Gladstone
Healthy Harbour
Partnership

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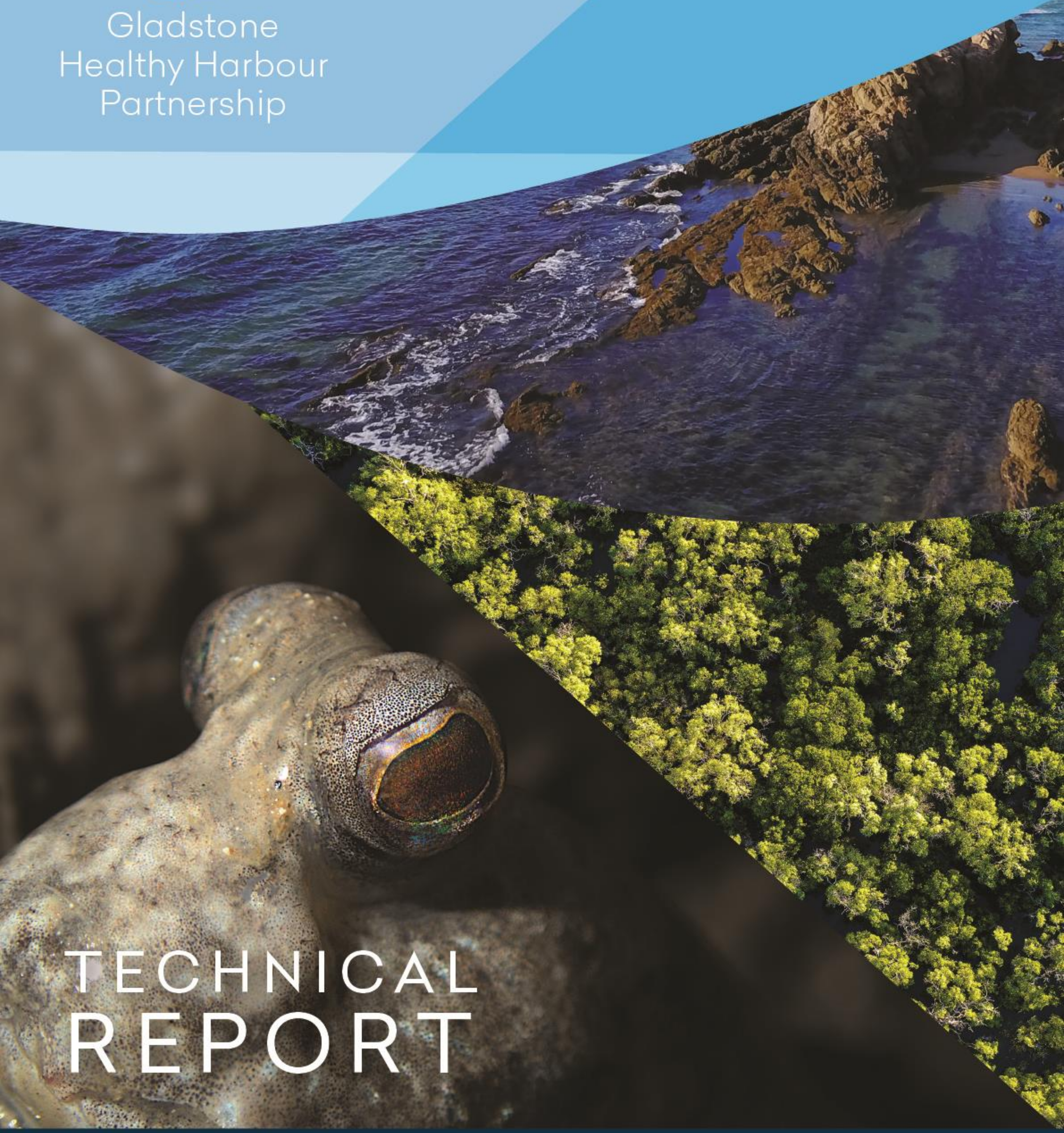

TECHNICAL REPORT

GLADSTONE HARBOUR REPORT CARD 2020

Authorship statement

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

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Gladstone Healthy Harbour Partnership partners

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

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Executive summary

Context

The 2020 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 2019 to 30 June 2020 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).

Figure 1: Grading scheme used to convert scores to grades in the 2020 Gladstone Harbour Report Card for each component of harbour health.

Overall component grades

The overall component scores and grades for the 2020 report card were: Environmental 0.66 (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.

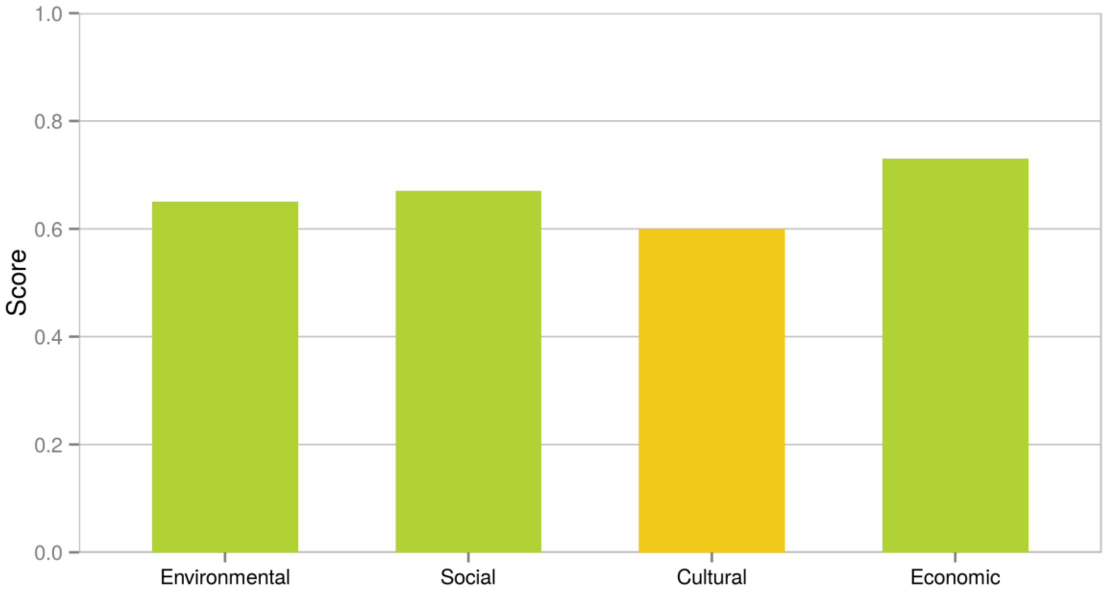


Figure 2: Overall scores for each of the four components of Gladstone Harbour Health in 2020.

Environmental health

The overall grade for the Environmental component was a B (0.66). This was the first time this grade has been achieved since the first report card in 2015. The water and sediment quality indicator group received a score of 0.92 (A), habitats a score of 0.50 (C) and fish and crabs a score of 0.56 (C) (Table 1). Water and sediment quality scores were similar to the previous year (0.88 in 2019). Habitats improved from 0.45 (D) in 2019 to 0.50 (C) in 2020, a result of a higher score for seagrass. The overall score for fish and crabs also improved in 2020 owing to a higher score for fish recruitment.

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

Zone	Indicator groups		
	Water and sediment quality	Habitats (seagrass, corals and mangroves)	Fish and crabs
1. The Narrows	0.88	0.77	0.64
2. Graham Creek	0.91	0.64	0.65
3. Western Basin	0.93	0.66	0.84
4. Boat Creek	0.87	0.46	0.60
5. Inner Harbour	0.89	0.63	0.57
6. Calliope Estuary	0.95	0.58	0.52
7. Auckland Inlet	0.89	0.65	0.50
8. Mid Harbour	0.92	0.39	0.66
9. South Trees Inlet	0.92	0.80	0.54
10. Boyne Estuary	0.95	0.26	0.60
11. Outer Harbour	0.98	0.36	0.69
12. Colosseum Inlet	0.93	0.72	0.66
13. Rodds Bay	0.92	0.77	0.47
Harbour score	**0.92**	**0.50**	**0.56**

Water and sediment quality

Water quality received a score of 0.89 (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 (0.95, A) which was 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. Twelve of the thirteen zones received a very good score, with the remaining zone receiving a good score (Table 2). Compared to the previous year, scores for the physicochemical group increased at all thirteen zones as a result of higher scores for turbidity (which indicate lower levels of turbidity). Similarly, the nutrient harbour score (0.73, B) increased for the second consecutive year since the 2018 score of 0.47 (D) due to the cumulative effects of higher scores for all three measures (total nitrogen, total phosphorous and chlorophyll-*a*). Dissolved metal scores of 0.96 – 1.00 (A) were uniformly very good for the sixth consecutive year.

Table 2: Water quality indicator scores for the 2020 Gladstone Harbour Report Card. Scores from 2019 and 2018 are shown for comparison.

Water quality	Physico-chemical	Nutrients	Dissolved metals	2020	*2019*	*2018*
1. The Narrows	0.93	0.63	1.00	0.85	*0.74*	*0.71*
2. Graham Creek	0.98	0.76	1.00	0.91	*0.79*	*0.78*
3. Western Basin	0.97	0.75	0.96	0.89	*0.77*	*0.72*
4. Boat Creek	0.89	0.69	0.98	0.85	*0.68*	*0.63*
5. Inner Harbour	0.94	0.68	0.95	0.85	*0.82*	*0.80*
6. Calliope Estuary	1.00	0.84	0.99	0.94	*0.80*	*0.76*
7. Auckland Inlet	0.83	0.66	0.97	0.82	*0.77*	*0.74*
8. Mid Harbour	0.87	0.75	1.00	0.87	*0.86*	*0.81*
9. South Trees Inlet	0.96	0.67	1.00	0.87	*0.83*	*0.76*
10. Boyne Estuary	0.98	0.72	1.00	0.90	*0.88*	*0.79*
11. Outer Harbour	1.00	0.89	1.00	0.96	*0.93*	*0.92*
12. Colosseum Inlet	0.99	0.69	1.00	0.89	*0.88*	*0.83*
13. Rodds Bay	0.93	0.73	1.00	0.89	*0.83*	*0.74*
Harbour score	**0.94**	**0.73**	**0.99**	**0.89**	***0.81***	***0.76***

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, nickel and zinc).

Table 3: Sediment quality indicator scores for the 2020 Gladstone Harbour Report Card. Scores from 2019 and 2018 are shown for comparison.

Zone	Metals and metalloid	2020	*2019*	*2018*
1. The Narrows	0.91	0.91	*0.92*	*0.90*
2. Graham Creek	0.90	0.90	*0.91*	*0.94*
3. Western Basin	0.98	0.98	*0.98*	*0.98*
4. Boat Creek	0.89	0.89	*0.92*	*0.91*
5. Inner Harbour	0.93	0.93	*0.92*	*0.95*
6. Calliope Estuary	0.95	0.95	*0.96*	*0.95*
7. Auckland Inlet	0.95	0.95	*0.94*	*0.91*
8. Mid Harbour	0.97	0.97	*0.94*	*0.95*
9. South Trees Inlet	0.96	0.96	*0.96*	*0.94*
10. Boyne Estuary	1.00	1.00	*0.99*	*0.97*
11. Outer Harbour	0.99	0.99	*0.97*	*0.96*
12. Colosseum Inlet	0.97	0.97	*0.96*	*0.99*
13. Rodds Bay	0.96	0.96	*0.98*	*0.97*
Harbour score	**0.95**	**0.95**	***0.95***	***0.95***

Habitats

The overall score for habitats was satisfactory (0.50, C) for the first time in the GHHP program owing to an increase in the seagrass score. The seagrass score improved substantially in the past two years—from 0.40 (D) in 2018 to 0.79 (B) in 2020. The coral score remained very poor (0.14, E) and was slightly lower than that recorded in 2019. The overall score for mangroves was based on monitoring completed in 2019 and therefore the score was identical (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 2020 was 0.79 (B) indicating a good overall condition (Table 4). This result was the second successive year of marked improvement from previous report cards in which overall seagrass condition was poor. Moreover, the overall seagrass condition in 2020 was the best in the past decade. At the zone level, overall condition scores improved at six of the seven monitoring zones from the previous report card. Thirteen of the fourteen monitored meadows were in satisfactory, good or very good condition. The harbour's seagrass meadows are continuing to recover following several years of poor condition. Results suggest that improvements in seagrass condition were largely a result of environmental factors, that were characterized by drier than average conditions.

Table 4: Seagrass indicator scores for the 2020 Gladstone Harbour Report Card. Scores from 2019 and 2018 are shown for comparison. Please note, scores may differ by ±0.01 to those reported by Smith et al. (2020) due to bootstrapping used to calculate GHHP report card scores (see Logan et al., 2016).

Zone	Meadow	Biomass	Area	Species composition	Overall meadow	2020	*2019*	*2018*
1. The Narrows	21	0.90	0.97	0.97	0.90	0.90	*0.71*	*0.42*
3. Western Basin	4	1.00	0.91	0.96	0.91	0.80	*0.69*	*0.45*
	5	0.92	0.92	0.89	0.91			
	6	0.91	0.90	0.80	0.85			
	7	0.73	0.73	1.00	0.73			
	8	0.91	0.82	0.60	0.71			
	52–57	0.72	1.00	1.00	0.72			
5. Inner Harbour	58	0.70	0.97	0.74	0.70	0.70	*0.21*	*0.09*
8. Mid Harbour	43	0.31	0.95	0.58	0.31	0.43	*0.52*	*0.46*
	48	0.75	0.91	0.33	0.54			
9. South Trees Inlet	60	1.00	1.00	0.99	1.00	1.00	*0.89*	*0.85*
13. Rodds Bay	94	1.00	0.86	1.00	0.86	0.90	*0.49*	*0.10*
	96	1.00	1.00	0.96	0.99			
	104	0.91	0.85	0.95	0.85			
Harbour score						0.79	*0.59*	*0.40*

Corals

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

In 2020, corals were in very poor condition for the third consecutive year, receiving 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). Although the coral cover score was identical and the macroalgal cover score increased slightly compared to the previous year, juvenile density and change in hard coral cover scores decreased considerably and resulted in the diminished overall harbour score. Ongoing pressures such as high macroalgal cover and the widespread presence of the bio-eroding sponge *Cliona orientalis* and acute disturbances, such as the high water temperatures in early 2020, appear to be hindering the recovery of the coral communities of Gladstone Harbour.

Table 5: Coral indicator scores for the 2020 Gladstone Harbour Report Card. Scores from 2019 and 2018 are shown for comparison.

Zone	Coral cover	Macroalgal cover	Juvenile density	Change in hard coral cover	2020	*2019*	*2018*
8. Mid Harbour	0.09	0.15	0.15	0.44	0.21	*0.19*	*0.28*
11. Outer Harbour	0.08	0.00	0.08	0.13	0.07	*0.17*	*0.20*
Harbour score	**0.08**	**0.07**	**0.12**	**0.28**	**0.14**	***0.18***	***0.24***

Mangroves

Scores for the mangrove indicator have remained relatively 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) slightly lower than the score of 0.60 (C) in 2018. 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	2020 / 2019	*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 0.56 (C). Bream recruitment received a score of 0.64 (B), which was a marked improvement on the 2019 score of 0.27 (D). The mud crab indicator received a poor score of 0.39 (D), which was lower than the score of 0.47 (D) received in the previous year. The fish health indicator received a good score of 0.69 (B), which was identical to the score received in 2019.

Fish health

The harbour score for fish health was 0.69 (B), being the average of the harbour scores for 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 and owing to COVID-19 restrictions limiting community-collected data. The overall score for visual fish condition was 0.72 (B), while the overall score for the fish health assessment index was 0.67 (B) (Table 7). The health assessment index was calculated by scoring and summing visual inspection scores for numerous 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 the recording the incidence of parasites and deformities, and fish body condition determined from the length weight relationship. Measures of fish body condition are widely used to assess the health of individual or groups of fish.

While the overall score for fish health (0.69, B) was identical to 2019, the two years are not directly comparable as there was a lower fishing effort in 2020. The reduction in effort, resulting from COVID-19 restrictions and a reduced budget, led to lower sample sizes and fewer fish species assessed for both fish health sub-indicators.

Table 7: Overall fish health assessment index (HAI) species and harbour scores from 2019 to 2020.

Fish health assessment Index (HAI)	HAI 2020	*HAI 2019*
Bream	ND	*0.78*
Barred Javelin	0.84	*0.77*
Barramundi	0.55	*0.58*
Blue Catfish	0.61	*0.60*
Mullet	ND	*0.73*
Harbour score	**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 2020.

Visual fish condition (VFC)	FVA	FBC	VFC 2020	*VFC 2019*
Yellow-finned Bream	0.97	0.44	0.71	*0.61*
Pikey Bream	0.99	0.48	0.74	*0.81*
Barred Javelin	0.97	ND	ND	*0.99*
Dusky Flathead	0.98	ND	ND	*0.52*
Mangrove Jack	0.98	ND	ND	*0.56*
Harbour score			**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 2020 was 0.64 (C). This was a marked improvement from the 2019 score (0.27), which is the lowest score since fish recruitment was included in the report card in 2016 (Table 9). This improvement may be a response to the prevailing climatic conditions. While total rainfall in the 2019–20 reporting year was below average, rainfall in January and February 2020 was greater than the monthly average and greater than rainfall recorded in January and February 2019, which were particularly dry months. Freshwater inflows have been linked to estuarine productivity with productivity declining in drier years and the improved result may be a result of improved inflows. However, as fish recruitment has been a highly variable report card indicator further investigations are required to determine the extent of the relationship between prevailing climatic conditions and bream recruitment in Gladstone Harbour and its tributaries.

Table 9: Bream recruitment scores for 12 harbour zones and the overall harbour score from 2016 to 2020.

Zone	2020	*2019*	*2018*	*2017*	*2016*
1. The Narrows	0.63	*0.18*	*0.58*	*0.75*	*0.30*
2. Graham Creek	0.92	*0.17*	*0.77*	*0.58*	*0.44*
3. Western Basin	0.98	*0.13*	*0.79*	*0.78*	*0.36*
4. Boat Creek	0.38	*0.32*	*0.61*	*0.47*	*0.36*
5. Inner Harbour	0.63	*0.16*	*0.67*	*0.64*	*0.33*
6. Calliope Estuary	0.66	*0.28*	*0.70*	*0.79*	*0.43*
7. Auckland Inlet	0.80	*0.53*	*0.87*	*0.91*	*0.53*
8. Mid Harbour	0.62	*0.12*	*0.58*	*0.71*	*0.29*
9. South Trees Inlet	0.39	*0.25*	*0.69*	*0.71*	*0.43*
10. Boyne Estuary	0.51	*0.32*	*0.52*	*0.74*	*0.54*
12. Colosseum Inlet	0.63	*0.39*	*0.61*	*0.71*	*0.45*
13. Rodds Bay	0.52	*0.33*	*0.59*	*0.74*	*0.58*
Harbour score	**0.64**	***0.27***	***0.66***	***0.71***	***0.40***

Mud crabs

Seven zones were sampled to collect data on three mud crab sub-indicators: sex ratio, abundance and prevalence of rust lesions. Sex ratio 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 2020 was 0.39 (D), a lower score compared to previous years (Table 10). Sex ratio was very poor in five of the six zones where this could be calculated. Abundance scores ranged from very good to very poor, however, the overall score was lower than in 2019. Scores for prevalence of rust lesions were good to very good at four zones (indicating low levels of this condition) and poor at two zones (indicating higher levels of this condition). As only three mud crabs were caught in Auckland Creek a score was not calculated for this zone.

Table 10: Mud crab indicator scores for the 2020 Gladstone Harbour Report Card. Scores from 2019 and 2018 are shown for comparison.

Zone	Sex Ratio	Abundance (CPUE)	Prevalence of rust lesions	2020	*2019*	*2018*
1. The Narrows	0.00	1.00	0.80	0.60	*0.63*	*0.66*
2. Graham Creek	0.00	0.18	0.84	0.34	*0.45*	*0.44*
4. Boat Creek	0.29	1.00	0.84	0.71	*0.48*	*0.51*
5. Inner Harbour	0.00	0.19	0.99	0.39	*0.48*	*0.52*
6. Calliope Estuary	0.00	0.13	0.45	0.19	*0.43*	*0.52*
7. Auckland Inlet	NC	0.00	NC	NC	*NC*	*NC*
13. Rodds Bay	0.06	0.13	0.45	0.21	*0.36*	*0.38*
Harbour score	**0.06**	**0.38**	**0.73**	**0.39**	***0.47***	***0.49***

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 relatively 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 2020. Social health will be assessed again in 2021–22. The 2019 Social component scores are used for the 2020 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 2020 and 2019 reporting years. Scores from 2018 and 2017 are shown for comparison.

Indicator groups	Social indicators	2020 / 2019	2020 / 2019	*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' Indigenous cultural heritage. 'Sense of place' was last monitored in 2019 and these results are used in the 2020 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 relatively 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 2020. Scores from 2018 to 2016 are shown for comparison.

Indicator group	Indicators	2020 / 2019	2020 / 2019	*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, 2019 and 2020 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 2020/2019 score was determined by the scores from three indicator groups: economic performance 0.90 (A), economic stimulus 0.58 (C) and economic value 0.76 (B) (Table 14). While the overall economic health of Gladstone remained good, this score was influenced by reduced employment opportunities, and a lower score for socio-economic status. Commercial fishing received a poor score due to low gross value production and a lower net fishery productivity score. Shipping activity and tourism have remained strong.

Table 14: Scores for the economic indicator groups from 2016 to 2020. The 2018 to 2016 scores are shown for comparison.

Indicator group	Indicators	2020 / 2019	2020 / 2019	*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.

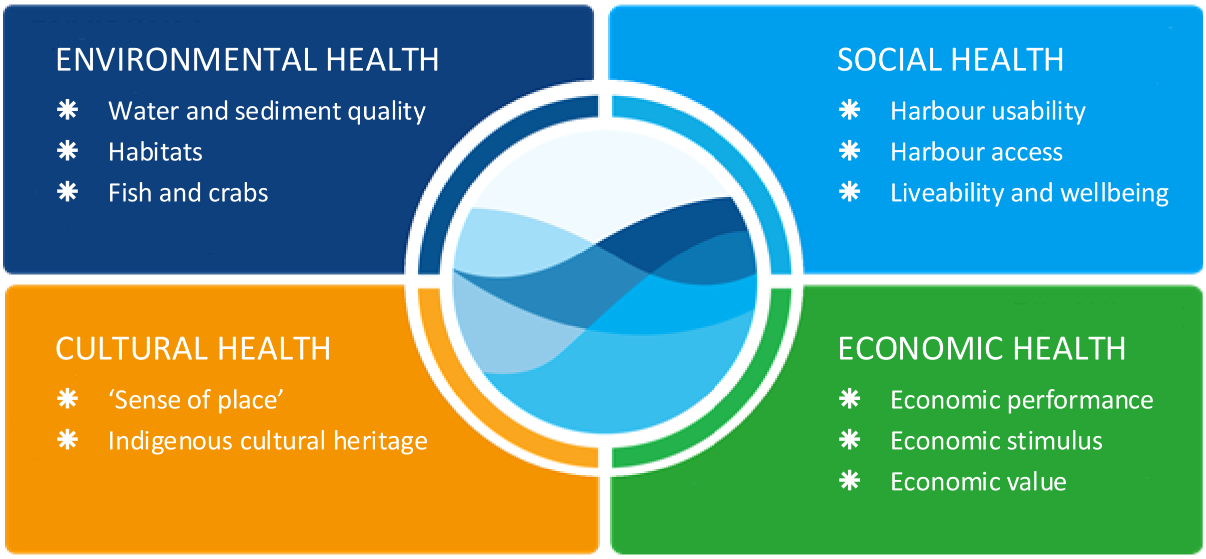


Figure 1.1: The four components of harbour health.

1.2. Reporting periods

The reporting period for the 2020 Gladstone Harbour Report Card was 1 July 2019 to 30 June 2020. 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 2019–20 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 2020 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.

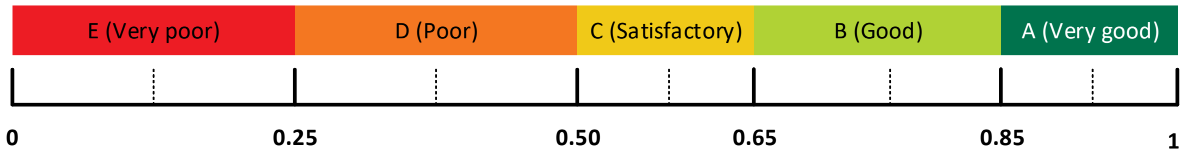


Figure 2.1: Grade ranges used in the 2020 Gladstone Harbour Report Card.

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).

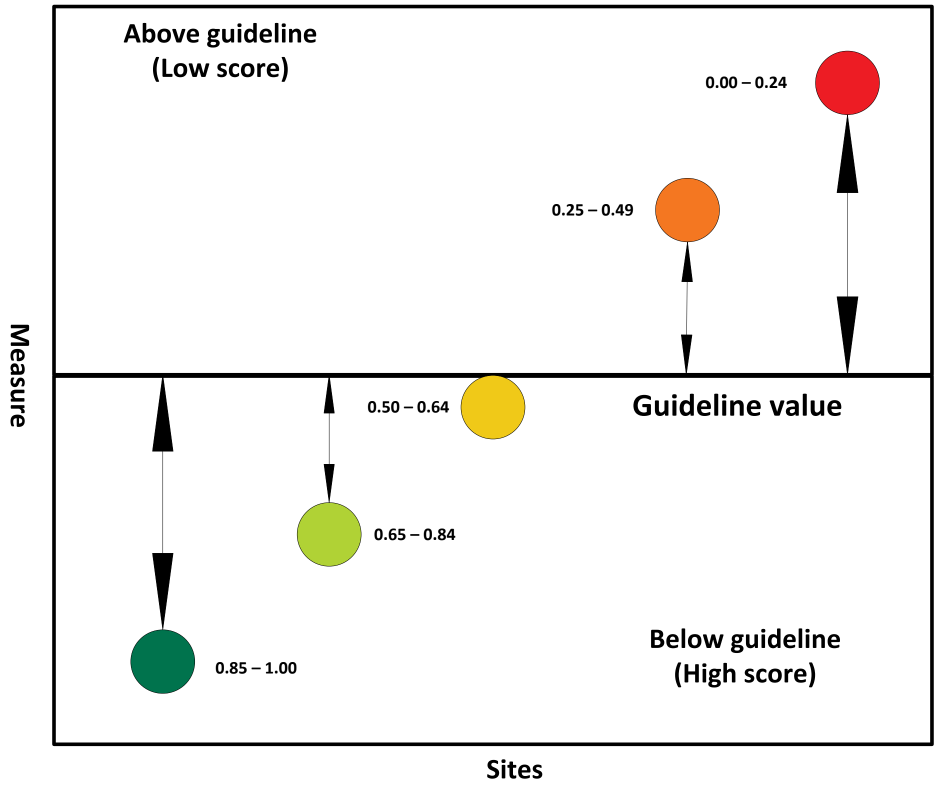


Figure 2.2: Water and sediment quality measures are scored relative to zone and measure specific guideline values.

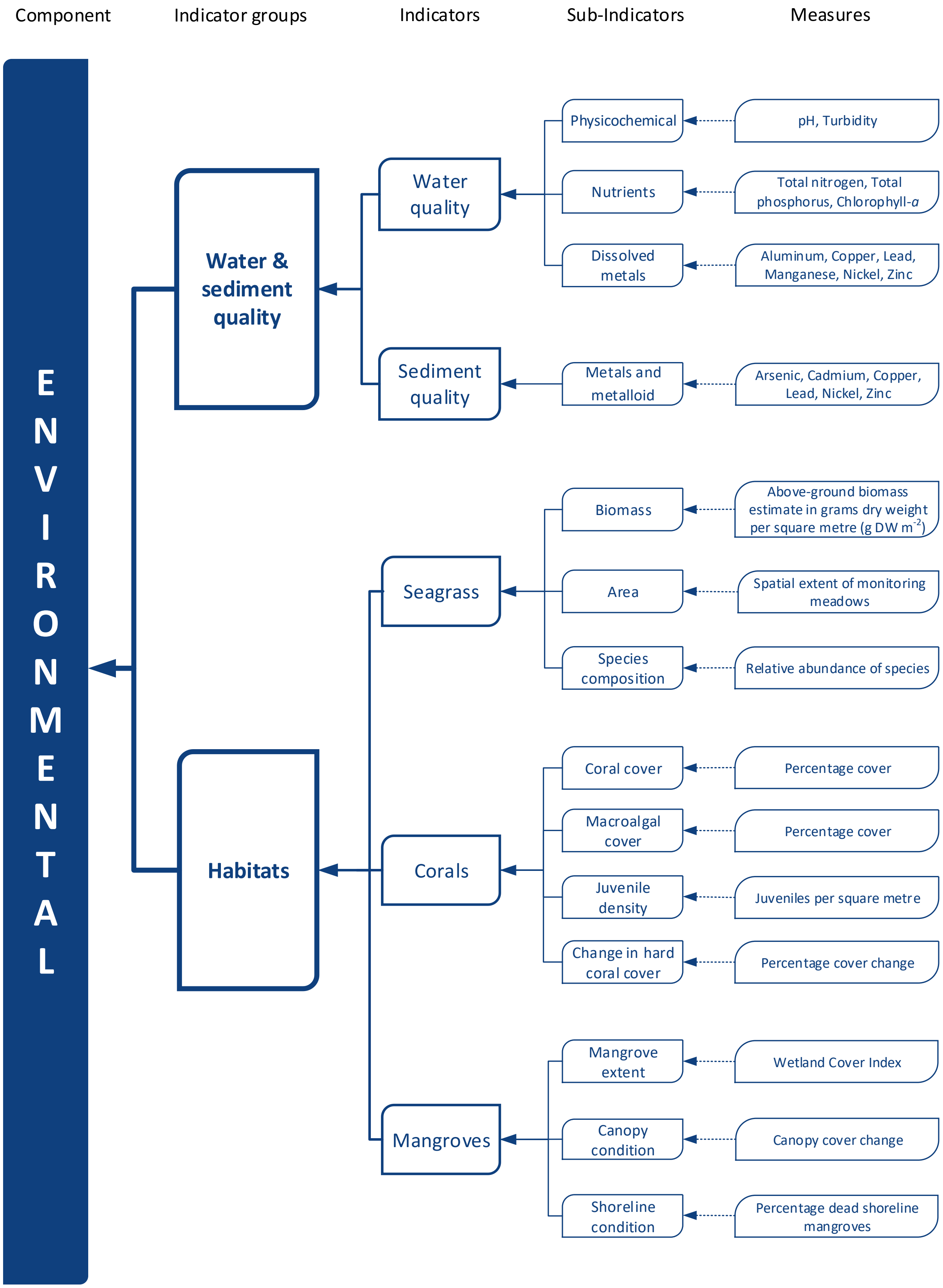


Figure 2.3a: The levels of aggregation used to determine the environmental scores and grades in the 2020 Gladstone Harbour Report Card. There are 3 environmental indicator groups, 8 indicators, 19 sub-indicators and 46 measures.

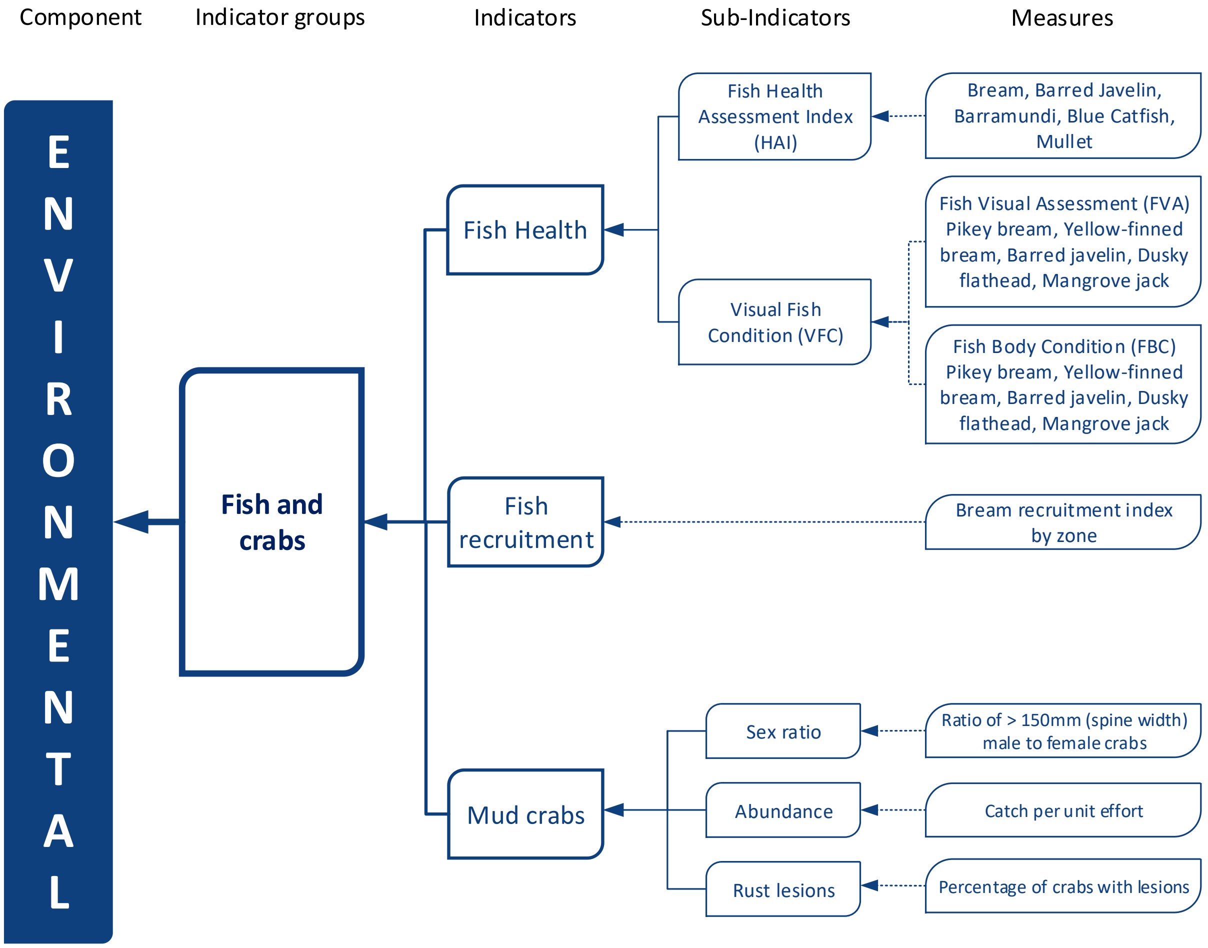


Figure 2.3b: The levels of aggregation used to determine the environmental scores and grades in the 2020 Gladstone Harbour Report Card. There are 3 environmental indicator groups, 8 indicators, 19 sub-indicators and 46 measures.

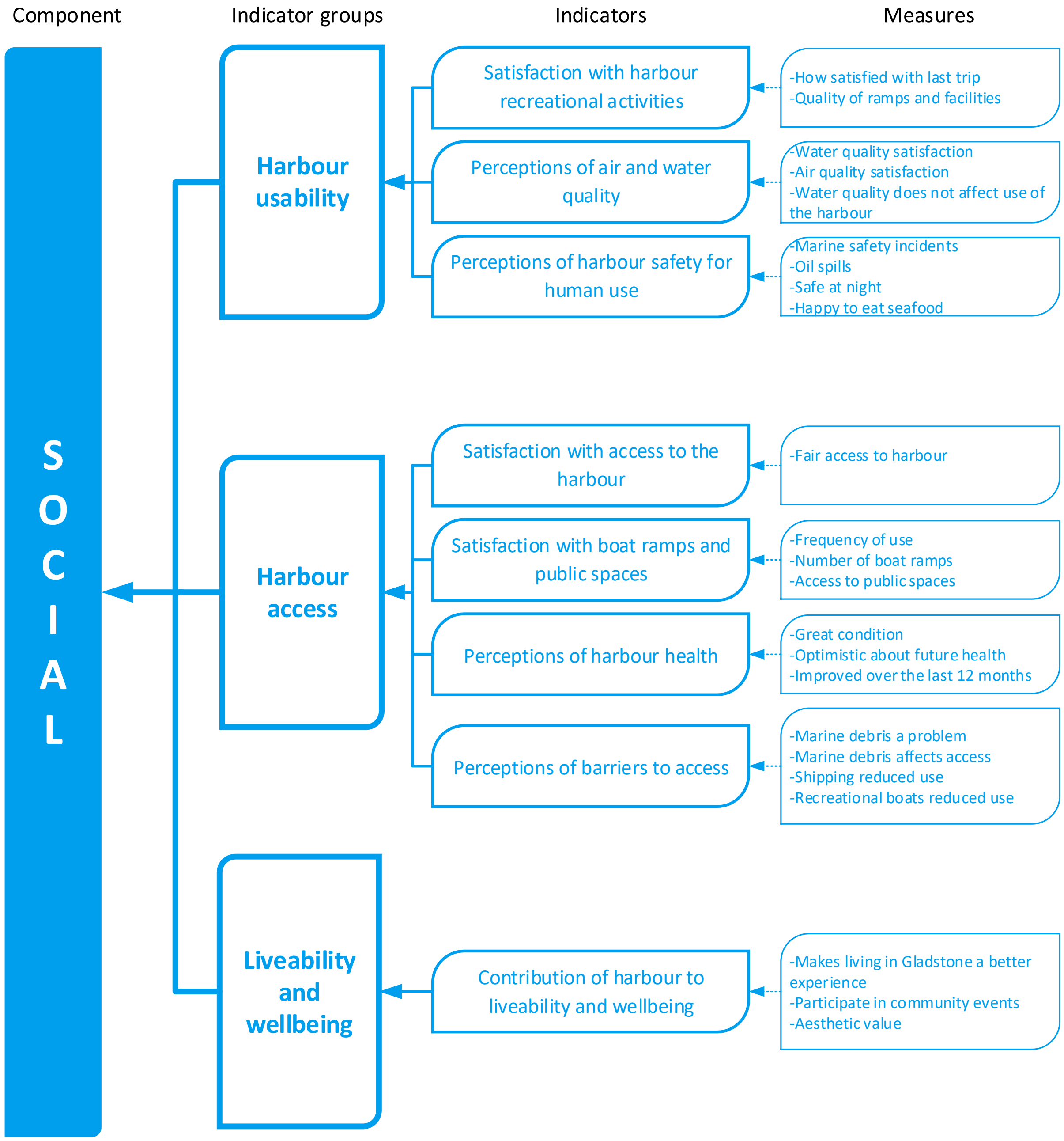


Figure 2.4: The levels of aggregation used to determine the social scores and grades in the 2020 Gladstone Harbour Report Card. There are 3 social indicator groups, 8 indicators and 23 measures.

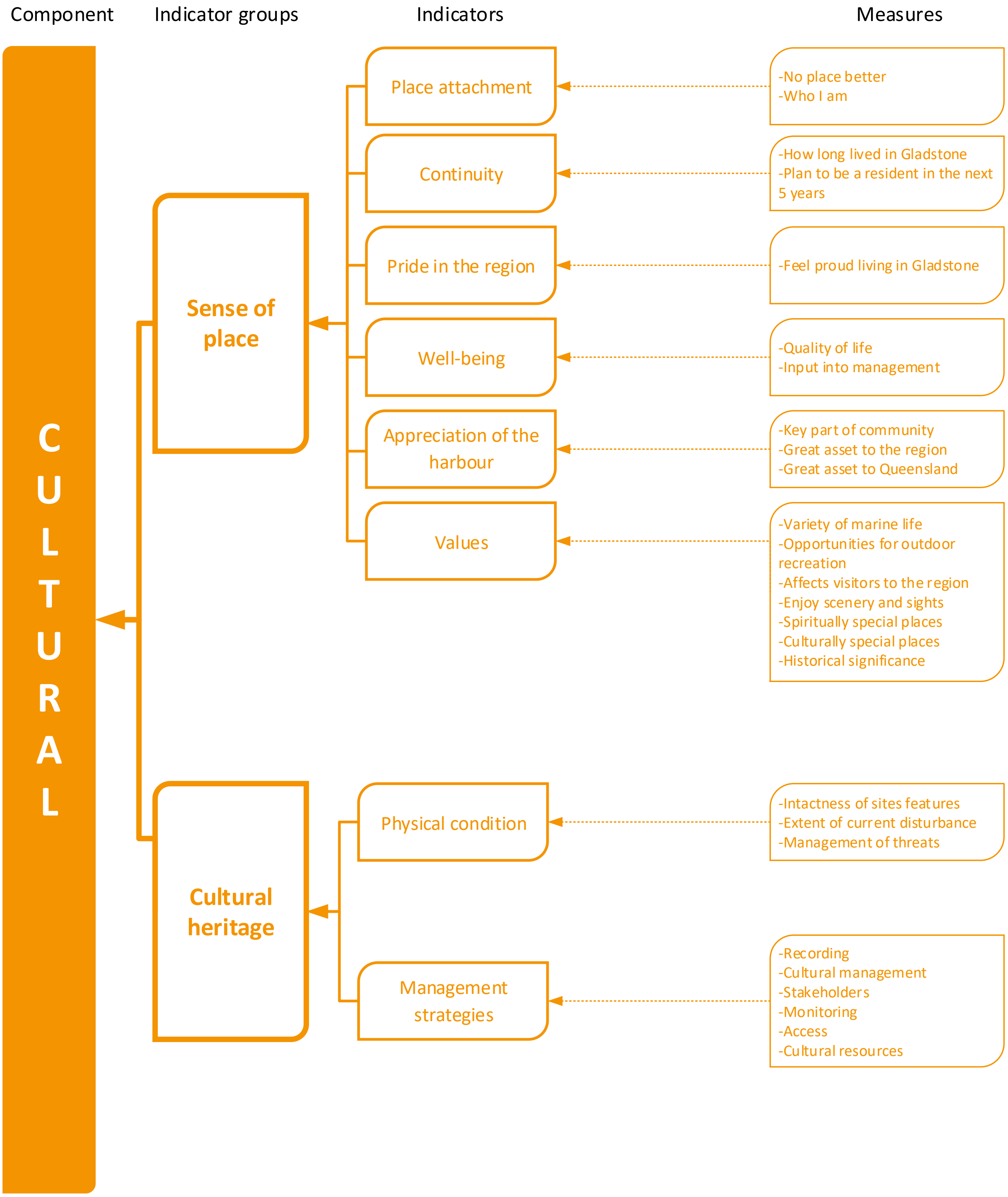


Figure 2.5: The levels of aggregation used to determine the cultural grades and scores in the 2020 Gladstone Harbour Report Card. There are 2 cultural indicator groups, 8 indicators and 26 measures.

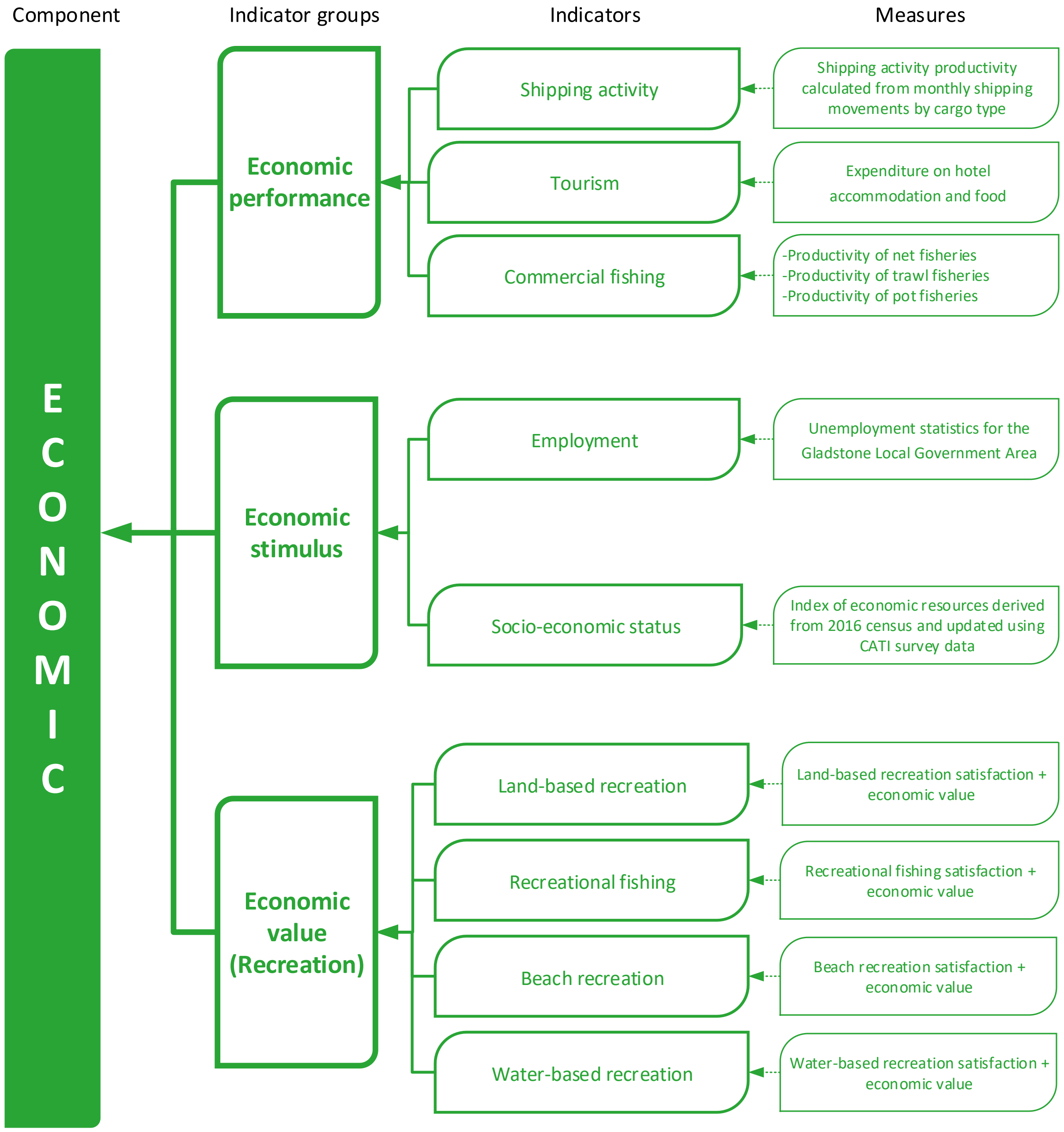
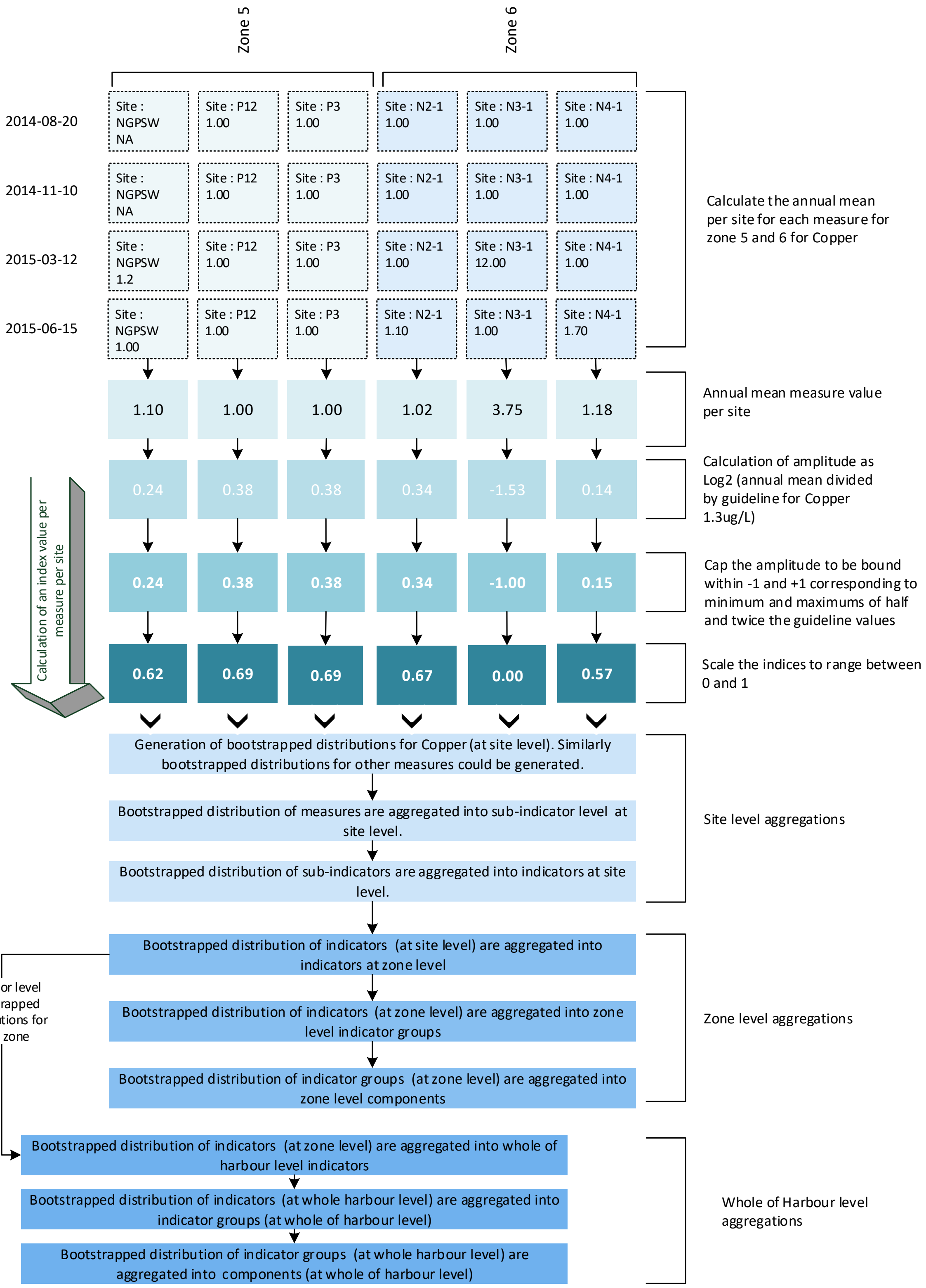


Figure 2.6: The levels of aggregation used to determine the economic scores and grades in the 2020 Gladstone Harbour Report Card. CATI = Computer-Assisted Telephone Interviewing. There are 3 economic indicator groups, 9 indicators and 11 measures.



	Site : NGPSW	Site : P12	Site : P3	Site : N2-1	Site : N3-1	Site : N4-1
2014-08-20	NA	1.00	1.00	1.00	1.00	1.00
2014-11-10	NA	1.00	1.00	1.00	1.00	1.00
2015-03-12	1.2	1.00	1.00	1.00	12.00	1.00
2015-06-15	1.00	1.00	1.00	1.10	1.00	1.70
Annual mean measure value per site	1.10	1.00	1.00	1.02	3.75	1.18
Calculation of amplitude as Log2 (annual mean divided by guideline for Copper 1.3ug/L)	0.24	0.38	0.38	0.34	-1.53	0.14
Cap the amplitude to be bound within -1 and +1 corresponding to minimum and maximums of half and twice the guideline values	0.24	0.38	0.38	0.34	-1.00	0.15
Scale the indices to range between 0 and 1	0.62	0.69	0.69	0.67	0.00	0.57

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 2020. The Social and Economic components received high confidence ratings in 2020 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 2020 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. While sample size was reduced for both fish health projects, the confidence rating remained at moderate. The reduction in numbers and species was a result of a lower budget for field work and the cancellation of the Boyne-Tannum Hook-Up, a major source of data for visual fish health, owing to COVID-19 restrictions.

Table 2.2: Confidence ratings for individual environmental indicators in 2020.

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 six years of monitoring. Minor changes to scoring methods in 2018.
Corals	High	Consistent methods used over six 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 report card.
Fish health	Moderate	Three years of monitoring (2018 – 2020) 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. Owing to reduced sampling in the 2020 reporting year the sample size for both indicators of fish health was lower than the previous year.
Fish recruitment	High	Five years of monitoring with consistent methods and data analysis.
Mud crabs	High	Four years of monitoring with an appropriate methodology. The benchmarks are based on local populations. Minor changes to scoring methods in 2020.

The confidence ratings for the Social, Cultural and Economic components remain unchanged from 2019 as the 2019 results are used for the 2020 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. 2020 Environmental Monitoring

The Environmental component for the 2020 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 2019 and 30 June 2020. As no new mangrove monitoring was conducted in the 2020 report card year the 2019 mangrove results are used for the 2020 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, 2014a) 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 (HEV) zones in Gladstone Harbour (The Narrows, Colosseum Inlet, Rodds Bay) to 24 µg/L in moderately disturbed (MD) zones (all other zones). This led to similar actual concentrations of aluminium being scored as very poor in HEV zones and very good in MD zones. This created the misleading impression that the aluminium concentrations were far worse in HEV zones than in MD zones. For this reason, the ISP applied the MD guideline of 24 µg/L across all zones for aluminium.

For the same reason, 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 MD 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 concentration-response 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 2021. Given 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 is applied to nickel (Ni). Water quality guideline values were selected for moderately disturbed systems.

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

- *Australian and New Zealand Standards for water quality and sediment sampling* (AS/NZS 5667.1:1998, 5667.4:1998, 5667.6:1998, 5667.12:1998)
- *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 2020 report card. Those data were based on samples collected from 51 sites across the 13 harbour zones in August and November 2019 and March and June 2020 (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 (NMI) 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 2020 Gladstone Harbour Report Card.

Indicator	Sub-indicator	Measure	Guideline source
Water quality	Physicochemical	pH	DEHP, 2014a
		Turbidity	DEHP, 2014a
	Nutrients	Total nitrogen (TN)	DEHP, 2014a
		Total phosphorus (TP)	DEHP, 2014a
		Chlorophyll-*a*	DEHP, 2014a
	Dissolved metals	Aluminium (Al)	Golding et al., 2014
		Copper (Cu)	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

Five 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 2020. Grab samples were collected for sediment quality measures using a stainless steel Ponar grab sampler (0.008 m^3 volume). These samples were deposited into a collection tub that had been triple rinsed with seawater and then photographed. All sediment quality measurements used the top 100 mm of the sample, which were deposited into laboratory-provided sample containers using pre acid-washed polypropylene trowels.

All sample containers were bagged and stored at 4° C and transported to the analysing laboratory, NMI, within their recommended holding times. For 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 (PAHs) 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 2020 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
		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 early October 2020, the ISP held a meeting to discuss QA/QC issues with the raw dataset for 2020 for the water and sediment quality data collected.

Following the meeting, the ISP recommended to exclude 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 had concentrations below that of the instrument's sensitivity.
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.

Sediment mercury was tested in 2020, however, the LOR value (0.2 mg/kg) increased from the previous year and was higher than the guideline value (0.15 mg/kg). As such, the ISP recommended to exclude sediment mercury from the report card analysis. When the sediment mercury LOR value was at an acceptable level in 2017 and 2019 this measure received the highest possible score (1.00) in all 13 zones, indicating extremely low concentrations of sediment mercury in these years.

3.1.2. *Water and sediment quality measures*

A total of 17 water and sediment quality measures were assessed and reported in the 2020 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).

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

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 2020 report card was 0.89 (A). This was the first time the water quality indicator received a very good score within the GHHP program. Twelve zones received very good scores (0.85–0.96, A) and Auckland Inlet received a B grade overall (Table 3.3). This was also the first time since 2017 that Boat Creek did not receive the lowest score of the 13 monitoring zones.

Table 3.3: Overall water quality sub-indicator, zone and harbour scores for the 2020 Gladstone Harbour Report Card. Overall zone and harbour scores from 2019 and 2018 are shown for comparison.

Water quality	Physico-chemical	Nutrients	Dissolved metals	2020	*2019*	*2018*
1. The Narrows	0.93	0.63	1.00	0.85	*0.74*	*0.71*
2. Graham Creek	0.98	0.76	1.00	0.91	*0.79*	*0.78*
3. Western Basin	0.97	0.75	0.96	0.89	*0.77*	*0.72*
4. Boat Creek	0.89	0.69	0.98	0.85	*0.68*	*0.63*
5. Inner Harbour	0.94	0.68	0.95	0.85	*0.82*	*0.80*
6. Calliope Estuary	1.00	0.84	0.99	0.94	*0.80*	*0.76*
7. Auckland Inlet	0.83	0.66	0.97	0.82	*0.77*	*0.74*
8. Mid Harbour	0.87	0.75	1.00	0.87	*0.86*	*0.81*
9. South Trees Inlet	0.96	0.67	1.00	0.87	*0.83*	*0.76*
10. Boyne Estuary	0.98	0.72	1.00	0.90	*0.88*	*0.79*
11. Outer Harbour	1.00	0.89	1.00	0.96	*0.93*	*0.92*
12. Colosseum Inlet	0.99	0.69	1.00	0.89	*0.88*	*0.83*
13. Rodds Bay	0.93	0.73	1.00	0.89	*0.83*	*0.74*
Harbour score	**0.94**	**0.73**	**0.99**	**0.89**	***0.81***	***0.76***

The physicochemical 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 three zones (Boat Creek, Auckland Inlet and the Mid Harbour) had good scores, with Auckland Inlet receiving the lowest score (0.65, B). The harbour score for the physicochemical sub-indicator (0.89, A) was the highest observed since 2015.

Like previous report cards, nutrients received the lowest score of 0.73 (B) amongst the water quality sub-indicators. However, nutrient scores improved compared to the previous year at most zones and overall received the highest score of the last six years. Eleven of the 13 monitoring zones had good scores ranging from 0.66 to 0.84 (Table 3.3). The Outer Harbour has the highest nutrient score (0.89, A) while The Narrows had the lowest nutrient score (0.63, 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 0.45 (D) to 1.00 (A) (Table 3.4).

Table 3.4: Scores for water quality measures for each of the 13 zones in the 2020 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	0.86	0.58	0.85	0.46	1.00	1.00	1.00	1.00	1.00	1.00
2. Graham Creek	1.00	0.96	0.59	1.00	0.68	1.00	1.00	1.00	1.00	1.00	1.00
3. Western Basin	1.00	0.94	0.60	0.99	0.66	0.83	0.91	1.00	1.00	1.00	1.00
4. Boat Creek	1.00	0.78	0.50	0.69	0.89	1.00	1.00	1.00	0.90	1.00	1.00
5. Inner Harbour	1.00	0.87	0.59	1.00	0.45	0.68	1.00	1.00	1.00	1.00	1.00
6. Calliope Estuary	1.00	1.00	0.62	1.00	0.89	1.00	0.91	1.00	1.00	1.00	1.00
7. Auckland Inlet	1.00	0.65	0.52	0.76	0.69	1.00	0.97	1.00	0.86	1.00	1.00
8. Mid Harbour	1.00	0.75	0.56	0.99	0.70	1.00	1.00	1.00	1.00	1.00	1.00
9. South Trees Inlet	1.00	0.91	0.60	0.84	0.56	1.00	0.98	1.00	1.00	1.00	1.00
10. Boyne Estuary	1.00	0.96	0.46	1.00	0.70	1.00	1.00	1.00	1.00	1.00	1.00
11. Outer Harbour	1.00	1.00	0.67	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
12. Colosseum Inlet	1.00	0.97	0.55	1.00	0.53	1.00	1.00	1.00	1.00	1.00	1.00
13. Rodds Bay	1.00	0.85	0.59	0.92	0.69	1.00	1.00	1.00	1.00	1.00	1.00
Harbour score	**1.00**	**0.89**	**0.57**	**0.93**	**0.68**	**0.96**	**0.98**	**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

All zones had consistently very good scores (0.96–1.00) for the dissolved metals sub-indicator (Table 3.3). The same was true at the measure level as five of the six metals received very good scores across the 13 zones (Table 3.4). The exception, aluminium, showed good scores at Western Basin (0.83, B) and Inner Harbour (0.68, B), with the remaining eleven zones showing consistently very good scores (1.00, A).

Sediment quality

The overall sediment quality scores were derived from one sub-indicator: metals and metalloid. Five metals (cadmium, copper, lead, nickel, zinc) and the metalloid arsenic were assessed. The harbour score for sediment quality was 0.95 (A)—identical to 2017, 2018 and 2019 scores.

Zone scores for sediment quality were all very good, ranging from 0.91 (A) in The Narrows to 1.00 (A) in Boyne Estuary (Table 3.5). This was a result of low concentrations of all measures (arsenic, cadmium, copper, lead, 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: Overall sediment quality sub-indicator, zone and harbour scores for the 2020 Gladstone Harbour Report Card. Overall zone and harbour scores from 2019 and 2018 are shown for comparison.

Zone	Metals and metalloid	Zone score 2020	*Zone score 2019*	*Zone score 2018*
1. The Narrows	0.91	0.91	*0.92*	*0.90*
2. Graham Creek	0.90	0.90	*0.91*	*0.94*
3. Western Basin	0.98	0.98	*0.98*	*0.98*
4. Boat Creek	0.89	0.89	*0.92*	*0.91*
5. Inner Harbour	0.93	0.93	*0.92*	*0.95*
6. Calliope Estuary	0.95	0.95	*0.96*	*0.95*
7. Auckland Inlet	0.95	0.95	*0.94*	*0.91*
8. Mid Harbour	0.97	0.97	*0.94*	*0.95*
9. South Trees Inlet	0.96	0.96	*0.96*	*0.94*
10. Boyne Estuary	1.00	1.00	*0.99*	*0.97*
11. Outer Harbour	0.99	0.99	*0.97*	*0.96*
12. Colosseum Inlet	0.97	0.97	*0.96*	*0.99*
13. Rodds Bay	0.96	0.96	*0.98*	*0.97*
Harbour score	**0.95**	**0.95**	***0.95***	***0.95***

Table 3.6: Scores for sediment quality measures for each of the 13 zones in the 2020 Gladstone Harbour Report Card.

Zone	Metals and metalloid					
	Arsenic	Cadmium	Copper	Lead	Nickel	Zinc
1. The Narrows	0.79	1.00	1.00	1.00	0.66	1.00
2. Graham Creek	0.60	1.00	1.00	1.00	0.81	1.00
3. Western Basin	0.92	1.00	1.00	1.00	0.94	1.00
4. Boat Creek	0.76	1.00	1.00	1.00	0.61	1.00
5. Inner Harbour	0.63	1.00	1.00	1.00	0.97	1.00
6. Calliope Estuary	0.91	1.00	1.00	1.00	0.82	1.00
7. Auckland Inlet	0.96	1.00	0.96	1.00	0.80	1.00
8. Mid Harbour	0.83	1.00	1.00	1.00	1.00	1.00
9. South Trees Inlet	0.85	1.00	1.00	1.00	0.93	1.00
10. Boyne Estuary	1.00	1.00	1.00	1.00	1.00	1.00
11. Outer Harbour	0.93	1.00	1.00	1.00	1.00	1.00
12. Colosseum Inlet	0.85	1.00	1.00	1.00	1.00	1.00
13. Rodds Bay	0.83	1.00	1.00	1.00	0.95	1.00
Harbour score	**0.84**	**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 report card in 2015, receiving a good grade (B) from 2015 to 2019 and a very good grade (A) for the first time in 2020 (Figure 3.1). In 2020, water quality was relatively uniform across the harbour, with all zones but one receiving a very good score overall. Compared to the previous year, scores for the physicochemical group improved at all thirteen zones due to higher scores for turbidity; nutrient scores improved at eleven of the 13 monitoring zones; and dissolved metals scores were consistently very good. Improvements in physicochemical and nutrient scores resulted in the highest water quality harbour score (0.89, A) since GHHP reporting began.

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

In both 2019 and 2020 Gladstone Harbour Report Cards, nutrient and turbidity scores improved compared to the previous year (2019 Technical Report). Improved nutrient and turbidity scores may have resulted from the lower-than-average rainfall and minimal discharge from the Boyne and Calliope rivers (Figures 6.4 to 6.7; GHHP, 2019). In the past decade, flow from the Calliope River was lowest in the preceding year (2019) and the second lowest in 2018 (Carter et al., 2020).

From 2017–2019, Boat Creek received the lowest nutrient, physicochemical (turbidity) and overall zone score. Although this was not the case in the current year, Boat Creek did generally score lower when compared with other zones. In 2020 Auckland Inlet received the lowest physicochemical (turbidity) score, second lowest nutrient score and lowest overall zone score. In contrast, Outer Harbour received the highest nutrient, physicochemical (turbidity) and overall zone score for the fourth consecutive year. These results indicate that the more ocean-influenced zones (such as Outer Harbour) have lower nutrient loads and improved water clarity—relevant to zone-specific WQOs—when compared to other monitoring 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 Auckland Inlet and 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, QA/QC and other comparison techniques used to elucidate trends in the water and sediment quality of Gladstone Harbour.

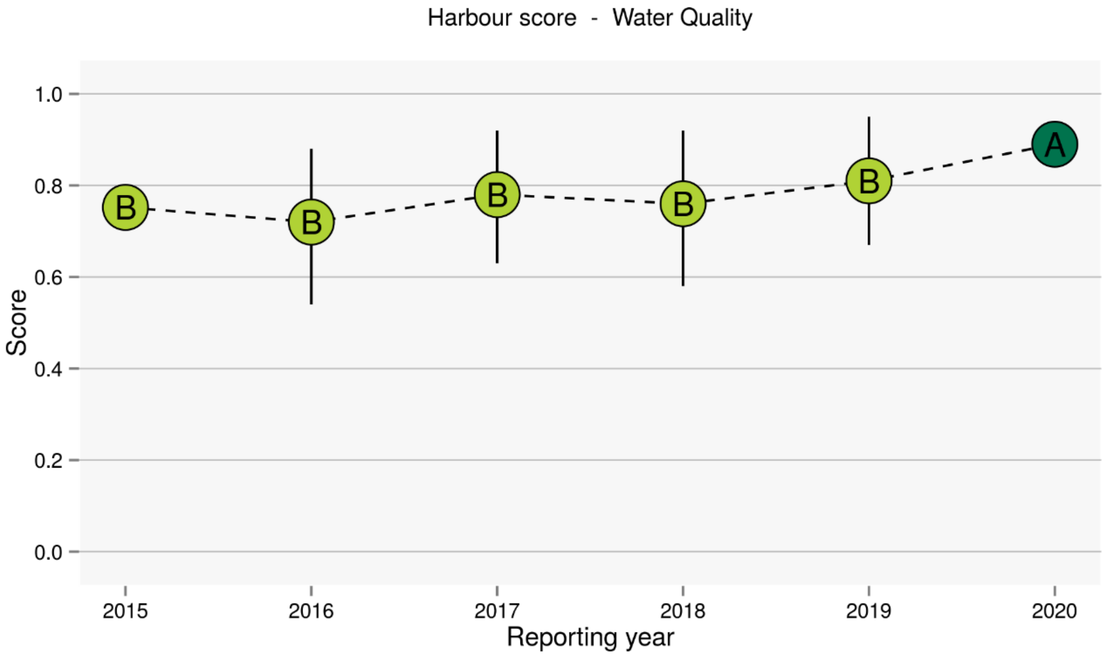


Figure 3.1: Trends in the harbour score for water quality, 2015 – 2020 (Error bars show 95% bootstrap confidence intervals).

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

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

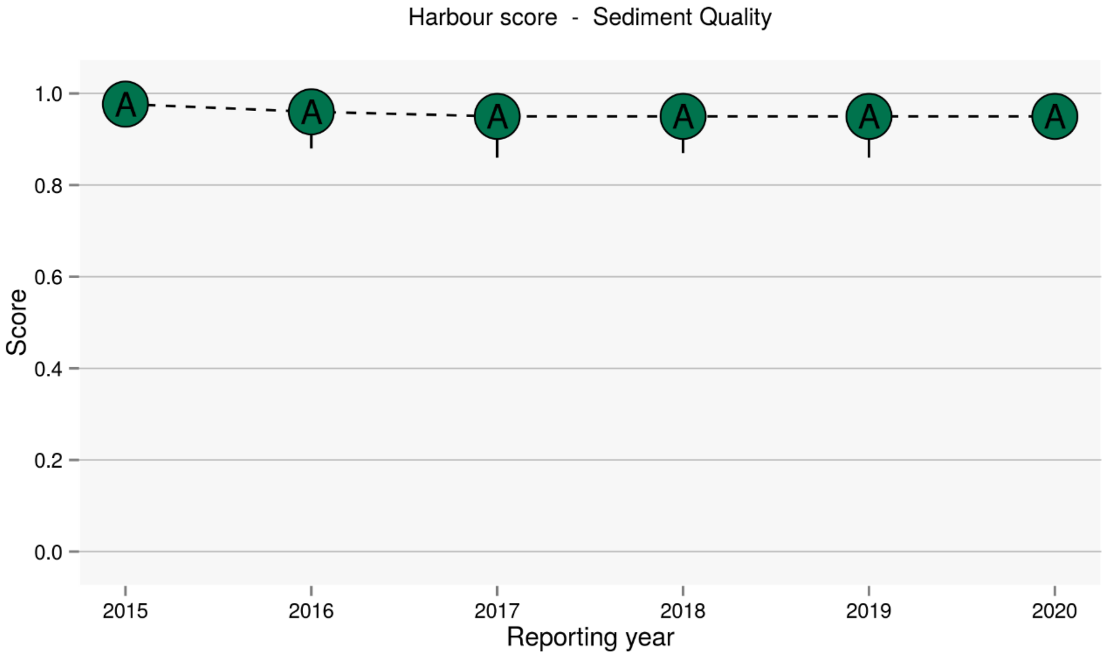


Figure 3.2: Trends in the harbour score for sediment quality, 2015 – 2020 (Error bars show 95% bootstrap confidence intervals).

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

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:

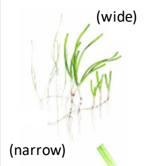
Zostera muelleri ssp. *capricorni*
Halophila ovalis
Halophila decipiens
Halophila spinulosa
Halodule uninervis (wide and narrow leaf)

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 both seagrass growth and the size and extent of seagrass meadows. This is due to a decrease in available light and the effects of sediments settling on seagrass leaves. In Gladstone Harbour, increases in turbidity may be associated with flooding, large tidal movements or dredging. At a local scale, dredging can impact seagrasses in several ways. Dredging can increase turbidity, directly remove seagrass, bury seagrass in dredge spoil, and destabilise the seafloor allowing for resuspension of sediments (York & Smith, 2013). While a number of factors can negatively impact seagrass growth, McCormack et al. (2013) indicated environmental conditions are key influences on seagrass meadow condition in Gladstone Harbour.

Information within the following sections are drawn from a seagrass monitoring project that commenced in 2002 (Carter et al., 2020; Smith et al., 2020), 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 GPC commissioned a fine-scale survey of seagrass within the Gladstone Port Limits (Rasheed et al., 2003). This baseline survey identified large areas of seagrass within the Gladstone Port Limits.

The annual seagrass monitoring program started in 2004 and currently assesses 14 representative intertidal and shallow subtidal seagrass meadows in Gladstone Harbour and Rodds Bay (Figures 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:

- **Biomass** – changes in average above-ground biomass within a monitoring meadow
- **Area** – changes in the total area of a monitoring meadow
- **Species composition** – changes in the relative proportions of species within a monitoring meadow

Why species composition is important

Figure 3.3: Seagrasses at low tide.

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

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

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

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

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

Biomass and species composition

Above-ground biomass was 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 10.7®. For each meadow a mapping precision estimate ranging from ≤10 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 2019 (Source: Smith et al., 2020).

Mapping precision	Mapping method
<10 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., 2015a).

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

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

Table 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., 2020).

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

3.2.4. Seagrass results

The overall score in the 2020 reporting year was 0.79 (B), indicating a good overall condition for seagrass. This is the second year of considerable recovery from the overall poor condition observed from 2015 to 2018. Moreover, the overall seagrass condition in 2020 was the best in the past decade (Carter et al., 2020). At the zone level, overall condition scores improved at six of the seven monitoring zones from the previous report card. The same six zones were graded good or very good, with Rodds Bay monitoring meadows in very good condition for the first time since 2009. Only the Mid Harbour showed a decreased seagrass score compared to the previous year. Overall, 13 of the 14 monitored meadows were in satisfactory, good or very good condition (Table 3.9). Nine of these meadows improved to pre-2010 condition, thus showing substantial recovery from the large-scale seagrass losses associated with flooding in the 2010–2011 period.

Table 3.9: Seagrass sub-indicator, overall meadow, zone and harbour scores for the 2020 Gladstone Harbour Report Card. Overall zone and harbour scores from 2019 and 2018 are shown for comparison. Please note, scores may differ by ±0.01 to those reported by Smith et al. (2020) due to bootstrapping used to calculate GHHP report card scores (see Logan et al., 2016).

Zone	Meadow	Biomass	Area	Species composition	Overall meadow	2020	*2019*	*2018*
1. The Narrows	21	0.90	0.97	0.97	0.90	0.90	*0.71*	*0.42*
3. Western Basin	4	1.00	0.91	0.96	0.91	0.80	*0.69*	*0.45*
	5	0.92	0.92	0.89	0.91			
	6	0.91	0.90	0.80	0.85			
	7	0.73	0.73	1.00	0.73			
	8	0.91	0.82	0.60	0.71			
	52–57	0.72	1.00	1.00	0.72			
5. Inner Harbour	58	0.70	0.97	0.74	0.70	0.70	*0.21*	*0.09*
8. Mid Harbour	43	0.31	0.95	0.58	0.31	0.43	*0.52*	*0.46*
	48	0.75	0.91	0.33	0.54			
9. South Trees Inlet	60	1.00	1.00	0.99	1.00	1.00	*0.89*	*0.85*
13. Rodds Bay	94	1.00	0.86	1.00	0.86	0.90	*0.49*	*0.10*
	96	1.00	1.00	0.96	0.99			
	104	0.91	0.85	0.95	0.85			
Harbour score						0.79	*0.59*	*0.40*

Zone 1 – The Narrows

The Narrows has one monitored meadow at Black Swan Island, an intertidal meadow with variable biomass. The overall score for this meadow was 0.90 (A), having improved for the second consecutive year since the poor condition in 2018. Moreover, an overall very good seagrass condition was last observed in The Narrows in 2009. Improvements from the previous year were driven by increases in seagrass biomass—which more than doubled—and presence of the historically dominant species, *Z. muelleri*. Species composition was in very good condition, with *Z. muelleri* accounting for 96% of the mean biomass.

Zone 3 – Western Basin

Western Basin contains six monitored seagrass meadows, five of which are intertidal and one subtidal (Meadow 7). In 2020 the overall zone score improved compared to the previous year and was graded as good (0.80, B). All six monitored meadows in Western Basin showed a good or very good seagrass condition. When compared to 2019 results, Meadows 4, 5, 6 and 8 showed improved scores. This was largely driven by an increased presence of historically persistent species (*Z. muelleri*) and/or increases in area. The two remaining meadows had lower scores than the previous year due to condition declines in biomass and area (Meadow 7) and biomass only (Meadow 52-28).

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 good condition (0.70, B), a marked improvement from the poor to very poor condition of the past six years. In 2020 all three sub-indicators showed a condition improvement compared to the previous year. The greatest improvements were shown in area and biomass, with the former at near record levels (0.97, A) and the latter in a good condition (0.70, B). Species composition was also in good condition (0.74, B), with *Z. muelleri* accounting for 48% of the meadow area.

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 declined from satisfactory to poor (0.31, D). Despite an increase in area at Meadows 43 and 48—both of which were in very good condition (A)—biomass and species composition scores resulted in overall poor (0.31, D) and satisfactory (0.54, C) conditions respectively. At Pelican Banks, biomass was poor for the third consecutive year and below the baseline value since 2011. Although showing a decline from 2019, biomass was good (0.75, B) at Meadow 48; however, species composition received the lowest score (0.33, D) for the third consecutive year. The higher prevalence of smaller, colonising species (*H. spinulosa* and *H. ovalis*) of seagrass has resulted in a satisfactory or lesser condition at Meadow 48 since 2013.

Zone 9 – South Trees Inlet

This zone has one monitored meadow which sits off the northern tip of South Trees Island. Meadow 60 is an intertidal meadow and the second smallest of the monitored meadows. The overall condition of this meadow remains very good (1.00, A), with all three sub-indicators in very good condition for the third consecutive year. This marks the fourth year of improved seagrass condition from the overall poor condition (0.48, D) in 2016. Area has remained above the baseline value (~6 ha) for the sixth consecutive year and species composition has remained very good (>80% of the dominant species *Z. muelleri*) for the fourth consecutive year. Biomass was also very good and well above the baseline—about twice the highest recorded biomass since monitoring began in 2002.

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 very good (0.90, A) in 2020, having improved for the second consecutive year from a very poor (0.10, E) condition in 2018. All three sub-indicators showed score improvements at all three meadows, with Meadows 94 and 104 also demonstrating grade changes. The three sub-indicators also showed similar patterns among zones: biomass was at record or near record levels, the score for area improved for the fourth consecutive year and species composition was dominated by *Z. muelleri* (at or near 100%). Biomass was at record levels for Meadow 94 and Meadow 96, with the latter also demonstrating a record high for area.

3.2.5. Seagrass conclusions

The overall condition of monitored seagrass meadows in Gladstone Harbour was good in the 2020 reporting year and the best in the past decade of monitoring. For the second consecutive year, the overall seagrass condition has improved from the poor condition of 2015 to 2018. Nine meadows improved to pre-2010 conditions illustrating a marked recovery across the majority of monitoring zones (Table 3.10). Even on a smaller timescale, overall condition scores improved at six of the seven monitoring zones from the previous report card. Rodds Bay and Inner Harbour showed the greatest overall improvement with very good condition for the first time since 2009. 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). Both 2018 and 2019 (preceding years to the most recent report cards) showed below average rainfall and minimal discharge form the Calliope River (Figures 6.4 and 6.7; GHHP, 2019). In the past decade, flow from the Calliope was lowest in 2019 and the second lowest in 2018 (Carter et al., 2020). Dry, benign weather conditions cause an increase in benthic light, which has created ideal conditions for seagrass growth in Gladstone Harbour. Slightly below-average daytime tidal exposure this reporting year likely provided further protection from extreme desiccation and thermal stress for the region's intertidal seagrasses (e.g. Chartrand et al. 2019; Unsworth et al. 2012 as cited in Carter et al., 2020). There has been a general trend in improvement in seagrass meadows along Queensland's east cost between Cairns and Port Curtis since widespread losses in 2009 and 2010 (Smith et al., 2020). However, recovery has varied by location, local climate events and the severity of the initial seagrass losses. For instance, Townsville meadows were quick to recover from initial losses in 2009, however, showed declines in the most recent reporting year due to severe localised flooding (e.g. Bryant et al., 2019 as cited in Smith et al., 2020). Other areas suffered setback due to other weather events (e.g. TC Debbie) at different times, although the past two years have demonstrated general improvement in seagrass meadows across Queensland's east coast. In context with the state, Gladstone Harbour zones had some of the best seagrass conditions and recovery in the 2020 reporting year (Smith et al., 2020).

The exception to recovery in Gladstone Harbour was the Mid Harbour, which showed a poor and slightly declined condition compared to the previous year. The poor condition results from significant losses in biomass at Pelican Banks and declining species composition since 2015. As there are no obvious differences in environmental factors or anthropogenic activity, the condition in the Mid Harbour may have resulted from grazing pressure. Dugong feeding trails were observed during every survey in the zone in November 2019 and in a previous study which examined dugong feeding patterns in Port Curtis (Rasheed et al. 2017). While it is unclear if there is an increase in grazing pressure at Pelican Banks, overgrazing from dugongs and turtles may be inhibiting this meadow's recovery.

In 2009 and 2010, Rodds Bay seagrass meadows were severely impacted by flooding events (Table 3.10). By 2011, there was a complete loss of all three monitoring meadows. Seagrass recovery at Rodds Bay has been slow compared to other zones, however, the most recent two years have shown a dramatic improvement in condition—from very poor in 2018 to very good in 2020. This was the first time since 2009 that seagrass condition was very good at Rodds Bay. Biomass was at record levels for

Meadow 94 and Meadow 96, with the latter also demonstrating a record high for area. While the initial re-establishment of seagrass meadows was lengthy at Rodds Bay, results indicate the overall meadow condition can quickly return under favourable growing conditions.

Seagrass meadows in Gladstone Harbour started 2020 with a high level of resilience to external pressures, both natural or planned maintenance and capital dredging. Notable improvements in biomass and species composition provide a strong foundation to deal with future pressures. Meadows in the harbour are likely to have preserved and replenished their seedbanks, further strengthening their resilience and recovery capacities (e.g. Reason et al., 2017 as cited in Smith et al., 2020). If favourable environmental conditions remain, it is expected that seagrass condition would be maintained in Gladstone Harbour zones in the 2021 reporting year.

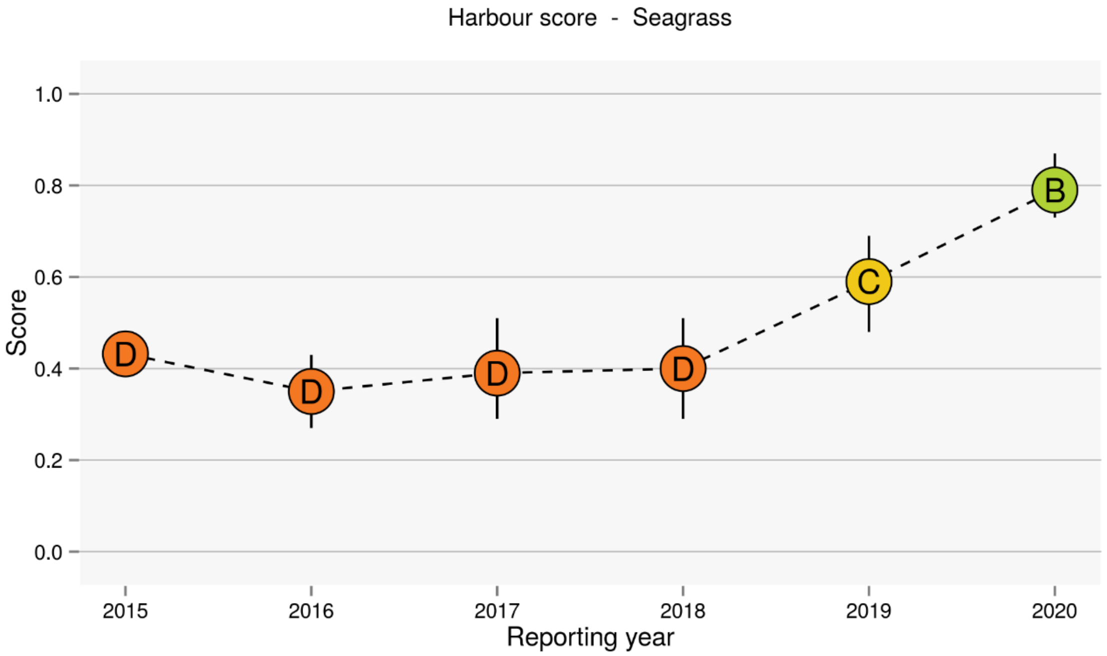


Figure 3.4: Trends in the harbour score for seagrass, 2015 – 2020 (Error bars show 95% bootstrap confidence intervals).

Table 3.10: Grades for individual seagrass monitoring meadows from annual (November) surveys, 2002–2019 (Source: Carter et al., 2019). Please note, report card and monitoring years differ (e.g. 2020 Report Card = 2019 monitoring). Grades for 2019 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
1. The Narrows	**21**								A	B	B	C	E	D	D	C	D	B	A
3. Western Basin	**4**	B		C	D	B	A	B	A	E	D	B	D	D	C	B	D	C	A
	5	C		D	C	B	B	A	C	D	D	C	E	D	D	C	C	C	A
	6	B		D	C	B	A	B	A	E	D	D	D	B	B	B	D	C	A
	7	B		B	E	A	D	B	D	E	E	E	D	B	B	D	E	A	B
	8	A		D	E	B	B	B	B	C	E	D	E	D	D	E	D	D	B
	52-57*								C	E	E	B	B	C	D	B	B	A	B
5. Inner Harbour	**58**	B		D	B	D	B	B	B	E	D	C	E	D	D	D	E	E	B
8. Mid Harbour	**43**	B		B	B	C	C	A	B	B	C	C	C	C	D	E	D	D	D
	48	B		C	B	B	A	B	E	D	D	D	C	D	D	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
13. Rodds Bay	**94**	A		D	A	B	A	A	E	E	E	E	E	D	E	E	E	C	A
	96	B		D	C	B	A	A	B	D	E	D	E	D	D	D	E	B	A
	104	B		D	B	B	B	A	C	E	E	E	E	C	D	E	E	D	A

3.2.6. Seagrass addendum

Gladstone Healthy
Harbour Partnership

Independent Science Panel

7 September 2021

Error in calculation of 2020 seagrass biomass scores addendum

In March 2021, the TropWATER JCU team reached out to Gladstone Healthy Harbour Partnership to inform of a calculation error in the 2020 seagrass biomass scores. As this was a particularly good year for seagrass in Gladstone harbour, the error in calculation in biomass scores was not picked up during the analysis and subsequent reporting.

The overall conclusions presented in the 2020 seagrass summary report and 2020 technical report remain the same—with the seagrass indicator receiving a good overall condition (B grade). The reported very high biomasses and the trends and meadow grades are unchanged for almost all monitoring meadows. There was however a minor score change for the seagrass indicator and some score changes at the zone level when the error in calculation was corrected:

Zone level

- **The Narrows** – score decrease by 10 points (*please note this is a single meadow zone*)
- **Western Basin** – score increase by 1 point
- **Inner Harbour** - score unchanged
- **Mid Harbour** – score decrease by 1 point
- **South Trees Inlet** – score decrease by 1 point
- **Rodds Bay** – score decrease by 3 points

Indicator level

- **Seagrass** – score decrease by 2 points

Indicator group level

- **Habitats** – score unchanged*

Component level

- **Environment** – score unchanged*

The TropWATER JCU team have updated their quality assurance/quality control checks so that this error cannot occur again. The team have also confirmed this was an isolated occurrence in 2020.

The Gladstone Healthy Harbour Partnership would like to inform the public of this error for transparency, accuracy, and accountability.

*Based on corrected scores for both seagrass and coral indicators

3.2.7. Corals

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

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

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

Four sub-indicators of coral health were measured to calculate the coral score for the 2020 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.

3.2.8. 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 30 April 2020 and included the following three methodologies:

1. Photo point intercept transects

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

2. Juvenile corals

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

3. Disturbances

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

3.2.9. 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.

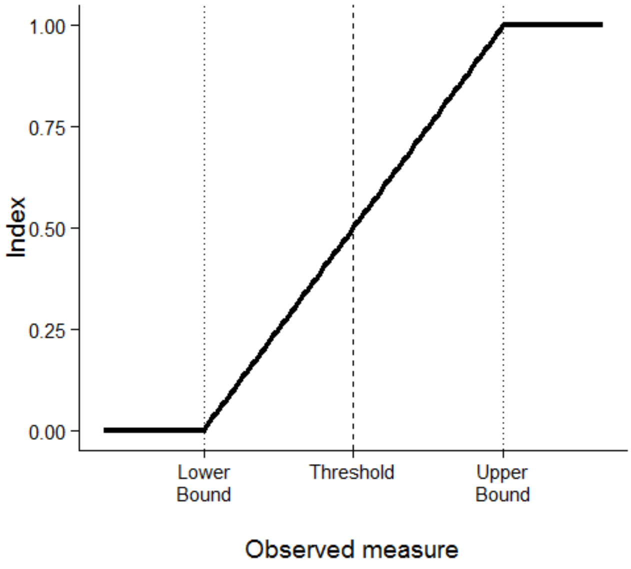


Figure 3.5: Generic scoring of the coral sub-indicators based on the threshold and bounds outlined in Table 3.11.

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.

3.2.10. Coral results

The overall grade for the 2020 report card was an E (0.14) for the third successive 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. Coral cover (0.08, E) received an identical score to 2019 while juvenile density (0.12, E) declined and macroalgae cover (0.07, E) slightly improved. The overall score for change in hard coral cover remained poor (0.28, D), however, this was a decrease compared to the previous year. Both the Mid Harbour and the Outer Harbour demonstrated very poor coral condition and received scores of 0.21 and 0.08 (E) respectively (Table 3.12). In comparison with 2019 scores, the overall score of the Mid Harbour marginally improved while the Outer Harbour 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 2020, four reefs showed marginally higher coral cover compared to the previous year. Scuba surveys at Facing Island and Seal Rocks South, both of which showed a decline, indicated that bio-eroding sponges continue to negatively impact coral colonies at these reefs. Although minor fluctuations in scores have occurred since GHHP monitoring began in 2015, all six monitored reefs had very poor coral cover scores for the sixth 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 2020, macroalgal cover condition was very poor (0.07, E), showing a slight improvement from the 2019 score (0.02, E). Rat Island (0.60, C) was the only reef that scored above 0.00 (Table 3.13) for the second consecutive year and has shown the greatest variation since 2015 (Table 3.14). Despite improvements (i.e. a decline) in macroalgae cover at five of the six reefs from the previous year, this sub-indicator was graded E for the sixth consecutive year. Macroalgae communities in the Outer Harbour continue to be dominated by brown macroalgae, *Sargassum* and *Lobophora*. Species composition in the Mid Harbour has continued to be more variable, with communities at Rat Island and Farmers Reef dominated by the red macroalgae *Asparagopsis* and Facing Island dominated by the brown macroalgae *Sargassum*. Manning Reef was primarily composed of brown macroalgae.

The size for juvenile corals can indicate their age as corals spawn annually. Juvenile coral colonies in the 0–2 cm range can broadly be considered a result of the previous spawning event. Juvenile coral colonies in the 2–5 cm range are estimated to be between one and two years old. For the second year since monitoring began in 2015, juvenile density was in very poor condition (0.12, E) at the harbour level (Table 3.12)—a further decline from the 2019 score of 0.23 (E). Scores for juvenile coral density were predominantly very poor at the reef level, with only Farmers Reef receiving a poor score (0.30, D). Despite slightly more juvenile corals per square metre at four of the six reefs, these improvements were insufficient to offset sharp declines at Facing Island and Seal Rocks South, the latter of which resulted in the decreased overall juvenile density shown in 2020. Of note was the general absence of the fast-growing, branching corals of the family Acroporidae across the harbour.

The overall change in hard coral cover score remained poor (0.28, D), however, showed a decrease when compared to the overall score in 2018 (0.41, D). Please note that years in which a disturbance occurs (such a bleaching events) are excluded for score calculation of this sub-indicator. As bleaching was evident at Seal Rocks, the decline in coral cover at Seal Rocks South and very minor increase at Seal Rocks North were not accounted for the overall change in hard coral cover score in 2020.

Table 3.12: Coral sub-indicator scores for the Mid Harbour and Outer Harbour and overall zone and harbour scores (Costello et al., 2020).

Zone	Coral cover	Macroalgal cover	Juvenile density	Change in hard coral cover	Overall score
8. Mid Harbour	0.09	0.15	0.15	0.44	0.21
11. Outer Harbour	0.08	0.00	0.08	0.13	0.07
Harbour score	**0.08**	**0.07**	**0.12**	**0.28**	**0.14**

Table 3.13: Individual coral sub-indicator values and scores by reef (Costello et al., 2020).

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	9.13	0.11	48.50	0.00	0.63	0.00	-4.38	0.67
Farmers Reef	5.89	0.07	23.29	0.00	3.90	0.30	2.37	0.46
Manning Reef	1.25	0.02	60.13	0.00	1.77	0.08	0.62	0.31
Rat Island	11.63	0.15	12.25	0.60	3.09	0.22	0.62	0.31
11. Outer Harbour								
Seal Rocks North	1.90	0.02	66.24	0.00	1.08	0.01	0.89	0.25
Seal Rocks South	10.13	0.13	43.00	0.00	2.47	0.15	-0.63	0.00

3.2.11. Coral conclusions

The overall score for corals remained very poor (0.14, E) in 2020 (Figure 3.6; Table 3.12). Although coral cover was broadly consistent to previous years and macroalgal cover showed a slight improvement since 2019, juvenile density and change in hard coral cover scores decreased considerably compared to 2019 (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 (Costello et al., 2020). 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. 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 (Costello et al., 2020). The poor to very poor scores for change in hard coral cover are also likely to be influenced by coral-macroalgae interactions, as genera such as *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 Costello et al., 2020). 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). High water temperatures in early 2020 were an additional hindrance to coral recovery. This was particularly evident at the two Outer Harbour reefs, which showed numerous colonies of fast-growing corals (*Acroporidae* and *Pocilloporidae*) were at least partially bleached. Although in low densities, the presence of *Acropora* juveniles remains an encouraging sign as these species were widespread on the reefs prior to flooding in 2013 and key to their recovery. Improvements in macroalgae scores at most reefs were also promising, however, these improvements were still well below the threshold to receive a satisfactory score and, in most cases, score better than 0.00. At present, the reefs in Gladstone Harbour remain dominated by the presence of brown and red macroalgae.

In the broader context of inshore reefs on the Great Barrier Reef, the coral communities in Gladstone Harbour score poorly compared with other reefs monitored by the MMP. Reefs monitored by GHHP were most similar to severely impacted reefs, such as Peak and Pelican islands (Keppel Bay) and Daydream and Double Cone islands (the Whitsundays), or incipient reefs which have never shown well developed coral communities, such as King Reef. Keppel Bay inshore reefs were most impacted by the

2011 flood while those in the Whitsundays were impacted by TC Debbie in 2017. These coral communities, along with those in Gladstone Harbour, shared characteristics such as low coral cover, high macroalgae cover or a combination of the two (Costello et al., 2020). Of concern, is that reefs at Peak and Pelican islands have shown negligible recovery since the 2011 floods.

Corals in Gladstone Harbour were in very poor condition and demonstrated limited recovery potential in 2020. 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—settlement and growth rates of coral larva are likely to be low if the high macroalgal cover and its associated negative pressures persist.

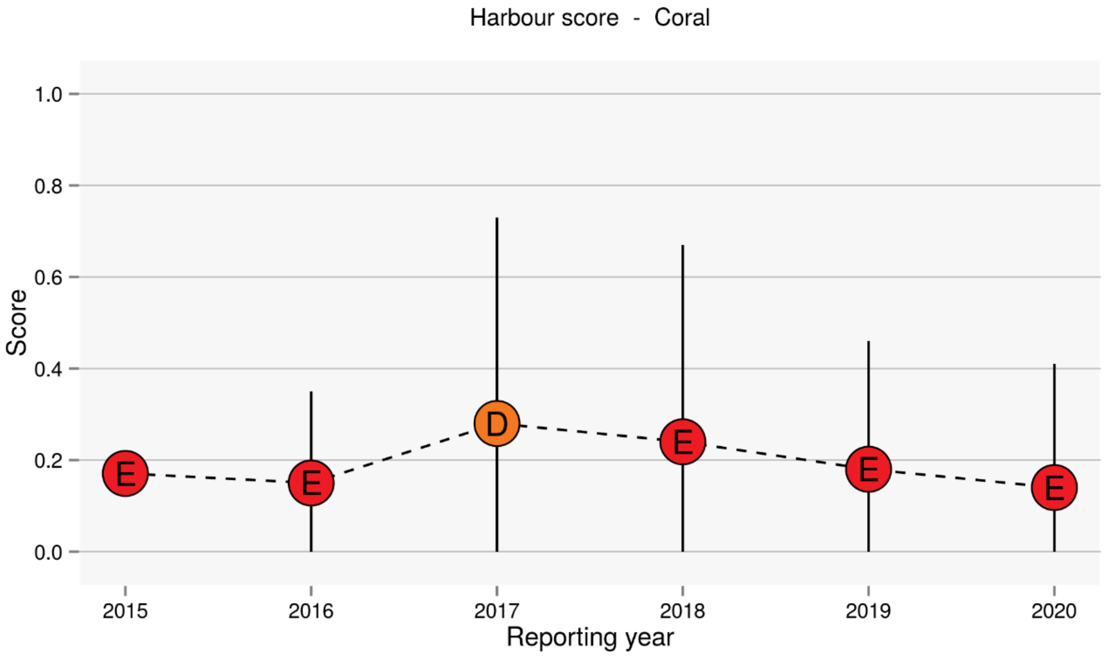


Figure 3.6: Trends in the harbour score for coral, 2015 – 2020 (Error bars show 95% bootstrap confidence intervals).

Table 3.14: A comparison of coral sub-indicator scores for the Mid Harbour and Outer Harbour for surveys conducted from 2015 to 2020 (Costello et al., 2020).

Zone	Reef	Year	Scores Coral cover	 Macroalgal cover	 Juvenile density	 Change in hard coral cover	Reef Score
8. Mid Harbour	Facing Island	2015	*0.16*	*0.00*	*0.41*		*0.19*
		2016	*0.08*	*0.00*	*0.46*		*0.18*
		2017	*0.12*	*0.00*	*0.25*	*0.50*	*0.22*
		2018	*0.11*	*0.46*	*0.16*	*0.33*	*0.27*
		2019	*0.17*	*0.00*	*0.16*	*0.67*	*0.25*
		2020	0.11	0.00	0.00	0.67	0.20
	Farmers Reef	2015	*0.06*	*1.00*	*0.26*		*0.44*
		2016	*0.09*	*0.00*	*0.39*		*0.16*
		2017	*0.09*	*0.95*	*0.53*	*0.50*	*0.52*
		2018	*0.04*	*0.17*	*0.53*	*0.33*	*0.27*
		2019	*0.04*	*0.00*	*0.31*	*0.13*	*0.12*
		2020	0.07	0.00	0.30	0.46	0.21
	Manning Reef	2015	*0.00*	*0.00*	*0.12*		*0.04*
		2016	*0.00*	*0.00*	*0.33*		*0.11*
		2017	*0.01*	*0.00*	*0.22*	*0.51*	*0.18*
		2018	*0.00*	*0.00*	*0.40*	*0.27*	*0.17*
		2019	*0.01*	*0.00*	*0.17*	*0.29*	*0.12*
		2020	0.02	0.00	0.08	0.31	0.10
	Rat Island	2015	*0.08*	*0.50*	*0.11*		*0.23*
		2016	*0.07*	*0.29*	*0.46*		*0.27*
		2017	*0.08*	*1.00*	*0.31*	*0.24*	*0.41*
		2018	*0.09*	*1.00*	*0.28*	*0.26*	*0.41*
		2019	*0.14*	*0.09*	*0.31*	*0.59*	*0.28*
		2020	0.15	0.60	0.22	0.31	0.32
11. Outer Harbour	Seal Rocks North	2015	*0.00*	*0.00*	*0.42*		*0.14*
		2016	*0.00*	*0.00*	*0.47*		*0.16*
		2017	*0.01*	*0.00*	*0.36*	*0.25*	*0.15*
		2018	*0.01*	*0.00*	*0.42*	*0.34*	*0.19*
		2019	*0.01*	*0.00*	*0.19*	*0.46*	*0.17*
		2020	0.02	0.00	0.01	0.25	0.07
	Seal Rocks South	2015	*0.10*	*0.00*	*0.25*		*0.12*
		2016	*0.17*	*0.00*	*0.32*		*0.16*
		2017	*0.12*	*0.00*	*0.51*	*0.50*	*0.28*
		2018	*0.09*	*0.00*	*0.48*	*0.33*	*0.22*
		2019	*0.14*	*0.00*	*0.26*	*0.33*	*0.18*
		2020	0.13	0.00	0.15	0.00	0.07

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

Table 3.15: Causes of coral mortality at time of survey. Survey area of 200 m^2 at each reef. Data from 2019 included for comparison. No data are included for Manning Reef as ongoing mortality was absent in 2020. Bio-eroding sponge is primarily *Cliona orientalis* (Costello et al., 2020). Minimal bleaching was noted via correspondence with project team. Differentiation of bleaching level not included in project report although data was captured to classify disturbance (bleaching) level.

Reef	Year	Damage	Genus	Colonies affected
Facing Island	2019	Bio-eroding sponge	*Porites*	17
	2020	Bio-eroding sponge	*Porites*	22
		Minimal bleaching		
Farmers Reef	2019	Bio-eroding sponge	*Cyphastrea*	5
			Turbinaria	1
	2020	Bio-eroding sponge	*Cyphastrea*	7
		Minimal bleaching		
Rat Island	2019	Bio-eroding sponge	*Cyphastrea*	6
			Plesiastrea	2
			Turbinaria	2
	2020	Bio-eroding sponge	*Cyphastrea*	8
			Favites	1
			Plesiastrea	1
			Turbinaria	4
		Black Band Disease	*Turbinaria*	1
		Minimal bleaching		
Seal Rocks North	2020	Bleaching		
Seal Rocks South	2019	Minimal bleaching		
		Bio-eroding sponge	*Turbinaria*	8
	2020	Bio-eroding sponge	*Turbinaria*	9
		Physical		
		Bleaching	*Acropora*	
		Bleaching	*Pocillopora*	
		Bleaching		

3.2.12. Coral addendum

Gladstone Healthy
Harbour Partnership

Independent Science Panel

7 September 2021

Error in calculation of 2020 coral (change in hard coral cover) scores addendum

In July 2021, the AIMS inshore coral team reached out to Gladstone Healthy Harbour Partnership to inform of a calculation error in the 2020 coral (change in hard coral cover) scores. This occurrence was due to an issue with the scripting code.

The overall conclusions presented in the 2020 coral report and 2020 technical report remain the same—with the coral indicator receiving a very poor condition (E grade). There was however a minor score change for the coral indicator and score changes at the zone level when the error in calculation was corrected:

Zone level

- **Mid Harbour** – score decrease by 1 point
- **Outer Harbour** – score increase by 7 points

Indicator level

- **Coral** – score increase by 3 points

Indicator group level

- **Habitats** – score unchanged*

Component level

- **Environment** – score unchanged*

The AIMS team have updated the scripting code so this error cannot occur again. Both the AIMS inshore coral and Data and Information Management System teams have also confirmed this was an isolated occurrence in 2020.

The Gladstone Healthy Harbour Partnership would like to inform the public of this error for transparency, accuracy, and accountability.

*Based on corrected scores for both 2020 seagrass and 2020 coral indicators

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 2020 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 2019–20 reporting year (01/07/2019–30/06/2020) 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 2020 reporting year:

- Data collected at the ABT Tournament
- 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.

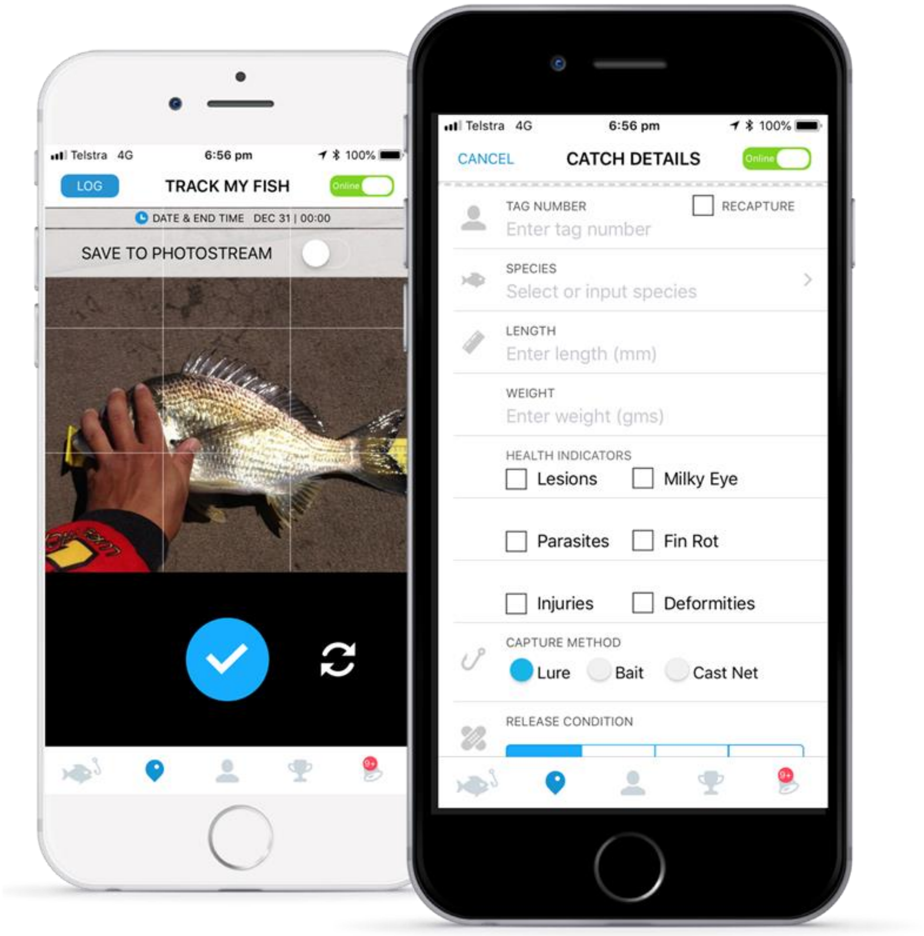


Figure 3.8: Data for the visual fish condition index was collected by fishers using the [Trackmyfish app.]()

Over the course of the study period, 1 July 2019 to 30 June 2020, a total of 1,030 images of the six target species were captured using the Trackmyfish app (Figure 3.9). Human and machine fish visual assessments were made for each condition with close to 100% agreement between the two.

Data for fish body condition was collected by Infofish Australia who undertook line fishing and recorded the length and weight of 27 yellow-finned bream and 70 pikey bream from within Gladstone Harbour. This replaced data collection from the Boyne-Tannum Hook-Up which was cancelled this year owing to COVID-19 restrictions.

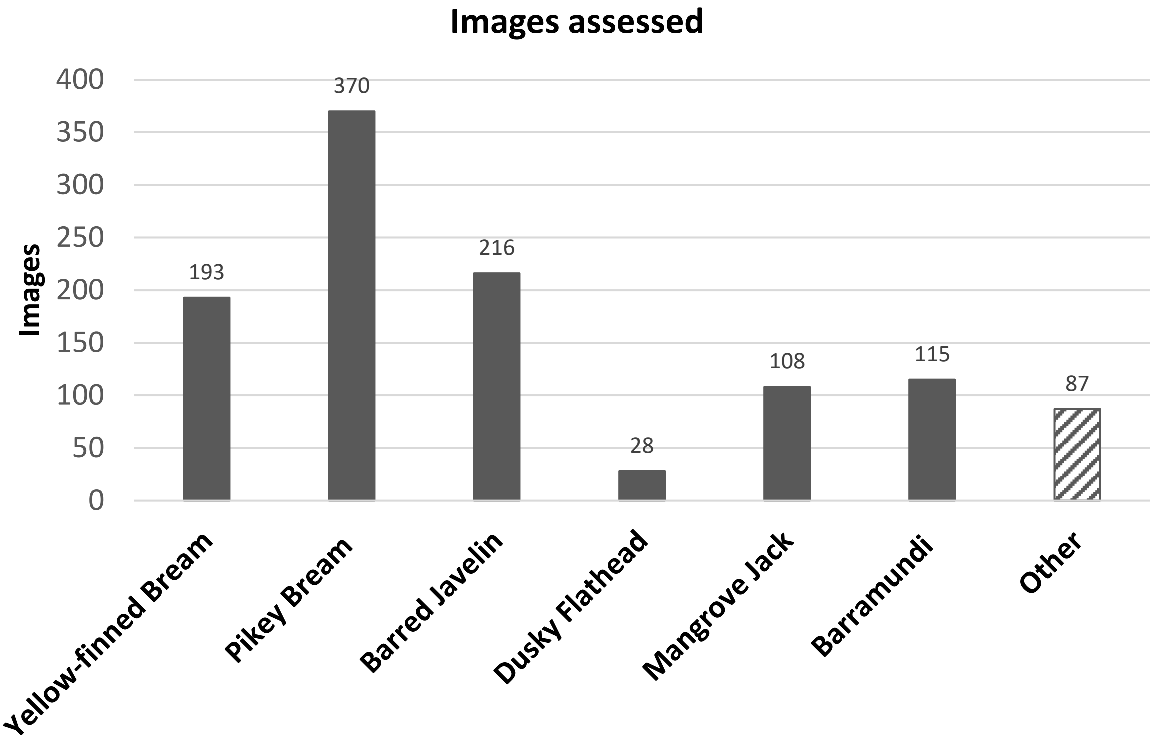


Figure 3.9: Number of images of each of the six target species captured using the Trackmyfish App over the 2020 reporting year.

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 2019-20 reporting year in Gladstone Harbour in Spring 2019. The surveys in Gladstone Harbour were designed to produce an even catch effort across the northern, central and southern areas of the harbour with a focus on inshore and estuarine sites, this included 11 environmental monitoring zones.

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

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

A total of 126 fish 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 fish 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 both external and internal health parameters are assessed. The fish visual assessment is based on external indicators of health only and fish are released alive after processing. The five variable conditions assessed are fins, skin, eyes, parasites, and deformities. All parameters are scored between 0 and 30 depending on the severity of the condition with the most severe conditions receiving the highest score (Table 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 2020.

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., 2017) 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 2020 report card were calculated using data from Spring 2019 as follows:

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

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

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

Table 3.16: Scoring for nine variable conditions used in the health assessment index in 2020 (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 2020 was 0.69 (B), made up from a visual fish condition score of 0.72 and an overall score of 0.67 for the health assessment index. For both studies the overall harbour score is applied to each of the 13 environmental monitoring zones and indicates good fish health across the harbour.

Visual fish condition

The overall score for visual fish condition was 0.72 (B) comprised of an overall harbour score for fish visual assessment of 0.98 (A) and a score of 0.46 (D) for fish body condition. All species assessed for fish visual assessment received a very good score ranging from 0.97 to 0.99. While all species received very good scores for FVA, there was no data for FBC for four species: barred javelin, dusky flathead, mangrove jack, and barramundi. Hence these species were not used in the calculation of either the fish visual assessment or overall visual fish condition scores. Those scores were based entirely on the scores received for yellow-finned bream and pikey bream (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 2019–20 reporting year.

Fish Species	Fish visual assessment	Fish body condition	Visual fish condition
Yellow-finned bream	0.97	0.44	0.71
Pikey bream	0.99	0.48	0.74
Barred javelin*	0.97	NA	NA
Dusky flathead*	0.98	NA	NA
Mangrove jack*	0.98	NA	NA
Barramundi*	0.98	NA	NA
Harbour score			**0.72**

*Not used in the calculation of the overall score

Overall detection of visible pathologies was low, with no incidence of parasites or deformities detected and only one incidences of eye health issues detected (Table 3.18). For all species, the most detected condition was fins where detection ranged from 11% in dusky flathead to 40% in mangrove jack. However, the recorded severity of the condition was low. Skin was the next most recorded condition, although both the detection rate and severity were low (Table 3.19 & 3.20).

Table 3.18: Number of visual fish health incidences detected and species scores for six species of fish in the 2019–20 reporting year.

Species	N	Fins	Skin	Eyes	Parasites	Deformities
Yellow-finned bream	193	55 (29%)	2 (1%)	0	0	0
Pikey bream	370	68 (18%)	9 (2%)	0	0	0
Barred javelin*	216	83 (38%)	0	0	0	0
Dusky flathead*	28	3 (11%)	0	0	0	0
Mangrove jack*	108	43 (40%)	0	0	0	0
Barramundi*	115	22 (19%)	1 (1%)	1 (1%)	0	0
Total	1117	292 (26%)	12 (1%)	1 (0.1%)	0	0

*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 2019–20 reporting year.

Condition (Score)	No active erosion (0)	Light active erosion (10)	Moderate active erosion with some haemorrhage (20)	Severe active erosion with some haemorrhage (30)	N
Species					
Yellow-finned bream	138 (71%)	50 (26%)	5 (3%)	0	193
Pikey Bream	302 (82%)	62 (16%)	6 (2%)	0	370
Barred javelin*	133 (62%)	76 (35%)	6 (3%)	0	215
Dusky flathead*	25 (89%)	3 (11%)	0	0	28
Mangrove jack*	65 (60%)	43 (40%)	0	0	108
Barramundi*	93 (81%)	22 (19%)	0	0	115

*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 2019–20 reporting year.

Condition (Score)	Normal no aberrations (0)	Mild skin aberrations (10)	Moderate skin aberrations (20)	Severe skin aberrations (30)	N
Species					
Yellow-finned bream	191 (99%)	2 (1%)	0	0	193
Pikey bream	361 (97%)	8 (2%)	1 (1%)	0	370
Barred javelin*	216 (100%)	0	0	0	216
Dusky flathead*	28 (100%)	0	0	0	28
Mangrove jack*	108 (100%)	0	0	0	108
Barramundi*	114 (99%)	1 (1%)	0	0	115

*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 two fish species caught in Gladstone Harbour in June 2020 (Table 3.21). Weight (g) and length (mm) was recorded for 97 fish, 70 pikey bream and 27 yellow-finned bream, and the relative condition factor score was calculated for each species by comparing this data to the historic mean. This mean was derived from historic data recorded during the Boyne-Tannum Hook-Up from 2003 to 2018; data was available for all years except 2009 and 2011.

The overall score for fish body condition was 0.46 (D) a result of both species assessed pikey bream (0.48) and yellow-finned bream (0.44) having poor scores. This indicates that in 2020, the mean fish body condition was below the long-term average (2003 – 2019) for each species (Figure 3.10).

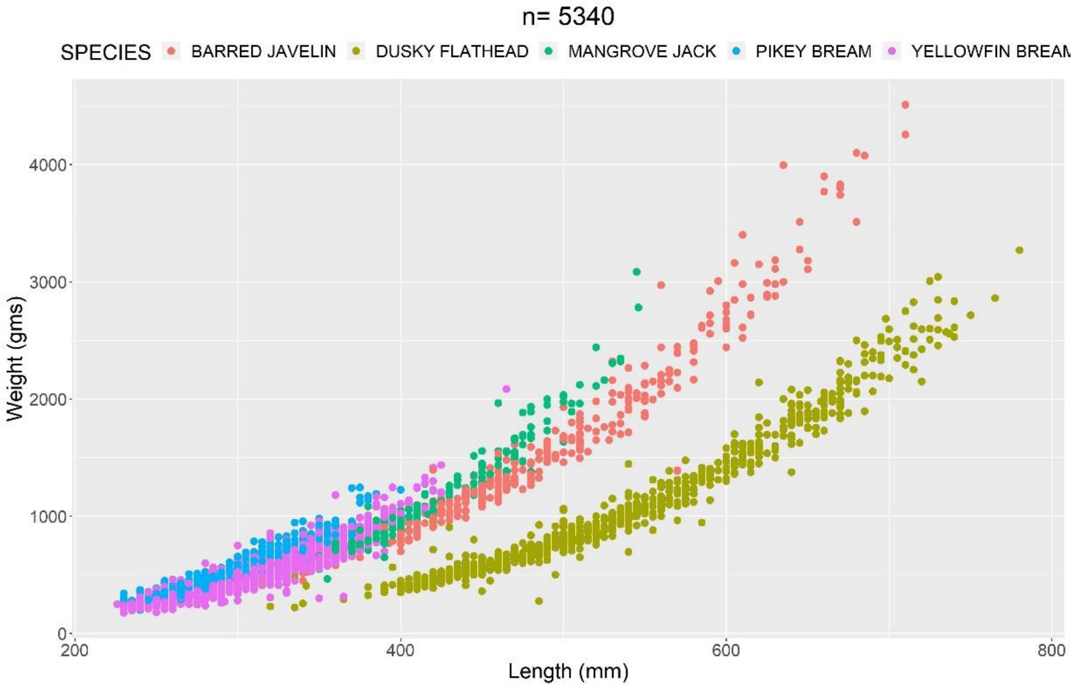


Figure 3.10: Length weight relationship for five fish species from the Boyne-Tannum Hook-Up from 2003 – 2019.

Table 3.21: Relative condition factor calculated for two species in 2020.

Species	(N)	Relative condition factor			
		Min	Max	Mean	Historic mean
Yellow-finned bream	27	0.80	1.22	0.97	1.00
Pikey bream	70	0.81	1.42	0.99	1.01

Health assessment index

The overall health assessment index score was 0.67 (B). One of the three monitored fish species received a good score barred javelin (0.84) and the remaining two species blue catfish (0.61) and barramundi (0.55) received satisfactory 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 1.82 for barramundi. The highest score (poorest health) in all species was for the liver, although barramundi had identical scores for liver and parasites.

The percentage of fish with a detectable pathology (any score greater than 0) indicated that there was a greater prevalence of liver or parasite issues than for any other parameter in all species (Table 3.24 and 3.25). Overall, the lowest percentage of detections was for eyes, spleen and hindgut.

Table 3.22: Overall health assessment index scores for five fish species and the overall score for Gladstone Harbour in 2020.

Species	Bream	Barred javelin	Barramundi	Blue catfish	Mullet
Species score	NA	0.84	0.55	0.61	NA
Harbour Score	**0.67**				

Table 3.23: Average measures and health assessment index (HAI) total scores for fish caught in Gladstone Harbour in Spring 2019. Organ scores ranged from 0 to 30 and HAI scores ranged from 0 to a possible maximum of 270.

Taxa / Measure	Barramundi (n = 11)	Bream (n = 0) No score	Barred javelin (n = 31)	Blue catfish (n = 32)	Mullet* (n = 4) No score
Skin	1.82	ND	0	1.25	0
Eyes	0	ND	0	0	0
Fins	2.73	ND	0.32	2.50	0
Gills	2.73	ND	0	0	0
Spleen	0	ND	0	0	0
Kidney	2.73	ND	0.97	5.63	0
Hindgut	0	ND	0	0	0
Liver	13.64	ND	14.52	17.81	7.50
Parasites	13.64	ND	3.55	6.25	0
HAI score	**37.27**	**ND**	**19.35**	**33.44**	**7.50**

* Scores for mullet were not used in the calculation of the final score for HAI owing to the small sample size (n = 4).

Table 3.24: Number of health assessment index positive score (10 – 30) detected for skin, eye, fins and gills for five target groups in the 2020 reporting year.

Species	N	Skin	Eyes	Fins	Gills
Barramundi	11	2 (18%)	0	3 (27%)	2 (18%)
Barred javelin	31	0	0	1 (3%)	0
Blue catfish	32	4 (13%)	0	8 (25%)	0
Mullet	4	0	0	0	0
Total	78	6 (8%)	0	12 (15%)	2 (3%)

Table 3.25: Number of health assessment index positive score (10 – 30) detected for spleen, kidney, hindgut, liver and parasites for five target groups in the 2020 reporting year.

Species	N	Spleen	Kidney	Hindgut	Liver	Parasites
Barramundi	11	0	2 (18%)	0	5 (45%)	9 (82%)
Barred javelin	31	0	1 (3%)	0	15 (48%)	9 (29%)
Blue catfish	32	0	6 (19%)	0	19 (59%)	14 (44%)
Mullet	4	0	1 (16%)	0	2 (33%)	2 (33%)
Total	78	0	10 (13%)	0	41 (53%)	34 (44%)

Overall

The overall score for fish health in 2020 was the aggregation of the two fish health projects (Table 3.26). 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 3.26: Overall fish health scores for Gladstone Harbour in 2020.

Visual fish condition	**Fish health assessment index**	**Overall fish health 2020**
0.72	0.67	**0.69**

3.3.5. Fish health conclusions

Visual fish condition

In 2020 the overall score for visual fish condition was 0.72, however, unlike the previous year the score was based on the results of two species of fish, pikey bream and yellow-finned bream, compared to five species in 2019. This was a result of the cancellation of the Boyne-Tannum Hook-Up which is the primary source of fish body condition data for this sub-indicator. Additionally, owing to the change in the calculation of fish body condition from Fulton's K to a relative condition factor, the results for this metric are not directly comparable with the previous year. Fish visual assessment scores for the two bream species used to calculate the visual fish health score were similar to those recorded in 2019, as were the scores for the three fish species excluded from the overall score calculation.

Noting that different fish species were assessed in the visual fish condition and the fish health assessment index—the overall detection levels for three external variable conditions; skin, eyes and fins (Tables 3.29 and 3.35)—were generally low. The fish visual assessment reported 1% of all fish sampled had a positive score for skin condition, while the health assessment index reported 8% of the total fish sampled had a positive score for skin. Similarly, the fish visual assessment reported 0.1% of fish had a positive score for eyes and the health assessment index reported 0%. However, there was a greater difference with the detection of fin issues (FVA 26% and HAI 15%). The reason for this discrepancy is not clear but could relate to the difference in species composition as fins and other external parameter scores varied between species (Tables 3.18 and 3.24).

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

While both species of bream received very good scores for fish visual assessment (0.97 and 0.99) the scores for fish body condition were poor. This was a result of both species assessed having a mean body condition that was below the long-term average (2003 – 2019). The average length of fish assessed for body condition was lower than the long-term average (Sawynok et al., 2020) which may have skewed the results. It may also be possible that the lower scores for fish body condition this year and in the previous year are also influenced by variation in environmental conditions.

Health assessment index

The overall score for the health assessment index remained good in 2020 (0.67) compared to 0.69 in 2019. However, this was based on a lower sample size derived from one sampling event in Spring 2019 whereas in the previous year Spring and Autumn sampling was conducted.

Owing to both the lower sample size and reduction in species numbers from five in 2019 to three in 2020 the results are not directly comparable to those recorded in the previous year.

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 2019–20 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 2019 and March 2020 (Figure 3.11). The Outer Harbour zone was excluded from the surveys as there were no suitable bream habitats (Table 3.27). Where possible within each zone, a minimum of two sites were selected to cover the upper tidal limit and another selected within the daily tidal 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, 2020).

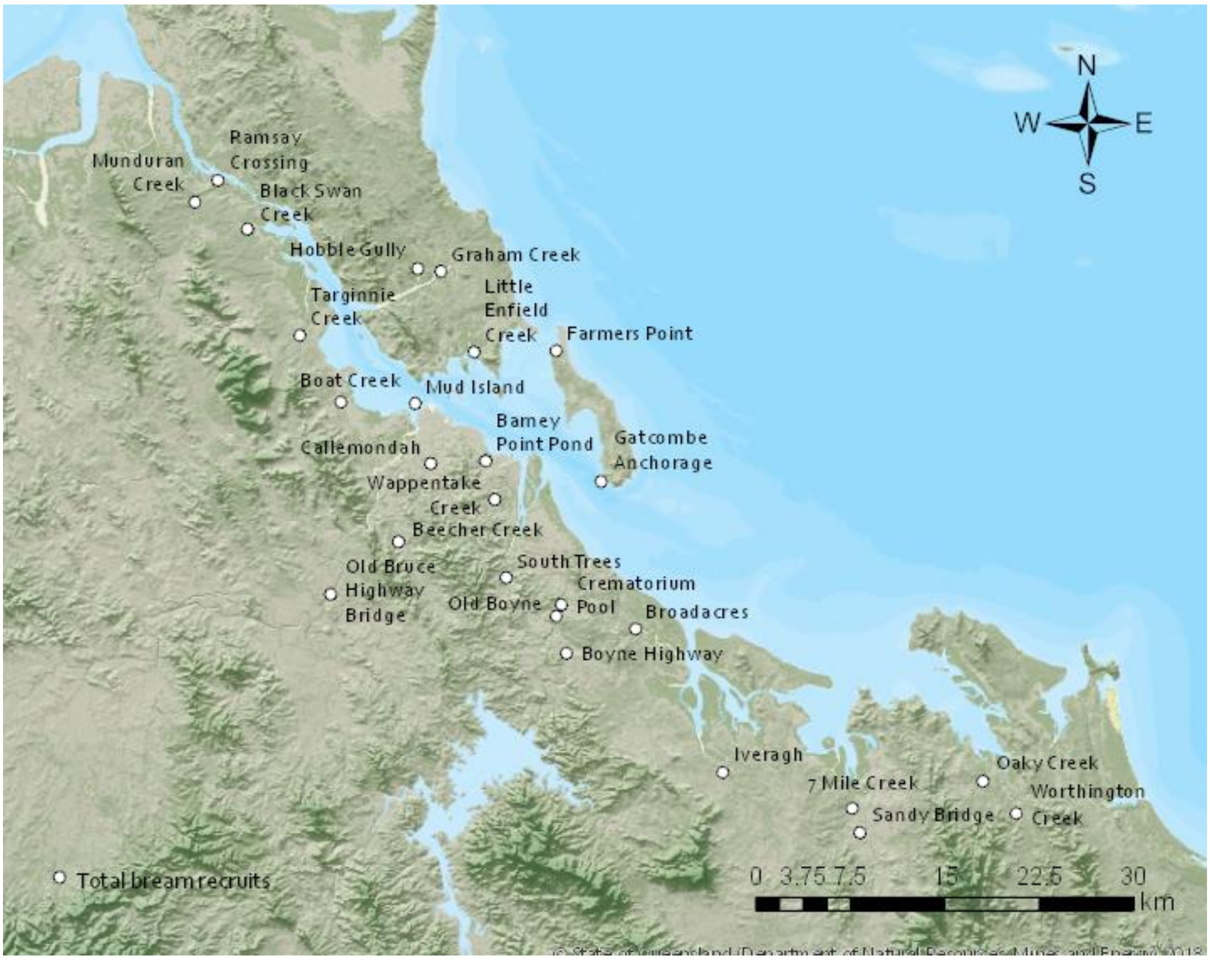


Figure 3.11: Bream nursery habitats surveyed around Gladstone Harbour between December 2019 and March 2020.

Each site was sampled 20 times using a standard castnet (monofilament net with a drop of 2.4 m, mesh size 20 mm and spread of 3.6 m). Species were identified in the field and the length of each species, site ID, GPS coordinates, type of substrata, vegetation and site photographs were recorded at each site. Surveys were not done if the water temperature exceeded 32°C (Sawynok & Sawynok, 2019) (Figure 3.12).

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

Table 3.27: Number of sites surveyed and number of juvenile bream caught and released in each GHHP monitoring zone.

Harbour zone	Sites	Yellow-finned bream	Pikey bream
Zone 1. The Narrows	Ramsay Crossing	7	74
	Munduran Creek	6	1
	Black Swan Creek	2	33
	Targinnie Creek	25	20
Zone 2. Graham Creek	Graham Creek	0	60
	Hobble Gully	2	84
Zone 3. Western Basin	Wiggins Island	25	15
Zone 4. Boat Creek	Boat Creek	0	2
Zone 5. Inner Harbour	Little Enfield Creek	9	39
	Barney Point Pond	0	0
Zone 6. Calliope Estuary	Beecher Creek	13	9
	Old Bruce Highway Bridge	23	18
Zone 7. Auckland Inlet	Callemondah	30	37
Zone 8. Mid Harbour	Farmers Point	1	0
	Gatcombe Anchorage	6	12
Zone 9. South Trees Inlet	Wappentake Creek	2	1
	South Trees	10	13
	Crematorium Pool	14	7
Zone 10. Boyne Estuary	Old Boyne	15	5
	Boyne Highway	40	0
Zone 11. Outer Harbour	*Not surveyed*		
Zone 12. Colosseum Inlet	Broadacres	16	14
	Iveragh	19	2
Zone 13. Rodds Bay	Oaky Creek	30	12
	7 Mile Creek	7	15
	Worthington Creek	20	2
	Sandy Bridge	8	0
Total	**26 sites**	**330**	**475**

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. A number of potential environmental predictors related to fish habitats were also tested to determine if they helped to explain variation in the juvenile catch data. The estimates were aggregated (using the bootstrapping technique) to obtain the report card results.

The final statistical model comprises:

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

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

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

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

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

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

3.3.9. Fish recruitment results

Overall, the fish recruitment score for 2020 was 0.64 (C), indicating a satisfactory condition. Of the 12 zones monitored, two zones had very good scores, two zones had good scores, two zones had satisfactory scores and two zones had poor scores. Except for Boat Creek all zone scores were higher than the previous year (Table 3.28) and the overall score was similar to the scores recorded in 2017 and 2018 (Figure 3.13).

The total number of bream caught in the 2020 reporting year was 805, nearly twice the number bream caught in the 2019 reporting year (444). The total number of yellow-finned bream was 330 up from 248 in the previous year. The total number of pikey bream was 475 up from 196 in 2019. The total number of casts in 2020 (2080) was identical to the number of casts in 2020.

Table 3.28: Fish recruitment scores for all harbour zones and overall harbour score for fish recruitment.

Zone	2020	*2019*	*2018*	*2017*	*2016*
1. The Narrows	0.63	0.18	*0.58*	*0.75*	*0.30*
2. Graham Creek	0.92	0.17	*0.77*	*0.58*	*0.44*
3. Western Basin	0.98	0.13	*0.79*	*0.78*	*0.36*
4. Boat Creek	0.38	0.32	*0.61*	*0.47*	*0.36*
5. Inner Harbour	0.63	0.16	*0.66*	*0.64*	*0.33*
6. Calliope Estuary	0.66	0.28	*0.70*	*0.79*	*0.43*
7. Auckland Inlet	0.80	0.53	*0.86*	*0.91*	*0.53*
8. Mid Harbour	0.62	0.12	*0.59*	*0.71*	*0.29*
9. South Trees Inlet	0.39	0.25	*0.69*	*0.71*	*0.43*
10. Boyne Estuary	0.51	0.32	*0.52*	*0.74*	*0.54*
11. Outer Harbour	Not surveyed	*Not surveyed*	*Not surveyed*	*Not surveyed*	*Not surveyed*
12. Colosseum Inlet	0.63	0.39	*0.61*	*0.71*	*0.45*
13. Rodds Bay	0.52	0.33	*0.59*	*0.74*	*0.58*
Harbour score	**0.64**	**0.27**	***0.66***	***0.71***	***0.40***

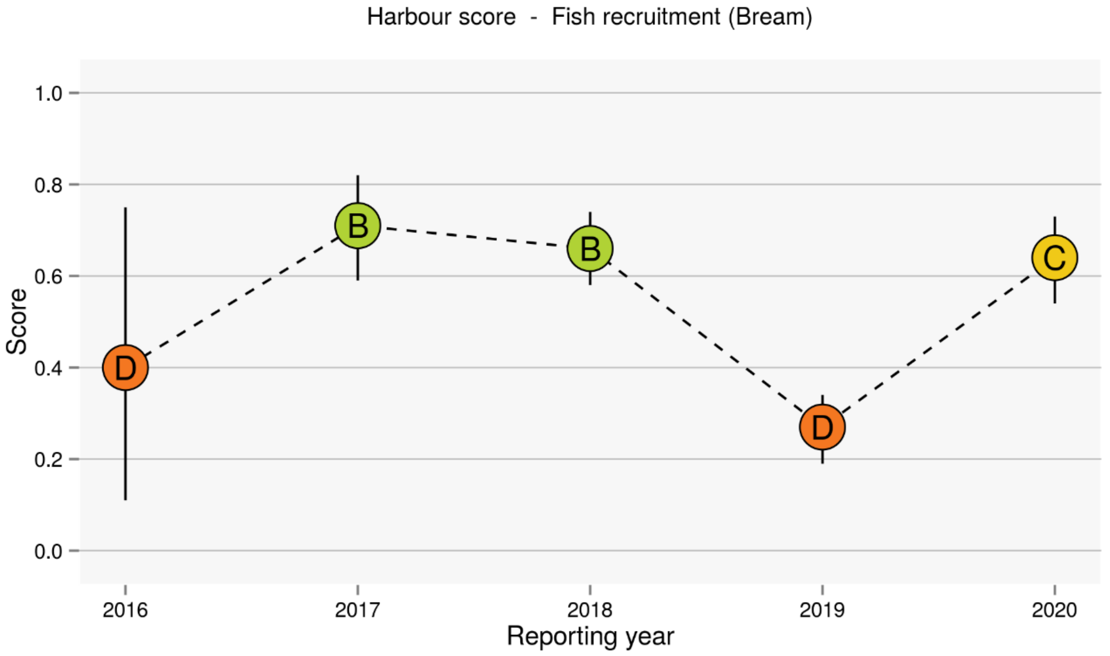


Figure 3.13: Trends in the harbour score for fish recruitment, 2016 – 2020 (Error bars show 95% bootstrap confidence intervals).

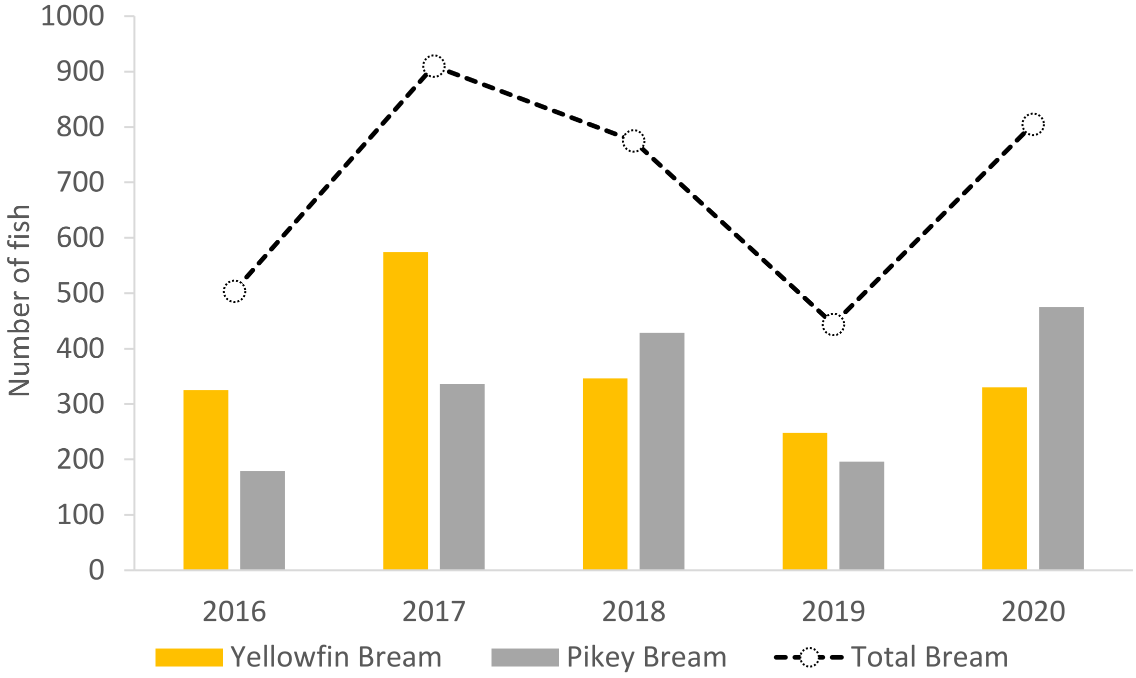


Figure 3.14: Yellow-finned and pikey bream recruits from 2016 to 2020 fish recruitment surveys.

The ratio of yellow-fined bream (41% of the total bream catch) to pikey bream (59% of the total catch) changed from the previous year where more yellow-fined bream (56%) were caught than pikey bream (44%) (Figure 3.14).

3.3.10. Fish recruitment conclusions

Recruitment plays a key role in a fishery population. The 2020 score of 0.64 (C) is a marked improvement on the previous year's score of 0.27 and above the 5-year average of 0.54. The improvement in the overall score may be a response to the prevailing climatic conditions. While annual rainfall at Gladstone Airport was lower than the annual average rainfall it was greater than the previous year and was above average or close to average in the months where bream recruitment surveys were conducted (see Figure 6.5).

3.3.11. Mud crabs

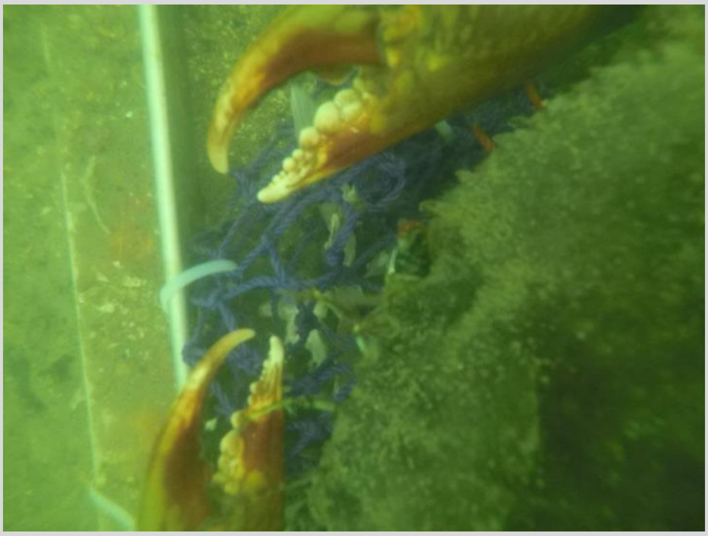


Figure 3.15: Mud crab feeding at a Baited Retrievable Underwater Video during the pilot study in 2017 (Photo courtesy of CQU).

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 both 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 3.29). Two sites were excluded from future monitoring. Rodds Bay site A was excluded owing to insufficient mud crab habitat to accommodate the number of pots required and South Trees Inlet owing to a very low catch rate in the initial survey.

Table 3.29: GHHP zones assessed as permanent report card mud crab monitoring sites in 2017. From the nine sites assessed seven were included in the report card and recommended for ongoing mud crab monitoring.

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

Mud crab monitoring

Two rounds of mud crab monitoring were conducted in 2020—a summer (warm, wet season) survey from 4–7 March and a winter (cool, dry season) survey from 15–20 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 3.30). 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 3.30: 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

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

2. Abundance: catch per unit effort (CPUE)

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

3. Visual health: prevalence of rust lesions

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

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 3.31). Calculated index values lower than the worst-case scenario scored 0; values higher than the benchmark value scored 1. This resulted in a range of scores between 0 and 1. 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 3.31: Calculation of mud crab scores for the 2020 report card.

Measure	Benchmark	Worst-case scenario	Method
Sex ratio	Male to female sex ratio of 2:1 from an unfished Central Queensland population at Eurimbula Creek (Flint et al., 2019b) **(2)**	25th percentile of Long-Term Monitoring Program data **(0.25)**	1–((x-B)/(WCS-B)) Where: x=recorded CPUE B=benchmark (2) WCS=worst-case scenario (0.25)
Abundance (CPUE)	Moving average of 75th percentile of the combined 2017, 2018, 2019 & 2020 scores **(1.95)**	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., 2019b). As the Long-Term Monitoring Program data are the longest time series available, the worst-case scenario was set from this data at the 25th percentile (0.25).

Abundance was indirectly measured as catch per unit effort (CPUE)—total catch divided by the number of pots within each of the seven monitoring zones. The benchmark for abundance (measured as CPUE) was set as the 75th percentile of the past three years. An accumulating average of the 75th percentile will be used for up to 10 years to account for natural variability. Using the accumulating average from 2017–2020, the benchmark for 2020 was 1.95 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 2020 report card was 0.39 (D). This was a result of very poor to poor scores for sex ratio (0.00–0.29), abundance scores ranging from very poor to very good (0.00–1.00) and poor to very good scores for prevalence of rust lesions (0.45–1.00) (Table 3.32). The condition of mud crab populations in the harbour was graded poor for the third consecutive year. Moreover, the overall score has steadily decreased each year since the peak in 2017 (0.55, C). Please note the overall harbour score has been influenced by the change in scoring methods, however, the change in score is only marginal.

The zone with the highest overall scores were Boat Creek (0.71, B) and The Narrows (0.63, D), both of which had very good scores for abundance (1.00, A) and good scores for prevalence of rust lesions (0.84 and 0.80, B). Boat Creek had an improved zone score due to a higher sex ratio score. For the remaining four zones, Graham Creek (0.39, D) and Inner Harbour (0.39, D) received poor scores while Calliope Estuary (0.19, E) and Rodds Bay (0.21, E) received very poor scores (Table 3.32). An overall score for Auckland Creek was not calculated for the third consecutive year, as only three crabs were caught in this zone over the two sampling periods.

Table 3.32: Overall mud crab sub-indicator, zone and harbour scores for the 2020 Gladstone Harbour Report Card. Overall zone and harbour scores from 2019 to 2018 are shown for comparison.

Zone	Sex ratio	Abundance (CPUE)	Prevalence of rust lesions	2020	*2019*	*2018*
1. The Narrows	0.00	1.00	0.80	0.60	*0.63*	*0.66*
2. Graham Creek	0.00	0.18	0.84	0.34	*0.45*	*0.44*
4. Boat Creek	0.29	1.00	0.84	0.71	*0.48*	*0.51*
5. Inner Harbour	0.00	0.19	0.99	0.39	*0.48*	*0.52*
6. Calliope Estuary	0.00	0.13	0.45	0.19	*0.43*	*0.52*
7. Auckland Inlet	NC	0.00	NC	NC	*NC*	*NC*
13. Rodds Bay	0.06	0.13	0.45	0.21	*0.36*	*0.38*
Harbour score	**0.06**	**0.38**	**0.73**	**0.39**	***0.47***	***0.49***

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

Sex ratio (based on legal size limit)

In 2020, five zones received very poor scores (0.00 to 0.06, E). Of these, four zones received the lowest score possible (0.00, E) with Rodds Bay receiving a marginally better score (0.06, E). A score for Auckland Creek could not be calculated due to an insufficient catch (n < 5) while Boat Creek received a poor score (0.29, D), which was the highest sex ratio score of 2019. When the two sampling periods were combined, six of the seven zones had more than two females to every one male crab. The exception to this was Boat Creek, which had an average of 1.45 females to every one male crab (Table 3.33). Overall, the harbour score for sex ratio (0.06, E) was comparable to the 2019 score of 0.08 (E).

Table 3.33: Sex ratio of legal-sized mud crabs (carapace width >150 mm) in March and June 2020 by zone. Note, figures for sex ratio represent actual male-to-female crab ratios and not GHHP scores.

Zone name	**March 2020**			**June 2020**		
	Males	Females	Sex ratio	Males	Females	Sex ratio
1. The Narrows	3	58	0.05	5	7	0.71
2. Graham Creek	0	3	0.00	2	5	0.40
4. Boat Creek	2	4	0.50	7	8	0.88
5. Inner Harbour	0	2	0.00	1	4	0.25
6. Calliope Estuary	1	4	0.25	1	6	0.17
7. Auckland Inlet	/	/	NC	1	2	0.50
13. Rodds Bay	3	10	0.05	1	1	1.00
Harbour average			**0.14**			**0.56**

NC: Not calculated

Abundance: catch per unit effort (CPUE)

For the third consecutive year the highest catch rate was recorded in The Narrows where there was an average of 3.5 mud crabs per pot (Tables 3.34). Both The Narrows and Boat Creek received the highest possible score (1.00, A) for abundance. Abundance scores at the remaining five zones were very poor (E), with scores ranging from 0.00 at Auckland Inlet to 0.19 at Inner Harbour. Overall, the harbour score for abundance decreased from 0.47 (D) in 2019 to 0.38 (D) in 2020, although the grade remained the same.

Table 3.34: Catch per unit effort (CPUE) for pots set in seven harbour zones during the March and 2020 mud crab surveys.

Zone name	March 2020			June 2020		
	Pots	Crabs caught	CPUE	Pots	Crabs caught	CPUE
1. The Narrows	20	93	4.65	20	45	2.25
2. Graham Creek	20	5	0.25	20	17	0.85
4. Boat Creek	7*	13	1.86	18	43	2.39
5. Inner Harbour	20	7	0.35	20	16	0.80
6. Calliope Estuary	20	9	0.45	20	10	0.50
7. Auckland Inlet	20	0	0	20	3	0.15
13. Rodds Bay	20	14	0.70	20	5	0.25
Harbour average			**1.18**			**1.03**

*Eight pots were submerged at Boat Creek and unable to be collected until the following low tide. As such, these pots were not included in the March 2020 dataset.

Visual health: prevalence of rust lesions

A low incidence of rust lesions was recorded at four of the harbour zones: The Narrows, Graham Creek, Boat Creek and Inner Harbour. The former three zones received good scores (0.80 – 0.84, B) while Inner Harbour received a very good score (0.99, A). Calliope Estuary and Rodds Bay received poor scores (0.45, D), both of which had a higher prevalence of rust lesions during the June 2020 sample. A score for prevalence of rust lesions was not calculated in Auckland Inlet owing to the insufficient number of crabs caught, however, the three crabs caught in this zone had no lesions (Table 3.35). Overall, the 2020 score for this sub-indicator was lower than those previously recorded (0.86 – 0.98, A); however, the incidence of lesions was only slightly higher than in previous years.

Table 3.35: Number and percentage of mud crabs with external lesions (rust spot) in March and June 2020 by zone.

Zone name	March 2020		June 2020	
	# with lesions	% with lesions	# with lesions	% with lesions
1. The Narrows	10	10.75	4	8.89
2. Graham Creek	0	0.00	2	11.76
4. Boat Creek	3	23.08	2	4.65
5. Inner Harbour	0	0.00	1	6.25
6. Calliope Estuary	1	11.11	3	30.00
7. Auckland Inlet	/	NC	0	0.00
13. Rodds Bay	2	14.29	2	40.00
Harbour average		**9.87**		**14.51**

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 0.39 (D) was lower than the 2019 score 0.47 (D) (Figure 3.16). This result was driven by a mix of lower zone scores for abundance—which included the zero for Auckland Inlet for the first time—and/or prevalence of rust lesions (Table 3.35). Please note the inclusion of a single zone with an insufficient catch for the abundance sub-indicator (such as Auckland Inlet) has only a marginal impact on the overall harbour score.

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 2020, 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, the lowest recorded since GHHP monitoring began in 2017. 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. Most of the zones where this measure could be calculated received good or very good scores (Table 3.35). These scores indicate a low prevalence of rust spot lesions across the harbour. The average incidence of rust spot lesions across the seven monitored zones was 12.2% for the combined February and June survey periods, considerably lower than the 37% incidence recorded in 2012 (Dennis et al., 2016) or roughly half of the 22% recorded in the late 1990s by Andersen et al. (2000).

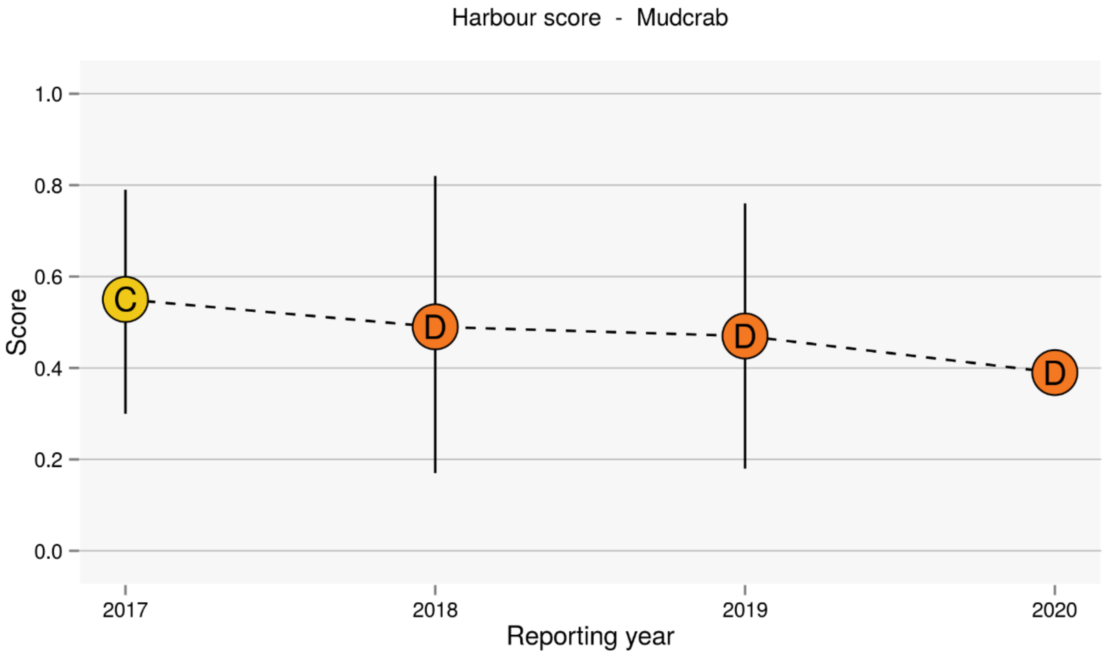


Figure 3.16: Trends in the harbour score for mud crabs, 2017 – 2020 (Error bars show 95% bootstrap confidence intervals).

3.4. Environmental component and indicator groups results

The overall Environmental component score for the 2020 report card was 0.66 (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 0.92 (A), habitats 0.50 (C), and fish and crabs 0.56 (C) (Table 3.36).

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 2020 and the mangroves scores are based on the survey work conducted in 2019.

Table 3.36: 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	0.77*	0.64~
2. Graham Creek	0.91	0.64	0.65~
3. Western Basin	0.93	0.66*	0.84
4. Boat Creek	0.87	0.46	0.60~
5. Inner Harbour	0.89	0.63*	0.57
6. Calliope Estuary	0.95	0.58	0.52~
7. Auckland Inlet	0.89	0.65	0.50
8. Mid Harbour	0.92	0.39*#	0.66
9. South Trees Inlet	0.92	0.80*	0.54
10. Boyne Estuary	0.95	0.26	0.60
11. Outer Harbour	0.98	0.36#	0.69
12. Colosseum Inlet	0.93	0.72	0.66
13. Rodds Bay	0.92	0.77*	0.47~
Harbour score	**0.92**	**0.50**	**0.56**

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

4. Other data used in the Calculation of 2020 Report Card scores

Report card monitoring between 2014 and 2020 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 previous 6-years (2014 to 2019).

From 2020, there will be 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 2020 report card the results for the Social, Cultural and Economic components and the mangrove indicator are those presented in the 2019 report card. These results are presented in sections 4.1 to 4.4.

The move to less frequent monitoring of less variable indicators is an approach is 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 2020 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.

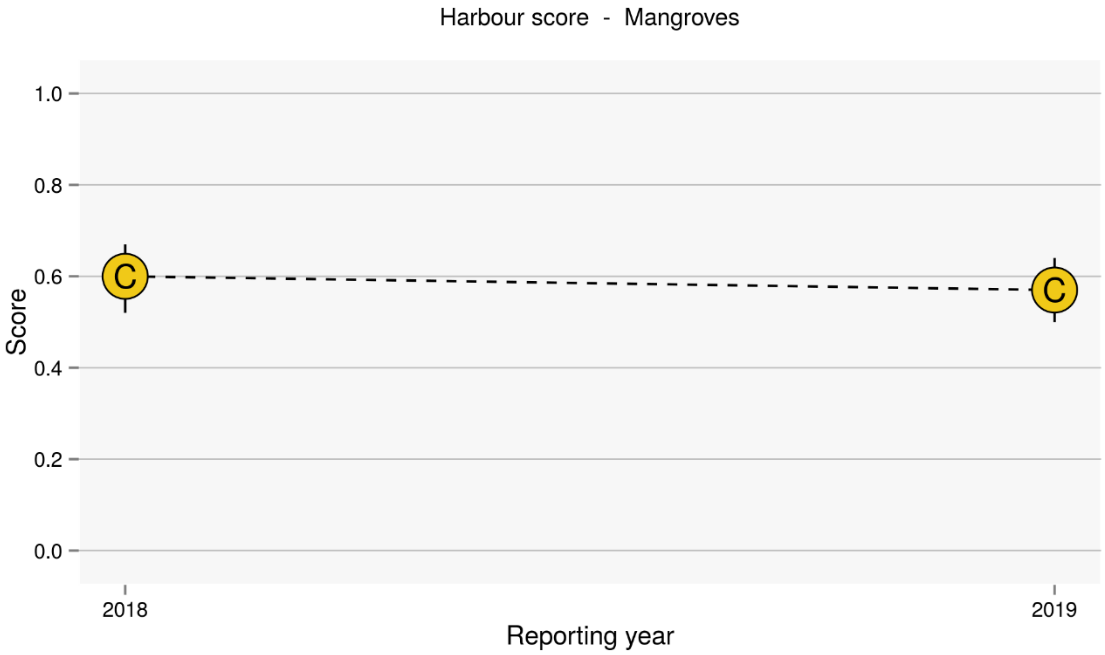


Figure 4.1: Change in overall mangrove score between 2018 and 2019 (Error bars show 95% bootstrap confidence intervals).

4.1.2. Overall mangrove results 2019

The overall score for mangroves in Gladstone Harbour in 2019 was 0.57 (C). Three zones were in good condition and eight zones were considered satisfactory (Table 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 2020 and 2021 report cards the Social score from 2019 will be used. While it is not clear what impact COVID-19 would have had on the overall Social score in 2020, it is important to note that this would have only impacted four months of the 2019-20 report card year—the period from when the pandemic was declared until the end of the report card year on 30 June. 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.

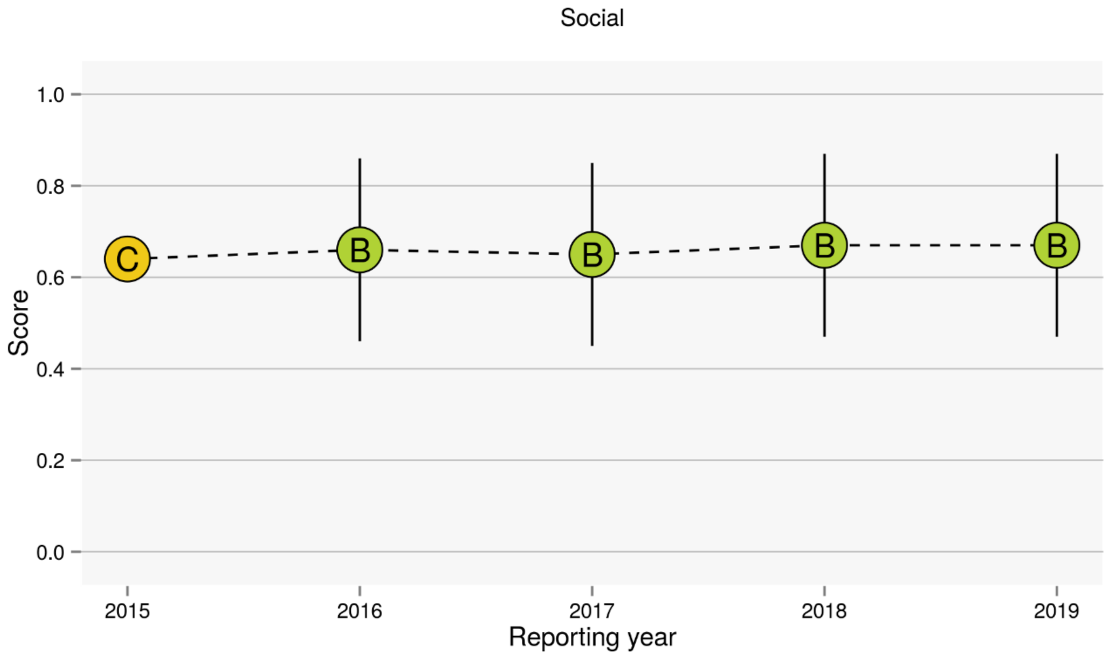


Figure 4.2: Change in the overall Social score between 2015 and 2019. Error bars were not calculated for the 2015 score as this score was calculated prior to the use of the DIMS in 2016 (Error bars show 95% bootstrap confidence intervals).

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).

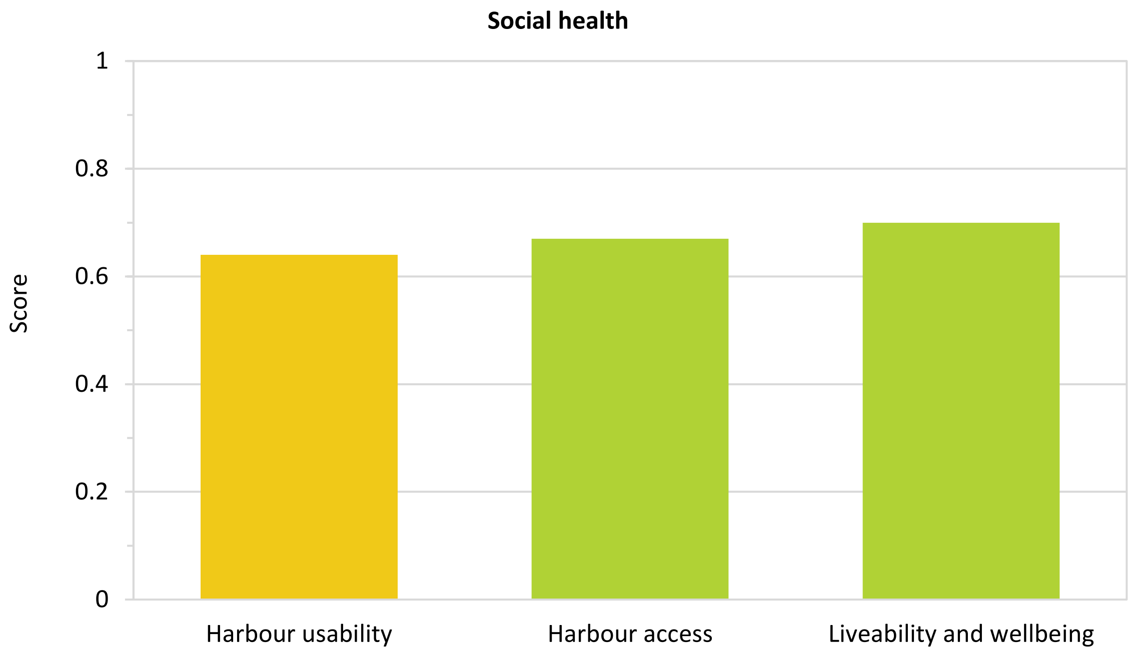


Figure 4.3: Indicator group scores within the Social component of harbour health in the 2019 Gladstone Harbour Report Card.

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 both 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 2020 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.

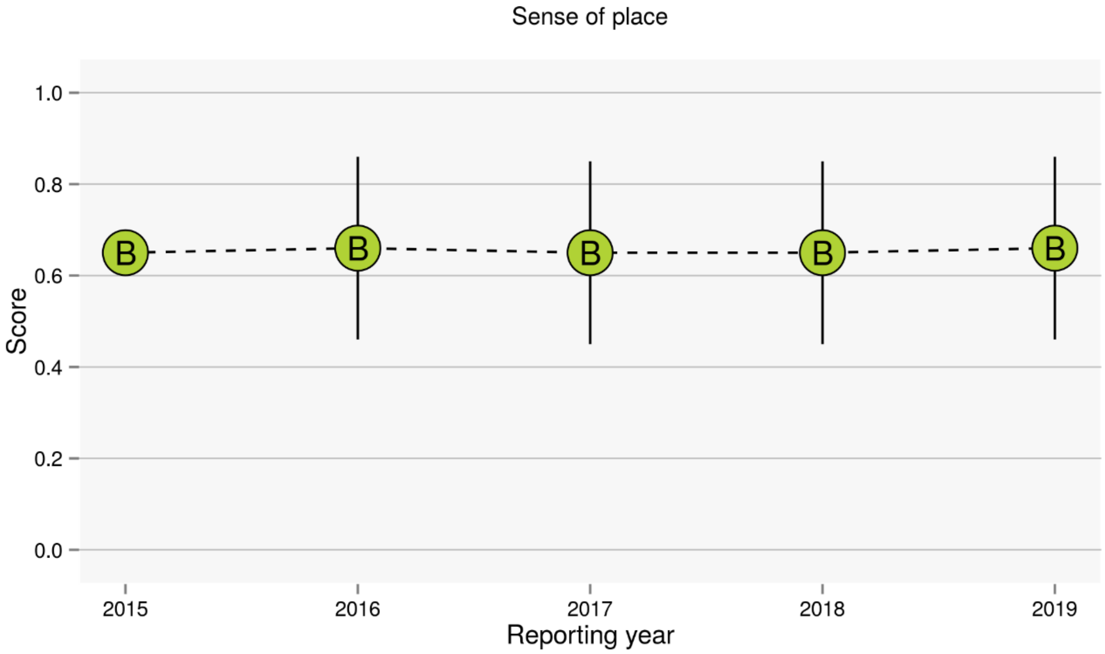


Figure 4.4: Changes in the 'sense of place' score from 2015 to 2019 (Error bars show 95% bootstrap confidence intervals).

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

4.3.1. Overall Cultural Health 2019

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).

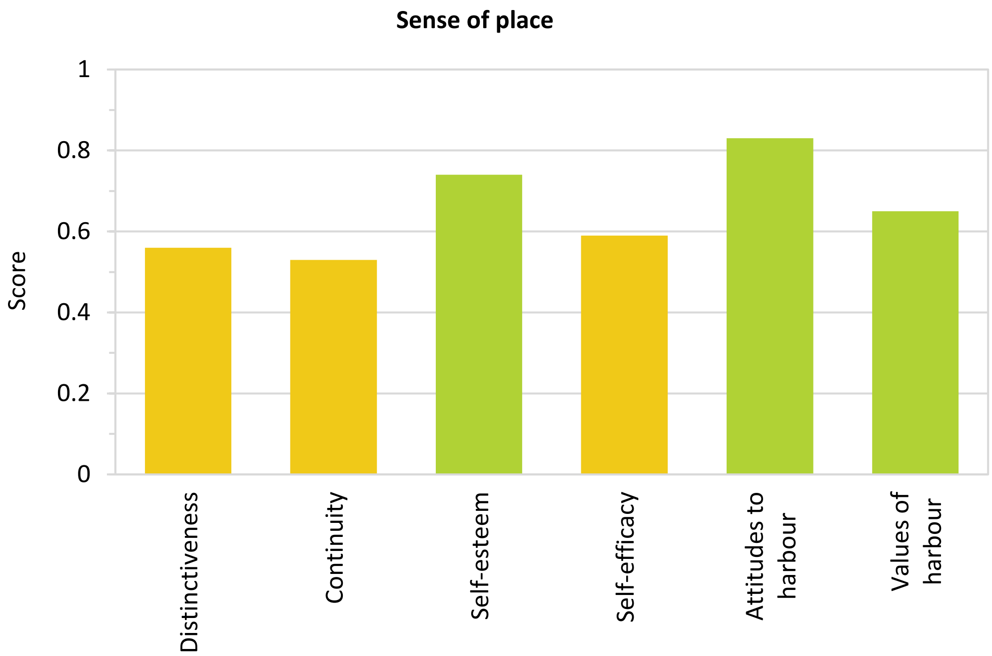


Figure 4.6: Indicator scores for 'sense of place' indicator group used for Cultural health in the 2018 Gladstone Harbour Report Card.

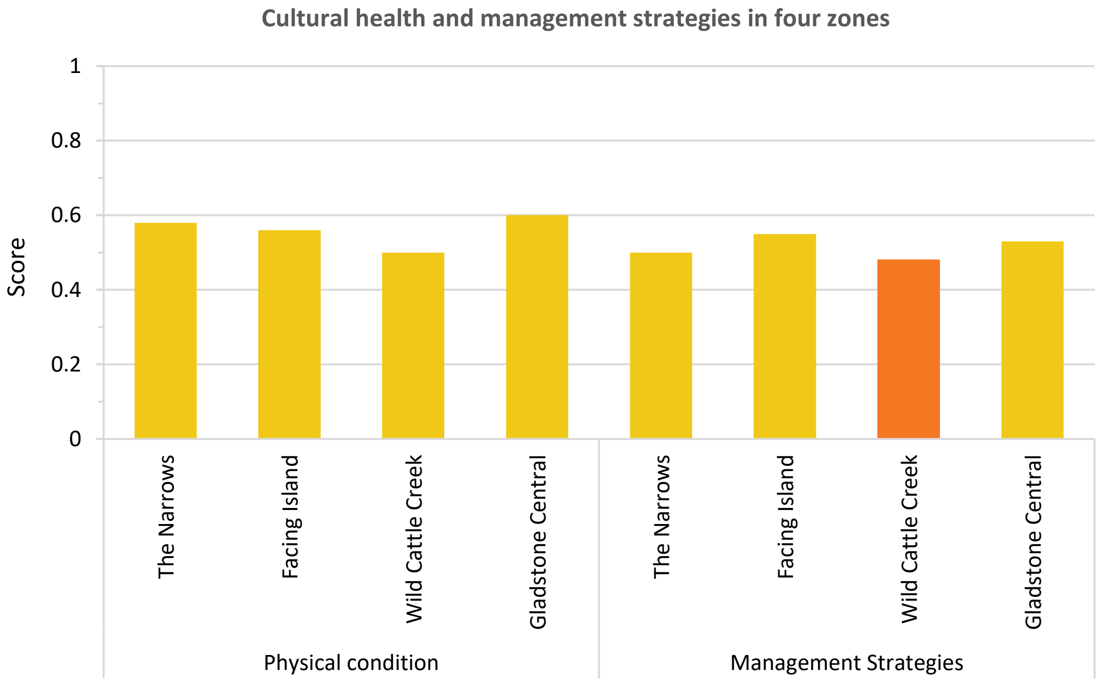


Figure 4.7: Indicator scores for physical condition and management strategies across four reporting zones in the 2018 Gladstone Harbour Report Card.

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 2020 and 2021 report cards. It is not clear what impact the COVID-19 pandemic would have had on the overall Economic score. While there has been some decline in other measures of economic health, including value of building approvals and the number of businesses actively trading in Gladstone (see Section 6.4), it is not clear if these declines were attributable to the pandemic or had other underlying causes. 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.

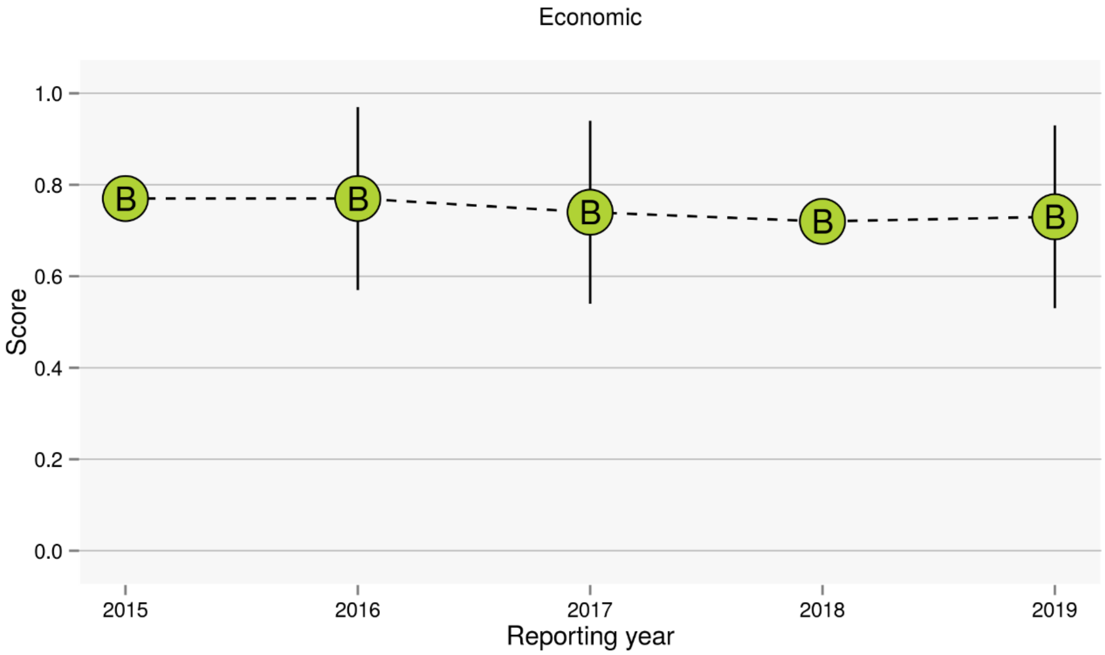


Figure 4.8: Changes to the overall Economic component score between 2015 and 2019 (Error bars show 95% bootstrap confidence intervals).

4.4.1 Overall Economic Health

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).

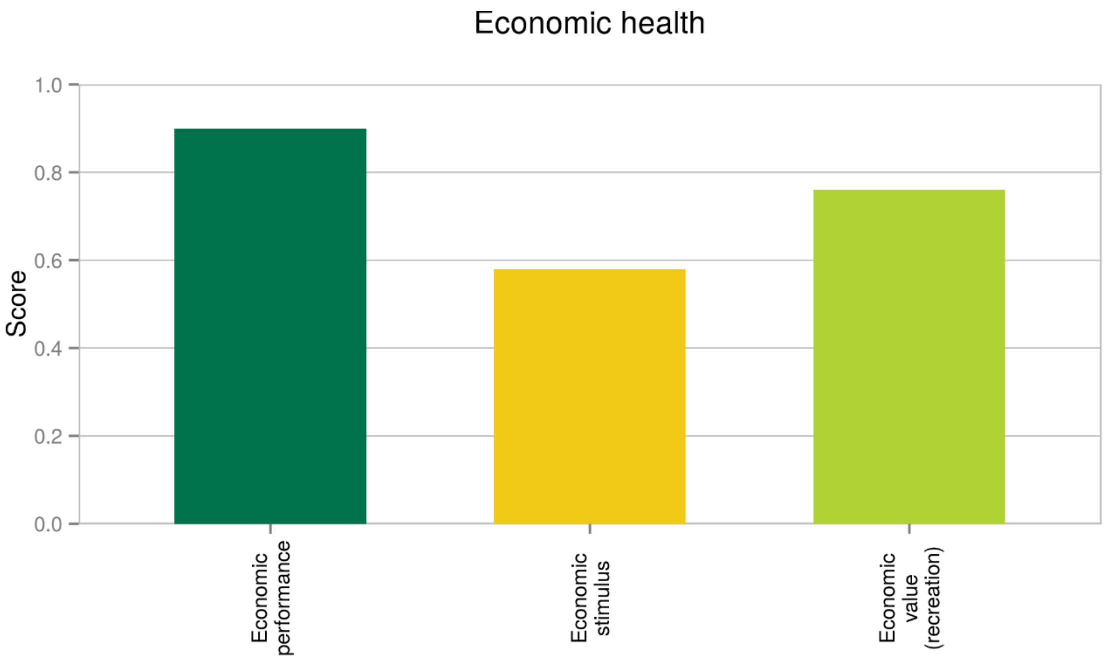


Figure 4.9: The scores for each of the three economic indicator groups in the 2019 Gladstone Harbour Report Card.

5. Iconic species of Gladstone Harbour

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

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

Dolphins

The Australian humpback dolphin *Sousa chinensis*, the bottlenose dolphin *Tursiops truncates*, and the Indo-Pacific (inshore) bottlenose dolphin *Tursiops aduncus* have been observed in Gladstone Harbour (DEHP, 2014b). The Indo-Pacific humpback dolphin is an EPBC-listed migratory species and is listed as near threatened in Queensland under the *Nature Conservation Act 1992*. Humpback dolphins in the Capricorn–Curtis coast region form two geographically distinct sub-populations, referred to as the Fitzroy River and the Port Curtis Indo-Pacific humpback dolphin sub-populations (Cagnazzi, 2013). In surveys between 2006 and 2008, the Fitzroy River and Port Curtis populations were estimated to be 115 and 84 individuals respectively. In 2011, abundance estimates for both sub-populations declined to about 104 and 45 dolphins respectively. While the reason for this decline was not established in this study, such declines may be a result of emigration related to large flood events or mortality (Cagnazzi, 2013).

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

From the survey work conducted between 2014 and 2016 Cagnazzi (2017) provided a population estimate of approximately 140 – 162 adult Australian humpback dolphins and between 100 – 163 Australian snubfin dolphins in the Port Alma and Port Curtis area.

Dugongs

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

Dugong feeding trails were mapped at five seagrass meadows within Port Curtis, Pelican Banks, South Tree Inlet, Wiggins Island and Rodds Bay in 2015 and 2016 (Rasheed et al, 2017) and small numbers of dugongs were sighted during recent dolphin surveys of the Port Alma and Port Curtis region (Cagnazzi, 2015, 2016). Satellite tracking of a female and sub-adult male in 2014 revealed extensive time spent on the seagrass meadows at Pelican Banks but also use of areas close to the shore around South Trees Island and The Narrows (Cleguer et al., 2015[a]). Tracking of one sub-adult male revealed that after tagging the dugong moved from Gladstone Harbour to Shoalwater Bay where it remained for 86 days before the transmitter was detached (Cleguer et al., 2015[b]).

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

Marine turtles

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

- green turtle *Chelonia mydas* – EPBC status: vulnerable, marine and migratory. Isolated green turtle nesting has been recorded within the port limits of Port Curtis, but not annually.
- flatback turtle *Natator depressus* – EPBC status: endangered, marine and migratory. The flatback turtle is the dominant species of turtle recorded as nesting on the beaches of Port Curtis. Most nesting occurs on the southern end of Curtis Island, with low density nesting on seaward beaches within the port limits. Thirty clutches of eggs were recorded on Curtis Island during the 2018–19 nesting season (Limpus et al, 2019)
- loggerhead turtle *Caretta caretta* – EPBC status: endangered, marine, and migratory. Isolated loggerhead turtle nesting has been recorded within the port limits of Port Curtis, but not annually.
- hawksbill turtle *Eretmochelys imbricata* – EPBC status: vulnerable, marine and migratory. There are no records of this species nesting within a 500km radius of Port Curtis.
- olive ridley turtle *Lepidochelys olivacea* – EPBC status: endangered, marine and migratory. There are no records of this species nesting in eastern Australia.

- leatherback turtle *Dermochelys coriacea* – EPBC status: endangered, marine and migratory. Leatherback turtles are rarely recorded in the waters of Port Curtis.

An acoustic and satellite tagging study between 2013 and 2014 documented the movement of green turtles within the harbour (Babcock et al., 2015). The study revealed that during high tide, green turtles would move into shallower areas that generally contained more food than the deeper areas of the harbour and would shift into slightly deeper water at the edge of channels at low tide. Babcock et al. (2015) also found that green turtles in the vicinity of Wiggins Island feed predominantly on red algae growing on mangroves, whereas turtles at Pelican Banks feed primarily on seagrasses. Further work has shown that green turtles foraging at Pelican Banks and Colosseum Inlet make regular movements between these estuarine waters and open waters, and that green turtles foraging at South Trees Inlet make little use of port infrastructure for foraging or resting areas (Limpus et al., 2018).

Migratory shorebirds

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

In 2019, five surveys of shore bird roosting sites were conducted in January, February, March, August and October at the Fitzroy Estuary, North Curtis Island, Port Curtis, Western Basin Reclamation Area, Colosseum Inlet, Mundoolin and Rodds Peninsula. Although annual surveys have been conducted between 2013 and 2018 this was the first comprehensive survey since 2012 (Wildlife Unlimited, 2020).

The Curtis Coast as a whole supports internationally significant numbers of migratory shorebirds. The shorebird habitat present on the Curtis Coast is of great conservation value and provides an extremely important refuge to multiple critically endangered, endangered and vulnerable shorebird species.

Between 2,407 and 10,301 birds were recorded in each of the survey rounds with the highest number of birds recorded in January 2019 and the lowest in August 2019. The number of species recorded ranged from 15 species in August to 19 species in February, March, and October. The 10 most abundant species (total number recorded in the 5 surveys) were: Eastern Curlew *Numenius madagascariensis* (7,910), Bar-tailed Godwit *Limosa lapponica* (6,760), Lesser Sand Plover *Charadrius mongolus* (6085), Grey-tailed Tatler *Tringa brevipes* (3,785), Whimbrel *Numenius phaeopus* (3,744), Great Knot *Calidris tenuirostri* (2,990), Terek Sandpiper *Xenus cinereus* (2,542), Greater Sand Plover *Charadrius leschenaultia* (2,072) and Curlew Sand Piper *Calidris ferruginea* (526) (Wildlife Unlimited, 2020).

6. Gladstone Harbour drivers and pressures

6.1. 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 6.1). 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 6.2).

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. Hence the social and economic pressures discussed below have not affected the scores presented in the report card.

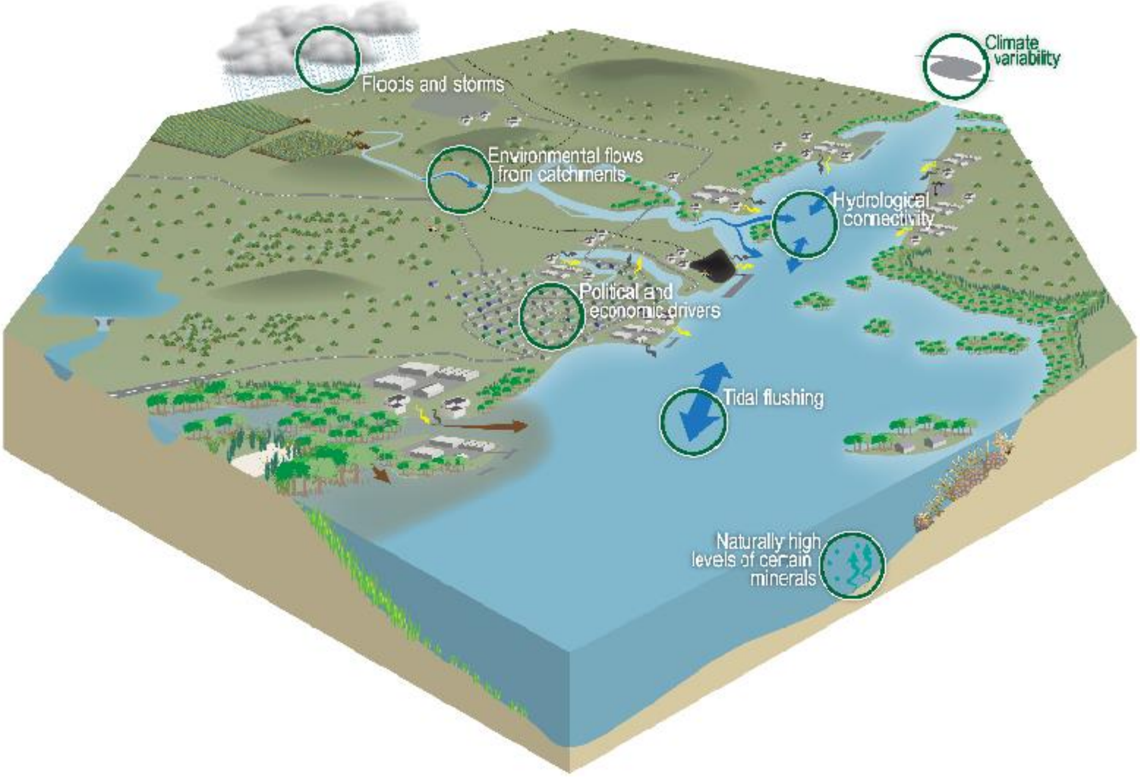


Figure 6.1: Major drivers of environmental change within Gladstone Harbour (Source: McIntosh et al., 2014).

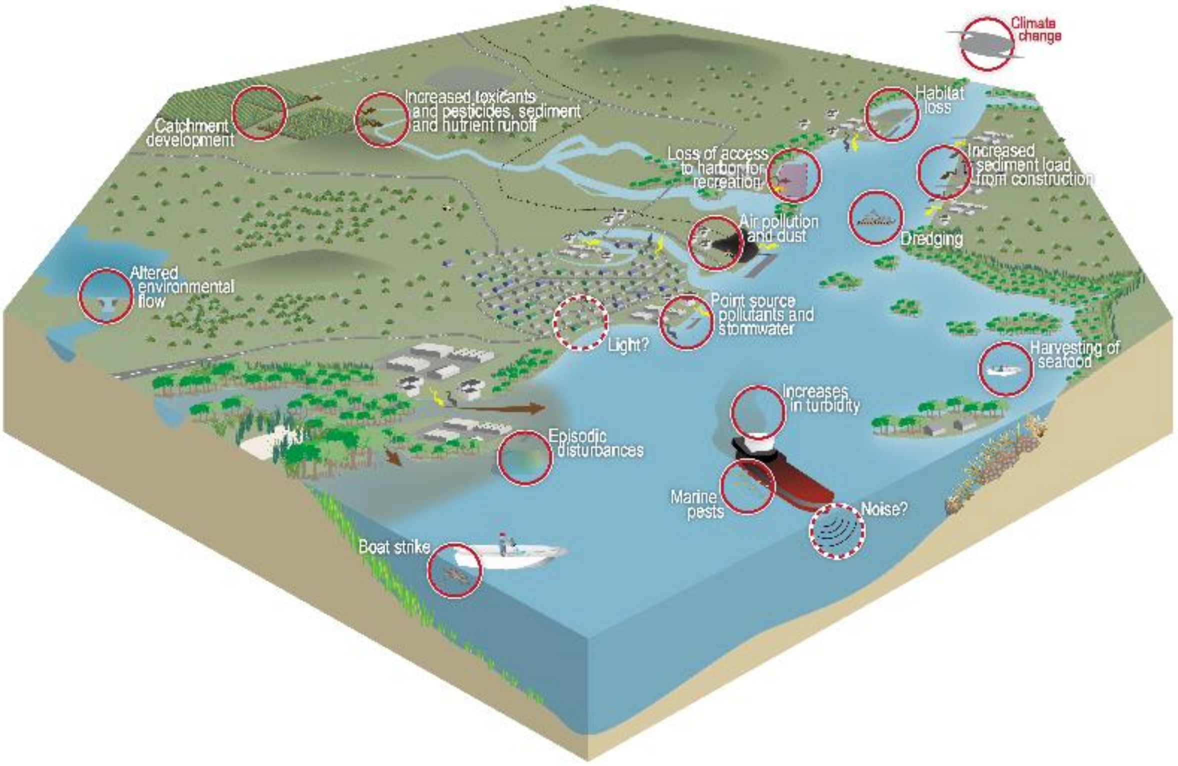


Figure 6.2: Pressures which can drive environmental change within Gladstone Harbour (Source: McIntosh et al., 2014).

6.2. Climate

Gladstone has a subtropical climate with an average maximum of 27.4°C and an average minimum of 18.1°C (Figure 6.3). 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.

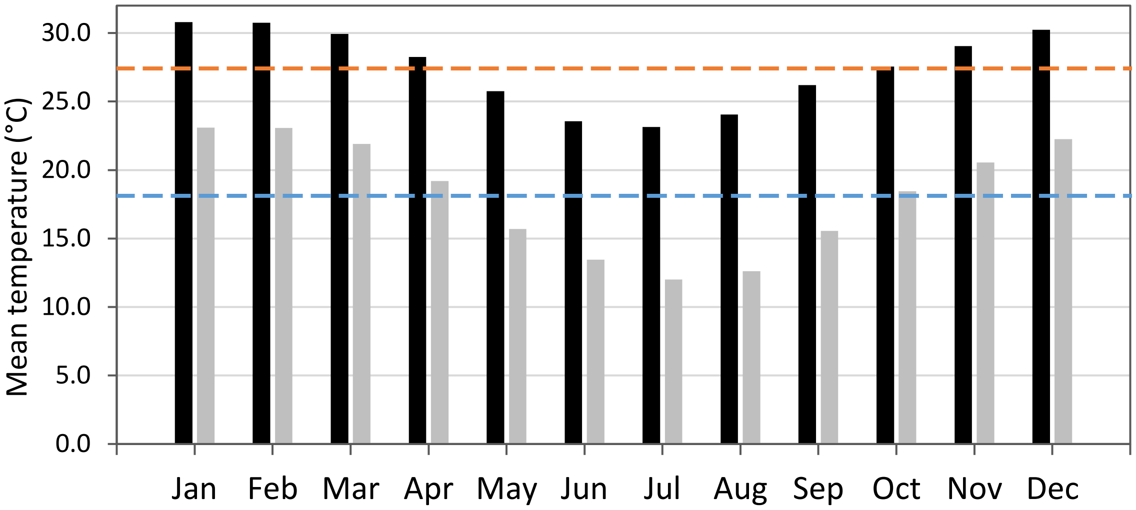


Figure 6.3: Average maximum and minimum monthly temperatures at the Gladstone Airport weather station from 1994–2020. Temperatures shown as follows: average maximum monthly for 2020 (black bars), average minimum monthly for 2020 (grey bars), annual maximum average (orange dashed line, 27.4° C), annual minimum average (blue dashed line, 18.1° C). Values were obtained from BOM (http://www.bom.gov.au/climate/data/index.shtml).

2019–20 rainfall

In the 2019–20 reporting year (July 2019 to June 2020), total rainfall recorded at Gladstone Airport was 641 mm—well below the annual average of 856 mm (Figure 6.4). Total monthly rainfall was variable when compared to mean monthly rainfall of the past 26 years (Figure 6.5). Across the reporting year rainfall was below average with 10 months recording dryer than average conditions. The exception were January and February both of which were above average. The driest period was June through to September in which the total rainfall was just 28 mm for the four-month period. The driest month was September (2.6 mm), and the wettest month was February (244 mm).

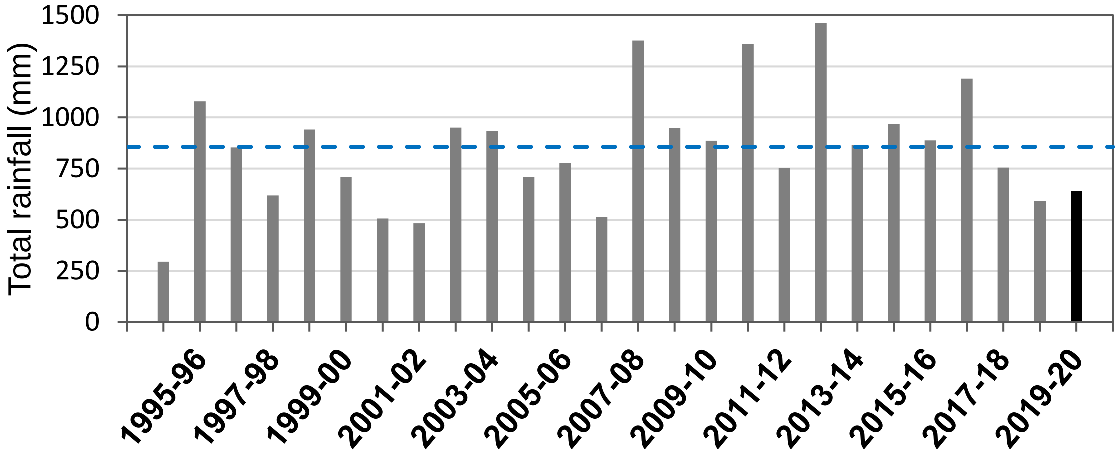


Figure 6.4: Annual rainfall (mm) by reporting year at the Gladstone Airport weather station from 1994–1995 to 2019–2020. Blue dashed line represents the annual mean of total rainfall from 1994–2020 (856 mm). Values were obtained from BOM (http://www.bom.gov.au/climate/data/index.shtml).

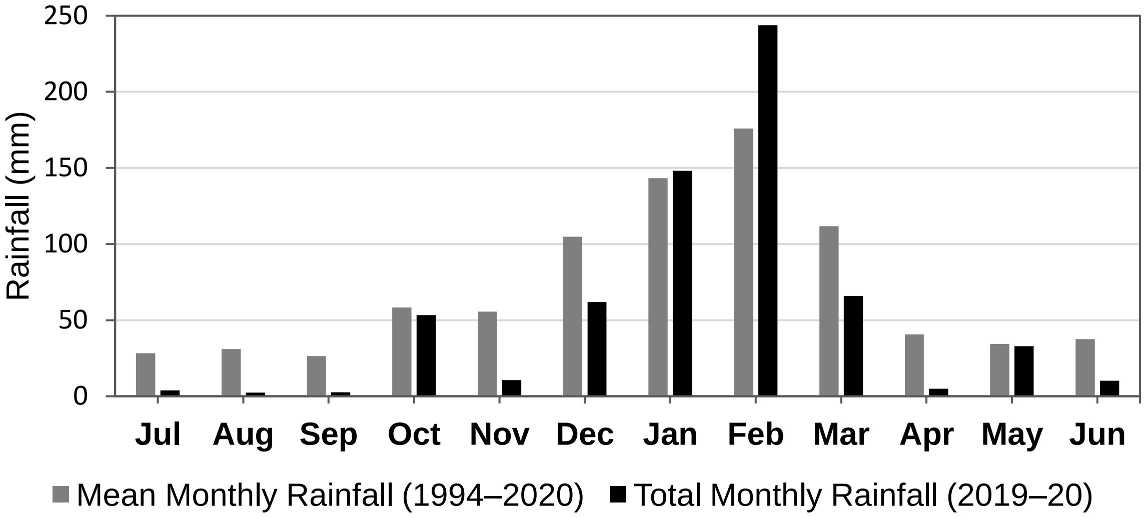


Figure 6.5: Mean monthly rainfall (mm) at the Gladstone Airport weather station (1994–2020) compared to total monthly rainfall for the 2019–20 reporting year. Values were obtained from BOM (http://www.bom.gov.au/climate/data/index.shtml).

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 6.1. 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 2020 show two brief but significant high flow events occurring with the passage of TC Marcia and ex TC Debbie (Figure 6.6). 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 2019–20 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 February and March, and close to the median in January (Figure 6.7). The highest monthly discharge (July) in the current reporting year was approximately 2.2 times lower than the long-term median of that month. There was also negligible stream discharge in January and June 2019 and no stream discharge in February 2019 from the Calliope River.

Table 6.1: 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	165,223	Mean	20,977
Median	99,114	Median	2,727
Maximum flow (2012–13)	916,693	Maximum flow (1973–74)	401,837

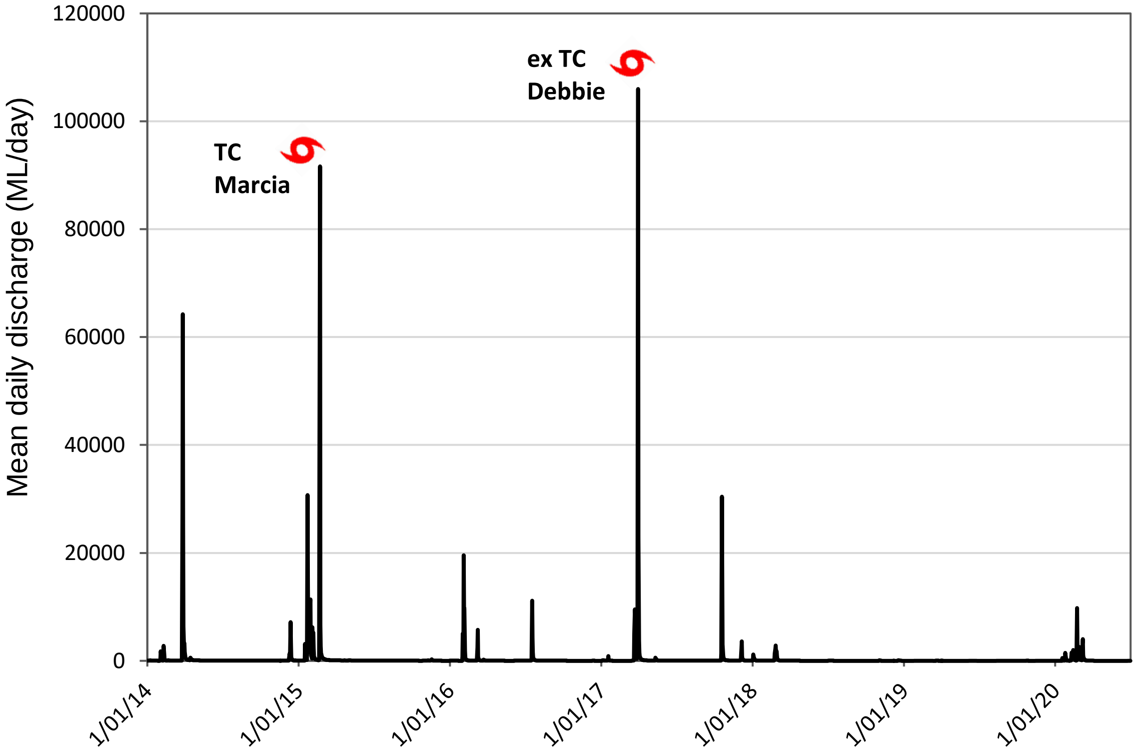


Figure 6.6: Mean daily Calliope River flows recorded at Castlehope between January 2014 and June 2020. Values were obtained from DNRM (https://water-monitoring.information.qld.gov.au/).

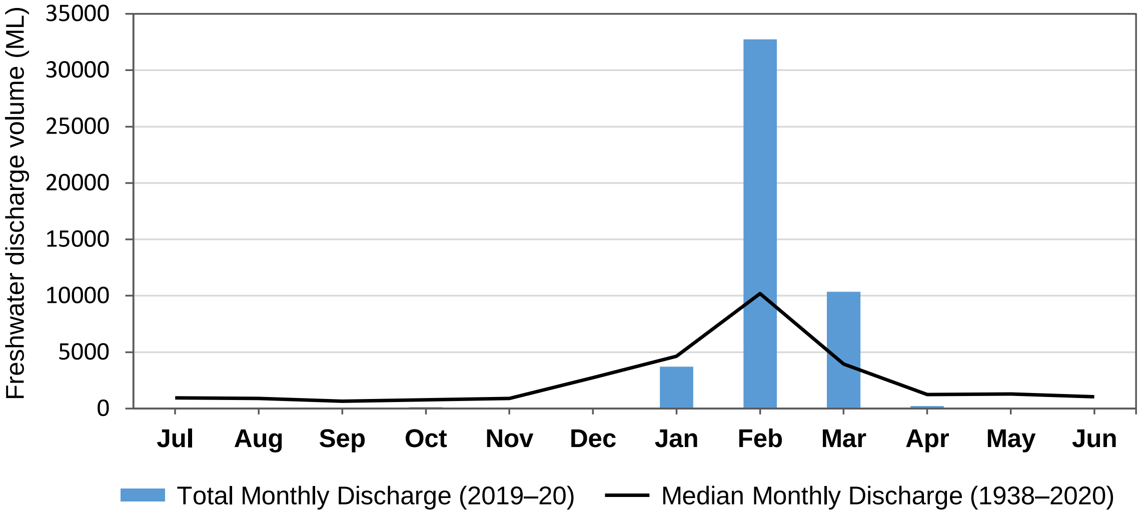


Figure 6.7: Monthly water discharge (July 2019 to June 2020) and median monthly water discharge (October 1938 to June 2020) of the Calliope River at Castlehope. Values were obtained from DNRM (https://water-monitoring.information.qld.gov.au/).

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 (AHD) (Table 6.2). Since the height of the dam wall was raised in 2002, it has overtopped six times—in 2002, 2010, 2013, 2015, and twice in 2017. No overtopping occurred in the 2019–20 report card year (Figure 6.8).

Table 6.2: 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	18-Oct-17	40.80	832,263	107.14	7,101
Highest level	27-Jan-13	48.3	1,498,586	192.9	10,810

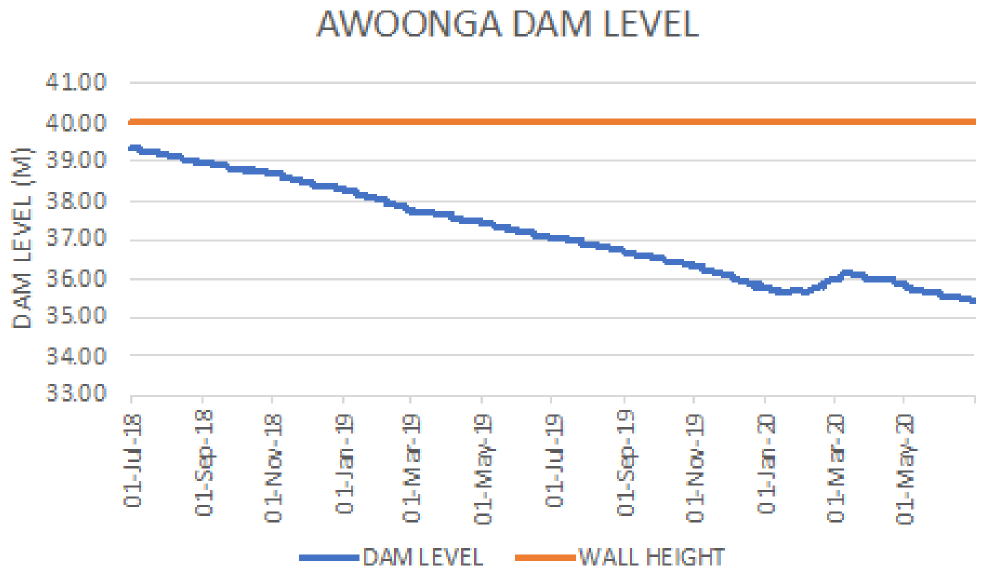


Figure 6.8: Awoonga Dam levels July 2018 to May 2020 (Source: Sawynok et al., 2020).

6.3. 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 6.9).

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 6.10 and 6.11). Much of the flow from the Boyne River into Port Curtis is restricted by Awoonga Dam, constructed in phases beginning in the 1960s. The current spillway height of 40 m AHD was achieved in 2002. In periods of normal flow, it would be expected that coarser sediment particles would settle behind the structure.

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

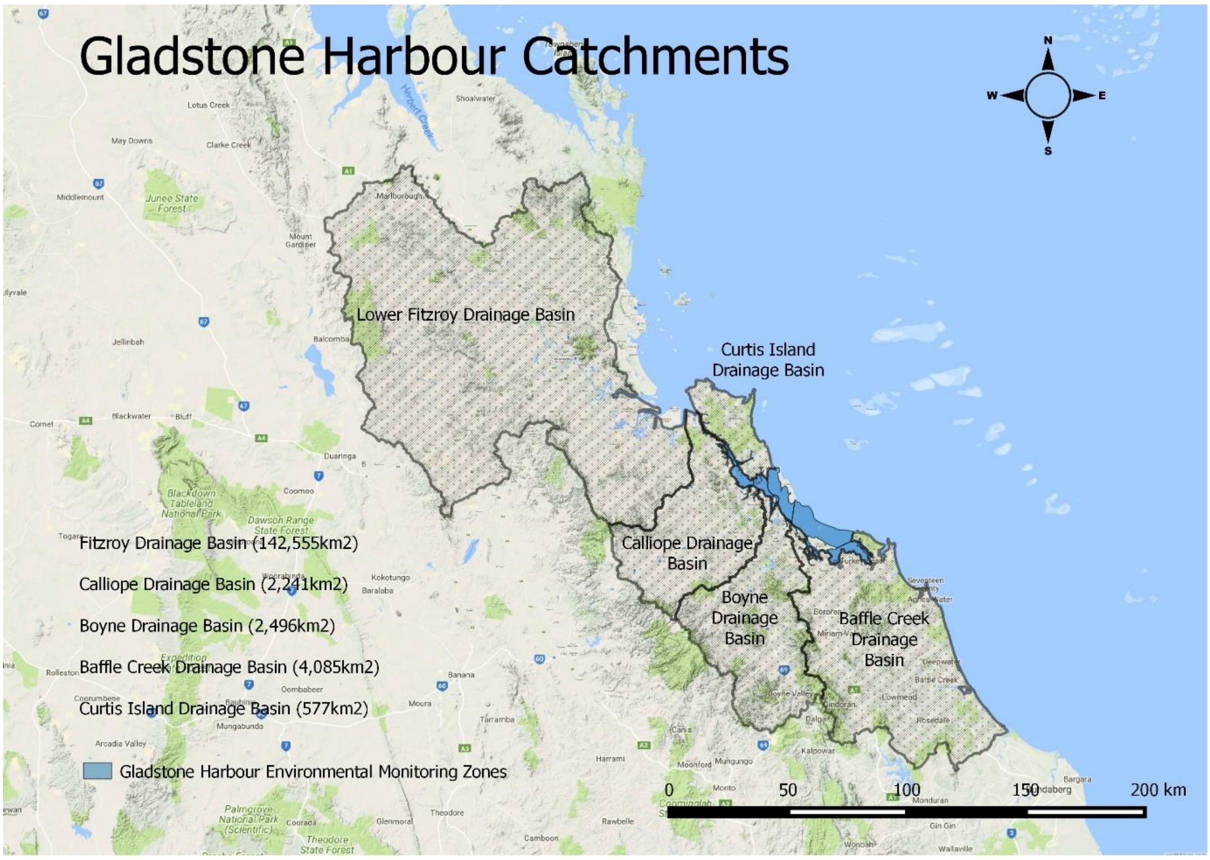


Figure 6.9: Drainage basins surrounding the Gladstone Harbour environmental monitoring zones.

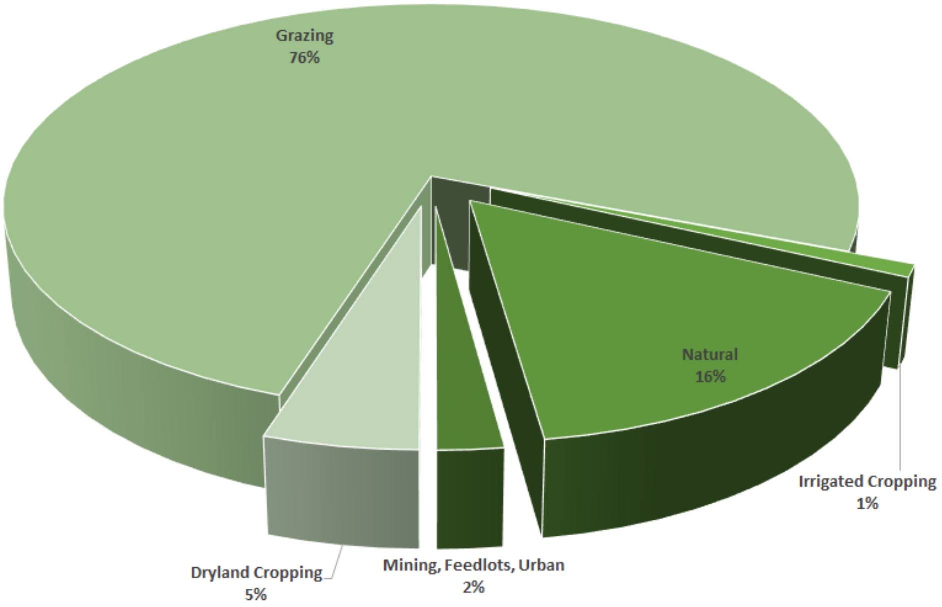


Figure 6.10: Land use in the Boyne catchment (Data source QSpatial, Land use mapping – Fitzroy NRM region 2009, Catchment boundaries, Queensland Wetland*Info*).

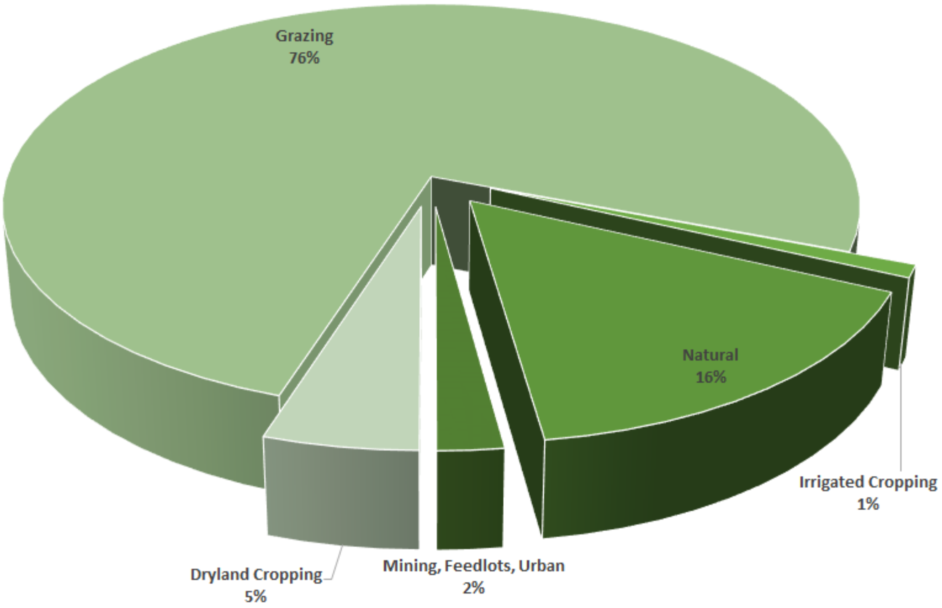


Figure 6.11: Land use in the Calliope catchment (Data source QSpatial, Land use mapping – Fitzroy NRM region 2009, Catchment boundaries, Queensland Wetland*Info*).

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 6.12). 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.

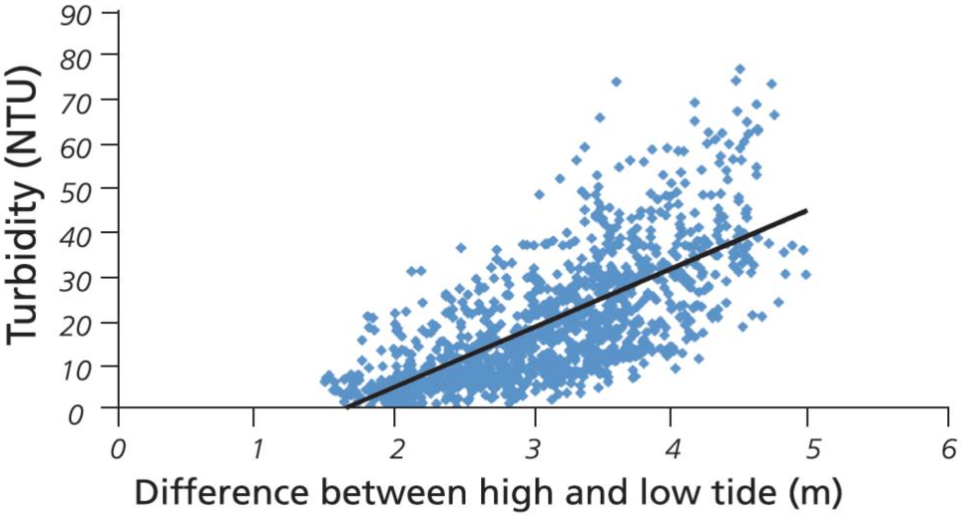


Figure 6.12: The relationship between tidal movement and turbidity in Gladstone Harbour (DEHP 2014 personal communication). NTU: nephelometric turbidity unit.

6.4. Social and economic pressures

Gladstone is an industrial hub of international significance owing to its large-scale production and export facilities. The Gladstone Region's social and economic growth and development patterns have been strongly influenced by the rapid development of the manufacturing, construction and retail trade sectors. This has resulted in a steady increase in Gladstone's population from 2011 (57,890 people) to 2019 (63,412 people) (economy.id.com.au downloaded July 2020).

The value of residential building approvals has declined following a sharp peak in 2012–13 when residential approvals reached $450 million. However, in the 2019–20 financial year the total value of residential approvals was $33 million up from $21 million in the previous year. The value of non-residential building approvals has also declined sharply over the same period from a peak of $400.1 million in 2012–13 to $32.3 million in 2019–20. This was also below the figure of $92 million recorded in 2018–19.

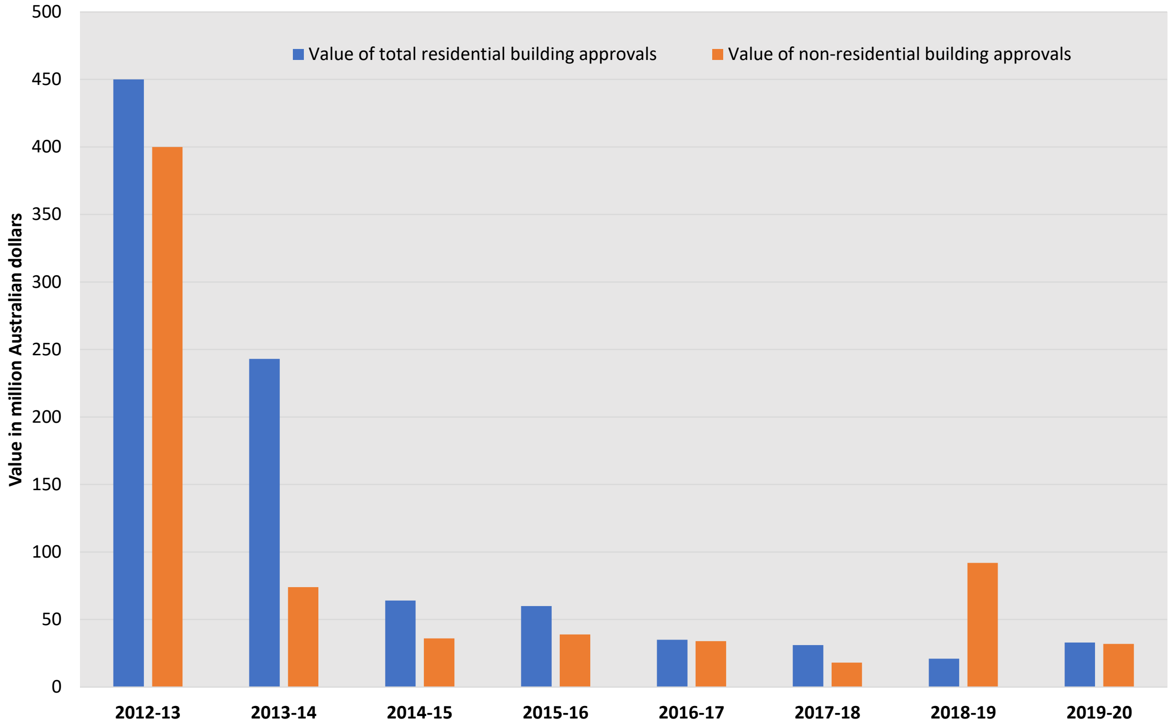


Figure 6.13: The value of residential and non-residential building approvals and approved new dwellings in Gladstone LGA from 2013 2019 (.id community downloaded January 2020).

The number of businesses actively trading in Gladstone also steadily declined from 2014 (4,092) to (3,701) in June 2019. This trend is also reflected in the total employment figures for Gladstone which have declined from 31,712 in 2014 financial year to 29,008 in the 2019 financial year (.id community downloaded July 2020).

Figure 6.14: The number of actively trading businesses in Gladstone 2014 to 2018 (.id community downloaded January 2020).

The three LNG processing and export facilities projects on Curtis Island, QCLNG, APLNG and GLNG, moved from the construction to operational phase during the 2015–16 financial year. As the LNG plants reached full capacity, in September 2016 a $17 million investment was made by GLNG and QCLNG to build a new marine operations terminal catering for the daily ferries and vessels to Curtis Island (Queensland Government, 2016).

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

7. Guide to the infrastructure supporting the report card

7.1. Data Information Management System

The GHHP Data Information Management System (DIMS) is an essential infrastructure developed by AIMS which allows a range of users to store, calculate and visualise report card raw data and results (Figure 7.1). Given the large social, cultural, economic and environment monitoring datasets used to inform a report card, this system will help to systematically and consistently manage the data with a reliable backup system. The DIMS will also be an information source for the website that can collate and analyse different data types and produce graphical outputs and tables.

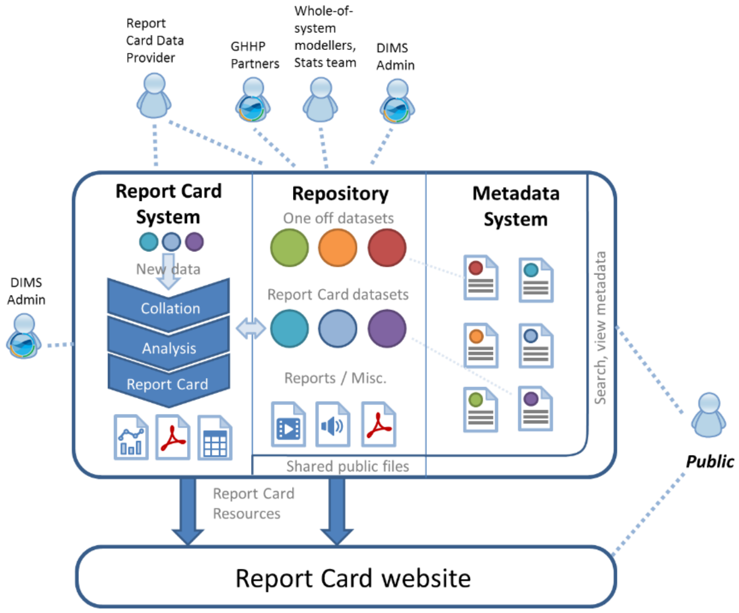


Figure 7.1: Schematic diagram of the links between the report card website and the Data Information Management System (DIMS) to illustrate major components and primary inputs and outputs (Diagram courtesy Australian Institute of Marine Science).

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 7.2).

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.

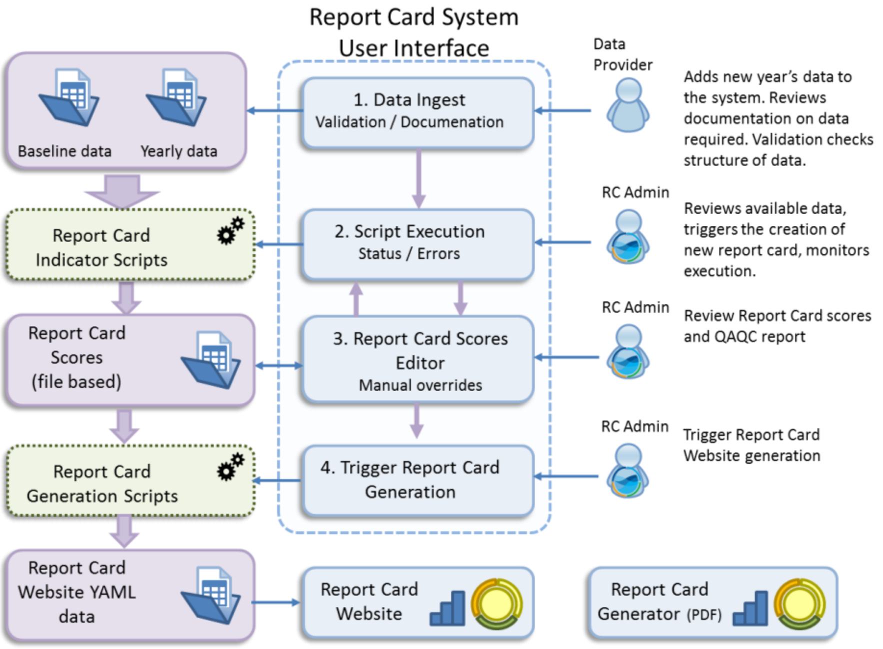


Figure 7.2: Schematic diagram of the report card system showing all data ingestion, script execution and report cards results generation modules (Diagram courtesy Australian Institute of Marine Science).

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

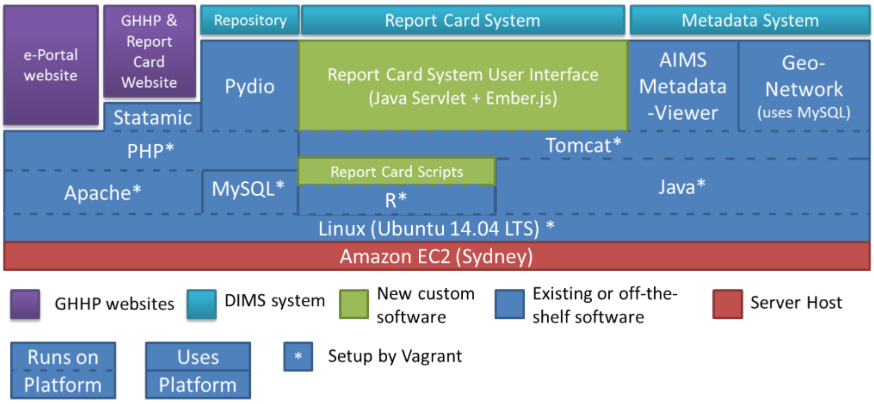


Figure 7.3: Software infrastructure underlying the Data Information Management System (DIMS) operations (Diagram courtesy Australian Institute of Marine Science).

7.2. The Gladstone Harbour Model

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

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

Gladstone Harbour Model Domain

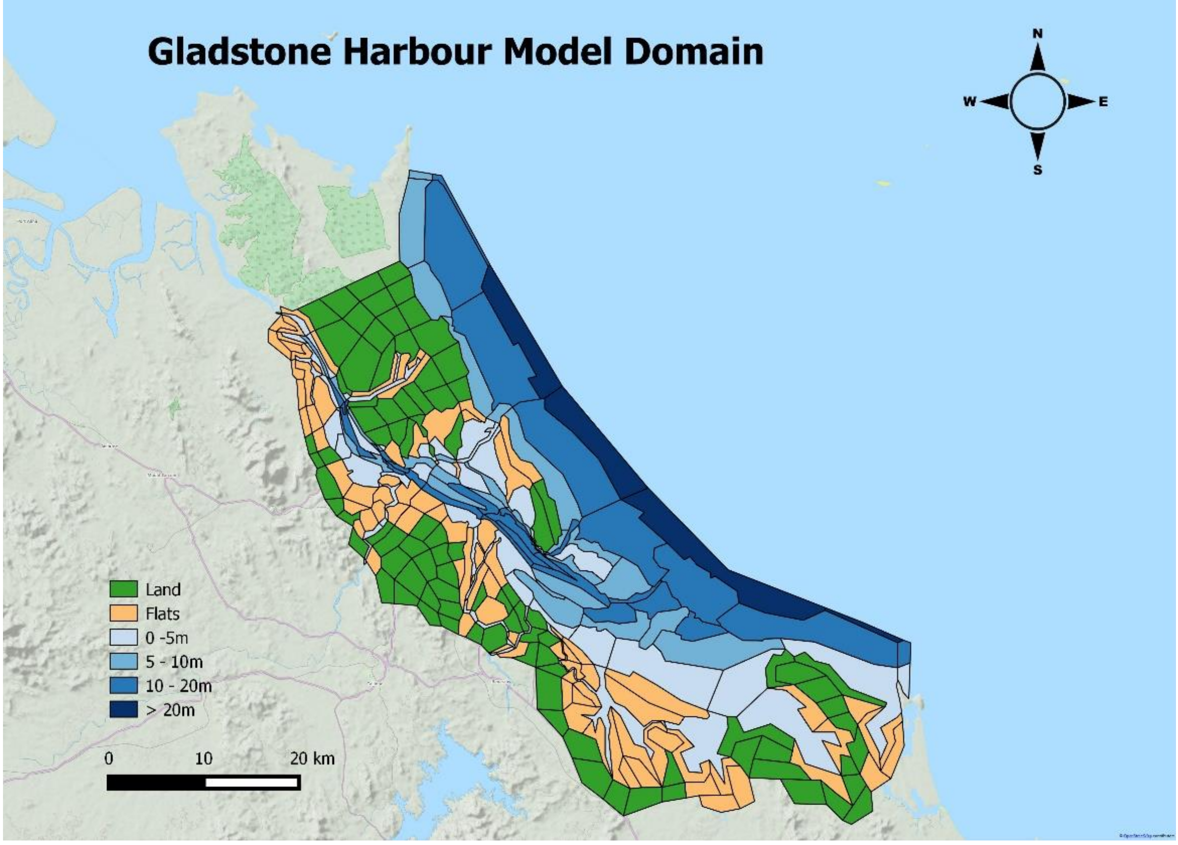


Figure 7.4: The area modelled in the GHHP Atlantis model includes the harbour and surrounding area.

The area modelled in the GHHP Atlantis model consist of 305 boxes including 190 land boxes and 115 wet boxes. The properties represented in each box are based on the available geomorphology of sediments and soils, water column properties; temperature, salinity, dissolved oxygen, major current patterns, and distribution of habitats (Figure 7.4).

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

Physical (Hydrodynamic) and Biogeochemical Model

Hydrodynamic model

The hydrodynamic model drives water circulation within the modelled harbour (Figure 7.5). Outputs from the model include three-dimensional distributions of water velocity, temperature, salinity, density, passive tracer movements, mixing coefficients and sea-level. The inputs required by the model include forcing due to wind, atmospheric pressure gradients, surface heat and water fluxes and open-boundary conditions such as tides. Initial and open boundary conditions were provided by CSIRO's eReefs model. Freshwater flows are introduced to the model corresponding to the Calliope and Boyne river flows.

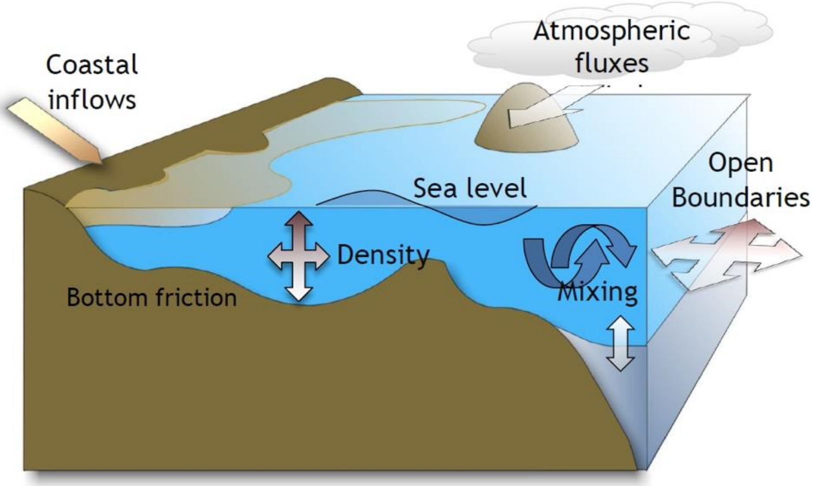


Figure 7.5: Physical processes represented in the hydrodynamic model.

Biogeochemical model

This component of the model captures the water quality dynamics of Gladstone Harbour. It provides a direct link between the hydrodynamic models and the system models. It models water-column processes which integrate hydrodynamic, sediment transport and biogeochemical modules (Figure 7.6).

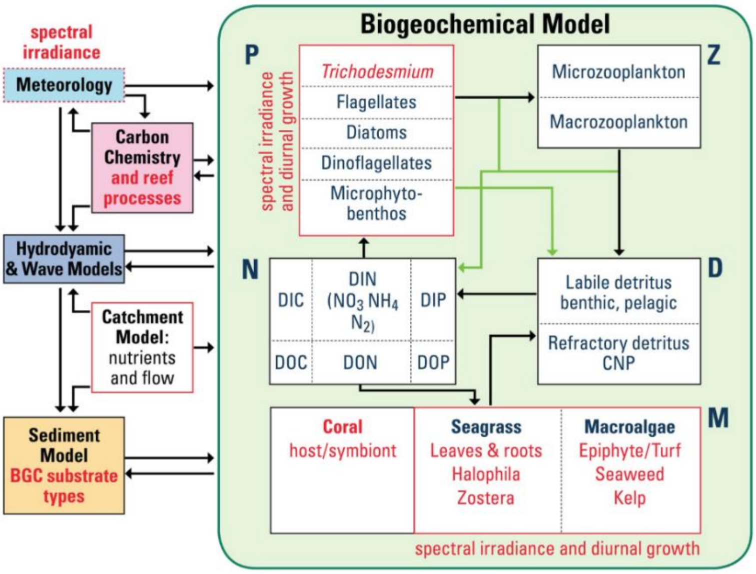


Figure 7.6: Components and processes within the Biogeochemical model.

Ecosystem Elements and Marine Food Webs

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

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

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

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

The Human Elements, Social and Economic, of Gladstone Harbour

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

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

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

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

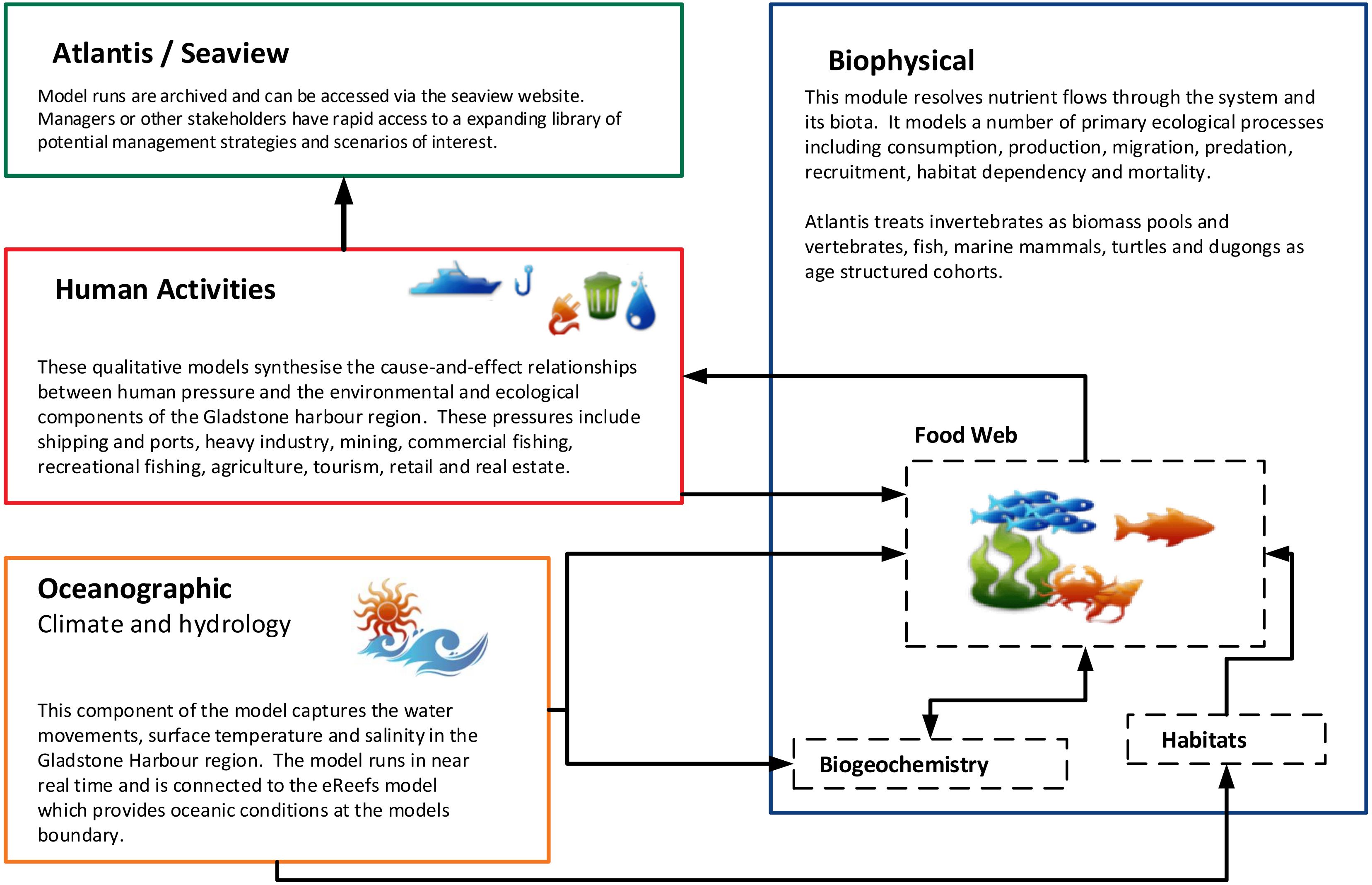
Discussions at these workshops let the researchers draw qualitative models of how the system is linked together and how it responds to change. These qualitative models where then converted into quantitative model components for use in the systems model.

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

The final model - the whole of system model - brings all the other models and outputs together. This model is used to improve our understanding of the potential outcomes and interactions between the many factors, human and natural that can affect the health of Gladstone Harbour (Figure 7.7).

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

Figure 7.7: Putting it all together the full system model.



Atlantis / Seaview

Model runs are archived and can be accessed via the seaview website. Managers or other stakeholders have rapid access to a expanding library of potential management strategies and scenarios of interest.

Human Activities

These qualitative models synthesise the cause-and-effect relationships between human pressure and the environmental and ecological components of the Gladstone harbour region. These pressures include shipping and ports, heavy industry, mining, commercial fishing, recreational fishing, agriculture, tourism, retail and real estate.

Oceanographic

Climate and hydrology

This component of the model captures the water movements, surface temperature and salinity in the Gladstone Harbour region. The model runs in near real time and is connected to the eReefs model which provides oceanic conditions at the models boundary.

Biophysical

This module resolves nutrient flows through the system and its biota. It models a number of primary ecological processes including consumption, production, migration, predation, recruitment, habitat dependency and mortality.

Atlantis treats invertebrates as biomass pools and vertebrates, fish, marine mammals, turtles and dugongs as age structured cohorts.

Initial results

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

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

Further information

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

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

8. Geographical scope

8.1. 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 (DEHP) developed the current 13 zones (Figure 8.1). These zones were also used to define regionally specific water quality objectives for the Capricorn Coast (DEHP, 2014a).

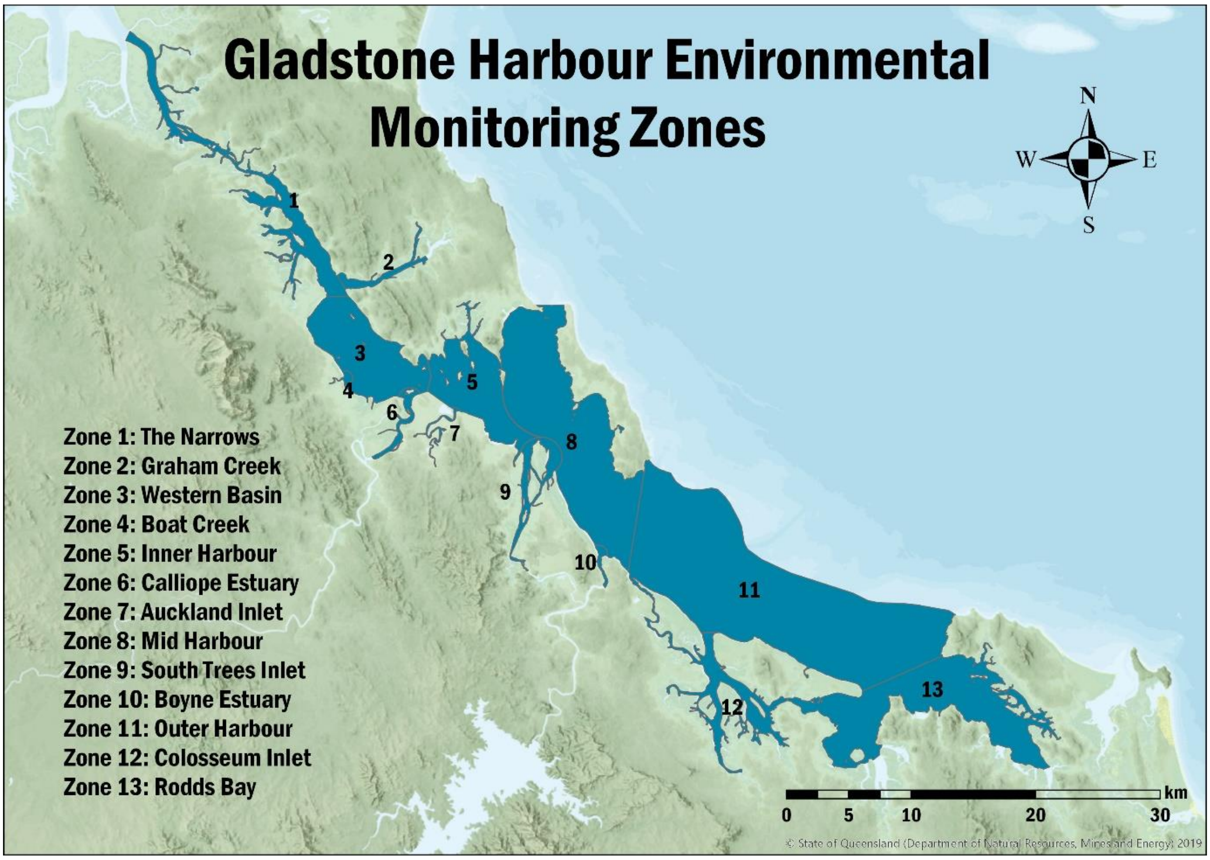


Figure 8.1: The 13 Gladstone Harbour zones for which environmental parameters were measured for the 2019 Gladstone Harbour Report Card.

Figure 8.2: 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 8.3: The Narrows photographed from the south with Keppel Bay in the distance.

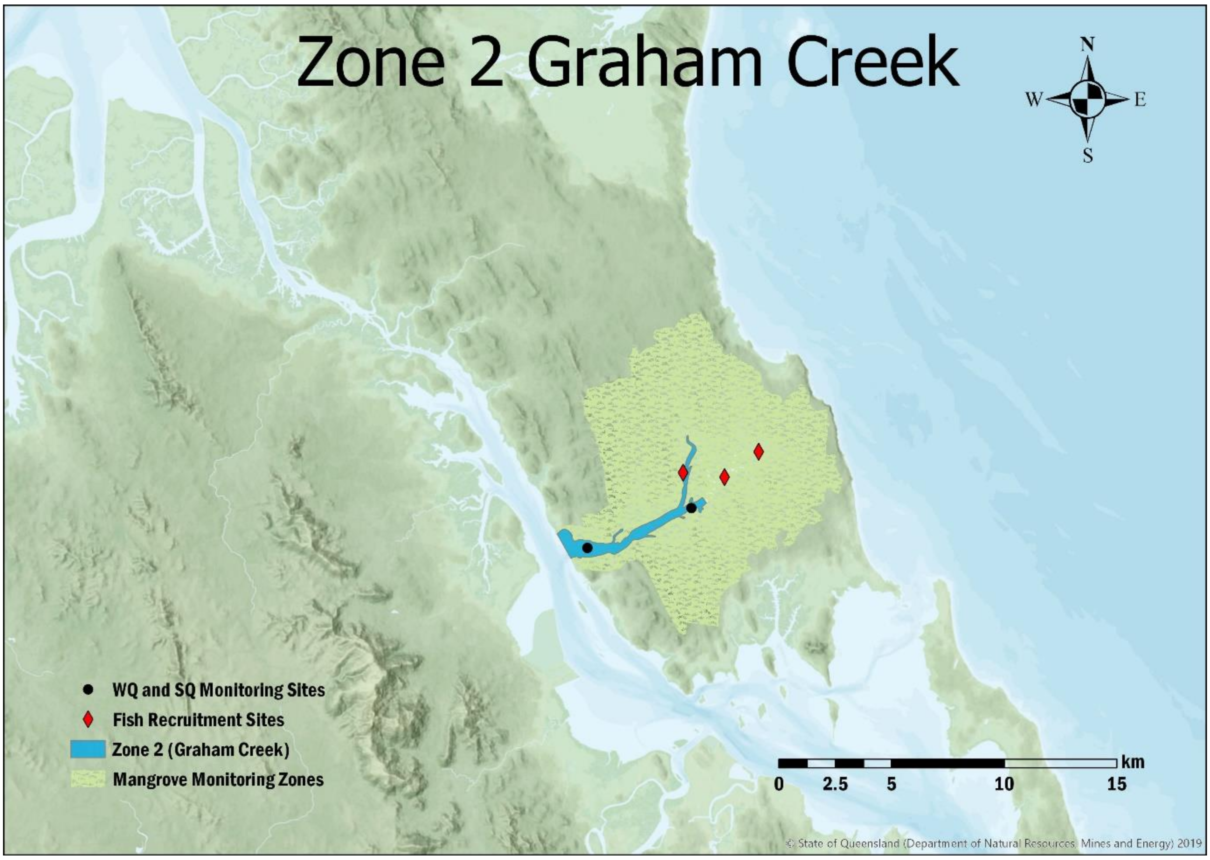


Figure 8.4: Habitat types and sampling sites in Graham Creek.

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 8.5: 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.

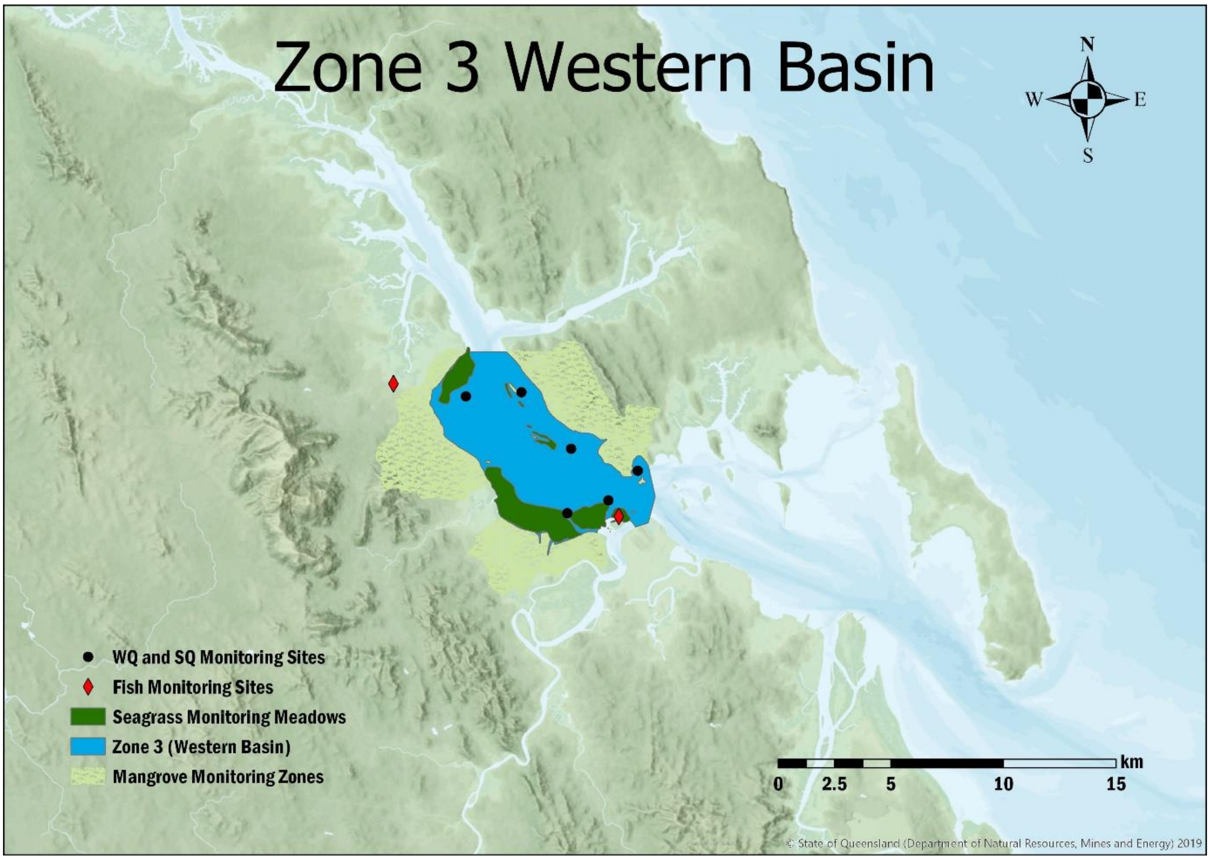


Figure 8.6: Habitat types and sampling sites in the Western Basin.

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

Zone area: 39.19 km^2
Fish health monitoring

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

Figure 8.7: The south-western corner of Curtis Island, showing two liquid natural gas plants in the foreground and the Western Basin in the distance.

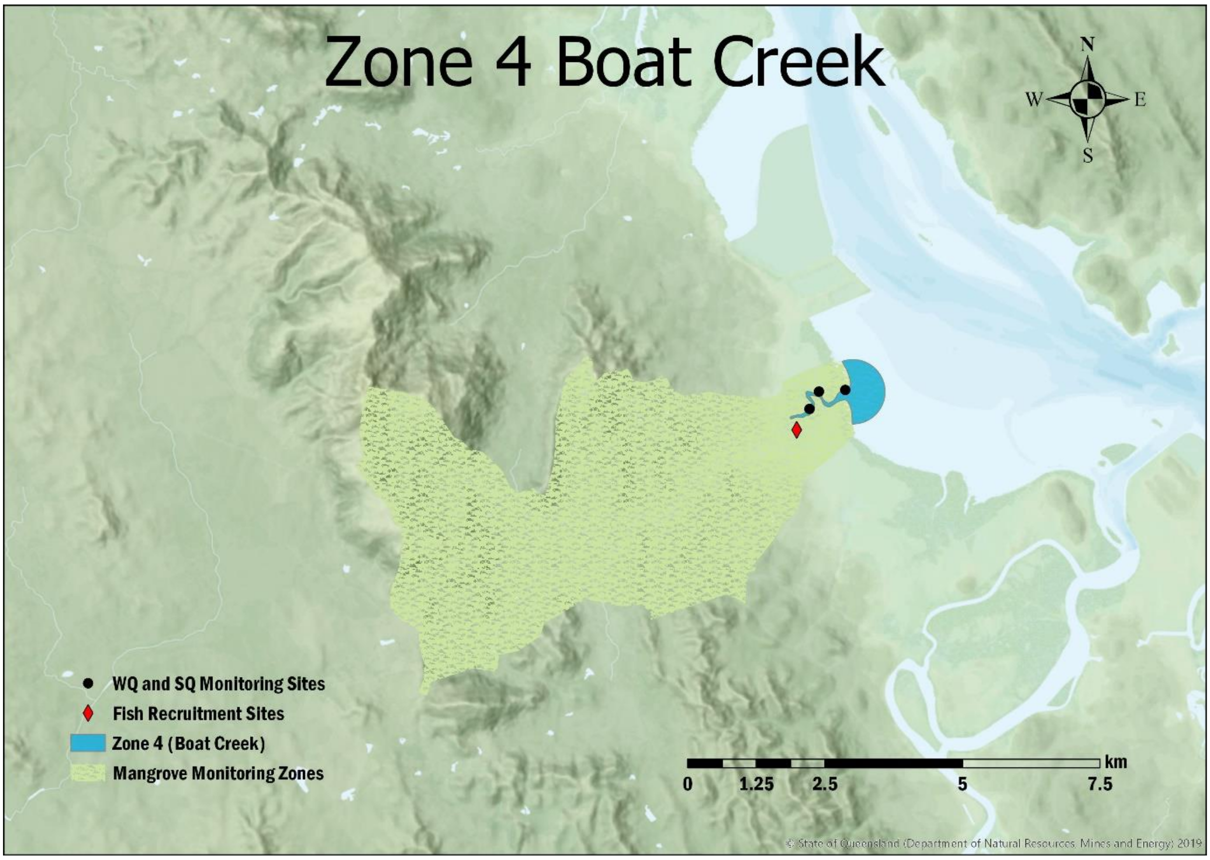


Figure 8.8: Habitat types and sampling sites in Boat Creek.

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

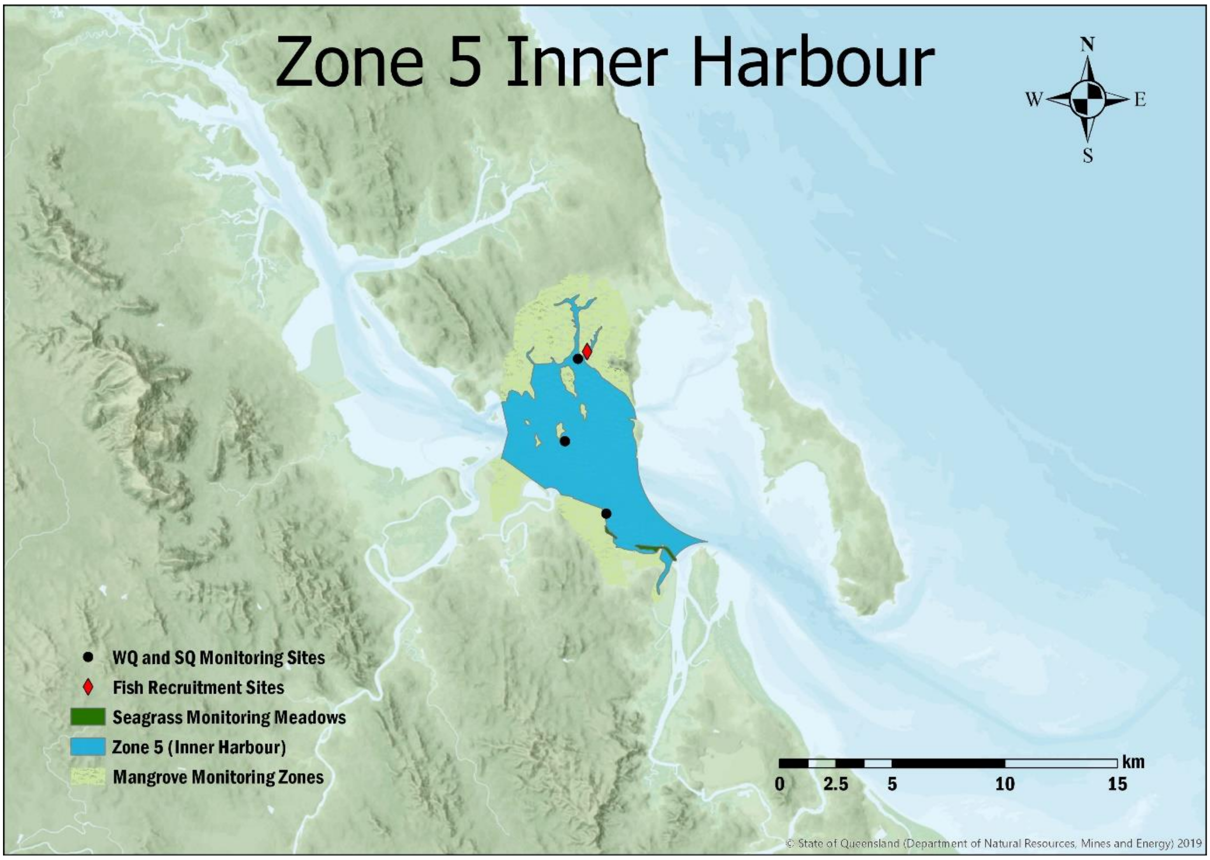


Figure 8.10: Habitat types and sampling sites in the Inner Harbour.

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.

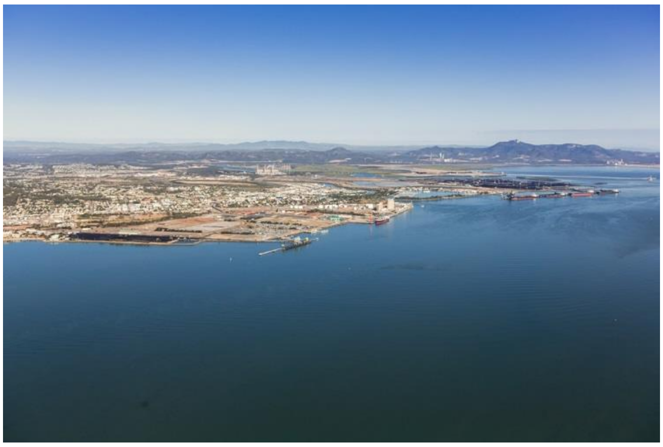


Figure 8.11: The Inner Harbour photographed from the north-east, with Auckland Point wharves and the City of Gladstone on the left and the RG Tanna coal loading facility on the right.

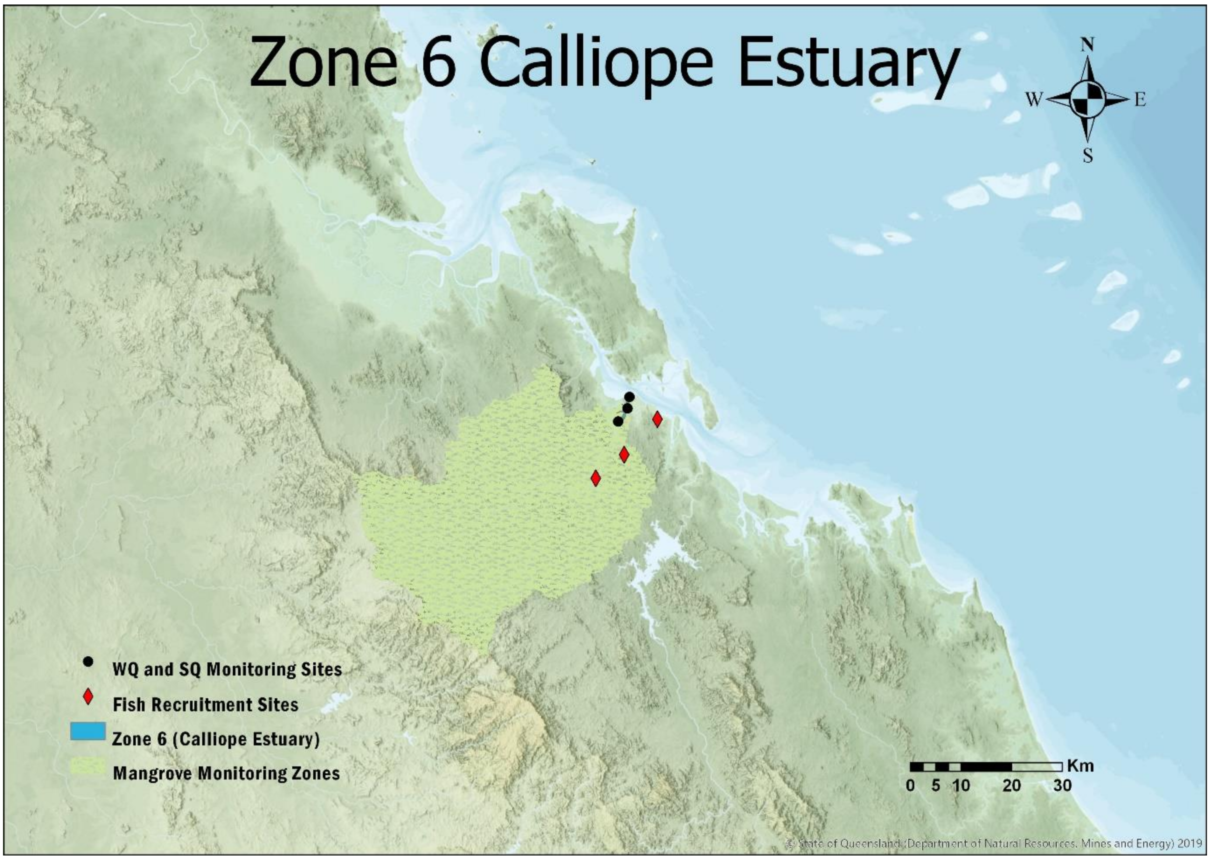


Figure 8.12: Habitat types and sampling sites in Calliope Estuary.

Three water and sediment quality monitoring sites	Zone area: 7.71 km^2
Two fish recruitment monitoring sites	Fish health monitoring
One mud crab monitoring site	

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

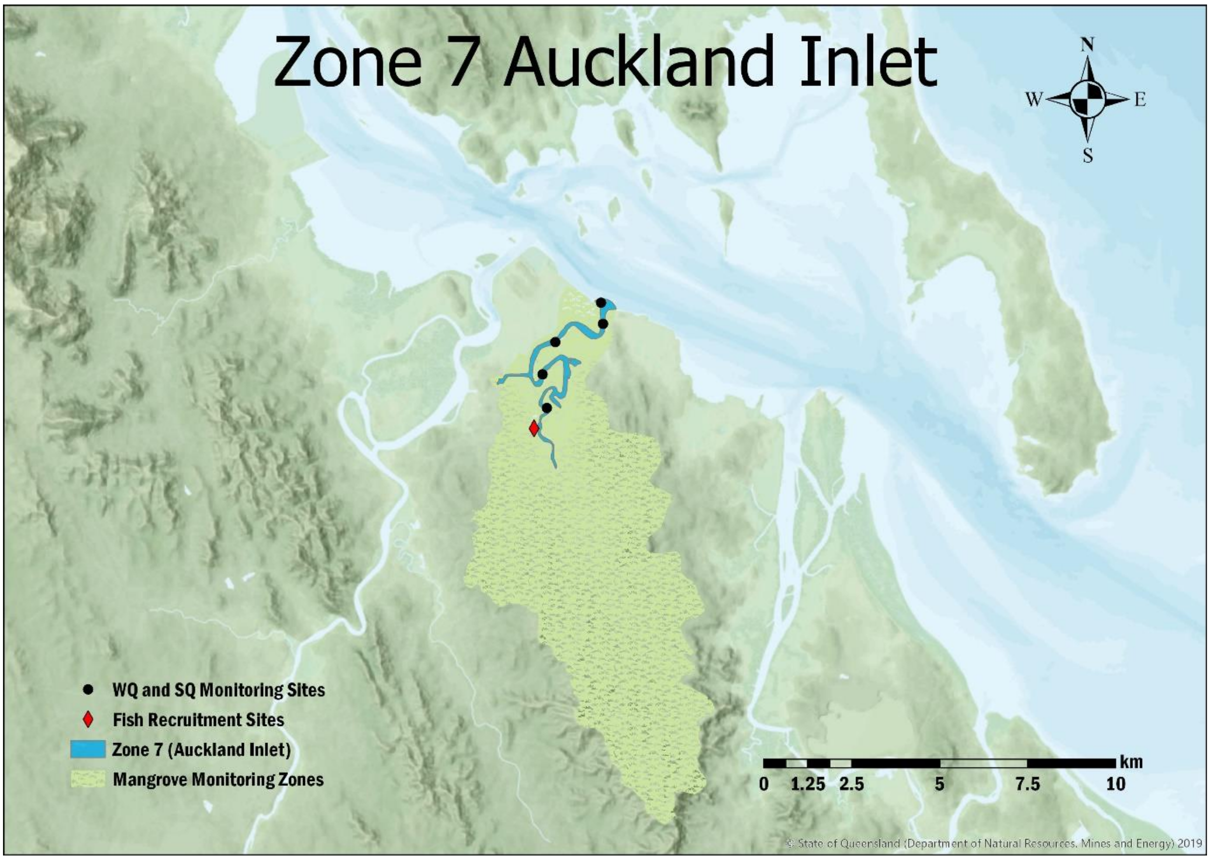


Figure 8.14: Habitat types and sampling sites in Auckland Inlet.

Five water and sediment quality monitoring sites	Zone area: 1.33 km^2
One fish recruitment monitoring site	Fish health monitoring
One mud crab monitoring site	

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

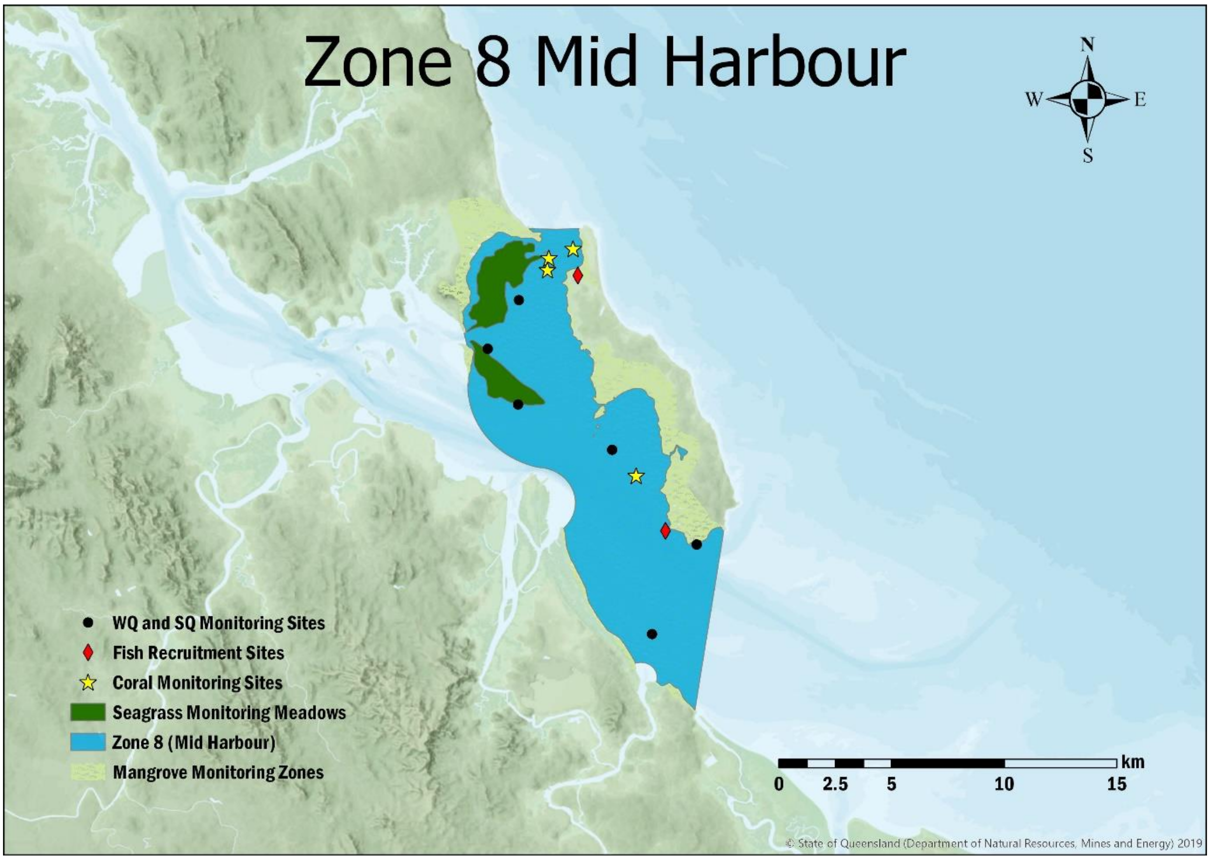


Figure 8.16: Habitat types and sampling sites in the Mid Harbour.

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.

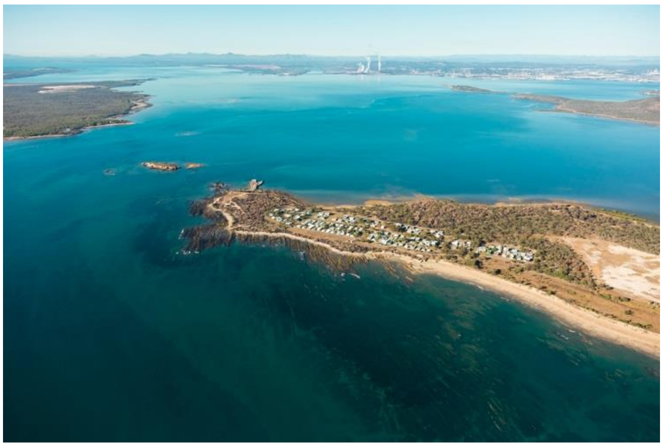


Figure 8.17: The Mid Harbour photographed from north-east. Curtis Island is in the foreground and the Inner Harbour is in the background.

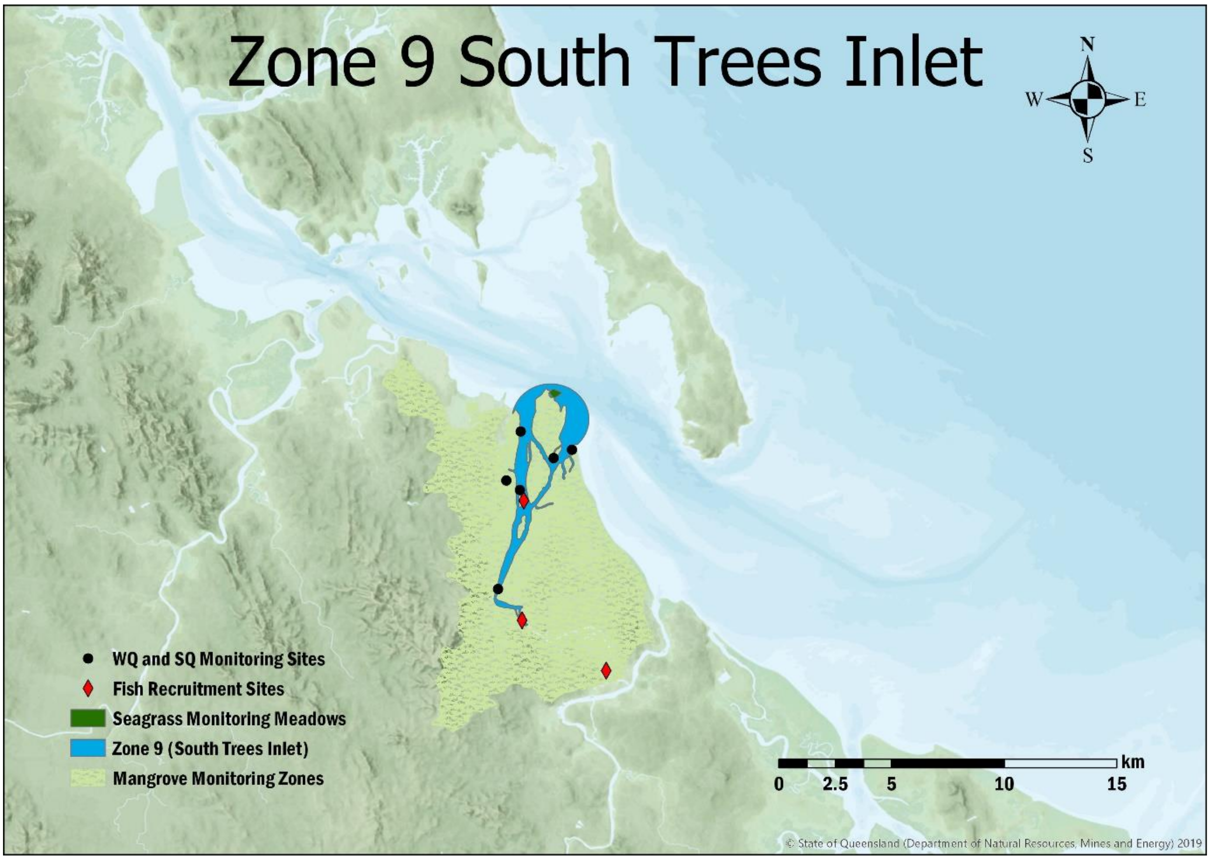


Figure 8.18: Habitat types and sampling sites in South Trees Inlet.

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

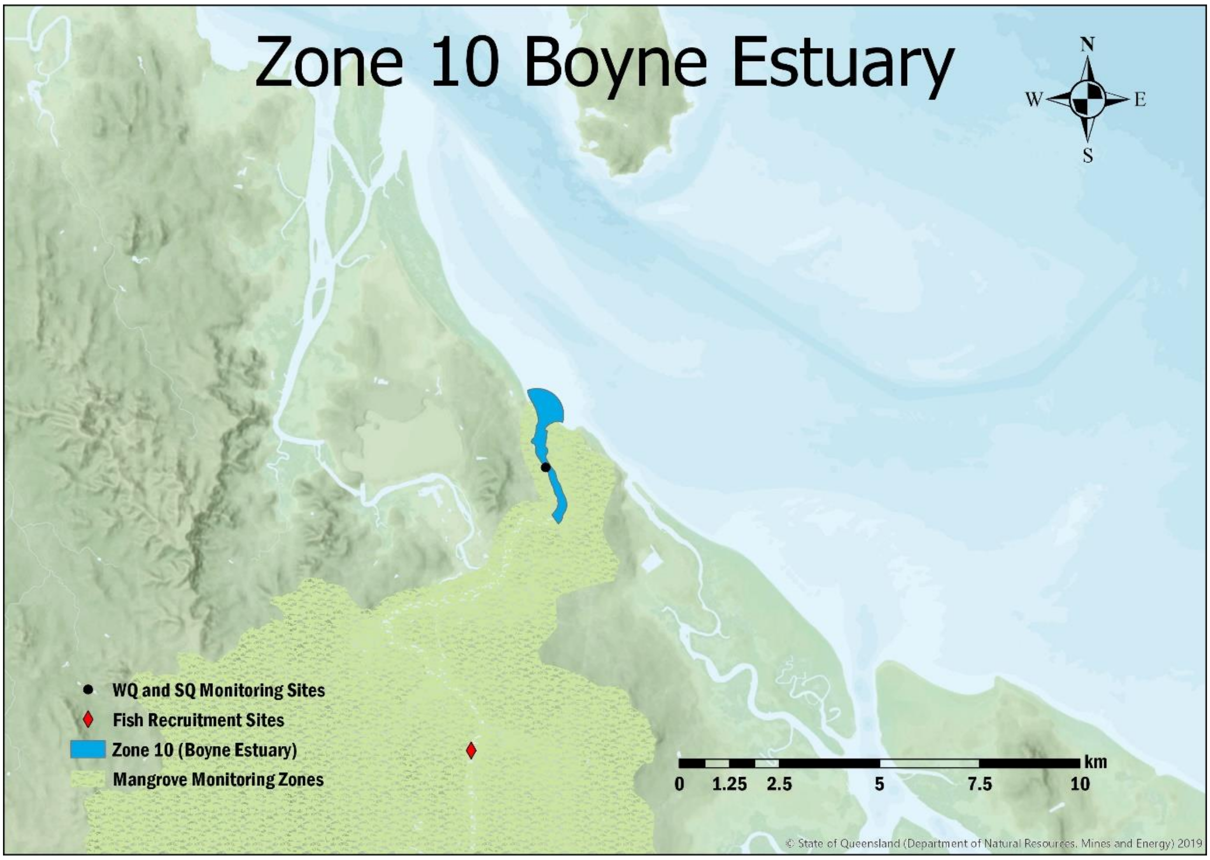


Figure 8.20: Habitat types and sampling sites in Boyne Estuary.

One water and sediment quality monitoring site	Zone area: 3.62 km^2
Two fish recruitment monitoring sites	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 8.21: The mouth of the Boyne River photographed from the north-east. Boyne Island is on the right and Tannum Sands on the left.

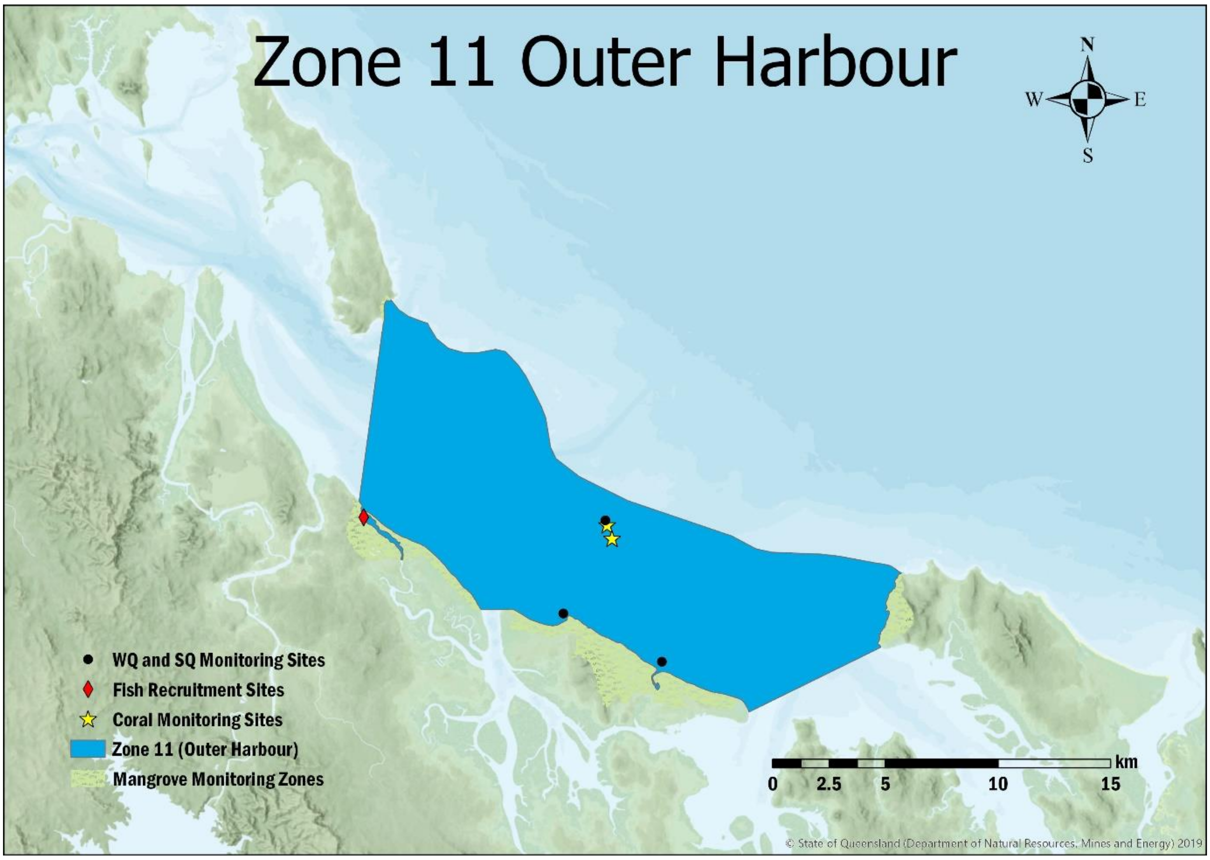


Figure 8.22: Habitat types and sampling sites in the Outer Harbour.

Three water and sediment quality monitoring sites	Zone area: 176.97 km^2
Two coral monitoring sites	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.

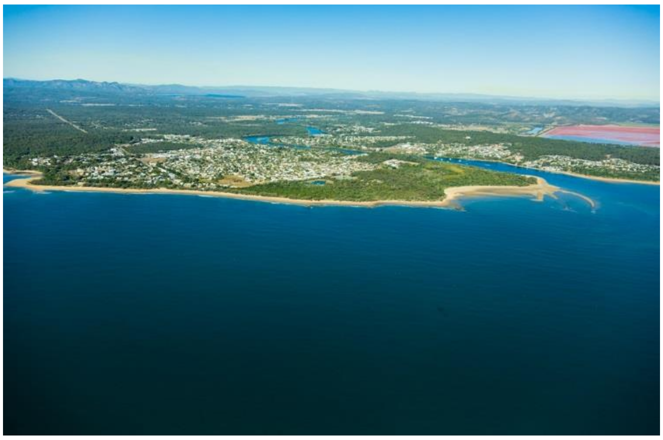


Figure 8.23: The Outer Harbour and Tannum Sands photographed from the north-east. Boyne Island and one of Gladstone's red mud (bauxite) dams are on the right.

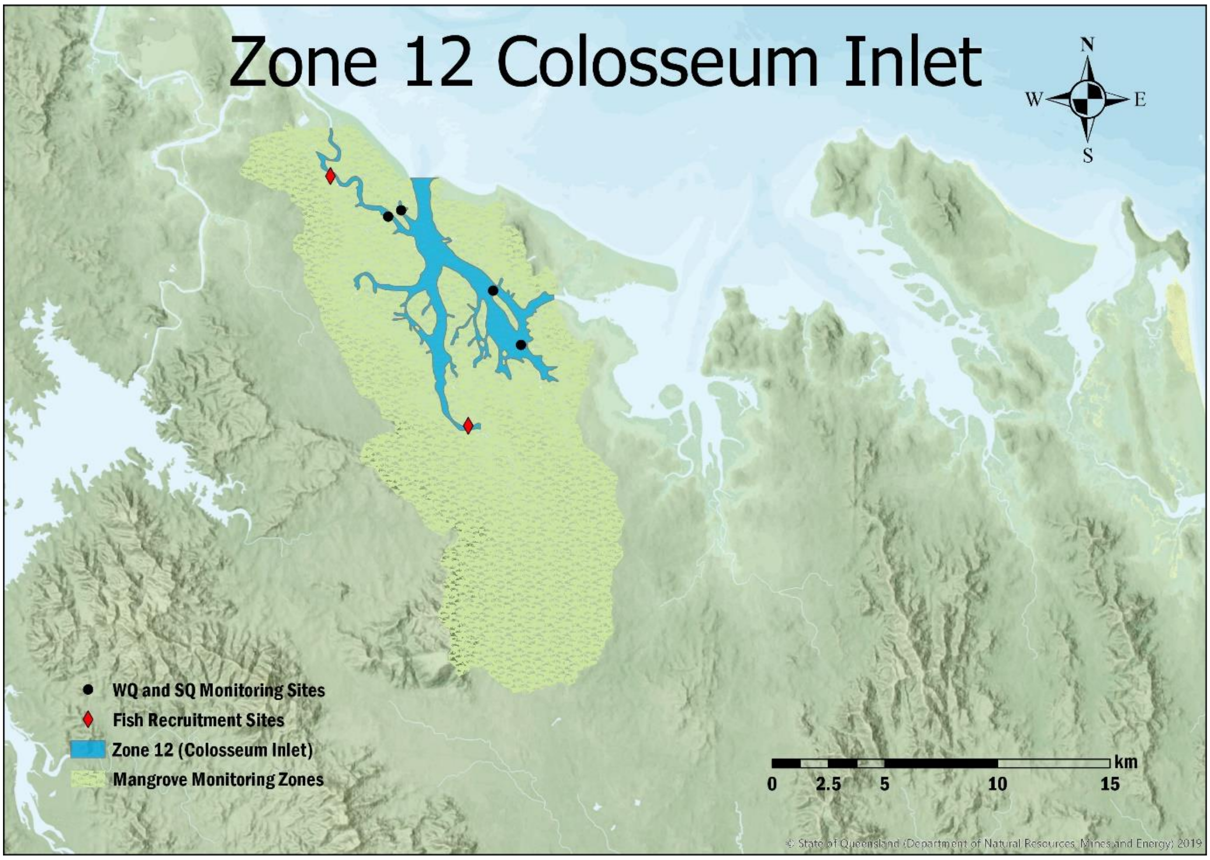


Figure 8.24: Habitat types and sampling sites in Colosseum Inlet.

Four water and sediment quality monitoring sites	Zone area: 18.98 km^2
Two fish recruitment monitoring sites	Fish health monitoring

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

Figure 8.25: The northern entrance to Colosseum Inlet showing Wild Cattle Island on the right and Hummock Hill Island on the left.

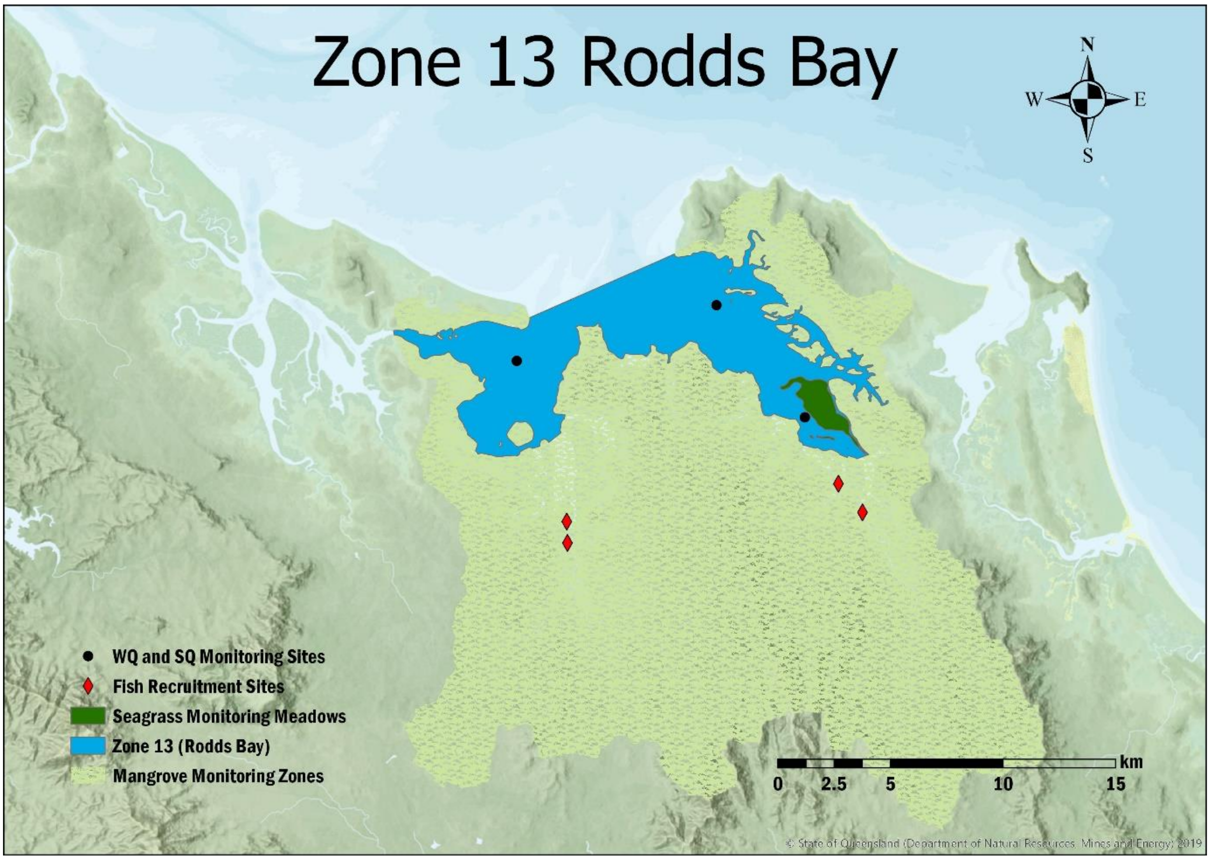


Figure 8.26: Habitat types and sampling sites in Rodds Bay.

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

8.2. 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 8.28). Hotel occupancy rates were based on the Gladstone Local Government Area (LGA) (Figure 8.28). The Gladstone Ports Corporation (GPC) provided the shipping data for the Port of Gladstone.

Commercial fishing data were collected from the area within the Queensland Fisheries S30 Grid (QFish S30) and nearby open coastal waters of Mackay (Grid O25) and Rockhampton/Yeppoon (Grid R29) (Figure 8.29).

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).

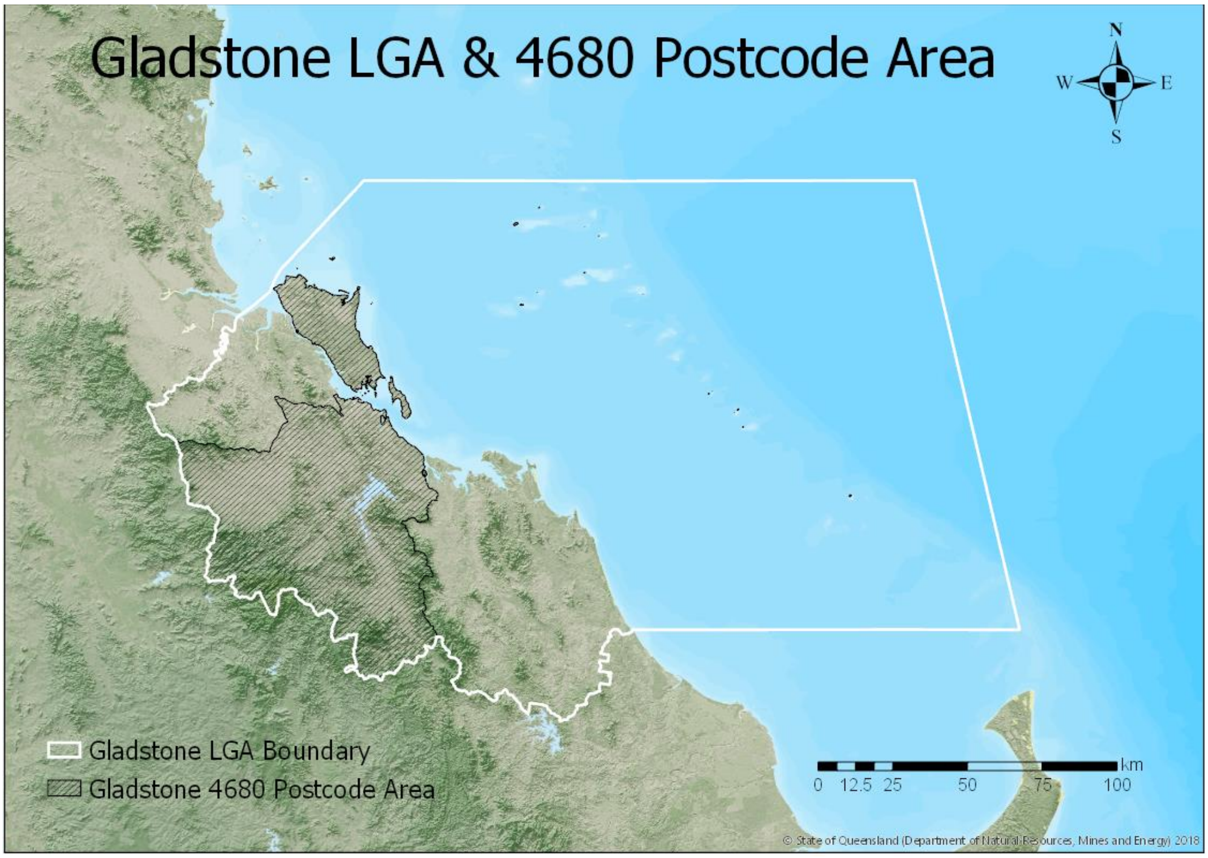


Figure 8.28: The Gladstone Region showing the mainland extent of the Gladstone Local Government Area (LGA) and the Gladstone 4680 postcode area. Both were used to define areas from which some social, cultural, and economic data were collected.

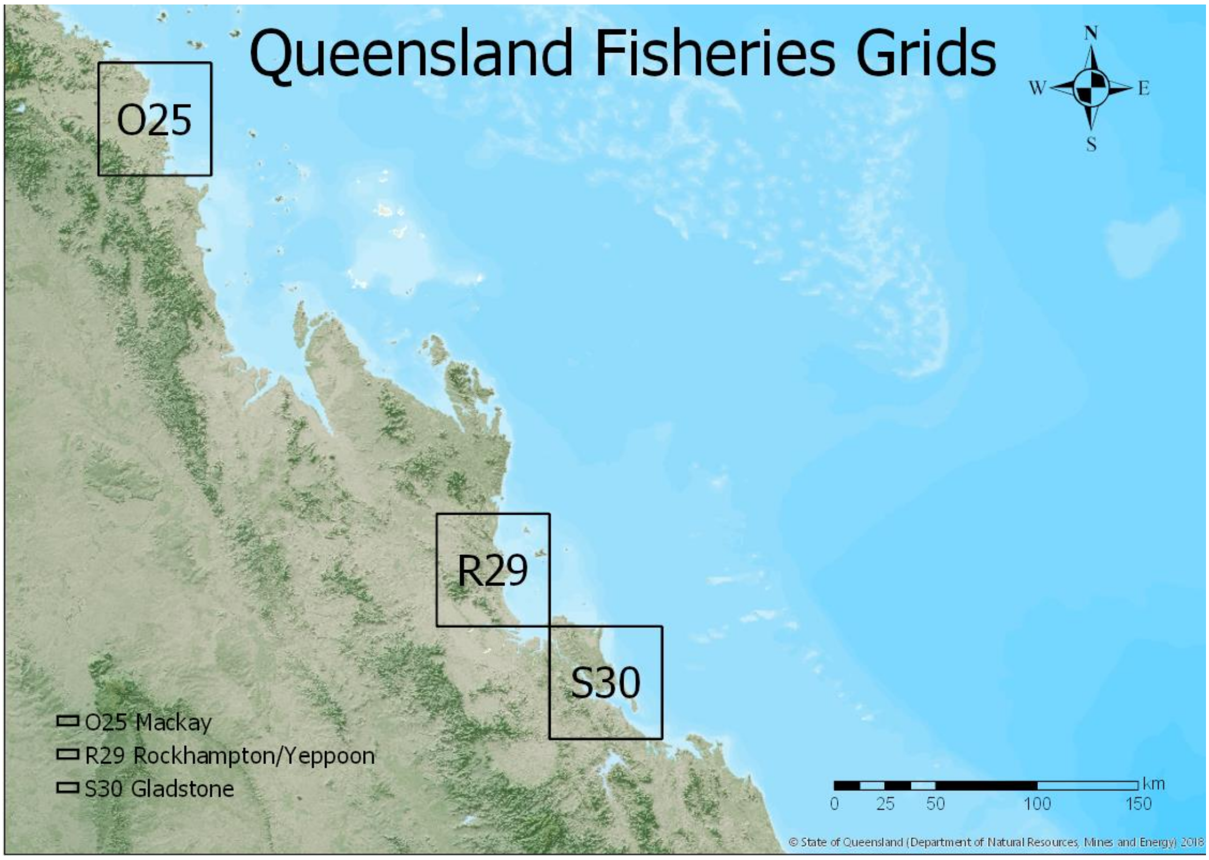


Figure 8.29: The Queensland Fisheries S30 (Gladstone), R29 (Rockhampton and Yeppoon) and O25 (Mackay) Grids. Data from these grids are used to calculate the commercial fishing indicator.

Data for the Indigenous cultural heritage indicator group were collected from four zones within the LGA boundary: The Narrows, Facing Island, Gladstone Central and Wild Cattle Creek (Figure 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 both the mainland and parts of Curtis Island. The score for the Narrows is based on six sites documented in 2016, three sites documented in 2017 and one site documented in 2018. The cultural locus site is a 2 km long quarry site which was used by Traditional Owners to quarry silcrete to manufacture stone tools. The Traditional Owners and Elders also identified a stone arrangement which resembles a crocodile and linked with 'Gu-ra-bi' dreaming at Mt Larcom as of similar cultural significance, so weighted it similar to the quarry site. A number of stone arrangements were found in the north of The Narrows and a number of semi-permanent pools were found in the south-east parts of the zone. A close examination of the material found during the surveys suggested the area was disturbed in the past by fire, water activity, cattle and trampling.

Facing Island

Facing Island is located approximately 7 km east of the Gladstone Central Business District (CBD). The island covers approximately 57 km^2 land area and mainly consists of long sandy beaches. A total of seven sites have been identified in annual field surveys since 2016 and six sites within this zone were resurveyed in 2018. The cultural locus site for the Facing Island is a large shell midden. Stone tools and shell scatters are located in the south-eastern part of the Facing Island.

Gladstone Central

The Gladstone Central zone covers approximately 173 km^2 area around the Gladstone CBD. This zone has been chosen for monitoring as it has a large number of sites which are of cultural significance to Traditional Owners and Elders for fishing, hunting, boating, traditional meetings and ceremonies. This zone had been further extended in 2017 and includes sites near Boyne and Calliope rivers. Barney Point was identified as the cultural locus site in 2017 as Traditional Owners and Elders see this site as being a positive place of significant cultural and social meaning, and more representative of the area than the Police Creek area previously chosen as a cultural locus site in 2016. There are public walking tracks and interpretive signs in this zone explaining the ecology and history of Barney Point. A total of six sites have been identified for annual surveys within this zone since 2016 of which five were revisited in 2018.

Wild Cattle Creek

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

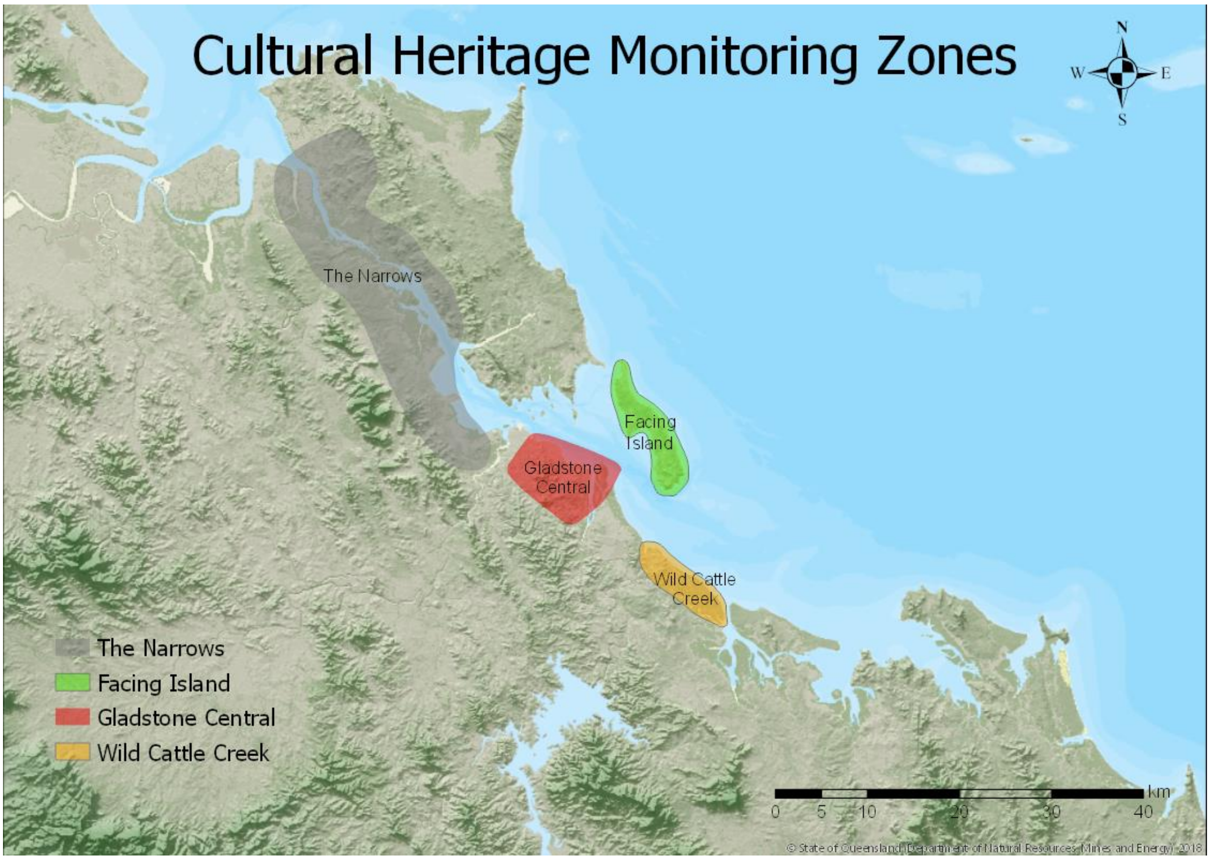


Figure 8.30: The four reporting zones from which data used to inform the Indigenous cultural heritage indicators for 2019 report card were collected.

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10. Glossary

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

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

QA/QC	Quality assurance/quality control – the processes used to ensure the quality of a product (QA), and then to assess whether the product or services meet quality standards then correct where necessary to meet those standards (QC). Raw data may contain errors or be in formats unsuitable for further analysis, so appropriate QC needs to be applied to assess and correct data.
QFish	Queensland Fishing
Raw data (also ‘primary data’)	Data that have not been processed or otherwise manipulated apart from QA/QC to ensure accuracy
RC	Report card
Reference condition	Recorded indicator values are compared against values from sites not impacted by human disturbance or alteration, or, which represent a control site considered to be ‘healthy’ (Connolly et al., 2013)
Standards	Legal limits permitted for a specific water body
TC	Tropical cyclone
TCM	Travel cost method
TropWATER	Centre for Tropical Water & Aquatic Ecosystem Research (James Cook University)
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	AIMS. (2014). *Design and architecture of the Data Information Management System (DIMS) for the GHHP Report Card monitoring data*. Project ISP009. Australian Institute of Marine Science, Townsville.

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.
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. 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.

Project name and institution	**Reports and publications**
ISP013-2015 Fish recruitment study Infofish Australia and Dr Bill Venables	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.
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.

Project name and institution	Reports and publications
	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.
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.

ISP016 **GHHP Gladstone fish health research program (a)** Gladstone Harbour Healthy Partnership, Fisheries Research and Development Canberra, AusVet Animal Health Services.	Fisheries Research Development Corporation. (2015). *Development of the Gladstone Healthy Harbour Partnership Fish Health Research Program.* FRDC, Canberra. Download the final report for this project
ISP016 **GHHP Gladstone fish health research program (b)** Australian Institute of Marine Sciences	Kroon, F.J., Streten, C., & Harries, S.J. (2016) *The use of biomarkers in fish health assessment worldwide and their potential use in Gladstone Harbour.* Australian Institute of Marine Science, Townsville. Download the final report for this project.
ISP016 **GHHP Gladstone fish health research program (c)** Infofish Australia Pty Ltd, 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.
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.
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.
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Appendix 2: Water quality objectives and guidelines used to calculate water quality scores

Zone	Physicochemical													
	Level of Protection	Turbidity		pH range		Nutrients			Metals					
		Dry (NTU)	Wet (NTU)	<40 ms/cm	>40 ms/cm	TN (µg/L)	TP (µg/L)	Chl-*a* (µg/L)	Al (µg/L)	Cu (µg/L)	Pb (µg/L)	Mn (µg/L)	Ni (µg/L)	Zn (µg/L)
1. The Narrows	HEV	7	15	7.2–8.2	7.4–8.3	170	20	1	24	1.3	4.4	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.

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
	Nickel (Ni)	21	ANZG, 2018
	Zinc (Zn)	200	ANZG, 2018