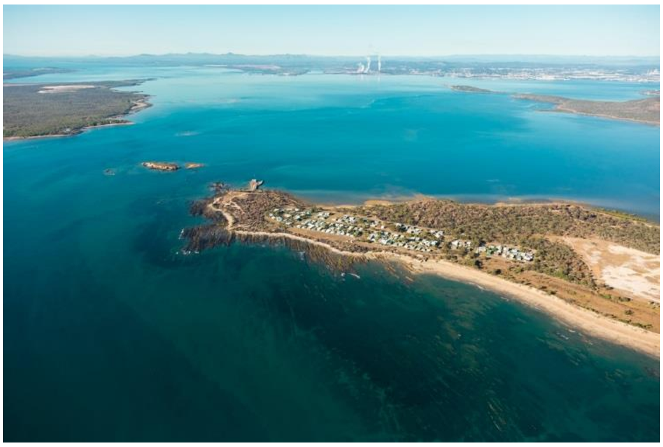


Figure 7.17: The Mid Harbour photographed from north-east. Curtis Island is in the foreground and the Inner Harbour is in the background.

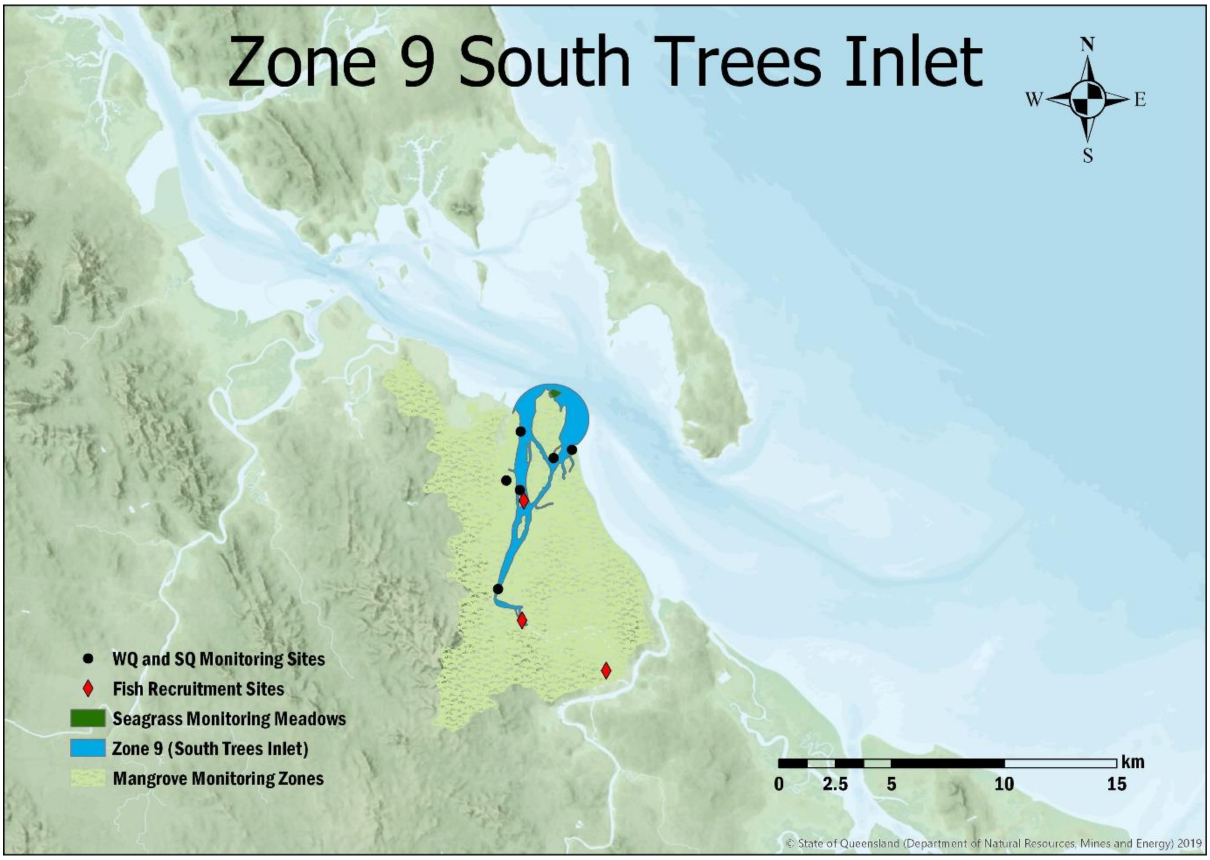


Figure 7.18: Habitat types and sampling sites in South Trees Inlet.

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

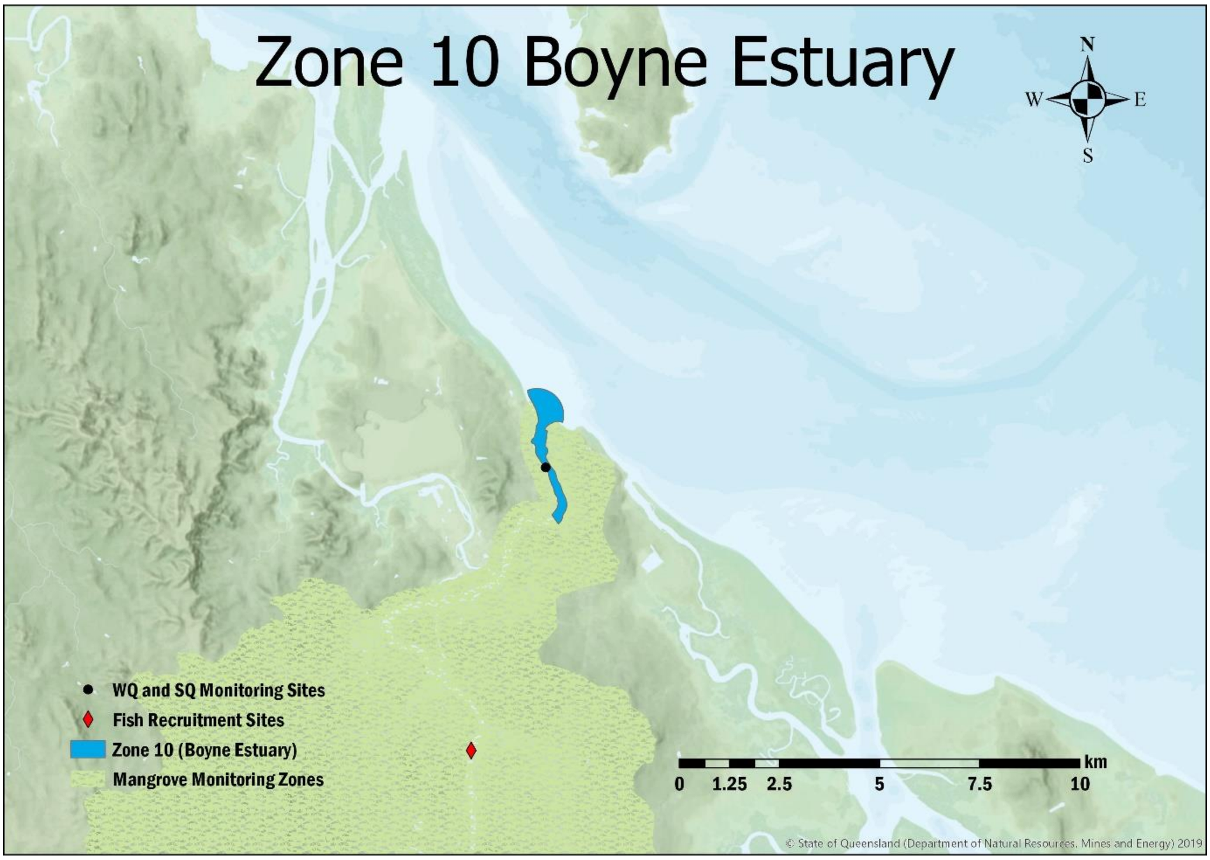


Figure 7.20: Habitat types and sampling sites in Boyne Estuary.

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

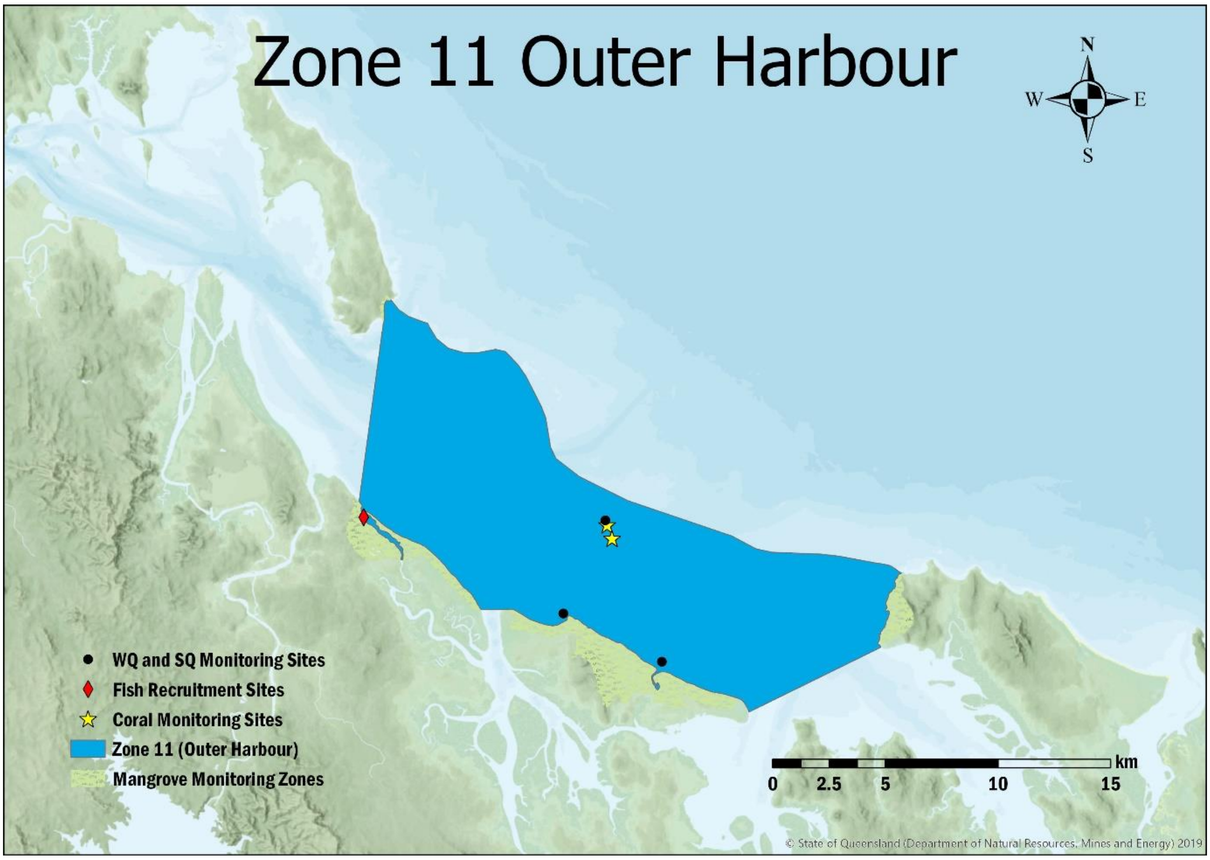


Figure 7.22: Habitat types and sampling sites in the Outer Harbour.

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.

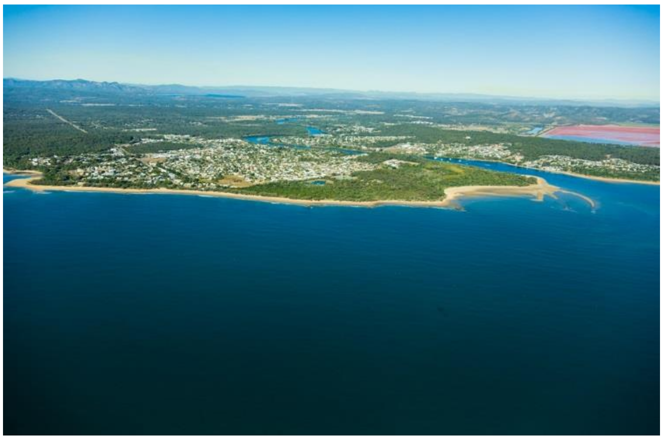


Figure 7.23: The Outer Harbour and Tannum Sands photographed from the north-east. Boyne Island and one of Gladstone's red mud (bauxite) dams are on the right.

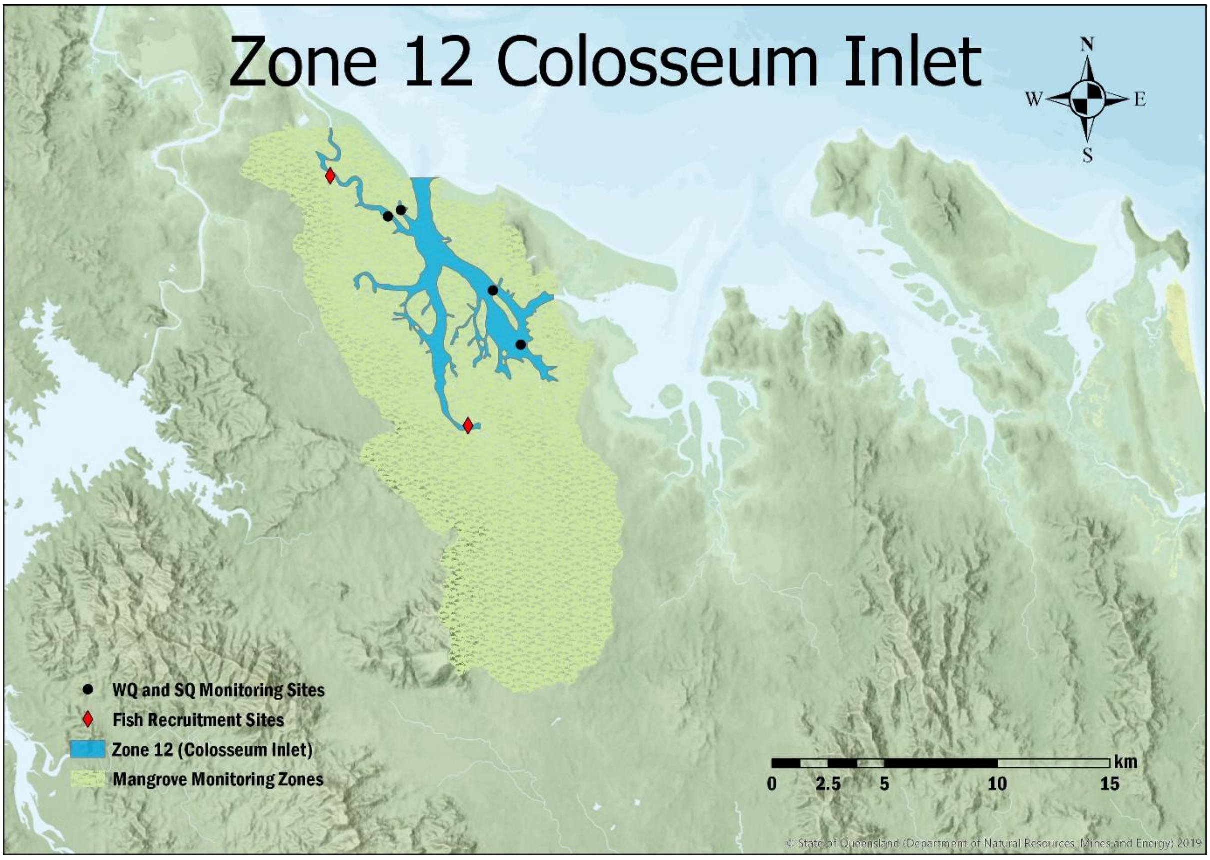


Figure 7.24: Habitat types and sampling sites in Colosseum Inlet.

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

Zone area: 18.98 km^2
Fish health monitoring

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

Figure 7.25: The northern entrance to Colosseum Inlet showing Wild Cattle Island on the right and Hummock Hill Island on the left.

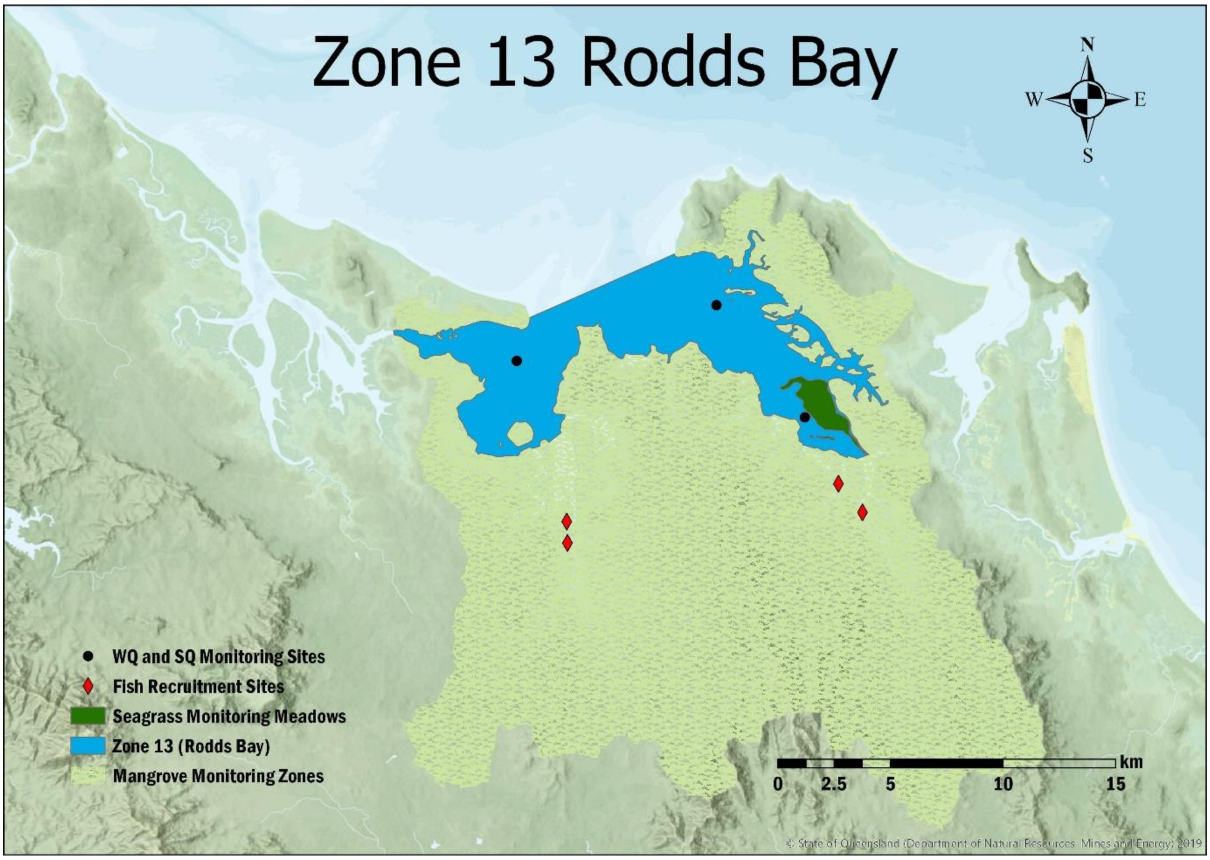


Figure 7.26: Habitat types and sampling sites in Rodds Bay.

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

7.2. 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 7.28). Hotel occupancy rates were based on the Gladstone Local Government Area (Figure 7.28). The Gladstone Ports Corporation provided the shipping data for the Port of Gladstone.

Commercial fishing data were collected from the area within the Queensland Fisheries S30 Grid (QFish S30) and nearby open coastal waters of Mackay (Grid O25) and Rockhampton/Yeppoon (Grid R29) (Figure 7.29).

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).

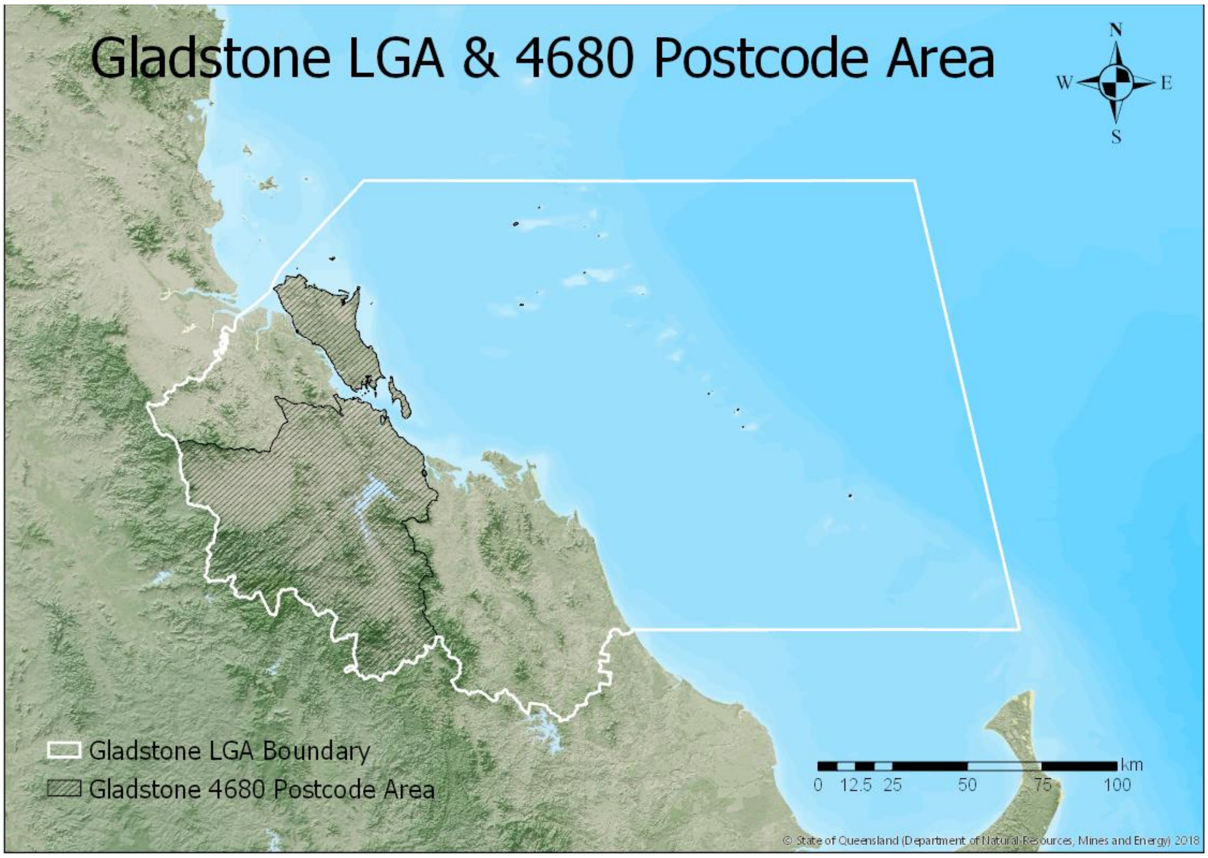


Figure 7.28: The Gladstone Region showing the mainland extent of the Gladstone Local Government Area and the Gladstone 4680 postcode area. Both were used to define areas from which some social, cultural, and economic data were collected.

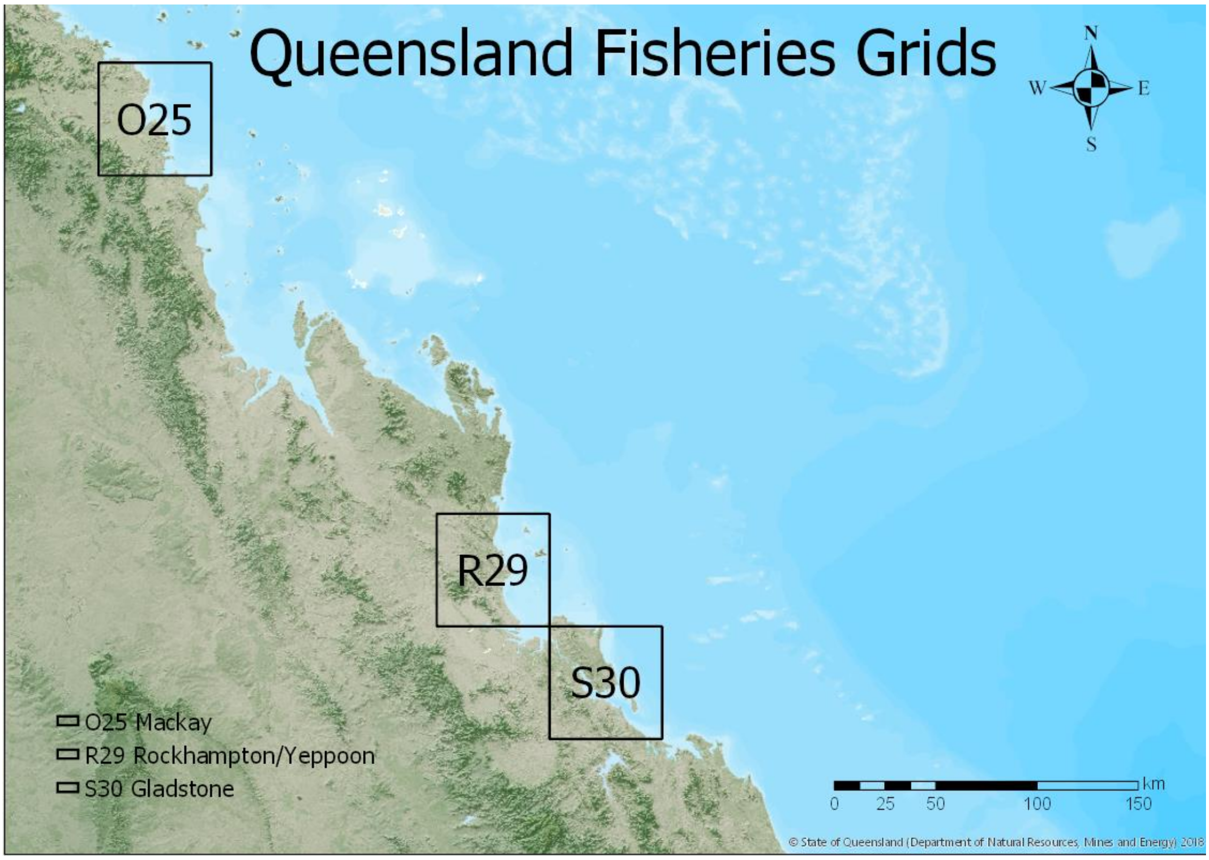


Figure 7.29: The Queensland Fisheries S30 (Gladstone), R29 (Rockhampton and Yeppoon) and O25 (Mackay) Grids. Data from these grids are used to calculate the commercial fishing indicator.

Data for the Indigenous cultural heritage indicator group were collected from four zones within the Gladstone Local Government Area boundary: The Narrows, Facing Island, Gladstone Central and Wild Cattle Creek (Figure 8.30).

The Narrows

The Narrows is the largest zone. It extends from Deception Creek to the Calliope River anabranch to the south and covers approximately 430 km^2 of the mainland and parts of Curtis Island. The score for the Narrows is based on six sites documented in 2016, three sites documented in 2017 and one site documented in 2018. The cultural locus site is a 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.

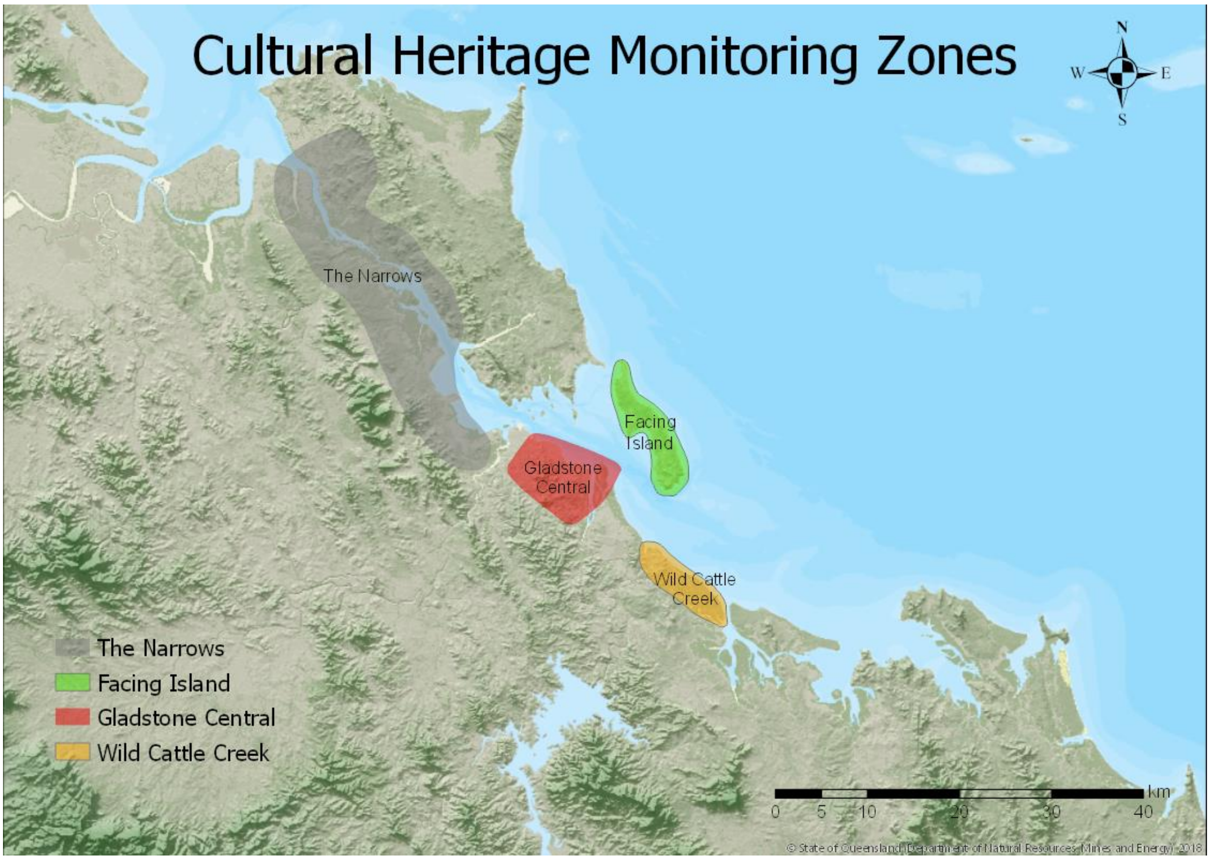


Figure 7.30: The four reporting zones from which data used to inform the Indigenous cultural heritage indicators for 2019 report card were collected.

8. Litter indicator

8.1. Litter

Litter is included as a formal indicator for the first time in the 2021 Gladstone Harbour Report Card. Results for the litter indicator are reported separately to the four components of harbour health (Environment, Social, Cultural and Economic) in the following sections.

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

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

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

The following methods are described as per that designed for the Dry Tropics Partnership for Healthy Waters Report Card (Whitehead, 2020) with filtering methods applied by UNSW as per Appendix 4.

8.2 Litter data collection

Seventy-nine clean-ups were recorded in the AMDI Database in 2020-21 in the Gladstone region. These clean-ups were one of two types: standardised 'ReefClean' sampling or non-standardised clean-ups.

8.2.1. Standardised 'ReefClean' sampling

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

8.2.2. *Non-standardised clean-ups*

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

8.3 Development of litter indicators and scoring

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

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

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

8.3.1. *Establishing the baseline*

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

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

8.3.2. *Litter index scoring*

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

The reference distribution was created by:

1. Calculating the number of items collected and number of hours spent cleaning.
2. Standardising catch per unit effort (CPUE) to an approximately normal distribution: $\log_e(\text{CPUE}) = \log_e(\text{items collected}) - \frac{1}{2}\log_e(\text{hours cleaned})$
3. $\log_e$(CPUE) was considered to index the individual sites within and between years.
4. Where sites were cleaned more than once in a year, $\log_e$(CPUE) was averaged over sites within a reporting year.
5. After ordering the $\log_e$(CPUE) values from smallest to largest, an empirical survivor function (ESF) was derived for the reference distribution (i.e. the probability of survival past time y which is independent of distributional assumptions.
6. The ESF was then created by plotting p (which equals [r + ½]/n), against $\log_e$(CPUE), with r the number of values greater in the sorted list, and n the total number of values.
7. Smoothing the ESF produced the working reference distribution and algorithm, which can be easily applied to present and future data.
8. The score corresponding to any $\log_e$(CPUE) value is then obtained using the smoothed ESF constrained to between zero and one.
9. From the smoothed ESF, the cut off values (‘very high pressure’ to ‘slight pressure’) can be determined (Figure 8.1; Table 8.1).

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

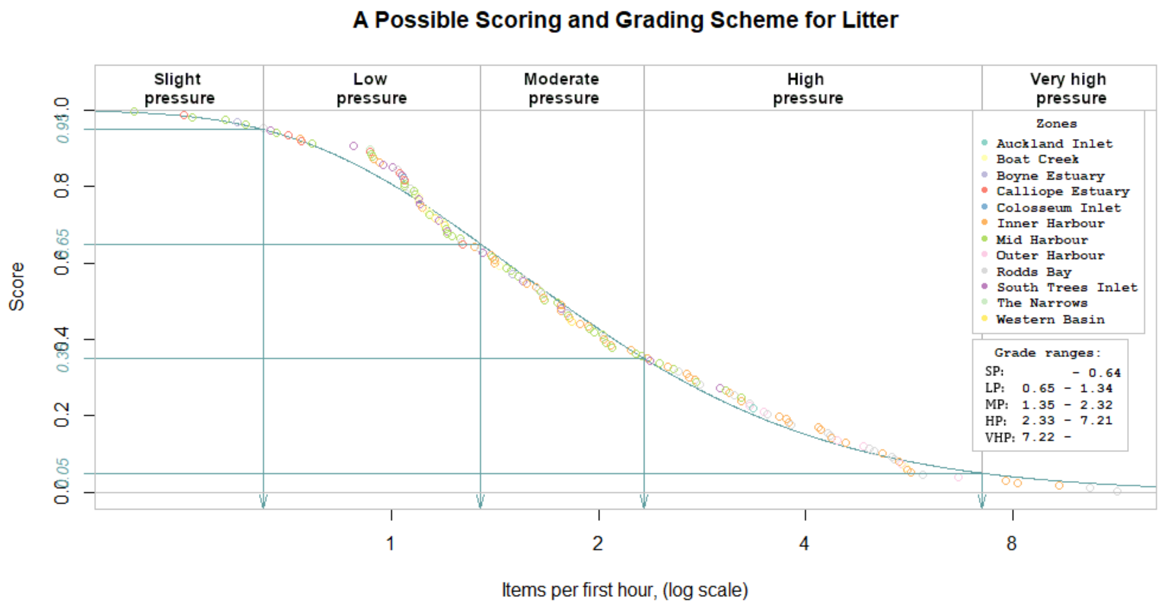


Figure 8.1: Transformation of standardised collection rates to scores and grades (CPUE vs scores).

8.3.3. Note about scoring used for litter indicator

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

Table 8.1: Scoring range guide to colours and textual context. Note that scoring range cut-offs are dependent on annual data distribution.

Colour	Context	Score range
(red)	Very high pressure	0 to 5
(orange)	High pressure	>5 to 35
(yellow)	Moderate pressure	>35 to 65
(light green)	Low pressure	>65 to 95
(dark green)	Slight pressure	>95

8.4. Litter results

For interpreting litter results, it is notable that score cut-off points are based on annual data distribution (see Figure 8.1) and refer to a scale of 'very high pressure' to 'slight pressure' (Table 8.1). Refer to Table 8.2 and Figure 8.2 for sites scores, with results summarised as:

- Scores ranged from 'high pressure' to 'low pressure' across the Gladstone region.
- The majority of clean-up sites in 2021 (n = 13 of 17) showed a lower mean total rubbish as compared to the four-year baseline, thus receiving a 'moderate pressure' score or better.
- Esplanade Beach (0.94) located in the Mid Harbour and Barney Point (0.79) located in the Inner Harbour were the highest scoring sites.
- Auckland Creek [Site ID 3402] (0.09), Lilley's Beach and Eastern Foreshore (both 0.10) were the poorest scoring sites. Lilley's Beach North End also showed high pressure (0.21). Lilley's Beach is a popular four-wheel driving area in the region, and it may therefore be impacted by higher levels of recreation.

Table 8.2: Litter scores by site across the Gladstone region for the 2021 Report Card. Note that scoring range cut-offs are dependent on annual data distribution.

Zone	Site Name	2021 Score
Western Basin	Fisherman's Landing*	0.61
Inner Harbour	Barney Point*	0.79
Auckland Creek	Auckland Creek (Site ID 2799)	0.50
	Auckland Creek (Site ID 3402)*	0.09
	Police Creek	0.48
Mid Harbour	Canoe Point (Site ID 796)*	0.48
	Esplanade Beach*	0.94
	North East Shore*	0.35
	Tannum Sands Main Beach	0.63
South Trees Inlet	Lilley's Beach North End*	0.21
Boyne Estuary	Canoe Point Conservation Area*	0.80
	Eastern Foreshore*	0.10
	Lilley's Beach*	0.10
Outer Harbour	Wild Cattle Creek Mouth, Tannum Sands	0.81
	Wild Cattle Island Beach NTH	0.57
Rodds Bay	The Esplanade Beach	0.73

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

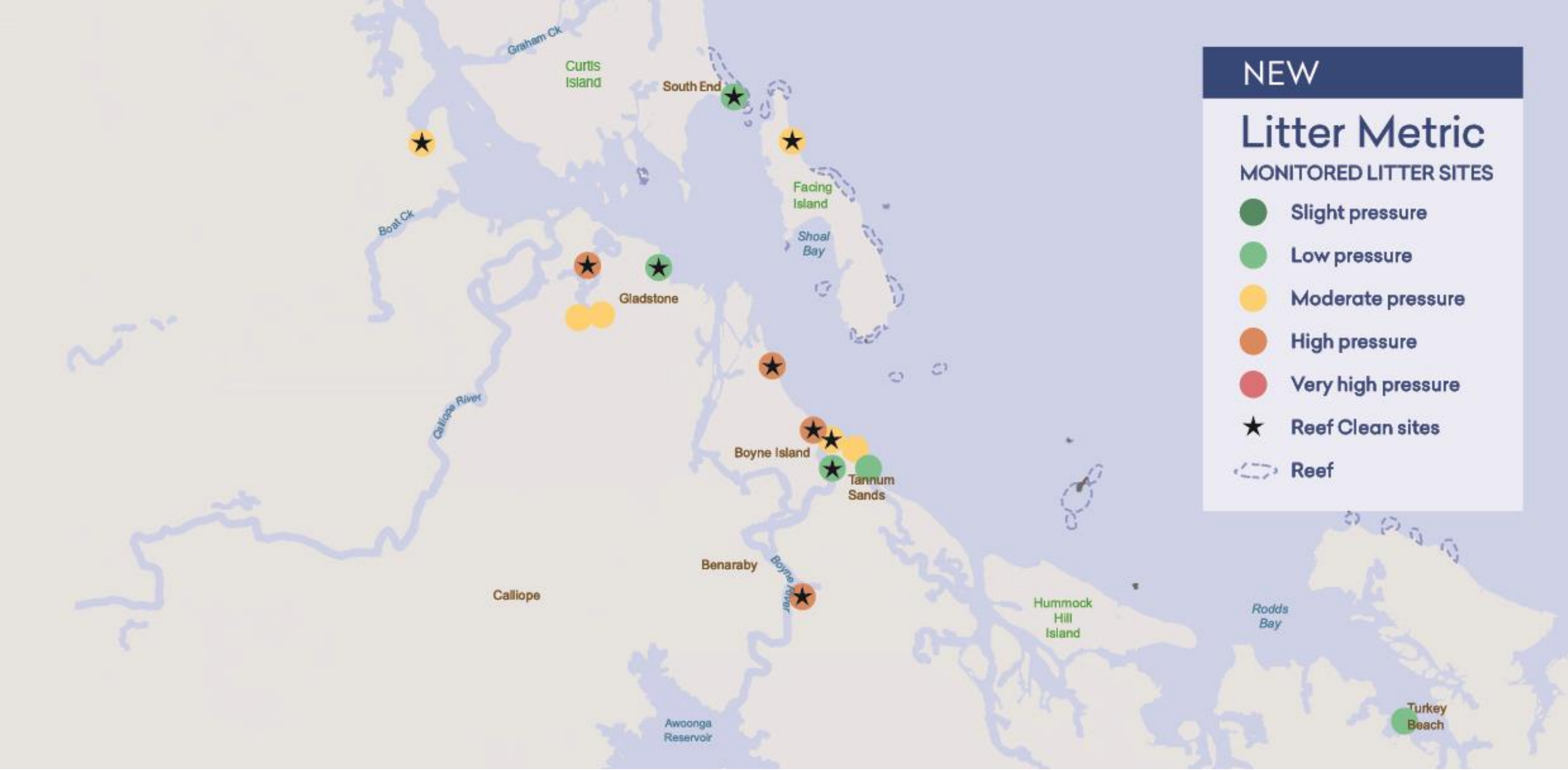


Figure 8.2: Map and grades of total litter at fourteen Gladstone Harbour sites in the 2020-21 reporting year.

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10. Glossary

Terms and acronyms	Definition
Asset	A particular feature of value to the GHHP for monitoring and reporting, e.g. seagrass meadows or swimmable beaches
Baseline	A point of reference from which to measure change
CATI	computer-assisted telephone interviewing
Component	The Gladstone Harbour Report Card will report on four components of harbour health: environmental, cultural, social and economic.
CPUE	Catch per unit effort
DIMS	Data Information Management System
Ecosystem health	An ecosystem that is stable and sustainable, maintaining its organisation and autonomy over time and its resilience to stress. Ecosystem health can be assessed using measures of resilience, vigour and organisation. Source: http://www.biodiversity.govt.nz/picture/doing/nzbs/glossary.html
Environmental indicators	Metrics derived from observation used to identify indirect drivers of environmental problems (e.g. population growth), direct pressures on the environment (e.g. overfishing), environmental condition (e.g. contaminant concentrations), broader impacts of environmental condition (e.g. health outcomes) or effectiveness of policy responses (de Sherbinin et al., 2013)
GHHP	Gladstone Healthy Harbour Partnership
Guidelines and criteria	Science-based numerical concentration limits or descriptive statements recommended to support a designated water use. Guidelines are not legally enforceable.
HAI	Health assessment index
Indicator	Numerical values that provide insight into the state of the environment, or human health etc. The environment is highly complex and indicators provide a simple, practical way to track changes in the state of the environment over time.
ISP	GHHP Independent Science Panel
Liveability	In this report, liveability is used to refer to a 'sense of place', quality of housing, provision of health services, recreation facilities, attraction of the urban environment and availability of services.
MC	GHHP Management Committee
Metadata	'data about data', the series of descriptors used to identify a particular dataset (e.g. author, date of creation, format of the data, location of the data points)
MMP	Marine Monitoring Program

Model/modelling	The creation of conceptual, graphical or mathematical models to describe, visualise or test abstract concepts and processes. Models help explain complex real-world interactions and add to our ability to understand how human actions impact on ecosystems. Models can be used to analyse scenarios to support decision making.
PCIMP	Port Curtis Integrated Monitoring Program
Physicochemical	Physical and chemical forces that influence the environment and the biodiversity and people within e.g. temperature, salinity
Point source	A single, identifiable localised source of a release e.g. a stormwater outlet

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

Appendix 1: Gladstone Healthy Harbour Partnership science projects

Project name and institution	Reports and publications
ISP001 Mapping and synthesis of data and monitoring in Gladstone Harbour Australian Institute of Marine Science	Llewellyn, L., Wakeford, M., & McIntosh, E. (2013). *Mapping and synthesis of data and monitoring in Gladstone Harbour*. A report to the Independent Science Panel of the Gladstone Healthy Harbour Partnership, August 2013. Australian Institute of Marine Science, Townsville. Download the final report for this project. View the GHHP ePortal
ISP002 Review of the use of report cards for monitoring ecosystem and waterway health	Connolly, R.M., Bunn, S., Campbell, M., Escher, B., Hunter, J., Maxwell, P., Page, T., Richmond, S., Rissik, D., Roiko, A., Smart, J., & Teasdale, P. (2013). *Review of the use of report cards for monitoring ecosystem and waterway health*. Report to: Gladstone Healthy Harbour Partnership, November 2013. Queensland, Australia. Download the final report for this project.
ISP003 Models and indicators of key ecological assets in Gladstone Harbour CSIRO Wealth from Oceans Flagship	Dambacher, J.M., Hodge, K.B., Babcock, R.C., Fulton, E.A., Apte, S.C., Plagányi, É.E., Warne, M., & Marshall, N.A. (2013). *Models and indicators of key ecological assets in Gladstone Harbour*. A report prepared for the Gladstone Healthy Harbour Partnership. CSIRO Wealth from Oceans Flagship, Hobart. 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.

Project name and institution	Reports and publications
ISP005 Piloting of social, cultural and economic data for the Gladstone Healthy Harbour Report Card CSIRO	Cannard, Windle, J., Tobin, R. (2016). *Final Report on the Status of Economic, Social and Selected Cultural Indicators for the Gladstone Harbour 2015 Report Card.* Report for the Gladstone Healthy Harbour Partnership. CSIRO Oceans and Atmosphere Flagship. Australia. Download the final report for this project. Windle, J., De Valck, J., Flint, N. & Star, M. (2016). *Final report on the status of the social, cultural ('sense of place') and economic components for the Gladstone Harbour 2016 Report Card.* Central Queensland University, Rockhampton. Download the final report for this project. Windle, J., De Valck, J., Flint, N. & Star, M. (2017). *Final report on the status of the social, cultural ('sense of place') and economic components for the Gladstone Harbour 2016 Report Card.* Central Queensland University, Rockhampton. Download the final report for this project. Windle, J., De Valck, J., Star M. and Flint, N. (2018) *Report on the status of the social, cultural ('sense of place') and economic components for the Gladstone Harbour 2018 Report Card*. Central Queensland University, Rockhampton. Download the final report for this project. De Valck, J., Star, M. & Flint, N. (2019) *Report on the status of the social, cultural ('sense of place') and economic components for the Gladstone Harbour 2019 Report Card.* Central Queensland University, Rockhampton. Download the final report for this project.
ISP006 Development of a Gladstone Harbour Model to support the Gladstone Healthy Harbour Report Card CSIRO Wealth from Oceans Flagship	Fulton, E.A. & van Putten, I. (2014) *Project ISP006: Milestone report December 2014*. CSIRO, Australia. Baird M., Margvelashvili N. (2015) *Receiving Water Quality & Sediment Scenarios:* Final Report. CSIRO, Australia. Fulton EA, Hutton T, van Putten IE, Lozano-Montes H and Gorton R (2017) *Gladstone Atlantis Model – Implementation and initial results*. Report to the Gladstone Healthy Harbour Partnership. CSIRO, Australia. Download the final report for this project.

Project name and institution	Reports and publications
ISP007 Development of connectivity indicators for the Gladstone Healthy Harbour Report Card CSIRO Wealth from Oceans Flagship, University of Queensland	Condie, S., Herzfeld, M., Andrewartha, J., Gorton, B., & Hock, K. (2015). *Project ISP007: Development of connectivity indicators for the 2014 Gladstone Harbour Report Card*. CSIRO Wealth from Oceans Flagship, Hobart, University of Queensland. Download the final report for this project. Condie, S., Herzfeld, M., Andrewartha, J., Gorton, B., & Hock, K. (2015). *Connectivity indicators for the 2015 Gladstone Harbour Report Card*. CSIRO Wealth from Oceans Flagship, Hobart, University of Queensland. Download the final report for this project. Condie, S., Herzfeld, M., Andrewartha, J., Gorton, B., & Hock, K. (2017). *Connectivity indicators for the 2016 Gladstone Harbour Report Card.* CSIRO Wealth from Oceans Flagship, Hobart, University of Queensland. Download the final report for this project Gorton, R., Condie, S. & Andrewartha, J. (2017) *2016-17 Connectivity indicators for the Gladstone Harbour Report Card*. CSIRO Oceans and Atmosphere, Hobart. Download the final report for this project.
ISP008 Provision of statistical support during the development of the Gladstone Harbour Report Card Queensland University of Technology	Johnson, S., Logan, M., Fox, D. & Mengersen, K. (2015). ISP008 Final Report (revised) *Provision of statistical support during the development of the Gladstone Harbour Report Card*. Queensland University of Technology, Brisbane.
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.* Australian Institute of Marine Science, Townsville. Download the final report for this project.
ISP009 Development of a Data Information Management System for the Gladstone Harbour Report Card monitoring data	Australian Institute of Marine Science. (2014). *Design and architecture of the Data Information Management System (DIMS) for the GHHP Report Card monitoring data*. Project ISP009. Australian Institute of Marine Science, Townsville.

Project name and institution	Reports and publications
ISP010 Statistical assessment of the fish indicators and score for the pilot report card Bill Venables, CSIRO Research Fellow	Venables, W.N. (2015). *GHHP Barramundi Recruitment Index Project Final Report*. Gladstone Healthy Harbour Partnership, Gladstone. Download the final report for this project.
ISP011 Seagrass indicators for the Gladstone Harbour Report Card Centre for Tropical Water & Aquatic Ecosystem Research	Bryant, C.V., Jarvis, J.C., York, P.H., & Rasheed, M.A. (2014). *Gladstone Healthy Harbour Partnership Pilot Report Card: ISP011 Seagrass Draft Report – October 2014*. 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, 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, James Cook University, Cairns. Download the final report for this project. Carter AB, Wells JN & Rasheed MA (2017). 'Gladstone Healthy Harbour Partnership 2017 Report Card, ISP011: Seagrass'. Centre for Tropical Water & Aquatic Ecosystem Research, James Cook University, Cairns. Download the final report for this project. Bryant CV, Carter AB, Chartrand KM, Wells JN & Rasheed MA (2018) *Gladstone Healthy Harbour Partnership 2018 Report Card, ISP011: Seagrass.* Centre for Tropical Water & Aquatic Ecosystem Research, James Cook University, Cairns. Download the final report for this project. Carter AB, Chartrand KM, Wells JN & Rasheed MA (2019) *Gladstone Healthy Harbour Partnership 2019 Report Card, ISP011: Seagrass*. Centre for Tropical Water & Aquatic Ecosystems Research, James Cook University, Cairns. Download the final report for this project.

Project name and institution	**Reports and publications**
ISP011 Seagrass indicators for the Gladstone Harbour Report Card Centre for Tropical Water & Aquatic Ecosystem Research	Carter A.B., Bryant C.V., Smith, T., Rasheed M.A. (2020) *Gladstone Healthy Harbour Partnership 2020 Report Card Summary, ISP011: Seagrass*. Centre for Tropical Water & Aquatic Ecosystem Research, Cairns. Download the final summary report for this project. Smith, T., Carter A.B. & Rasheed M.A., (2021) *Gladstone Healthy Harbour Partnership 2020 Report Card Summary, ISP011: Seagrass*. Centre for Tropical Water & Aquatic Ecosystem Research, Cairns. Download the final summary report for this project.
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. Download the final report for this project. Terra Rossa Consulting. (2017). *Developing Cultural Heritage Indicators for the Gladstone Healthy Harbour Partnership: Project ISP012 Final Report.* Terra Rossa Consulting, Perth. Download the final report for this project. Terra Rosa Consulting (2018) *Final Report: ISP012-2018: Indigenous Cultural Heritage Indicators for the Gladstone Harbour Report Card.* Terra Rosa Consulting, Western Australia. Download the final report for this project.
ISP013-2015 Fish recruitment study Infofish Australia and Dr Bill Venables	Sawynok, B., Parsons, W., Mitchell J., & Sawynok, S. (2015) *Gladstone fish recruitment 2015.* Report for the Gladstone Healthy Harbour Partnership, Gladstone. Venables, W.N. (2015). *GHHP barramundi recruitment index project final report*. Gladstone Health Harbour Partnership, Gladstone. Download the final report for this project.

Project name and institution	Reports and publications
ISP013-2015 Fish recruitment study Infofish Australia and Dr Bill Venables	Sawynok, B. & Venables, B. (2016) *Developing a fish recruitment indicator for the Gladstone Harbour Report Card using data derived from castnet sampling*. Report for the Gladstone Healthy Harbour Partnership, Gladstone. Download the final report for this project. Sawynok, B. & Venables, B. (2017) *Fish recruitment indicators for the Gladstone Harbour Report Card using data derived from castnet sampling 2017.* Report for the Gladstone Healthy Harbour Partnership, Gladstone. Download the final report for this project. Sawynok, B. & Venables, B. (2018) *Fish recruitment indicators for the Gladstone Harbour Report Card using data derived from castnet sampling 2018.* Report for the Gladstone Healthy Harbour Partnership, Gladstone. Download the final report for this project. Sawynok, B. & Sawynok, S. (2019) *Fish recruitment indicators for the Gladstone Harbour Report Card using data derived from castnet sampling 2019.* Report for the Gladstone Healthy Harbour Partnership, Gladstone. Download the final report for this project. Sawynok, B. & Sawynok, S. (2020) *Fish recruitment indicators for the Gladstone Harbour Report Card using data derived from castnet sampling 2020.* Report for the Gladstone Healthy Harbour Partnership, Gladstone. Download the final report for this project. Sawynok, B. & Sawynok, S. (2021) *Fish recruitment indicators for the Gladstone Harbour Report Card using data derived from castnet sampling 2021.* Report for the Gladstone Healthy Harbour Partnership, Gladstone. Download the final report for this project.

Project name and institution	Reports and publications
ISP014 Coral indicator pilot project Australian Institute of Marine Science	Thompson, A., Costello, P., & Davidson, J. (2015). *Development of coral indicators for the Gladstone Harbour Report Card, ISP014: Coral*. Australian Institute of Marine Science, Townsville. Download the report for this project. Thompson, A., Costello, P., & Davidson, J. (2016). *Development of coral indicators for the Gladstone Harbour Report Card, ISP014: Coral*. Australian Institute of Marine Science, Townsville. Download the final report for this project. Costello P., Thompson A., Davidson J. (2017) *Coral Indicators for the 2017 Gladstone Harbour Report Card 2017: ISP014.* Report prepared for Gladstone Healthy Harbour Partnership. Australian Institute of Marine Science, Townsville. For this project for this project. Costello P., Thompson A, Davidson J. (2018) *Coral Indicators for the 2018 Gladstone Harbour Report Card 2018: ISP014.* Report prepared for Gladstone Healthy Harbour Partnership. Australian Institute of Marine Science, Townsville. Download the final report for this project. Costello P., Thompson A., Davidson J. (2019) *Coral Indicators for the 2019 Gladstone Harbour Report Card 2019: ISP014.* Report prepared for Gladstone Healthy Harbour Partnership. Australian Institute of Marine Science, Townsville. Download the final report for this project. Costello P., Thompson A., Davidson J. (2020) *Coral Indicators for the 2020 Gladstone Harbour Report Card 2020: ISP014.* Report prepared for Gladstone Healthy Harbour Partnership. Australian Institute of Marine Science, Townsville. Download the final report for this project. Thompson A., Costello P. & Davidson J. (2021) *Coral Indicators for the 2021 Gladstone Harbour Report Card 2021: ISP014.* Report prepared for Gladstone Healthy Harbour Partnership. Australian Institute of Marine Science, Townsville. Download the final report for this project.

Project name and institution	Reports and publications
ISP015 Developing an indicator for mud crab (*Scylla serrata*) abundance in Gladstone Harbour	Brown, I.W. (2015). *Comments on Gladstone Healthy Harbour Partnership (GHHP) proposed Project ISP015: Developing an indicator for mud crab Scylla serrata abundance in Gladstone Harbour*. Report prepared for the Gladstone Healthy Harbour Partnership, Gladstone.
ISP015-2017 Developing Mud Crab Indicators for the Gladstone Harbour Report Card	Flint, N., Anastasi, A., De Valck, J., Chua, E., Rose, A., and Jackson, E.L. (2017). *Developing mud crab indicators for the Gladstone Harbour Report Card.* Report to the Gladstone Healthy Harbour Partnership. Central Queensland University, Rockhampton. Download the final report for this project. Flint, N., Anastasi, A., De Valck, J., and Jackson, E.L. (2018) *Mud Crab Indicators for the Gladstone Harbour Report Card.* Report to the Gladstone Healthy Harbour Partnership. Central Queensland University, Rockhampton. Download the final report for this project. Flint, N., De Valck, J., Anastasi, A., and Jackson, E.L. (2019). Mud crab indicators for the Gladstone Harbour Report Card. Report to the Gladstone Healthy Harbour Partnership. Central Queensland University, Rockhampton. Download the final report for this project. Flint, N., De Valck, J., Anastasi, A., and Jackson, E.L. (2020). Mud crab indicators for the Gladstone Harbour Report Card. Report to the Gladstone Healthy Harbour Partnership. Central Queensland University, Rockhampton. Download the final report for this project. Flint, N., De Valck, J. & Anastasi, A., (2021). Mud crab indicators for the Gladstone Harbour Report Card. Report to the Gladstone Healthy Harbour Partnership. Central Queensland University, Rockhampton. Download the final report for this project.
ISP016 **GHHP Gladstone fish health research program (a)** Gladstone Harbour Healthy Partnership, Fisheries Research and Development Canberra, AusVet Animal Health Services.	Fisheries Research Development Corporation. (2015). *Development of the Gladstone Healthy Harbour Partnership Fish Health Research Program.* FRDC, Canberra. Download the final report for this project

Project name and institution	Reports and publications
ISP016 **GHHP Gladstone fish health research program (b)** Australian Institute of Marine Sciences	Kroon, F.J., Streten, C., & Harries, S.J. (2016) *The use of biomarkers in fish health assessment worldwide and their potential use in Gladstone Harbour.* Australian Institute of Marine Science, Townsville. Download the final report for this project.
ISP016 **GHHP Gladstone fish health research program (c)** Infofish Australia Pty Ltd, Rockhampton.	Sawynok W, Sawynok S and Dunlop A (2018) *New Tools to Assess Visual Fish Health.* FRDC report, Infofish Australia Pty Ltd, Rockhampton. Download the final report for this project
ISP017 Additional PAH monitoring 2015 Port Curtis Integrated Monitoring Program	The results of the PAH sediment sampling were included in the 2015 Gladstone Harbour Report Card and supporting technical report and website.
ISP018 **Development of mangrove indicators for the Gladstone Harbour Report Card** JCU/TropWATER	Duke N.C., and Mackenzie J. (2018) *Project ISP018: Development of mangrove indicators for the Gladstone Harbour Report Card.* Report to Gladstone Healthy Harbour Partnership by TropWATER Centre. James Cook University, Townsville. Download the final report for this project. Duke N.C., and Mackenzie J. (2019) *Project ISP018-2019: Development of mangrove indicators for the 2019 Gladstone Harbour Report Card*. Report to Gladstone Healthy Harbour Partnership by TropWATER Centre. James Cook University, Townsville. Download the final report for this project.
ISP019 Coral coring in Gladstone Harbour to enable a comparison of pre- and post-industrial eras in Gladstone Harbour Australian Institute of Marine Science	Cantin, N.E., Fallon, S., Wu, Y. & Lough, J.M. (2018) *Project ISP019: Calcification and geochemical signatures of industrial development of the Gladstone Harbour from century old coral skeletons*. Report prepared for Gladstone Healthy Harbour Partnership. Australian Institute of Marine Science, Townsville, Qld. Download the final report for this project.
ISP020 Development of R scripts to calculate, aggregate and integrate cultural heritage indicators with Bayesian model and Data Information Management System	Pascoe, S. & Venables, B. (2016). *Draft report on the Development of R scripts to calculate, aggregate and integrate Cultural heritage indicators with GHHP Data Information Management System*. CSIRO, Brisbane.

Project name and institution	Reports and publications
ISP023a Development of fish health indicators for the 2019 Gladstone harbour Report Card.	Flint, N., Irving, A., Anastasi, A., De Valck, J. and Jackson, E.L. (2019). *A fish health indicator for the 2019 Gladstone Harbour Report Card*, *final report to the Gladstone Healthy Harbour Partnership*. Central Queensland University, Rockhampton. Download the final report for this project. Flint, N., Irving, A., Anastasi, A., De Valck, J. and Jackson, E.L. (2020) *A Fish Health Indicator for the 2020 Gladstone Harbour Report Card, final report to the Gladstone Healthy Harbour Partnership*. Central Queensland University, Rockhampton. Download the final report for this project. Flint, N., Irving, A., Anastasi, A., & De Valck, J. (2021) *A Fish Health Indicator for the 2021 Gladstone Harbour Report Card: Project Report ISP023-2021.* Central Queensland University, Rockhampton. Download the final report for this project.
ISP023b Development of visual fish health indicators using machine learning for the 2019 Gladstone harbour Report Card.	Sawynock, S., Sawynock, B., Dunlop, A. & Sawynock, P. (2019) *Visual fish health indicators for the Gladstone Harbour Report Card 2019*. Infofish Australia Pty Ltd, Rockhampton Queensland. Download the final report for this project. Sawynock, S., Sawynock, B., Dunlop, A. & Sawynock, P. (2019) *Visual fish health indicators for the Gladstone Harbour Report Card 2019*. Infofish Australia Pty Ltd, Rockhampton Queensland. Download the final report for this project. Sawynock, S., Sawynock, B., Dunlop, A. & Sawynock, P. (2020) *Visual fish health indicators for the Gladstone Harbour Report Card 2020*. Infofish Australia Pty Ltd, Rockhampton Queensland. Add link for this project. Sawynock, S., Sawynock, B., Reid, J. & Sawynock, P. (2021) *Visual fish health indicators for the Gladstone Harbour Report Card 2021*. Infofish Australia Pty Ltd, Rockhampton Queensland. Download the final report for this project.

Project name and institution	Reports and publications
Water and Sediment Quality Reports	Schultz, M., Uthpala, P., & Hansler, M. (2019) *Water and Sediment Quality Indicators for the Gladstone Harbour Report Card 2017.* Gladstone Healthy Harbour Partnership, Gladstone. Download the final report for this project. Hansler, M., Schultz, M. and Uthpala, P. (2020) *Water and Sediment Quality Indicators for the Gladstone Harbour Report Card 2018.* Gladstone Healthy Harbour Partnership, Gladstone. Download the final report for this project.

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

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

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

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

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

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

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

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

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

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

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

By: Jordan Gacutan (UNSW, Sydney)

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

On behalf of: Tangaroa Blue Foundation and UNSW, Sydney

Summary

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

Rationale:

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

Figures

Tables

Description

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

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

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

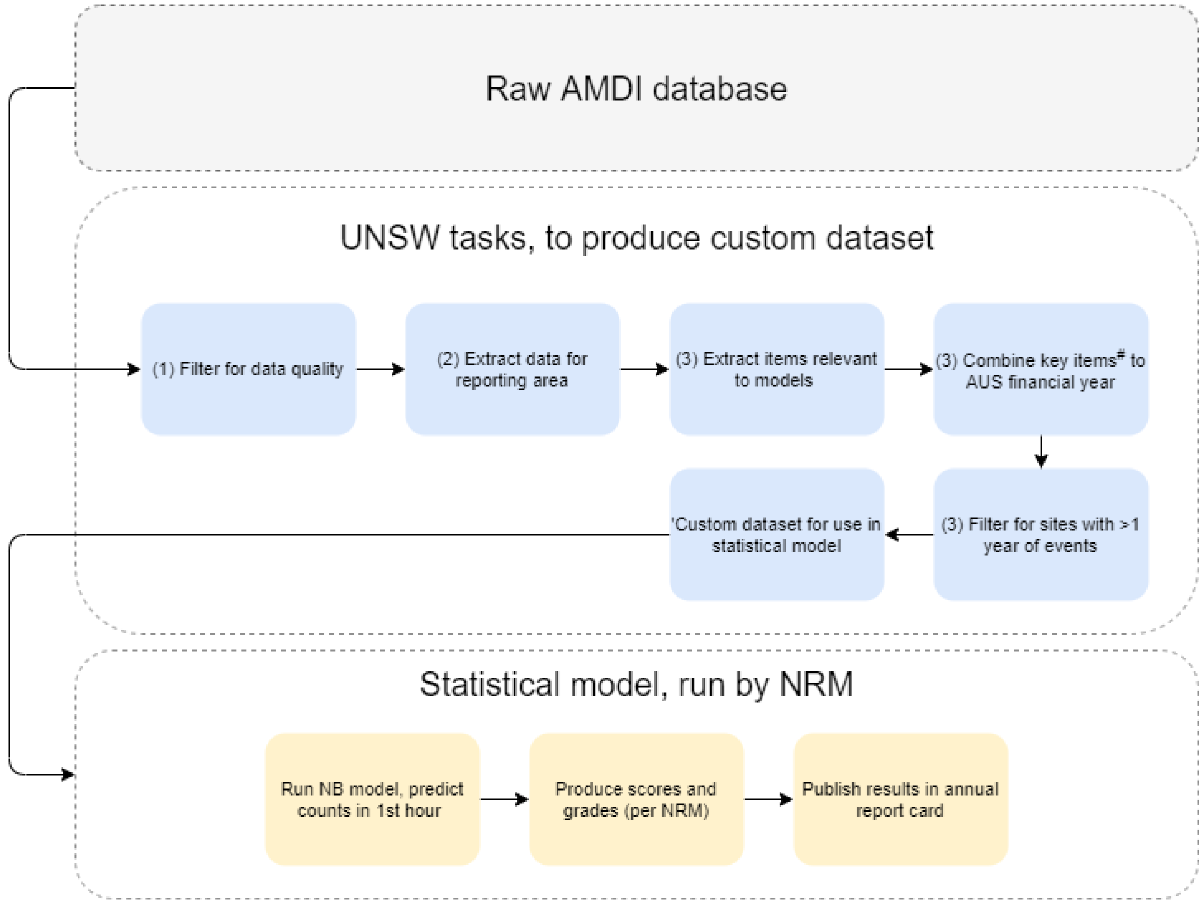

Figure A1. Data pipeline for project, to extract key items# (plastic bags, plastic bottles, single-use cutlery, and cigarettes) from the Australian Marine Debris Initiative (AMDI) database for annual use in a statistical model, for production of litter scores and grades. NRM = Natural Resource Management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

Filter for data quality

Filtering for data quality is taken from methods and related scripts of the publication, 'Continental trends in marine debris revealed by a decade of citizen science' (*in prep*). The filters used are presented in Table 1. As the work in is in preparation, scripts are currently unavailable.

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

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

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

Extract data for reporting areas

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

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

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

Manipulate extracted data for use in model

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

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

The resulting data was then provided to each NRM.

Appendix 5: Gladstone litter clean-up site data from 2014 to 2021

Table A3: Gladstone litter clean-up sites from 2014 to 2021 (financial years (FYs)) sourced from the Australian Marine Debris Initiative (AMDI) Database. Volunteer (vol.) number and hours are detailed for sites that were surveyed in 2020-21. Volunteer hours are presented as the number of volunteers x the number of hours done by each volunteer. The number of times a particular site was surveyed in past is represented by the corresponding number. Note, FY is displayed as per 2021 = 2020-21. *ReefClean survey sites (sites were surveyed using unstandardised methodology before the ReefClean program was launched in early 2019).

		2021 Survey			Past Surveys (no.)						
Zone	**Site**	**Vol. No.**	**Vol. Hours**	**No. of surveys**	**2020**	**2019**	**2018**	**2017**	**2016**	**2015**	**2014**
The Narrows	Phillipies Landing Rd						4				
Western Basin	**Fisherman's Landing***	**3**	**2.5**	**1**	3	6	6	1	5	2	
Boat Creek	Boat Creek Gladstone*				1		2				
	Yarwun					1					
Inner Harbour	**Barney Point***	**50**	**11.2**	**9**	13	12	6	5			
	Gladstone CBD	**83**	**97.5**	**24**	4						
	Hopper Road				4						
	Reg Tanna Park	**19**	**10**	**2**		1					
	Urban Surrounds	**34**	**18**	**4**							
	Mark Fulton Drive Channel*				1						
Calliope Estuary	Calliope River					3					
Auckland Inlet	Albion Park Mangroves				1						
	Auckland Creek (Site ID 2185)				1	14	1	1			
	Auckland Creek (Site ID 2798)					1	1				
	Auckland Creek (Site ID 2799)	**1**	**0.5**	**1**	2	1					
	Auckland Creek (Site ID 3440)				1						
	Briffany Creek							1	2		
	Briffney Creek					1	1				
	Bulgwon Park				1						

Zone	Site	2021 Survey			Past Surveys (no.)						
		Vol. No.	Vol. Hours	No. of surveys	2020	2019	2018	2017	2016	2015	2014
	Chappel St Mangroves				1						
	Glenlyon Rd				1						
	Hazelbrook Park					1					
	Lake Callemondah				6	1	3	2	3		
	Police Creek*	**11**	**1.5**	**2**	1	1					
	Tigalee Creek (Site ID 2254)						4				
	Tigalee Creek (Site ID 2444)					2	4	4			
	Tigalee Creek (Site ID 2796)						1				
	Tigalee Creek (Site ID 2797)					1					
	Tondoon Botanic Gardens				1		1				
	Wild Place							2			
	William Miskin Park Mangroves				1						
	Auckland Creek (Site ID 3402)*	**4**	**2.5**	**1**	3	1					
	Memorial Park Gladstone*	**1**	**1**	**1**							
Mid Harbour	Back Beach								1		
	Canoe Point (Site ID 2754)				1						
	Canoe Point (Site ID 796)*	**33**	**9**	**6**	10	27	7	8	2	2	
	Canoe Point Reserve					2	1				
	East Beach*				1					1	
	Esplanade Beach*	**22**	**1**	**1**	1	3			2		
	Facing Island North Point						2				
	North East Shore*	**48**	**8**	**3**	1	1	3	2	7	3	
	North West Shore*				2		1				
	South End Back Beach								1		
	South End Conservation Park Beach				6						
	Tannum Sands Main Beach	**34**	**2.5**	**2**	11	14	5	3	1		

		2021 Survey			Past Surveys (no.)						
Zone	**Site**	**Vol. No.**	**Vol. Hours**	**No. of surveys**	**2020**	**2019**	**2018**	**2017**	**2016**	**2015**	**2014**
South Trees Inlet	**Lilley's Beach North End***	**15**	**13**	**8**	3	5	7				
	Wapentake Wetlands				3		1				
Boyne Estuary	Boyne Island Conservation Site						2				
	Boyne Riverfront							1			
	Bray Park to Boyne River mouth					1	2		2	1	
	Canoe Point Conservation Area*	**12**	**5**	**2**	2						
	Eastern Foreshore*	**4**	**2.5**	**1**	3	2	2				
	Lilley's Beach*	**33**	**9.5**	**5**	7	12	16	8	4	3	1
	Lions Park					2					
	Truck Bay						1				
	Wyndham Park					5					
	Ibis Park*					1					
Outer Harbour	Wild Cattle Creek Boat Ramp*				1	3	2				
	Wild Cattle Creek Mouth				3	7	11	3	4	3	
	Wild Cattle Creek Mouth, Tannum Sands	**2**	**2**	**1**							
	Wild Cattle Creek Trail					1					
	Wild Cattle Island Beach NTH	**11**	**14**	**4**	4						
	Wild Cattle Island National Park NTH				2						
Colosseum Inlet	The Sands						1				
Rodds Bay	**The Esplanade Beach**	**3**	**1**	**1**		1	2				