Mud Crab Indicator for the 2024 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	09/09/2024
1.2	Final report	Flint, De Valck, Anastasi	09/10/2024

Executive summary

Giant mud crabs (*Scylla serrata*) are a recreationally and commercially important decapod species distributed across the Indo-Pacific Ocean. They are 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 eighth year of sampling, in 2024. The indicator scores and grades are reported for 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 March and July 2024. Scores and grades were calculated using the 2024 dataset for the three metrics within each of the seven recommended long-term monitoring zones in Gladstone Harbour. 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 2024.

Zone	Abundance (CPUE)	Prevalence of rust lesions	Sex ratio	Zone score 2024
1. The Narrows	0.88	1.00	0.06	0.65
2. Graham Creek	0.00	0.73	0.20	0.31
4. Boat Creek	1.00	1.00	0.25	0.75
5. Inner Harbour	0.21	0.96	0.09	0.42
6. Calliope Estuary	0.14	1.00	0.00	0.38
7. Auckland Inlet	0.00	1.00	0.05	0.35
13. Rodds Bay	0.04	1.00	0.00	0.35
Harbour Average	0.32	0.96	0.09	0.46

This year the harbour was graded D overall for the mud crab indicator, with the highest zone grades recorded at Boat Creek and The Narrows (B). Though a lower grade than for 2023, the overall harbour score is lower by only 0.05 (0.51, C in 2023; 0.46, D in 2024). This was an improvement in score from 2022 (0.39) and similar to the 2021 score (0.48). The multi-metric 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.

Overall, mud crab catch rates (abundance) were higher in 2024, but sex ratio was substantially lower. This year, all seven monitored zones were able to be graded, as more than five mud crabs ($n \geq 5$) were caught in each zone. 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.

The prevalence of rust lesions scored highly and was graded A in all zones except Graham Creek (B),, indicating absence or low incidence of rust lesions in 2024. 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.

CQUniversity has been working with Fisheries Queensland scientists on a project funded by FRDC to increase knowledge of mud crabs since 2019. The project will be completed in late 2024 and results are expected to be available for discussion shortly thereafter.

Contents

Introduction

Giant mud crabs (*Scylla serrata*) are a large, high-value decapod crustacean, subject to commercial, recreational and Indigenous fishing in all Australian states that they inhabit and across the Indo-Pacific. Gladstone is one of the highest-catch mud crab fishing regions in Australia. 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 the 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 include 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; Dennis et al., 2016).

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 relative **abundance of mud crabs** that are caught during the monitoring program provides a temporal and spatial 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 currently 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 2024 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, 2022 and 2023 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 approval number 24775)
- 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*., 2017-2023). Two mud crab surveys were undertaken in 2024 (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). In 2024, weather affected the timing of both sampling events, and they were conducted later in the year than usual in March and July. It was necessary to delay sampling at Rodds Bay a further two weeks as a strong wind warning prevented sampling on the planned date.

Table 1: Gladstone zones/sites sampled during March and July 2024.

Zone/site	Survey 1	Survey 2
Zone 1: The Narrows	06/03/2024	02/07/2024
Zone 2: Graham Creek	06/03/2024	02/07/2024
Zone 4: Boat Creek	07/03/2024	03/07/2024
Zone 5: Inner Harbour	05/03/2024	01/07/2024
Zone 6: Calliope Estuary	07/03/2024	03/07/2024
Zone 7: Auckland Inlet	05/03/2024	01/07/2024
Zone 13: Rodds Bay	08/03/2024	17/07/2024*

* NOTE: Bad weather (a strong wind warning and large swell) prevented fieldwork on the scheduled date of 04/07/2024, so sampling at Rodds Bay had to be delayed until the next suitable tide on 17/07/24.

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, and number, dimensions and 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.

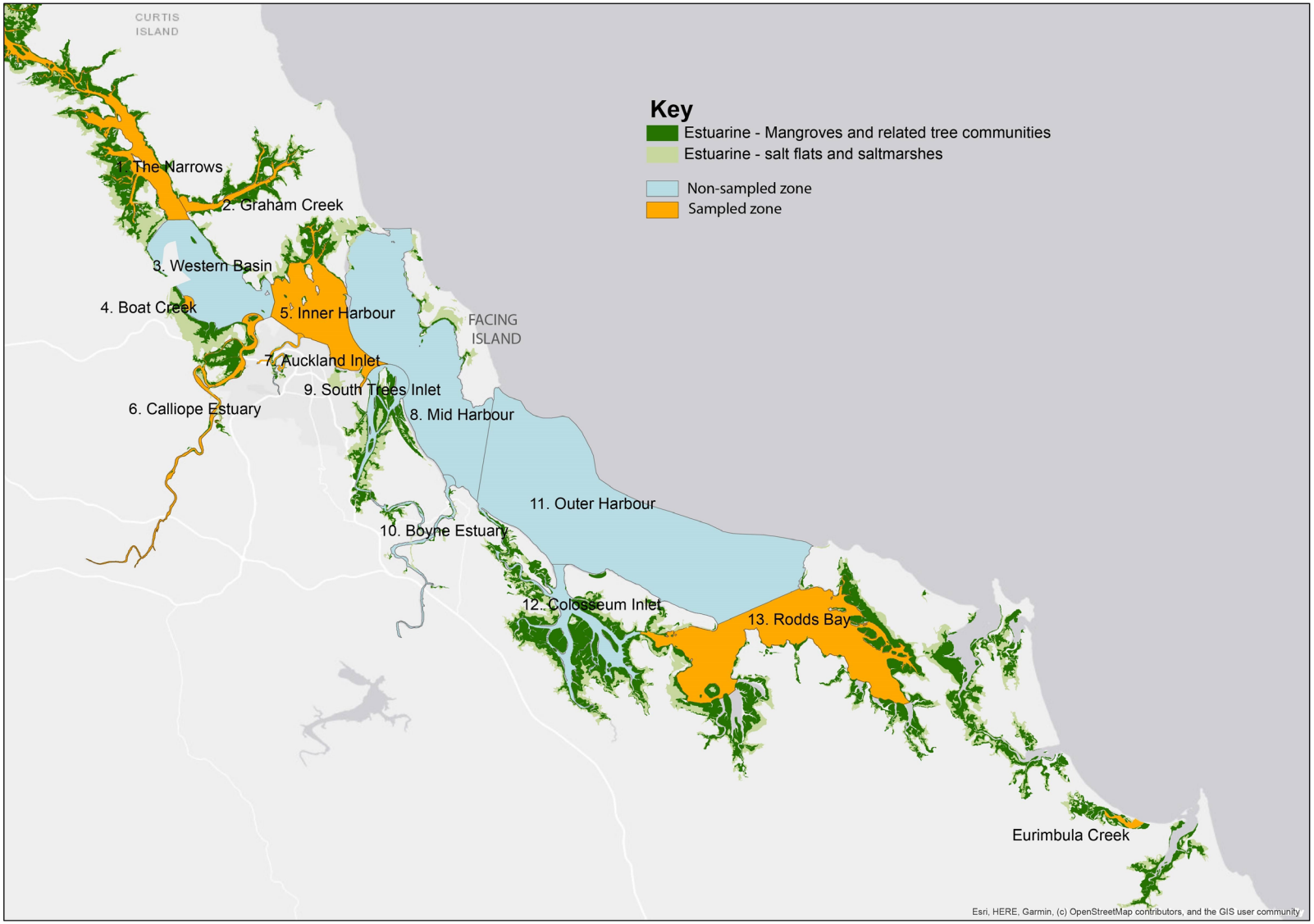

Figure 1: Map of the Gladstone Harbour zones showing long-term monitoring sites surveyed annually from 2017 through to 2024. The map also shows the location of Eurimbula Creek, which was sampled in 2018 and 2019 as a reference site for measures including sex ratios.

Data analysis

As in previous years, the data from the two field surveys (March and July 2024) 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.* (2017-2023). 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 eight years from 2017 to 2024). Notably, the CPUE in 2017 (3.5) was much higher than in every subsequent year, so the benchmark has been gradually dropping each year since then.

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) **2024: 1.3 (moving average of 75th %ile of 2017-2024)**	**0.25**	The function used to calculate scores for abundance is: 1-((x-B)/(WCS-B)) Where: x = recorded CPUE B = benchmark (1.3) 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

The March 2024 sampling event captured 79 mud crabs in the seven Gladstone Harbour zones, an improvement on catches in February 2023 (24 crabs) and February 2022 (33 crabs). Of these 79 mud crabs, 39 were male and 40 were female.

In July 2024, 83 mud crabs were caught across all Gladstone Harbour zones, again higher than the June 2023 catch of 70 crabs, and similar to the June 2022 catch of 84. More than five mud crabs were caught at all zones in 2024, so all zones could be scored and graded this year.

This year, the mud crabs were on average, smaller than in previous GHHP sampling events. The average size of mud crabs caught in March 2024 was 146.6 mm carapace notch width (Table 4) and in July 2024 was 150.4 mm (Table 5). A series of two-sample t-tests was conducted to compare this year's data with data from the previous year (2023) 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 March 2024 sample including both males and females is significantly different from 2023 ($p < 0.001$) but not significantly different to the historical dataset (0.5934). This result contrasts with previous years, when mud crabs collected during monitoring were typically significantly larger than the historical data.

When considered separately, male mud crabs caught in 2024 were significantly smaller than in 2023 for both March ($p < 0.001$) and July ($p=0.0266$) samplings. Female crabs were not significantly different in size than those female crabs caught in 2023 (Table 4 and 5). The results of two-sample t-tests found that females were significantly larger than males in both March 2024 ($t = -4.02$, $df = 76.98$, p-value < 0.001; Figure 2) and July 2024 ($t = -3.03$, $df = 62.72$, p-value = 0.004; Figure 3).

The largest average mud crab size in March 2024 was recorded from Rodds Bay (mean notch width of 166 mm) and the smallest from Calliope Estuary (118 mm notch width). In July 2024, the largest average mud crab size sampling was from Graham Creek (mean notch width of 166 mm) and the smallest at Boat Creek (139 mm).

Table 4: Notch width (in mm) of mud crabs caught in March 2024 in comparison to February 2023; February 2023 in comparison to February 2022; and March 2024 in comparison to historical data collected between 2001-2009 by Fisheries Queensland (significance level p < 0.05)

	FULL SAMPLE			MALES			FEMALES		
	March 2024	February 2023	Historical data (2001-2009)	March 2024	February 2023	Historical data (2001-2009)	March 2024	February 2023	Historical data (2001-2009)
Mean	146.63	157.54	145.45	138.41	157.13	135.12	154.65	157.75	151.67
Standard deviation	19.61	20.81	20.74	17.84	21.24	18.65	18.05	21.29	19.43
t-test	2024 < 2023	2023 > 2022	2024 > baseline	2024 < 2023	2023 > 2022	2024 > baseline	2024 < 2023	2023 > 2022	2024 > baseline
t value	-4.9427	0.70444	0.53605	-6.5521	1.8919	1.1516	-1.0864	-0.8174	1.0444
p value	4.31E-06	0.4882	0.5934	9.99E-08	0.1004	0.2567	0.284	0.4265	0.3027
Signif?	YES	NO	NO	YES	NO	NO	NO	NO	NO

Table 5: Notch width (in mm) of mud crabs caught in July 2024 in comparison to June 2023; June 2023 in comparison to June 2022; and July 2024 in comparison to historical data collected between 2001-2009 by Fisheries Queensland (significance level p < 0.05)

June 2024	FULL SAMPLE			MALES			FEMALES		
	July 2024	June 2023	Historical data (2001-2009)	July 2024	June 2023	Historical data (2001-2009)	June 2024	June 2023	Historical data (2001-2009)
Mean	150.36	153.19	145.45	143.87	150.39	135.12	154.42	155.68	151.67
Standard deviation	15.99	16.44	20.74	15.84	19.05	18.65	14.83	13.49	19.43
t-test	2024 > 2023	2023 > 2022	2024 > baseline	2024 > 2023	2023 > 2022	2024 > baseline	2024 > 2023	2023 < 2022	2024 > baseline
t value	-1.615	-1.086	2.7955	-2.328	1.661	3.126	-0.6051	-2.460	1.326
p value	0.1101	0.2811	0.0065	0.0266	0.1055	0.0038	0.548	0.0188	0.191
Signif?	NO	YES	YES	YES	NO	YES	NO	YES	NO

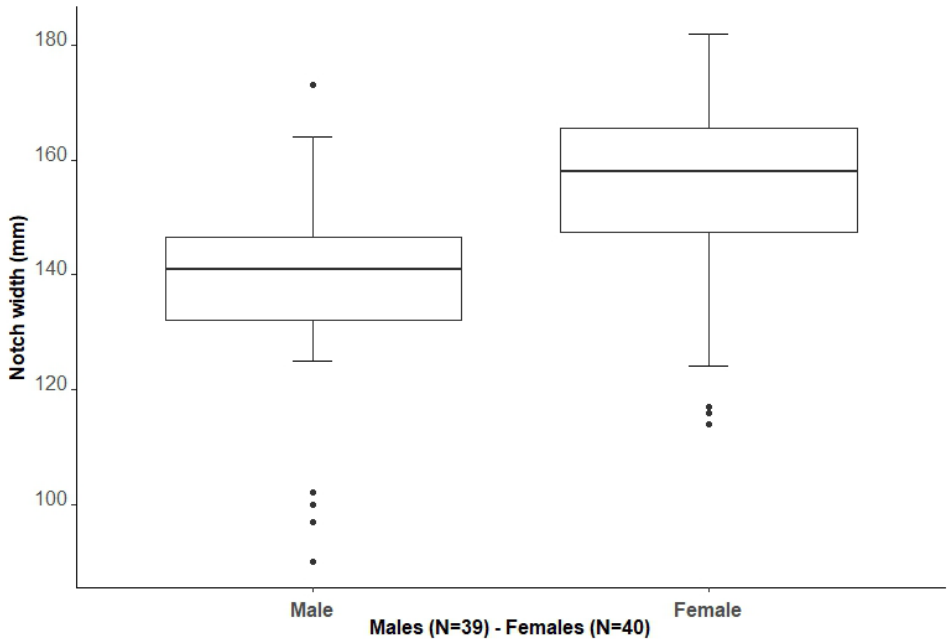

Figure 2: Notch width (mm) distribution of male and female mud crabs caught in March 2024. The box represents the middle 50% of ordered observations. Centre line is the median, the lower and upper edges correspond to the 25th and 75th percentiles. Whiskers extend from the box to the smallest and largest 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.

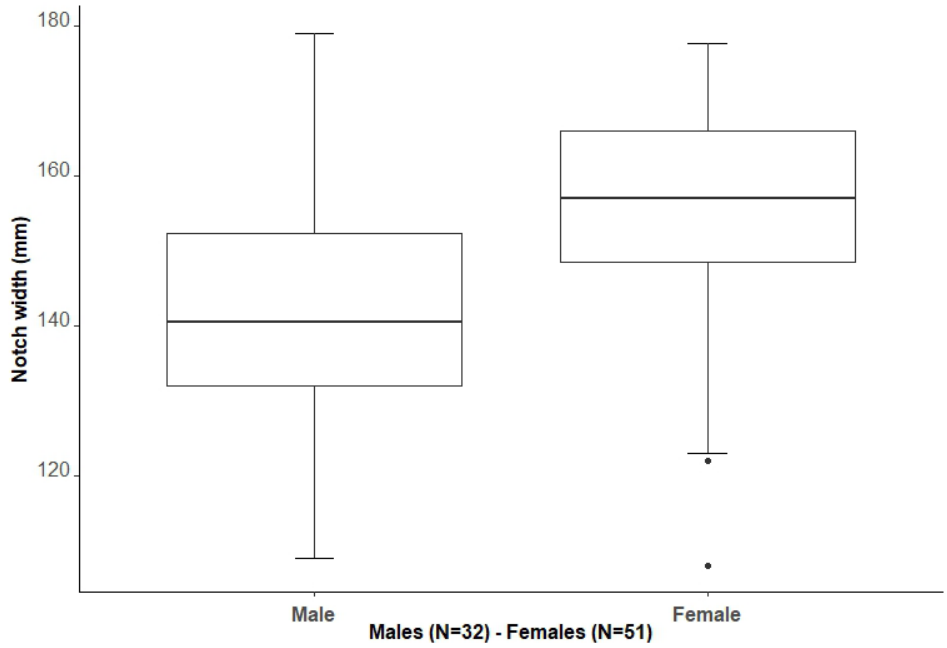

Figure 3: Notch width (mm) distribution of male and female mud crabs caught in July 2024. The box represents the middle 50% of ordered observations. Centre line is the median, the lower and upper edges correspond to the 25th and 75th percentiles. Whiskers extend from the box to the smallest and largest 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.

In March 2024, for the eighth consecutive year, total CPUE was again highest at The Narrows (n = 25) and CPUE was lowest at Auckland Inlet with only one mud crab captured (Table 6, Figure 4). In July 2024, CPUE was highest at Boat Creek (n = 35) followed by The Narrows (n = 25), and lowest at Calliope Estuary and Rodds Bay, with only one mud crab captured in each (Table 7, Figure 5).

Table 6: Catch (number of crabs) per unit effort (number of pots) (CPUE) in March 2024, by zone.

ZONE	ZONE NAME	# POTS	# MUD CRABS CAUGHT	CPUE
1	The Narrows	20	25	1.25
2	Graham Creek	20	4	0.20
4	Boat Creek	16	14	0.88
5	Inner Harbour	20	7	0.35
6	Calliope Estuary	20	17	0.85
7	Auckland Inlet	20	1	0.05
13	Rodds Bay	20	12	0.60

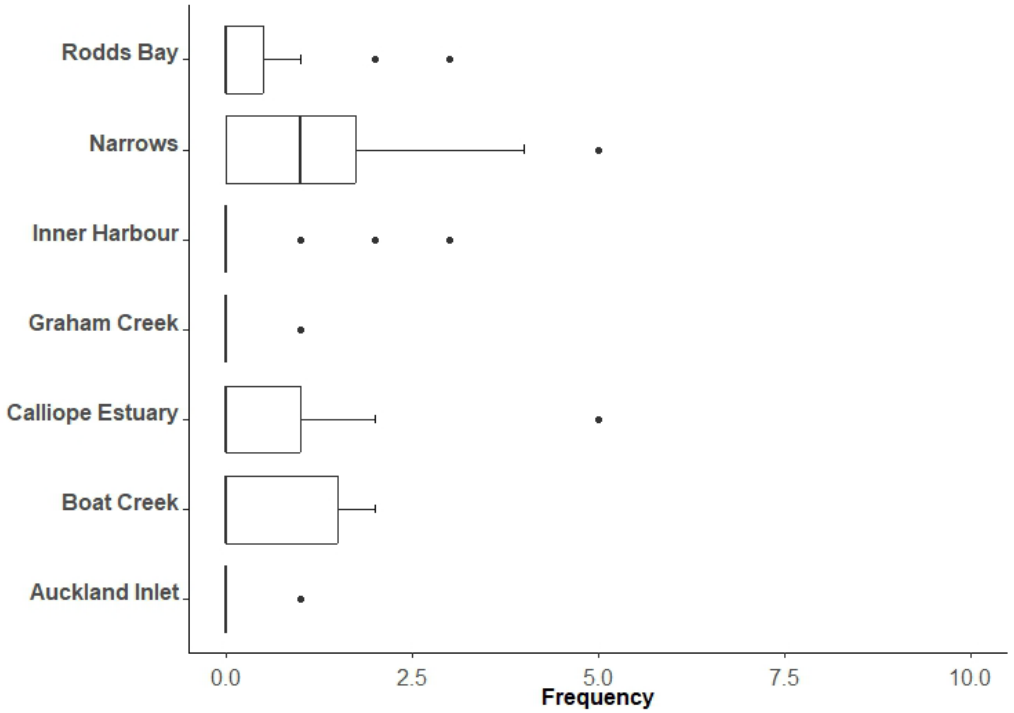

Figure 4: Number of mud crabs in each pot set in March 2024, by zone.

Table 7: Catch (number of crabs) per unit effort (number of pots) (CPUE) in July 2024, by zone.

ZONE	ZONE NAME	# POTS	# MUD CRABS CAUGHT	CPUE
1	The Narrows	20	25	1.25
2	Graham Creek	20	5	0.25
4	Boat Creek	16	35	2.19
5	Inner Harbour	20	12	0.60
6	Calliope Estuary	20	1	0.05
7	Auckland Inlet	20	4	0.20
13	Rodds Bay	20	1	0.05

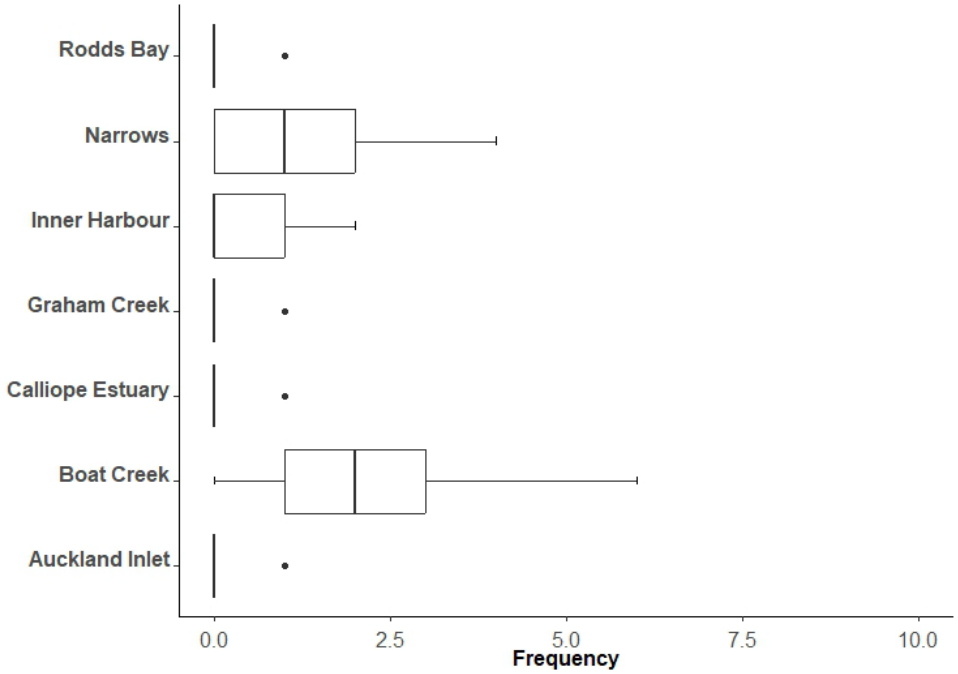

Figure 5: Number of mud crabs in each pot set in July 2024, by zone.

Sex ratio

In March and July 2024, as in previous years in Gladstone Harbour, more oversized female crabs were caught than oversized male crabs. A total of 100 mud crabs over the legal size limit of 150 mm carapace width (equivalent to 143 mm notch width) were caught in 2024, of which 27 were male. Sex ratios were low in most zones in both March and July (Table 8).

Table 8: Sex ratios of mud crabs with notch width > 143 mm, in March and July 2024, by zone. / = no data as no mud crabs of the relevant size/sex were captured.

ZONE	ZONE NAME	MARCH 2024 DATA			JULY 2024 DATA		
		Males	Females	Sex ratio	Males	Females	Sex ratio
1	The Narrows	5	6	**0.83**	3	16	**0.19**
2	Grahams Creek	1	2	**0.50**	2	3	**0.67**
4	Boat Creek	3	3	**1**	6	10	**0.60**
5	Inner Harbour	2	2	**1**	2	8	**0.25**
6	Calliope Estuary	0	8	**0**	/	1	**/**
7	Auckland Inlet	1	/	**/**	/	3	**/**
13	Rodds Bay	2	10	**0.20**	/	1	**/**

Rust lesions

None of the 79 mud crabs captured in March 2024 had rust lesions. There were three mud crabs with rust lesions encountered in July 2024 (of the 83 mud crabs caught), one each from Graham Creek, Boat Creek and Inner Harbour (Table 9).

Table 9: Number and percentage of mud crabs with rust spot lesions caught in March and July 2024, by zone. / = no data as no mud crabs were caught.

ZONE	ZONE NAME	MARCH 2024 DATA		JULY 2024 DATA	
		# with lesions	% with lesions	# with lesions	% with lesions
1	The Narrows	0	0%	0	0%
2	Graham Creek	0	0%	1	20%
4	Boat Creek	0	0%	1	2.9%
5	Inner Harbour	/	/	1	8.3%
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 2024 Gladstone Harbour Report Card included combined data from two monitoring events conducted in March and July 2024. Results for each measure are provided by zone in Table 10.

Table 10: Calculated index values for 2024, for each of the three measures in each of the seven long-term monitoring zones.

Zone	Zone name	Abundance (CPUE)	Prevalence of rust lesions	Sex ratio
1	The Narrows	1.25	0	0.36
2	Graham Creek	0.23	0.13	0.60
4	Boat Creek	1.53	0.02	0.69
5	Inner Harbour	0.48	0.50	0.40
6	Calliope Estuary	0.45	0	0
7	Auckland Inlet	0.13	0	0.33
13	Rodds Bay	0.33	0	0.18

Indicator scores and grades

Scores and grades for the mud crab measures for the 2024 Report Card are provided in Table 11.An overall score for the Mud Crab Indicator of 0.46 (D) has been calculated as the average of the three "Harbour Average" measure scores, and an overall grade is provided for each zone. This year, five or more mud crabs were caught in every zone, so scores and grades could be calculated for each zone.

Table 11: Scores and grades for mud crab measures and the 2024 mud crab indicator by Zone.

Zone	Abundance (CPUE)	Prevalence of rust lesions	Sex ratio	Zone score 2024
1. The Narrows	0.88	1.00	0.06	0.65
2. Graham Creek	0.00	0.73	0.20	0.31
4. Boat Creek	1.00	1.00	0.25	0.75
5. Inner Harbour	0.21	0.96	0.09	0.42
6. Calliope Estuary	0.14	1.00	0.00	0.38
7. Auckland Inlet	0.00	1.00	0.05	0.35
13. Rodds Bay	0.04	1.00	0.00	0.35
Harbour Average	0.32	0.96	0.09	0.46

Discussion

The Harbour Average was graded D in 2024, with a slightly lower score than in 2023 when it was graded C (0.51), but higher than in 2022, when it was also graded D (0.39). The overall grades for the Mud Crab Indicator for each zone are provided in Table 12.

Table 12: Summary of Zone results by grade for 2024.

Grade	Zones
A	None
B	Zone 1 – The Narrows Zone 4 – Boat Creek
C	None
D	Zone 2 – Graham Creek Zone 5 – Inner Harbour Zone 6 – Calliope Estuary Zone 7 – Auckland Inlet Zone 13 – Rodds Bay
E	None

The full set of scores and grades from previous years (2017, 2018, 2019, 2020, 2021, 2022 and 2023) are provided in Appendix 1, for comparison. Data collection and scoring methods used in 2024 were identical to those used in the last four years. As noted in previous reports, in 2020, the GHHP ISP recommended changing the way the Harbour Average score and grade is calculated, by averaging the scores for each measure across all zones first, then separately calculating the Harbour score as the average of the 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 2024 are directly comparable, while those from 2019 and earlier were calculated using a different averaging order.

Catches improved in 2024, in comparison to recent years. This year, no zones were graded E, and none could not be graded due to insufficient catch (n < 5). 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. Recruitment of juvenile mud crabs in Gladstone Harbour is not monitored, and 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. The first year of sampling (2017) appears to have been an abnormally high catch year in comparison to the 7 years that followed.

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 late this 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 2024, except Graham Creek which was graded B, but only one mud crab with rust lesions was caught there. Only three crabs had rust lesions, out of the total of 162 mud crabs caught. 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 thought 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). Currently the prevalence of lesions is so low that this level of detail is not justified.

In 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 lower in 2024, impacting the overall harbour grade. Sex ratio is potentially an ecologically important measure. We don't yet fully understand the implications of the sex ratio 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. All three of these research projects will be completed within the next ~ 6 months.

Following the 2021 change in management arrangements for the Queensland Mud Crab Fishery introducing Individual Transferable Quotas (ITQs) and a Total Allowable Commercial Catch (TACC),

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.*, 2017-2023), 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. A measure of the abundance of juveniles is a metric that would also be useful for fisheries management purposes.

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 eight years of Gladstone Harbour monitoring and the workshop discussions, the following recommendations were made in 2021 and some are still relevant now, 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: monthly mud crab surveys in Gladstone Harbour from mid-2022 and throughout 2023, will be available later in 2024 and may shed further light on the question of ideal temporal replication].*
- Consider increasing the number of zones sampled to include other estuaries in Gladstone Harbour (in particular, South Trees Inlet and Boyne Estuary). This would expand the dataset and increase the relevance of the indicator to additional portside industries.
- The workshop identified that 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 included several surveys at Eurimbula and the results will be available later in 2024].* Ideally Eurimbula Creek would be monitored every year, as a reference site for the Gladstone Harbour zones.
- Bioaccumulation of relevant metal(loid)s in Gladstone Harbour could be considered as a possible additional measure for future monitoring.
- Further research to determine the cause of rust lesions is recommended.

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Appendix 1 Previous scores and grades, from 2017 – 2023

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

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