Mud Crab Indicators for the 2023 Gladstone Harbour Report Card

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The authors would like to take this opportunity to respectfully acknowledge the Traditional Owners of the land on which we live, work and learn, and pay our respects to the Elders, past, present and future for they hold the memories, the traditions, the culture and hopes of Indigenous Australia. In particular, we pay our respects to the peoples on whose Country this research was carried out.

Version history

Version Number	Purpose/Changes	Prepared by	Date
1.1	Initial draft of interim report – to GHHP	Flint, De Valck, Anastasi	18/08/2023
1.2	Final report	Flint, De Valck, Anastasi	30/01/2024

Executive summary

Giant mud crabs (*Scylla serrata*) are a recreationally and commercially important species across the Indo-Pacific, an iconic seafood item, and have cultural value to Indigenous Australians. The Gladstone Harbour Report Card mud crab indicator has been monitored in seven Gladstone Harbour zones since 2017, and this report presents the results of the seventh year of sampling, in 2023. The indicator scores and grades cover three metrics: abundance (catch per unit effort), prevalence of rust lesions, and sex ratio, in each zone and across the harbour.

Two field sampling events were conducted in February and June 2023. Scores and grades were calculated using both of the 2023 data sets for the three metrics within each of the seven recommended long-term monitoring zones in Gladstone Harbour. The scores for each of the three measures were averaged across all zones first to give a harbour average for each measure, and then the average of the three harbour averages was calculated to provide a harbour-wide score and grade for the mud crab indicator.

The following scores and grades have been generated for 2023:

Zone	Abundance (CPUE)	Prevalence of rust lesions	Sex ratio	Zone score 2023
1. The Narrows	0.58	0.88	0.03	0.50
2. Graham Creek	0.00	1.00	0.09	0.36
4. Boat Creek	0.31	1.00	0.71	0.67
5. Inner Harbour	0.00	NC	NC	NC
6. Calliope Estuary	0.00	1.00	0.62	0.54
7. Auckland Inlet	0.00	1.00	0.00	0.33
13. Rodds Bay	0.00	1.00	1.00	0.67
Harbour Average	0.13	0.98	0.41	0.51

The mud crab indicator reflects a variety of pressures on mud crabs in Gladstone Harbour, including commercial fishing, recreational fishing, and environmental/habitat condition. Over short time periods, scores and grades are also potentially influenced by biological variability. This year the harbour was graded C overall for the mud crab indicator, with the highest zone grades recorded at Boat Creek and Rodds Bay (B).

The zone score and grade for Inner Harbour has not been calculated. Only 4 mud crabs were caught here in 2023 and the small sample size ($n < 5$) means it is not appropriate to calculate grades for this zone, except for the abundance measure.

Abundance (CPUE) scores were lower than in previous years due to particularly low catch in February 2023 (just like in February 2022), and as in previous years The Narrows had the highest zone score for this measure. As well as human impacts, there are a range of factors that can influence the catchability of mud crabs such as the moult state of crabs, reproductive cycles, lunar and diel cycles, temperature, water motion and habitat quality. In light of this potential for natural variability, the decision was taken in 2018 for abundance to be scored based on a moving average technique, using the average of the 75th percentile of scores for current and previous sampling years, up to 10 years. This long-term adjustment to the benchmark allows for annual harbour-wide changes in catchability and abundance, which are more likely to reflect natural variations.

With only 3 individuals (out of 94) showing lesions, the prevalence of rust lesions scored highly (graded A) in all zones except Inner Harbour, for was not scored. As previously identified for Gladstone Harbour, sex ratios of mud crabs over the legal-size limit (for males) tended towards

higher proportions of female mud crabs in most zones, a possible reflection of high participation in the sex-based fishery operating in Queensland. Overall, the harbour scored higher for the mud crab indicator in 2023 (0.51) than in 2022 (0.39) and was more similar to the 2021 score (0.48), resulting this year in a C grade.

Contents

Introduction

Giant mud crabs (*Scylla serrata*) are a large, high-value crustacean, subject to commercial, recreational and Indigenous fishing in all Australian states that they inhabit and across the Indo-Pacific. In 2014, the Gladstone Healthy Harbour Partnership (GHHP) Independent Science Panel (ISP) recommended the development of a mud crab indicator, given their importance in Gladstone Harbour (McIntosh *et al.*, 2014). In 2017, GHHP commissioned CQUniversity to develop mud crab indicators for the Gladstone Harbour Report Card (Project ISP015-2017). In subsequent years, GHHP has commissioned CQUniversity to monitor, score and grade the mud crab indicator, and to make refinements to methods when needed.

As described in previous annual reports on the Mud Crab Indicator, an important aspect of monitoring programs is that the outputs are reported in a way that is understandable and meaningful to stakeholders, managers, and the community. Biological indicators such as mud crabs can help to fulfil this requirement in ecosystem health report cards (Flint *et al.*, 2021). The OECD defines environmental indicators, as "[…] a parameter, or a value derived from parameters, that points to, provides information about and/or describes the state of the environment, and has a significance extending beyond that directly associated with any given parametric value. The term may encompass indicators of environmental pressures, conditions and responses." Using this definition, environmental indicators do not necessarily reflect only a single, individual environmental pressure. This is often particularly true for biological indicators, as animals are exposed to the cumulative effects of a range of pressures and conditions in their environment, which can result in a range of biological responses.

Local pressures on mud crabs in Gladstone Harbour extraction via fishing (restricted to males over 150 mm carapace width), coastal development affecting mangrove and estuarine habitat quality, changes in water quality, and local weather patterns including those associated with global climate change. The prevalence of disease is also an important consideration and in previous years rust shell lesions have been recorded in Gladstone Harbour (Andersen and Norton, 2001).

The GHHP mud crab indicator is composed of three measures, which were selected in 2017 through a rigorous scoring process against predefined selection criteria (Flint *et al.*, 2017), to address the range of pressures in the harbour. The three measures selected for inclusion in the mud crab indicator include: abundance (catch per unit effort – CPUE), the prevalence of rust lesions, and sex ratio (Flint *et al*., 2021). The indicator was incorporated into the Gladstone Harbour Report Card and has been scored and graded each year since 2017.

The metric of **abundance of mud crabs** that are caught during the monitoring program provides a comparison of catch rates, using a standardised and fishery-independent biannual survey. To control for potential monitoring variations that could arise due to capture technique, consistent methods are employed during each catch period. Catch rates of mud crabs can reflect a wide variety of natural and anthropogenic impacts on a population (Alberts-Hubatsch *et al.*, 2016a). Factors influencing the abundance of mud crabs may include localised and regional fishing pressure, habitat availability and habitat condition, the availability of food and proximity to suitable nursery grounds for the settlement of mud crab megalopae and metamorphosis to immature crabs. Climate has also been shown to impact the abundance of mud crabs (Meynecke *et al.*, 2015) so there is also potential for this indicator to be used to monitor climate effects on mud crabs in the longer term.

The **prevalence of rust lesions** measure reports the proportion of captured crabs that have 'rust spot' shell lesions. The lesions were first recorded by commercial fishers in Gladstone Harbour in 1994 (Andersen and Norton, 2001). The disease is not infectious and it is thought it could be related to inhibition of calcium uptake following sublethal copper exposure, although this has not yet been experimentally confirmed (Andersen and Norton, 2001; Flint *et al.*, 2021). Since rust spots are not

continuously observed in Gladstone Harbour, their prevalence at any given time provides an indication of environmental state. Rust spot lesions impact the seafood 'grade' of mud crabs, so are a concern for local fishers. Recording the presence of rust spot is a relatively straightforward and non-destructive monitoring tool.

The third measure used in the mud crab indicator is **sex ratio**. The major drivers of changes in sex ratio are recreational and commercial fishing pressure on male mud crabs over 150 mm carapace width (measured across the ninth posteriolateral spines, referred to as 'spine width' in this report). In Queensland, female mud crabs, and male mud crabs under 150 mm, may not be retained. Changes in the ratio of males to females in sex-based fisheries can indicate a change in fishing pressure (Pillans *et al.*, 2005; Alberts-Hubatsch *et al.*, 2016b). The impacts of shifts in sex ratio are not well understood but may have implications for population dynamics of mud crabs and reproductive success and may also influence ecosystem processes due to the different burrowing behaviours and movements exhibited by male and female crabs. Reproductive biology and the movements of female mud crabs are the topics of two PhD student projects at CQUniversity.

Objectives

The overall objectives of this project were to:

1. Conduct mud crab surveys of the 7 GHHP reporting zones consistent with the survey methods used in previous years and consisting of a summer (warm, wet season) survey and a winter (cool, dry season) survey.
2. Provide mud crab scores and grades for the 2023 Gladstone Harbour Report Card. Calculate scores and grades using the methods developed in the 2017 mud crab monitoring project and revised in 2020, and using the thresholds for sex-ratio and abundance used for the calculation of the 2018, 2019, 2020, 2021 and 2022 mud crab scores.

Methods

Field methods

The following permits and approvals are in place for this research:

- General Fisheries Permit (Queensland Department of Agriculture and Fisheries; Permit Number 263226)
- Animal Ethics Approval (CQUniversity Animal Ethics Committee; Approval Number 20633)
- Authorisation for research in the Great Barrier Reef Marine Park (Approval Number G17/05-027)
- Field Work Risk Assessment (CQUniversity Occupational Health and Safety Unit)

Field methods and gears were as described in previous years (see Flint *et al*., 2017-2022). Two mud crab surveys were undertaken in 2023 (Table 1), representing a summer (warm, wet season) and winter (cool, dry season) sample. The seven monitoring sites (Figure 1) were previously chosen through a quantitative selection process (Flint *et al.*, 2017) related to the availability of suitable habitat types and the occurrence of previous sampling sites, and have been surveyed twice annually since 2017. Eurimbula Creek was surveyed in 2018/19 as a reference site and to refine benchmarks. Details of these surveys were provided by Flint *et al.* (2019).

Table 1: Gladstone zones/sites sampled during February and June 2023.

Zone/site	Survey 1	Survey 2
Zone 1: The Narrows	15 February 2023	13 June 2023
Zone 2: Graham Creek	15 February 2023	13 June 2023
Zone 4: Boat Creek	16 February 2023	14 June 2023
Zone 5: Inner Harbour	14 February 2023	12 June 2023
Zone 6: Calliope Estuary	16 February 2023	14 June 2023
Zone 7: Auckland Inlet	14 February 2023	12 June 2023
Zone 13: Rodds Bay	17 February 2023	15 June 2023

At each sampling site / date, the following information was recorded:

- Zone and site name;
- GPS location;
- Date;
- Set time and retrieval time for each uniquely identified pot;
- The total number of animals of each species caught in every pot; and
- Water quality parameters (temperature, dissolved oxygen, conductivity, pH, turbidity, total dissolved solids, oxidation reduction potential and salinity) measured using a YSI ProDSS Multiparameter Sampling Instrument, recorded once before setting the first pot and once after retrieving the final pot (not reported but provided to GHHP).

For every mud crab captured at each site, the following information was recorded:

- Species;
- Sex;
- Carapace width (notch width) (mm); and
- Abnormalities: type, body location, dimensions of rust spot lesions, grade of rust spot lesions (source Andersen and Norton, 2001).

All bycatch species (including blue swimmer crabs, other crabs and fish) were also recorded. Blue swimmer crabs were opportunistically weighed, measured, and checked for abnormalities before release.

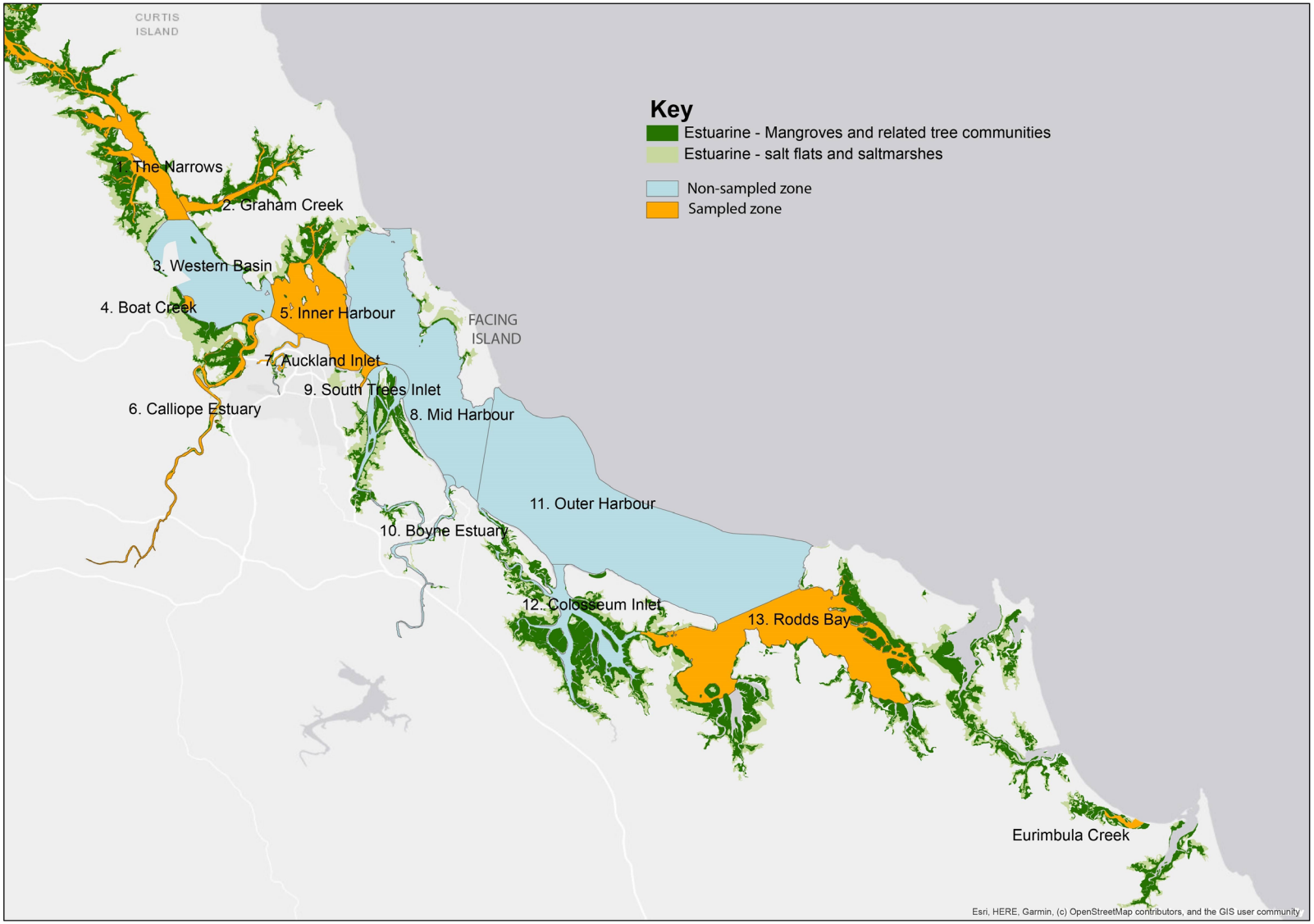

Figure 1: Map of the Gladstone Harbour zones showing long-term monitoring sites surveyed annually from 2017 through to 2023. The map also shows the location of Eurimbula Creek, which was sampled in 2018 and 2019 as a reference site for measures including sex ratios.

Data analysis

As in previous years, the data from the two field surveys (February and June 2023) were analysed separately and then together. Exploratory analyses included descriptive statistics, for example distribution plots (kernel density), and box plots for visual comparisons of differences and variance around the mean. All analyses were conducted in R version 4.3.0 (https://www.r-project.org/).

Scoring, grading and aggregation

The mud crab measures were calculated for each Zone, as follows:

- **Abundance** (CPUE)

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

- **Prevalence of rust lesions**

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

- **Sex ratio** based on oversize mud crabs

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

The formulae provided in Table 2 were used to score the mud crab measures, comparing each index value against the benchmark and worst case scenario (WCS) values. Using this method, index values worse than the WCS score a 0, while index values better than the benchmark score a 1 and all other index values range between these bounds. The method for determining benchmark and WCS values for each measure is described by Flint *et al.* (2017-2022). The Gladstone Harbour Report Card grading system is provided in Table 3.

Sex ratio of legal-sized crabs (> 150 mm carapace spine width, which is equivalent to a crab with 143 mm notch width) is calculated against a 'minimally disturbed' benchmark from the literature and sampling undertaken at an unfished estuary in central Queensland of 2:1 (Eurimbula Creek, Figure 1).

The benchmark for the abundance measure is updated annually, as a 10-year moving average of the 75th percentile of scores. Each year, the moving average of the 75th percentiles is recalculated (now seven years from 2017 to 2023). Notably, the CPUE in 2017 (3.5) was much higher than in every subsequent year.

Table 2: Benchmarks and scoring method for each of the three recommended measures. NC = not calculable. LTMP – long term monitoring program.

Measure	Benchmark	Worst case scenario	Method of calculation
Abundance (CPUE)	2017: 3.5 (75th %ile of 2017 scores) 2018: 2.5 (moving average of 75th %ile of 2017 and 2018 scores) 2019: 2.12 (moving average of 75th %ile of 2017, 2018 and 2019 scores) 2020: 1.95 (moving average of 75th %ile of 2017, 2018, 2019, 2020) 2021: 1.8 (moving average of 75th %ile of 2017, 2018, 2019, 2020) 2022: 1.6 (moving average of 75th %ile of 2017-2022) **2023: 1.5 (moving average of 75th %ile of 2017-2023)**	**0.25**	The function used to calculate scores for abundance is: 1-((x-B)/(WCS-B)) Where: x = recorded CPUE B = benchmark (1.5) WCS = worst case scenario (0.25)
Prevalence of rust lesions	**0.04**	**0.35**	The function used to calculate scores for prevalence is: 1-((x-B)/(WCS-B)) Where: x = recorded prevalence B = benchmark (0.04) WCS = worst case scenario (0.35)
Sex ratio	2017: 3 **2018+: 2**	**0.25**	The function used to calculate scores for sex ratio is: 1-((x-B)/(WCS-B)) Where: x = recorded sex ratio B = benchmark (2) WCS = worst case scenario (0.25)

Table 3: Gladstone Harbour Report Card grading scale (Source: GHHP, 2015).

Score	Grade
>=0.85	A
>=0.65, <0.85	B
>=0.5, <0.65	C
>=0.25, <0.5	D
0, <0.25	E

Results

Abundance and size

Only 24 mud crabs were caught in the seven Gladstone Harbour zones in February 2023, even less than the February 2022 catch of 33. Of these, 8 were male and 16 were female. A total of 70 mud crabs were caught across all Gladstone Harbour zones sampled in June 2023, again less than the 84 caught in June 2022. Less than five mud crabs were caught at Inner Harbour (n = 4) across February and June combined.

The average size of mud crabs caught in February 2023 was 157.5 mm carapace notch width (Table 4) and in June 2023 was 153.2 mm (Table 5). A series of two-sample t-tests was conducted to compare this year's data with data from the previous year (2022) and from the baseline (established from historical data for the 2001-09 period; Flint *et al.* 2017). The hypothesis being tested each time was whether this year's sample distribution (mean and variance) was equal to the distribution from the previous year and from the baseline. The full February 2023 sample including both males and females is not significantly different from 2022. When considered separately, neither male or female crabs were significantly different in size than those caught in February 2022 (Table 4). Mud crabs caught in June 2023 were not significantly larger than in June last year (Table 5). When testing each sex separately there was also no significant difference in size of males compared to June 2022, but females caught in June 2023 were significantly larger than those caught in June 2022.

This year, unlike in previous years, the results of two-sample t-tests found that females were not significantly larger than males in either February 2023 ($t = -0.07$, $df = 14.14$, $p = 0.95$; Figure 2) or June 2023 ($t = -1.32$, $df = 56.91$, $p = 0.19$; Figure 3).

The largest average mud crab size in February 2023 was recorded from Calliope Estuary (mean notch width of 175 mm) and the smallest from Boat Creek (138.2 mm notch width). In June 2023, the largest average mud crab size sampling was from Rodds Bay (mean notch width of 169.5 mm) and the smallest at Boat Creek (144.3 mm).

Table 4: Notch width (in mm) of mud crabs caught in February 2023 in comparison to February 2022; February 2022 in comparison to February 2021; and February 2023 in comparison to historical data collected between 2001-2009 by Fisheries Queensland (significance level $p < 0.05$)

	FULL SAMPLE			MALES			FEMALES		
	February 2023	February 2022	Historical data (2001-2009)	February 2023	February 2022	Historical data (2001-2009)	February 2023	February 2022	Historical data (2001-2009)
Mean	157.54	154.55	145.45	157.13	142.92	135.12	157.75	162.10	151.67
Standard deviation	20.81	21.53	20.74	21.24	19.45	18.65	21.29	19.74	19.43
2023-22 t-test	2023 > 2022	2022 > 2021	2023 > baseline	2023 > 2022	2022 > 2021	2023 > baseline	2023 > 2022	2022 > 2021	2023 > baseline
t value	0.70444	2.295	2.8472	1.8919	0.82226	2.9308	-0.8174	2.9539	1.1425
p value	0.4882	0.02844	0.009123	0.1004	0.427	0.022	0.4265	0.008151	0.2712
Signif?	NO	YES	YES	NO	NO	YES	NO	YES	NO

Table 5: Notch width (in mm) of mud crabs caught in June 2023 in comparison to June 2022; June 2022 in comparison to June 2021; and June 2023 in comparison to historical data collected between 2001-2009 by Fisheries Queensland (significance level p < 0.05)

	FULL SAMPLE			MALES			FEMALES		
	June 2023	June 2022	Historical data (2001-2009)	June 2023	June 2022	Historical data (2001-2009)	June 2023	June 2022	Historical data (2001-2009)
Mean	153.19	155.32	145.45	150.57	144.87	135.12	155.68	161.13	151.67
Standard deviation	16.44	15.81	20.74	19.75	15.55	18.65	13.49	12.76	19.43
2022-21 t-test	2023 > 2022	2022 > 2021	2023 > baseline	2023 > 2022	2022 > 2021?	2023 > baseline	2023 < 2022	2022 > 2021?	2023 > baseline
t value	-1.0863	1.8959	3.9373	1.580	0.8338	4.2827	-2.460	1.655	1.806
p value	0.2811	0.0615	0.0002	0.1251	0.4112	0.0002	0.0188	0.1038	0.0792
Signif?	NO	YES	YES	NO	NO	YES	YES	NO	YES

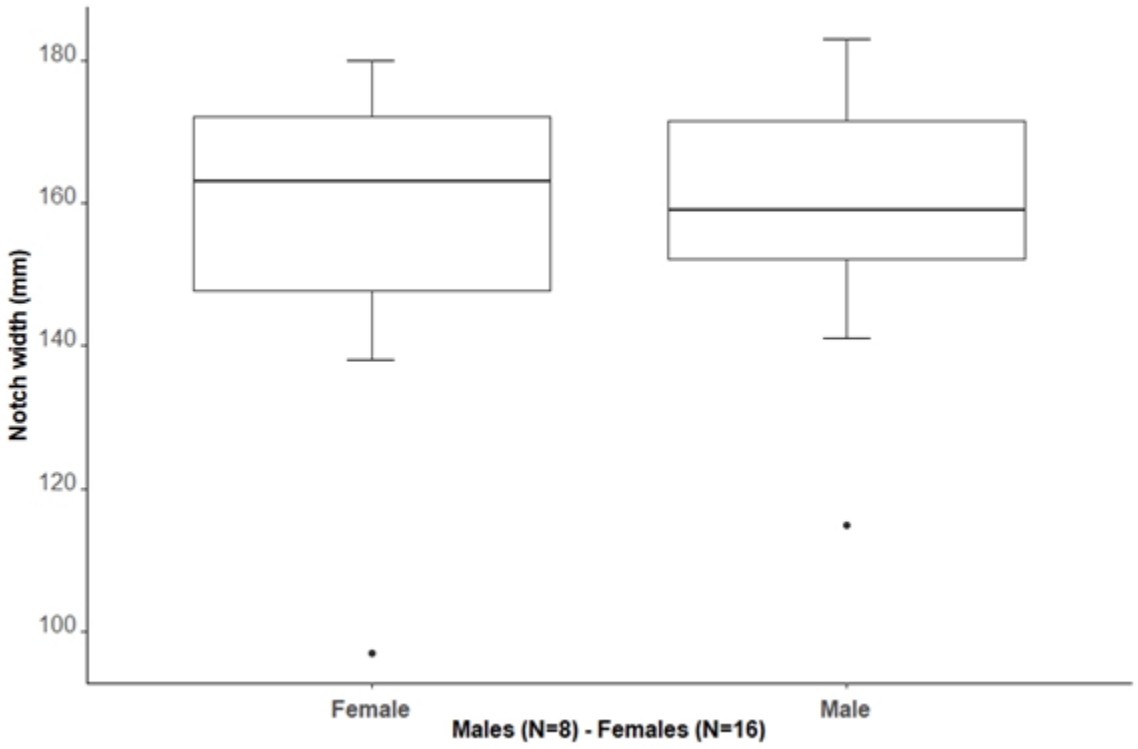

Figure 2: Notch width (mm) distribution of male and female mud crabs caught in February 2023. The box represents the middle 50% of ordered observations. Centre line is the median, the lower and upper edges correspond to the 25th and 75th percentiles. Whiskers extend from the box to the smallest and largest values no greater than 1.5 times the inter-quartile range. Data beyond the end of the whiskers are flagged as outliers and plotted individually as circles.

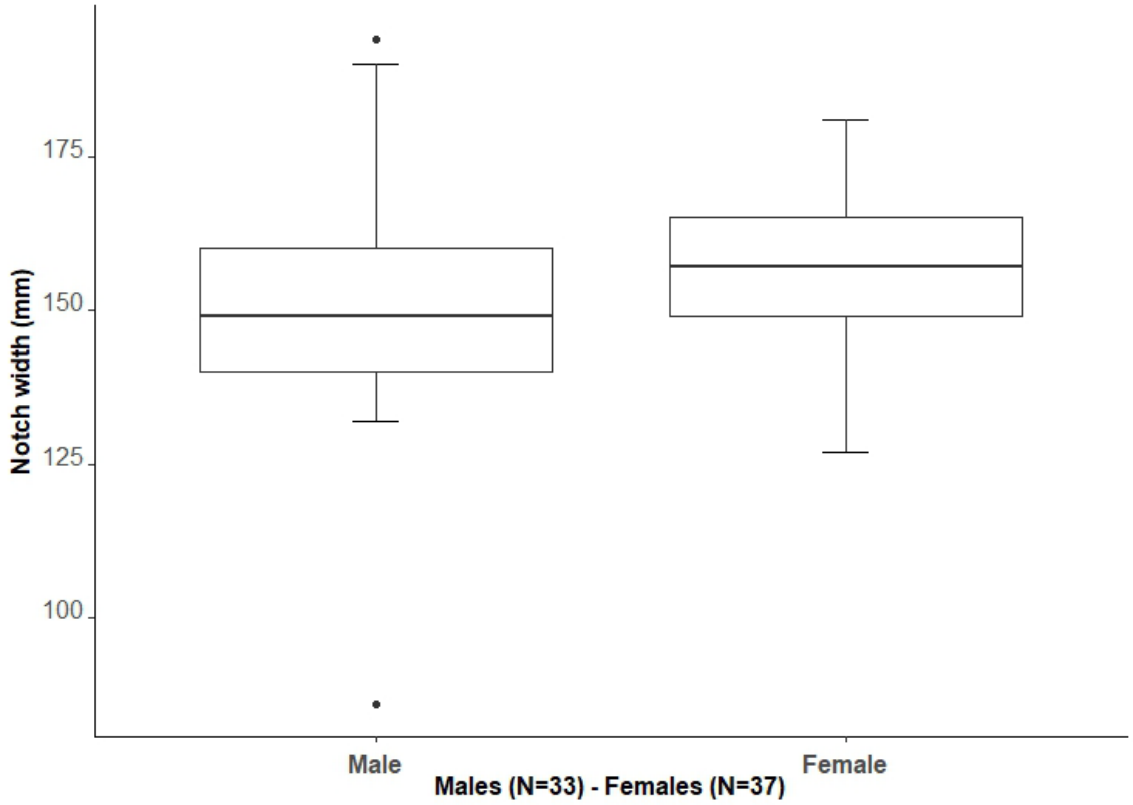

Figure 3: Notch width (mm) distribution of male and female mud crabs caught in June 2023.

In February 2023, for the seventh consecutive year, total CPUE was again highest at The Narrows. No mud crabs were caught at Inner Harbour or Auckland Inlet in February 2023 (Table 6, Figure 4). In June 2023, CPUE was also highest at The Narrows and was lowest at Inner Harbour, with only four mud crabs captured (Table 7, Figure 5).

Table 6: Catch per unit effort in February 2023, by zone.

ZONE	ZONE NAME	# POTS	# MUD CRABS CAUGHT	CPUE
1	The Narrows	20	10	0.50
2	Graham Creek	20	4	0.20
4	Boat Creek	15	5	0.33
5	Inner Harbour	20	0	0
6	Calliope Estuary	20	3	0.15
7	Auckland Inlet	20	0	0
13	Rodds Bay	20	2	0.10

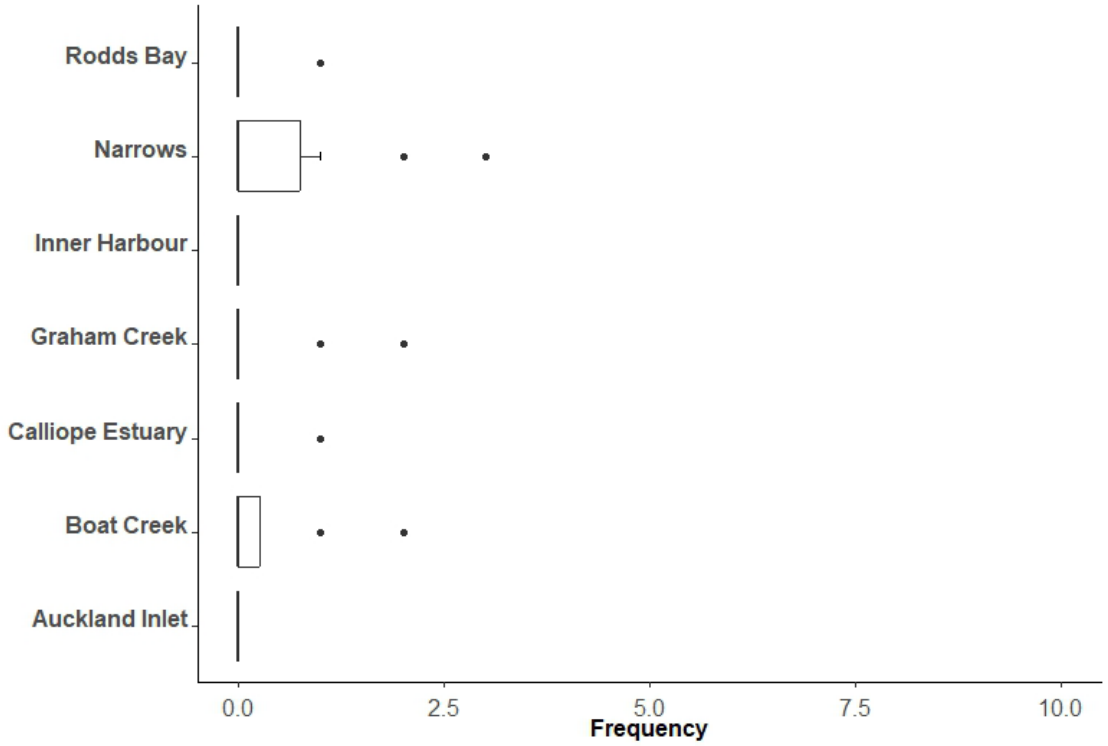

Figure 4: Number of mud crabs in each pot set in February 2023, by zone. No mud crabs were caught at Inner Harbour or Auckland Inlet.

Table 7: Catch per unit effort in June 2023, by zone.

ZONE	ZONE NAME	# POTS	# MUD CRABS CAUGHT	CPUE
1	The Narrows	20	29	1.4500
2	Graham Creek	20	5	0.2500
4	Boat Creek	16	15	0.9375
5	Inner Harbour	20	4	0.2000
6	Calliope Estuary	20	5	0.2500
7	Auckland Inlet	20	6	0.3000
13	Rodds Bay	20	6	0.3000

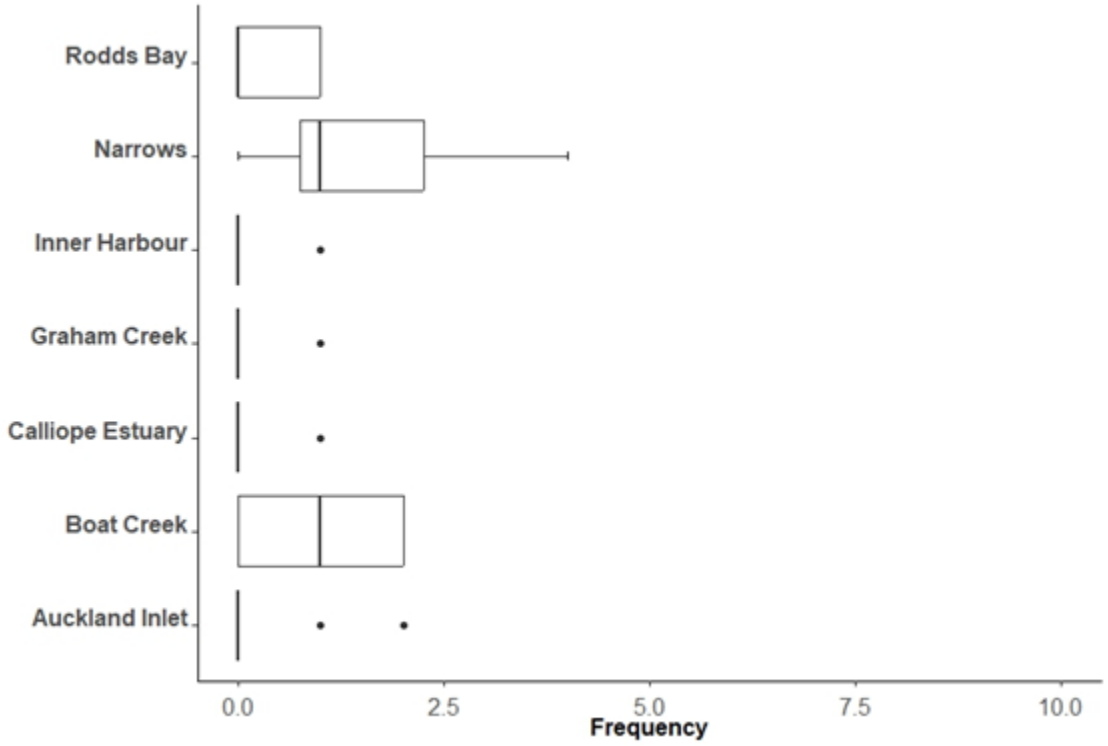

Figure 5: Number of mud crabs in each pot set in June 2023, by zone.

Sex ratio

In February and June 2023, as in previous years in Gladstone Harbour, more oversized female crabs were caught than oversized male crabs. A total of 69 mud crabs over the legal size limit of 150 mm carapace width (equivalent to 143 mm notch width) were caught in 2023, of which 25 were male. Sex ratios were low in most zones in both February and June (Table 8).

Table 8: Sex ratios of mud crabs with notch width > 143 mm, in February and June 2023, by zone.

ZONE	ZONE NAME	FEBRUARY 2023 DATA			JUNE 2023 DATA		
		Males	Females	Sex ratio	Males	Females	Sex ratio
1	The Narrows	3	6	**0.5**	4	17	**0.24**
2	Grahams Creek	0	3	**0**	2	2	**1**
4	Boat Creek	0	2	**0**	6	2	**3**
5	Inner Harbour	0	0	**/**	0	2	**0**
6	Calliope Estuary	2	1	**2**	2	2	**1**
7	Auckland Inlet	0	0	**/**	0	5	**0**
13	Rodds Bay	1	1	**1**	5	1	**5**

Rust lesions

None of the 24 mud crabs captured in February 2023 had rust lesions. There were three mud crabs with rust lesions encountered in June 2023 (of the 70 mud crabs caught), all three were from The Narrows (Table 9).

Table 9: Number and percentage of mud crabs with rust spot lesions caught in February and June 2023, by zone. / = no data as no mud crabs were caught.

ZONE	ZONE NAME	FEBRUARY 2023 DATA		JUNE 2023 DATA	
		# with lesions	% with lesions	# with lesions	% with lesions
1	The Narrows	0	0%	3	10.3%
2	Graham Creek	0	0%	0	0%
4	Boat Creek	0	0%	0	0%
5	Inner Harbour	/	/	0	0%
6	Calliope Estuary	0	0%	0	0%
7	Auckland Inlet	/	/	0	0%
13	Rodds Bay	0	0%	0	0%

Mud crab measure results by zone

The mud crab data set used to score each selected zone for the 2023 Gladstone Harbour Report Card included combined data from two monitoring events conducted in February and June 2023. Results for each measure are provided by zone in Table 10.

Table 10: Calculated index values for 2023, for each of the three measures in each of the seven long-term monitoring sites. NC = not calculable (Inner Harbour, n < 5 crabs caught in 2023).

Zone	Zone name	Abundance (CPUE)	Prevalence of rust lesions	Sex ratio
1	The Narrows	0.98	0.08	0.3
2	Graham Creek	0.23	0	0.4
4	Boat Creek	0.64	0	1.5
5	Inner Harbour	0.10	NC	NC
6	Calliope Estuary	0.20	0	1.3
7	Auckland Inlet	0.15	0	0
13	Rodds Bay	0.20	0	3

Indicator scores and grades

Scores and grades for the mud crab measures for the 2023 Report Card are provided in Table 11. Scores > 1 and < 0 were bounded by 0 and 1 in line with GHHP standard methods (GHHP, 2015). An overall score for the Mud Crab Indicator of 0.51 (C) has been calculated as the average of the three "Harbour Average" measure scores, and an overall grade is provided for each zone. Only four mud crabs were caught in Zone 5 – Inner Harbour. Given the small sample sizes (n < 5 mud crabs from 40 pots), there was insufficient data to calculate scores and grades for the prevalence of rust lesions or sex ratio measures in this zone in 2023.

Table 11: Scores and grades for mud crab measures and the 2023 mud crab indicator by Zone. NC = Not calculable, n < 5.

Zone	Abundance (CPUE)	Prevalence of rust lesions	Sex ratio	Zone score 2023
1. The Narrows	0.58	0.88	0.03	0.50
2. Graham Creek	0.00	1.00	0.09	0.36
4. Boat Creek	0.31	1.00	0.71	0.67
5. Inner Harbour	0.00	NC	NC	NC
6. Calliope Estuary	0.00	1.00	0.62	0.54
7. Auckland Inlet	0.00	1.00	0.00	0.33
13. Rodds Bay	0.00	1.00	1.00	0.67
Harbour Average	0.13	0.98	0.41	0.51

Discussion

The Harbour Average was graded C in 2023, with a slightly improved score from 2022 and 2021, when it was graded D. The overall grades for the Mud Crab Indicator for each zone are as follows:

A: No zones.

B: Zone 4 – Boat Creek, Zone 13 – Rodds Bay.

C: Zone 1 – The Narrows, Zone 6 – Calliope Estuary.

D: Zone 2 – Graham Creek, Zone 7 – Auckland Inlet.

E: No zones.

Not Calculable (n < 5 mud crabs caught): Zone 5 – Inner Harbour.

For comparison, the full set of scores and grades from previous years (2017, 2018, 2019, 2020, 2021 and 2022) are provided in Appendix 1. Data collection and scoring methods used in 2023 were identical to those used in the last three years. In 2020, the GHHP ISP recommended changing the way the Harbour Average score and grade is determined, by averaging the scores for each measure across all zones first, then calculating the Harbour score as the average of those three average measure scores. Previously, the overall indicator score for each zone was calculated first and the Harbour score was taken as the average of the zone scores. The change in averaging order was made to allow for the inclusion of CPUE results from low catch zones (particularly Auckland Inlet at that time) in the overall Harbour score/grade. Hence, the harbour average scores and grades from 2020 through to 2023 are directly comparable, while those from 2019 and earlier were calculated using a different averaging order.

Despite the lower catches in 2023, overall scores have improved slightly in most zones. This year, no zones were graded E, though Zone 5 – Inner Harbour could not be graded due to the low catch (n = 4). In situations where less than five mud crabs are caught in a zone, abundance can be scored but the sample size is insufficient to give a reliable indication of the prevalence of rust lesions or sex ratio. For the first time since 2018, Zone 7 – Auckland Inlet could be scored and graded in 2023, with a catch of just over the minimum sample size of 5 mud crabs (n = 6).

Similar to 2022, lower mud crab catches were experienced in 2023 than in previous years. The catch of mud crabs in baited pots can vary in response to a range of natural and anthropogenic factors, including weather variations such as rainfall and temperature, and lag effects of weather and other factors in previous years. The use of a 10-year moving average benchmark was adopted to eventually help to allow for natural variations in catch, but still allow any long-term declining trends (e.g., linked to extraction rates or recruitment limitation) to be identified. Mud crab populations rely on the presence of suitable habitat and on sufficient recruitment from adult populations. As recruitment of juvenile mud crabs in Gladstone Harbour is not monitored, the relationship between recruitment and adult abundance is not yet well understood. It is also possible that the times of year that adult crabs are active is gradually changing in response to climatological factors.

As described in the 2022 report, CQUniversity is currently collaborating with the Queensland Department of Agriculture and Fisheries on a research project funded by the Fisheries Research and Development Corporation (FRDC), to improve knowledge and assessment of Queensland mud crabs. One aspect of this project includes investigating intra-annual patterns in mud crab catches at several sites in Gladstone Harbour. The results of the FRDC project will be available next year and may assist in interpreting some of the longer-term patterns that have been observed through the Gladstone Harbour Report Card since 2017.

The prevalence of rust lesions measure was graded A in all zones in 2023, except Inner Harbour which could not be graded. As per previous reports, this measure is based on a moderately-high confidence benchmark and WCS developed using research data published by Andersen and Norton (2001) and Dennis *et al.* (2016), and data collected in June 2017 (Flint *et al.,* 2017, later published in Flint *et al*., 2021). The cause of rust shell lesions is likely to be related to inhibition of calcium uptake following exposure to some metals in the environment, possibly copper and zinc, although this has not been experimentally confirmed (Andersen *et al.*, 2000; Andersen and Norton, 2001). However, the exact reasons for changes in prevalence of rust shell lesions in Gladstone (and elsewhere) has never been definitively explained. This represents a knowledge gap that should ideally be addressed.

It is important to continue to monitor rust shell lesions in Gladstone, given the high prevalence that has been reported from the region at various times. Monitoring during non-event periods provides valuable baseline data and assurance that rust shell lesions are usually at low prevalence in the harbour. In the future, the measure could potentially be revised to incorporate lesion severity based on lesion size and whether the shell has been perforated (*sensu* Andersen and Norton, 2001).

In areas such as Queensland, where mud crabs are managed as a sex-based fishery, differences between the sex ratio (the ratio of legal-sized males to females of the same size) that cannot be explained by biological factors, are likely to be related to fishing pressure. The sex ratio measure was graded higher in 2023 than in earlier years. This may have been related to the lower catches of both female and male crabs. Sex ratio is potentially an ecologically important measure, as there may be implications for population dynamics of mud crabs and for ecosystem processes related to sex-biased behaviours such as burrow digging. Relevant research is underway by a PhD student at CQUniversity who is investigating the reproductive biology of female mud crabs, and another PhD student who is investigating habitat use and movements of male and female mud crabs. The FRDC project includes regular surveys at Eurimbula Creek where mud crabs are protected, which may assist in interpretation of the sex ratio measure.

Following the recent change in management arrangements for the Queensland Mud Crab Fishery, commercial fisheries data is now more detailed, and in future this may be useful for interpretation of the mud crab indicator results. The issue with this data source is that it relates to retained catch (i.e., large males) so it does not provide information on the whole mud crab population, and that there are sometimes long delays in data entry and availability. Nevertheless, commercial fishers set large numbers of pots and the resulting data could provide a valuable addition or cross reference to the mud crab indicator. Commercial catch data will continue to be monitored as an option for future reporting years, but at this stage the delay in data availability would not allow for inclusion in the annual mud crab indicator.

As described in the CQUniversity reports to GHHP since 2017 (Flint *et al.*, 2017-2022), an important criterion when selecting measures to include in the GHHP mud crab indicator when it was developed in 2017, was the monitoring cost and complexity. Technically-complex indicators, indicators that are very costly to monitor, or those requiring substantial additional research to allow them to be incorporated into the report card, were not considered practical. The GHHP mud crab indicator developed in 2017 is relatively simple to monitor in comparison to some other potential biological indicators that require laboratory analysis, and importantly, it also has minimal impacts on the target species, local ecosystem or stakeholders, as sampling is non-lethal and uses a low-impact fishing method.

In addition to the three current measures, two other potential measures were identified in 2017 (Flint *et al.,* 2017). These were bioaccumulation of metal(loid)s and recruitment to nursery grounds of juvenile crabs. The relative benefits of both have been discussed in previous reports, but both would involve additional monitoring costs.

With more than five years of data now available from Gladstone Harbour, additional statistical analyses have been commissioned by GHHP, investigating patterns in the indicator, measures and selected other variables. The results of this analysis will be provided separately.

Recommendations

The mud crab indicator has been successfully monitored in Gladstone Harbour since 2017, with some revisions to the scoring and grading methods made over time as more information became available. On 8 March 2021, the GHHP ISP organised a workshop on the mud crab indicator, inviting fisheries scientists from around Australia who work on mud crabs. Based on seven years of Gladstone Harbour monitoring and the workshop discussions, the following recommendations were made in 2021 and some are still relevant now in 2023 while others have been addressed either by GHHP or through other research projects involving CQUniversity:

- Continue to monitor the mud crab indicator, using the established monitoring methods, twice a year at the seven long term monitoring sites. Seasonal sampling should continue at a minimum, and more frequently if this becomes possible in future. *[Note: the FRDC project is currently undertaking monthly mud crab surveys in Gladstone Harbour from mid-2022 and throughout 2023, the results of this project will be available in mid-2024 and may shed further light on the question of ideal temporal replication].*
- With *[more than]* five years of data now available from Gladstone Harbour, additional statistical analyses could be undertaken, investigating not only patterns in the indicator measures as described above, but in other variables that are monitored (e.g., the sex ratio of smaller mud crabs and variability in catch in relation to weather variables). *[Note: as described above, this trend analysis has been commissioned by GHHP in 2023 and provided separately].*

- GHHP may wish to consider increasing the number of zones sampled to include other estuaries in Gladstone Harbour (e.g., South Trees Inlet and Boyne Estuary). This would expand the dataset and increase the relevance of the indicator to additional portside industries.
- It would be beneficial to sample again at Eurimbula Creek, to test whether similar declining catch trends are identified at this reference site. *[Note: the FRDC project is also undertaking surveys at Eurimbula during 2023 and the results will be available in mid-2024].*
- Bioaccumulation of relevant metal(loid)s in Gladstone Harbour could be considered as a possible additional measure for future monitoring.
- Research to determine the cause of rust lesions is recommended.

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Appendix 1 Previous scores and grades, from 2017 – 2022

Scores and grades for mud crab measures and the mud crab indicator by GHHP Zone for 2017.

Zone	Abundance (CPUE)	Prevalence of rust lesions	Sex ratio*	Zone score (grade) 2017
1. The Narrows	1.00 (A)	1.00 (A)	0.00 (E)	0.67 (B)
2. Graham Creek	0.52 (C)	0.95 (A)	0.36 (D)	0.61 (C)
4. Boat Creek	1.00 (A)	1.00 (A)	0.11 (E)	0.70 (B)
5. Inner Harbour	1.00 (A)	0.89 (A)	0.71 (B)	0.87 (A)
6. Calliope Estuary	0.14 (E)	0.90 (A)	0.36 (D)	0.47 (D)
7. Auckland Inlet	0.12 (E)	0.63 (C)	0.00 (E)	0.25 (D)
13. Rodds Bay	0.03 (E)	0.67 (B)	0.39 (D)	0.36 (D)
Harbour Average				0.56 (C)

Scores and grades for mud crab measures and the mud crab indicator by Zone for 2018.

Zone	Abundance (CPUE)	Prevalence of rust lesions	Sex ratio*	Zone score (grade) 2018
1. The Narrows	1 (A)	1 (A)	0 (E)	0.67 (B)
2. Graham Creek	0.3 (D)	1 (A)	0.03 (E)	0.44 (D)
4. Boat Creek	0.25 (D)	1 (A)	0.29 (D)	0.51 (C)
5. Inner Harbour	0.52 (C)	1 (A)	0.02 (E)	0.52 (C)
6. Calliope Estuary	0.47 (D)	1 (A)	0.11 (E)	0.52 (C)
7. Auckland Inlet	0 (E)	NC	NC	NC
13. Rodds Bay	0.2 (E)	0.90 (A)	0.06 (E)	0.39 (D)
Harbour Average				0.51 (C)

Scores and grades for mud crab measures and the mud crab indicator by GHHP Zone for 2019.

Zone	Abundance (CPUE)	Prevalence of rust lesions	Sex ratio*	Zone score (grade) 2019
1. The Narrows	1 (A)	0.90 (A)	0 (E)	0.63 (C)
2. Graham Creek	0.12 (E)	1 (A)	0.24 (E)	0.45 (D)
4. Boat Creek	0.46 (D)	0.94 (A)	0.05 (E)	0.49 (D)
5. Inner Harbour	0.67 (B)	0.70 (B)	0.08 (E)	0.48 (D)
6. Calliope Estuary	0.29 (D)	1 (A)	0 (E)	0.43 (D)
7. Auckland Inlet	0 (E)	NC	NC	NC
13. Rodds Bay	0.27 (D)	0.70 (B)	0.12 (E)	0.36 (D)
Harbour Average				0.47 (D)

Scores and grades for mud crab measures and the mud crab indicator by Zone for 2020.

Zone	Abundance (CPUE)	Prevalence of rust lesions	Sex ratio	Zone score 2020
1. The Narrows	1 (A)	0.80 (B)	0 (E)	0.60 (C)
2. Graham Creek	0.18 (E)	0.84 (B)	0(E)	0.34 (D)
4. Boat Creek	1 (A)	0.84 (B)	0.29 (D)	0.71 (B)
5. Inner Harbour	0.19 (E)	0.99 (A)	0(E)	0.39 (D)
6. Calliope Estuary	0.13(E)	0.45 (D)	0(E)	0.19 (E)
7. Auckland Inlet	0(E)	NC	NC	NC
13. Rodds Bay	0.13(E)	0.45 (D)	0.06(E)	0.22 (D)
Harbour Average	0.38 (D)	0.73 (B)	0.06(E)	0.39 (D)

Scores and grades for mud crab measures and the mud crab indicator by Zone for 2021.

Zone	Abundance (CPUE)	Prevalence of rust lesions	Sex ratio	Zone score 2021
1. The Narrows	1	0.92	0	0.64
2. Graham Creek	0.27	0.89	0	0.39
4. Boat Creek	0.83	0.94	0.03	0.60
5. Inner Harbour	0.63	0.47	0.07	0.39
6. Calliope Estuary	0.26	1.0	0.14	0.47
7. Auckland Inlet	0	NC	NC	NC
13. Rodds Bay	0.16	0.96	0.57	0.56
Harbour Average	0.45	0.86	0.14	0.48

Scores and grades for mud crab measures and the mud crab indicator by Zone for 2022.

Zone	Abundance (CPUE)	Prevalence of rust lesions	Sex ratio	Zone score 2022
1. The Narrows	0.85	0.90	0.00	0.58
2. Graham Creek	0.00	1.00	0.00	0.33
4. Boat Creek	0.32	0.98	0.43	0.58
5. Inner Harbour	0.11	0.32	0.00	0.14
6. Calliope Estuary	0.00	1.00	0.29	0.43
7. Auckland Inlet	0.00	NC	NC	NC
13. Rodds Bay	0.00	NC	NC	NC
Harbour Average	0.18	0.84	0.14	0.39