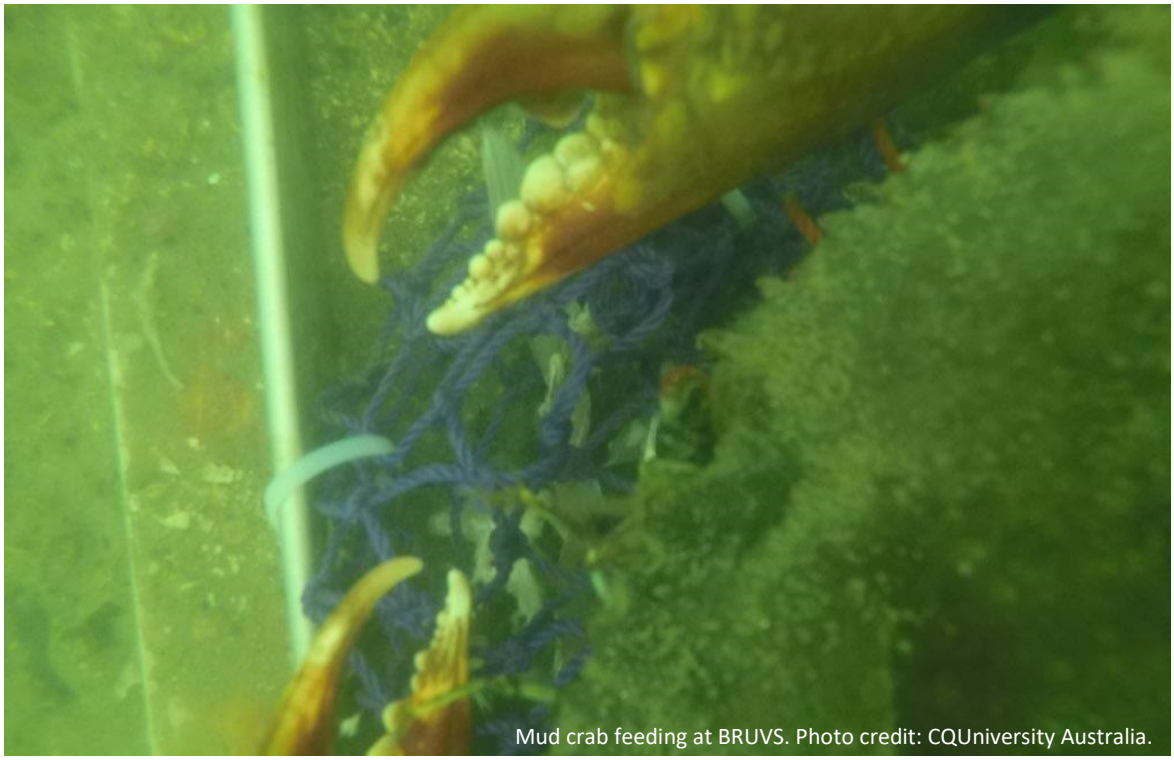
Mud Crab Indicators for the Gladstone Harbour Report Card: Project ISP015-2020



Mud crab feeding at BRUVS. Photo credit: CQUniversity Australia.

Nicole Flint, Jeremy De Valck, Amie Anastasi and Emma L. Jackson

Coastal and Marine Ecosystems Research Centre, CQUniversity

Prepared for the Gladstone Healthy Harbour Partnership

Gladstone Healthy Harbour Partnership

This report should be cited as: 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. CQUniversity Australia, Queensland.

Acknowledgements

This study was funded by the Gladstone Healthy Harbour Partnership (GHHP) and CQUniversity Australia. We thank John Rolfe and members of the GHHP Independent Science Panel (ISP), for useful comments and advice. Mac Hansler and Mark Schultz from GHHP provided ongoing project support. Many thanks to Evan Chua, Karl French, Dylan Charlesworth, Shaun Adlam and Rory Mulloy (CQUniversity) for field work and operational assistance, and Lindsay Salam (Gidarjil Development Corporation Ltd) for field work.

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.

Executive summary

Mud crabs (*Scylla serrata*) are recreationally and commercially important species in Gladstone Harbour, as well as an iconic seafood item, with cultural value to Indigenous Australians. The Gladstone Harbour mud crab indicator provides scores and grades for three metrics: abundance (catch per unit effort), prevalence of rust lesions and sex ratio.

In 2020, mud crab monitoring was conducted in seven Gladstone Harbour zones for the fourth consecutive year since the indicator was developed in 2017. Two field sampling events were conducted in March and June. Scores and grades were calculated using both data sets for the three metrics for each of the seven recommended long-term monitoring zones in Gladstone Harbour. Following a change in averaging order requested by the GHHP Independent Science Panel (ISP), each of the three measure scores were averaged across all zones first, and then the average of the three 'measure' harbour scores was calculated to obtain a harbour-wide score and grade for the mud crab indicator.

The following scores and grades have been calculated for 2020:

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

- NC – not calculable, n < 5

The scores and grades for the mud crab indicator reflect the variety of pressures on mud crabs in Gladstone Harbour, including commercial fishing, recreational fishing and environmental/habitat condition. Over short time periods, they are also potentially influenced by biological variability. The highest zone score in 2020 was for Boat Creek (0.71, B), followed by the Narrows (0.60, C).

As was the case in 2018 and 2019, the zone score and grade for Auckland Inlet has not been calculated, as only three mud crabs were caught across the two sampling periods. The small sample size (< 5) means it is not appropriate to calculate grades for this zone, except for the abundance measure.

Low grades for abundance of mud crabs (E) were recorded in all zones except the Narrows and Boat Creek, which were both graded A. As well as human impacts, there are many other 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 to allow abundance to be scored based on a moving average technique, of the average of the 75th percentile of scores for current and previous sampling years, up to 10 years. This allows the abundance benchmark to move in response to annual harbour-wide changes in catchability and abundance, which are more likely to reflect natural variations.

The prevalence of rust lesions scored lower in some zones this year than previously. Inner Harbour was graded A for this metric and the Narrows, Graham Creek and Boat Creek were graded B, and poor grades (D) were achieved for both Calliope Estuary and Rodds Bay. As previously identified for Gladstone Harbour, sex ratios of crabs over the legal size limit (for males) tended towards very high proportions of female mud crabs, a possible reflection of the sex-based fishery operating in

Queensland. In 2018 the sex ratio benchmark was updated considering new information from an unpublished Australian study of mud crab sex ratios in unfished estuaries. In 2019, data from a no-crabbing area (Eurimbula Creek) were collected and analysed and provided confirmation of the benchmark of two males to one female. This benchmark of 2 was maintained in 2020.

Overall, the harbour scored lower for the mud crab indicator in 2020 (0.39) than in 2019 (0.47), but the same grade was assigned (D).

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. The following recommendations are provided for 2021 onwards:

- Continue to monitor the mud crab indicator at the seven long-term monitoring sites
- Consider increasing the number of zones sampled to include other estuaries in Gladstone Harbour (e.g. South Trees Inlet and Boyne Estuary)
- Consider testing bioaccumulation as a possible additional measure for future monitoring
- In 2021, attention should be paid to whether the declining trends in abundance and rust lesion scores continue. It would be beneficial to sample again at Eurimbula Creek to test whether similar trends are identified at this reference site.

Contents

Introduction

Mud crabs are an important seafood product across Australasia. In Queensland, the 2019 total catch of the giant mud crab (*Scylla serrata*) was approximately 2,000 tonnes (The State of Queensland, 2019). As a recreationally and commercially important species in Gladstone Harbour and an iconic seafood item, with cultural value to Indigenous Australian peoples (Brewster, 2015), the Gladstone Healthy Harbour Partnership (GHHP) Independent Science Panel (ISP) selected mud crabs as an important indicator species to assess the health of 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). A mud crab indicator scoring abundance (catch per unit effort – CPUE), the prevalence of rust lesions and sex ratio, was subsequently incorporated into the Report Card and has been scored and graded each year since 2017.

The metric of abundance of mud crabs that are caught during the standardised independent monitoring program, aims to estimate changes in total abundance and population size (Dumas *et al.*, 2012; Meynecke *et al.*, 2012; Alberts-Hubatsch *et al.*, 2016), which are particularly relevant through time and between different sampling areas. To control potential monitoring variations that could arise due to capture technique and due to design constraints regarding sampling areas and sampling times, consistent methodologies are employed during each catch period. Abundance can reflect a wide variety of natural and anthropogenic impacts on a population (Alberts-Hubatsch *et al.*, 2016). Factors influencing 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*., 2012) 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 provides a record of how many of the captured crabs present with distinctive ‘rust spot’ shell lesions. These 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). The disease has also been reported in crabs found in the Fitzroy River and (with much lower prevalence) from crabs in Moreton Bay, Ayr (Andersen and Norton, 2001) and Stanage Bay (Dennis et al. 2016). Since rust spots are not continuously observed in Gladstone Harbour, their prevalence at any given time is likely to be an overall indicator of environmental state. There is potential for rust spot to impact on the local fishery, as it impacts on the seafood ‘grade’ of crabs. Recording the presence of rust spot is a relatively straightforward and non-destructive monitoring tool.

The final metric represented in the mud crab indicator is sex ratio. Recreational and commercial fishing are major factors driving the management of Queensland’s *S. serrata* population and exert pressure on fished stocks. In Queensland, only male mud crabs over 150 mm carapace width (measured across the ninth posteriolateral spines, referred to as ‘spine width’ in this report) may be retained by either commercial or recreational fishers. No female mud crabs, or any mud crabs under 150 mm, may be retained. In sex-based fisheries, changes in the ratio of males to females may be indicative of a change in fishing pressure (Heasman, 1980; Williams and Hill, 1982; Pillans *et al.*, 2005; Alberts-Hubatsch *et al.*, 2016). Shifts in sex ratio have implications for dynamics of the crab population and reproductive success and may also influence ecosystem processes due to the different behaviours of the sexes.

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 2020 Gladstone Harbour Report Card. Calculate scores and grades using the methods developed in the 2017 mud crab monitoring project with the revised thresholds for sex-ratio and abundance used for the calculation of the 2018 and 2019 mud crab scores. [Note: A revision in 2020, requested by the GHHP ISP, resulted in a different averaging method for determining the overall harbour score.]

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 192151)
- 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)

Two mud crab surveys were undertaken in 2020 (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.

Table 1: Gladstone zones/sites sampled during March and June 2020.

Zone/site	Survey 1	Survey 2
Zone 1: Narrows	5 March	15 June
Zone 2: Graham Creek	5 March	17 June
Zone 4: Boat Creek	6 March	18 June
Zone 5: Inner Harbour	4 March	19 June
Zone 6: Calliope Estuary	6 March	18 June
Zone 7: Auckland Inlet	4 March	19 June
Zone 13: Rodds Bay	7 March	20 June

Sampling dates and times were determined by tidal cycles. 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 at least five hours per pot. To comply with the conditions of Animal Ethics Approval, pots were placed so that they would still be submerged at low tide (preventing exposure mortality of any fish caught in the pots). Pots were placed as close as possible to mangrove habitats within this limit.

At each site and sampling event, 20 heavy duty 4-entry round collapsible crab pots were set a minimum of 100 m apart. The exception to this was Boat Creek, as fewer pots can be accommodated in this smaller system. Collapsible crab pots were purchased from a local tackle store, as they are easy to transport, assemble on the vessel and replace (Fisheries Queensland, 2009). Each pot was baited with one large sea mullet (*Mugil cephalus*) head, and all floats were attached with 10 m ropes and marked with researcher contact details and the Fisheries Queensland research permit number. Every float had a unique identifying number to allow any missing pots to be identified quickly during retrieval. The opening of each pot was secured with a cable tie, so that if crabs were removed by others this could be detected and recorded on retrieval.
At each sampling site, 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 the sex of all mud crabs caught; 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, 2003).

All bycatch species (including blue swimmer crabs, fish and other crabs) were also recorded. Blue swimmer crabs were opportunistically weighed, measured, and checked for abnormalities before release. All catch was released alive at the site of capture. Used baits were kept on board the vessel for later disposal on land, and not discarded at the sampling site, to reduce interference with commercial and recreational mud crabbers in the area.
Eurimbula Creek (Figure 1) was surveyed in 2018/19 as a reference site and to refine benchmarks. Details are provided by Flint et al. (2019).

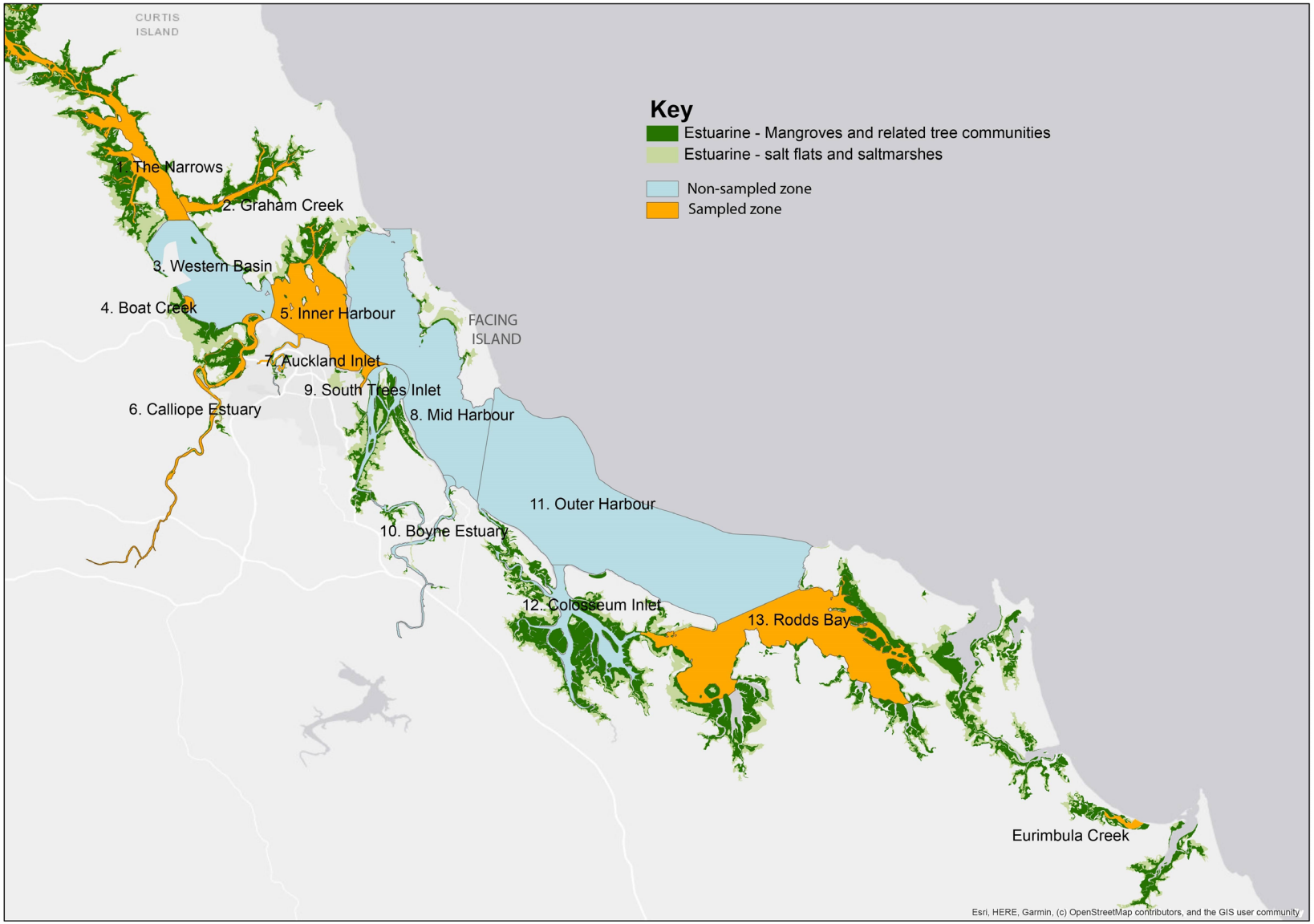


Figure 1: Map of the Gladstone Harbour zones showing long-term monitoring sites surveyed in 2017, 2018 and 2019. The map also shows the location of Eurimbula Creek, which was sampled in 2018 and 2019 to assess sex ratios.

Data analysis

Data from the two field surveys 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 4.0.2 (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 a pilot benchmark and a worst case scenario (WCS) value. 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, 2018, 2019). 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 international literature. In 2017 a conservative ratio of 3:1 (*sec.* Alberts-Hubatsch *et al*., 2016) was used as the benchmark for sex ratio (Flint *et al.*, 2017). In 2018 an unpublished thesis describing sex ratios in unfished Australian estuaries was made available (Butcher, 2004). The sex ratio in the thesis, 2 males:1 female, was equivalent to results in a separate study from an uncrabbed area in Moreton Bay (Pillans et al., 2005). As a result of this information, the benchmark for sex ratio has been updated to 2:1 for 2018. In 2019, the full set of data became available for an unfished region in Central Queensland (Eurimbula Creek, which is located approximately 20 km south of Rodds Bay), and confirmed the benchmark of 2:1, which was adopted and used in both 2019 and 2020.

The benchmark for the abundance measure was also updated in 2018. In 2017, the 75th percentile of the 2017 scores was used as the benchmark. In 2018, a moving average of the 75th percentile of this year (2018) and previous years (2017) scores was applied. In 2019, the moving average of the 75th percentile of this year (2019) and previous years (2018, 2017) scores was applied. This year, a similar approach was used, taking the moving average of the 75th percentiles for years 2017 to 2020. It is recommended that this approach continues in 2021 and beyond, using the 10-year moving average methodology.

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

Measure	**Benchmark** and basis	**Worst case scenario** and basis	**Method of calculation**
Abundance (CPUE)	2017: 3.5 crabs/pot (75th %ile of 2017 scores) 2018: 2.5 crabs/pot (moving average of 75th %ile of 2017 and 2018 scores) 2019: 2.12 crabs/pot (moving average of 75th %ile of 2017, 2018 and 2019 scores) 2020: 1.95 crabs/pot (moving average of 75th %ile of 2017, 2018, 2019, 2020) 2021+: Moving average of 75th %ile of scores for current and previous years, up to 10 years	**0.25** Min of 2017 data (0) 25th percentile of 2017 data (0) Min of LTMP data (0) 25th percentile of LTMP data (0) Catch rate of < 1 crab per allowable 4 pots (0.25)	The function used to calculate scores for abundance is: 1-((x-B)/(WCS-B)) Where: x = recorded CPUE B = benchmark (1.95) WCS = worst case scenario (0.25)
Prevalence of rust lesions	**4% = 0.04** Background level proposed by Sindermann, 1989 (5%) 25th percentile of 2017 data (4%)	**35% = 0.35** Dennis et al. 2016 mean prevalence in Gladstone Harbour (37%)	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 (based on unfished tropical mud crab populations from the literature, Alberts-Hubatsch et al., 2016) 2018: 2 (based on new information from Australian estuaries) **2019+: 2 (ratio from unfished crab populations including in the Central Queensland estuary of Eurimbula)**	**0.25** 25th percentile of LTMP data (0.25) Median of LTMP data (0.26) Mean of LTMP data (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

A total of 141 mud crabs were caught in the seven Gladstone Harbour zones in March 2020. Of these, 48 were male and 93 were female. A total of 139 mud crabs were caught across all Gladstone Harbour zones sampled in June 2020 including 98 males and 40 females. No mud crabs were caught at Auckland Inlet in March 2020 and only three in June 2020. Only five mud crabs were caught at Rodds Bay in June 2020.

The average size of mud crabs caught in March 2020 was 146.44 mm carapace notch width (Table 4) and in June 2020 was 141.57 mm (Table 5). A series of one-sample t-tests was conducted to compare this year's data with data from the previous year (2019) and from the benchmark (established from historical data for the 2001-09 period). The hypothesis being tested each time was whether this year's sample mean was equal to the means from the previous year and from the benchmark. Males caught in March 2020 were significantly smaller ($p < 0.01$) than in February 2019, but not statistically different from the benchmark (Table 4). Overall, the March 2020 sample showed no significant difference from the benchmark.

In contrast, mud crabs caught in June 2020 were significantly smaller than last year ($p < 0.01$) and the benchmark ($p < 0.01$) (Table 5). Individuals from both sexes were significantly smaller than last year (males: $p < 0.05$, females: $p < 0.1$) but were not different from the benchmark.

Similar to previous years, the results of the (one sample) t-tests found that females caught in March 2020 were significantly larger than males ($t = -8.21$, $df = 86.21$, $p < 0.001$; Figure 2). Females caught in June 2020 were also significantly larger than males ($t = -4.77$, $df = 50.86$, $p < 0.001$; Figure 3).

The largest average mud crab size in March 2020 was again recorded for Rodds Bay (mean notch width 154.67 mm) and the smallest for Graham (119.00 mm) (Figure 4), while the largest average mud crab size in June 2020 sampling was recorded for Auckland Inlet (mean notch width 164.33 mm) and the smallest at Boat Creek (134.84 mm) (Figure 5).

Table 4: Notch width (in mm) of mud crabs caught in March 2020, in comparison to February 2019 and historical data collected between 2001-2009 by Fisheries Queensland. (p>0.1 = not significant, 0.1>p>0.05 = weak significance, 0.05>p>0.01 = moderate significance, p<0.01 = strong significance)

	FULL SAMPLE			MALES			FEMALES		
	March 2020	Feb 2019	Historical data (2001-2009)	March 2020	Feb 2019	Historical data (2001-2009)	March 2020	Feb 2019	Historical data (2001-2009)
Mean	146.44	146.53	145.45	132.54	138.47	135.12	153.61	152.95	151.67
Standard deviation	17.13	22.52	20.74	14.98	18.14	18.65	13.38	23.7	19.43
2020-19 t-test comparison	2020 > 2019?	2019 > 2018?	2020 > benchmark?	2020 > 2019?	2019 > 2018?	2020 > benchmark?	2020 > 2019?	2019 > 2018?	2020 > benchmark?
t value	-0.0612	1.8282	0.68625	-2.7419	2.4743	-1.1929	0.47848	1.4576	1.4007
p value	0.9513	0.07035	0.4937	0.008615	0.0171	0.2389	0.6334	0.1504	0.1647
Signif?	No	Weak	No	Strong	Moderate	No	No	No	No

Table 5: Notch width (in mm) of mud crabs caught in June 2020, in comparison to June 2019 and historical data collected between 2001-2009 by Fisheries Queensland. (p>0.1 = not significant, 0.1>p>0.05 = weak significance, 0.05>p>0.01 = moderate significance, p<0.01 = strong significance)

	FULL SAMPLE			MALES			FEMALES		
	June 2020	June 2019	Historical data (2001-2009)	June 2020	June 2019	Historical data (2001-2009)	June 2020	June 2019	Historical data (2001-2009)
Mean	141.57	152.84	145.45	136.88	139.85	135.12	153.08	159.02	151.67
Standard deviation	16.48	18.34	20.74	12.04	16.12	18.65	20.06	15.98	19.43
2020-19 t-test comparison	2020 > 2019?	2019 > 2018?	2020 > benchmark?	2020 > 2019?	2019 > 2018?	2020 > benchmark?	2020 > 2019?	2019 > 2018?	2020 > benchmark?
t value	-8.0332	1.8234	-2.764	-2.4424	0.4611	1.4453	-1.8754	0.4140	0.4429
p value	0.0000	0.0699	0.00650	0.0164	0.6465	0.1516	0.06824	0.6796	0.6603
Signif?	Strong	Weak	Strong	Moderate	None	None	Weak	None	None

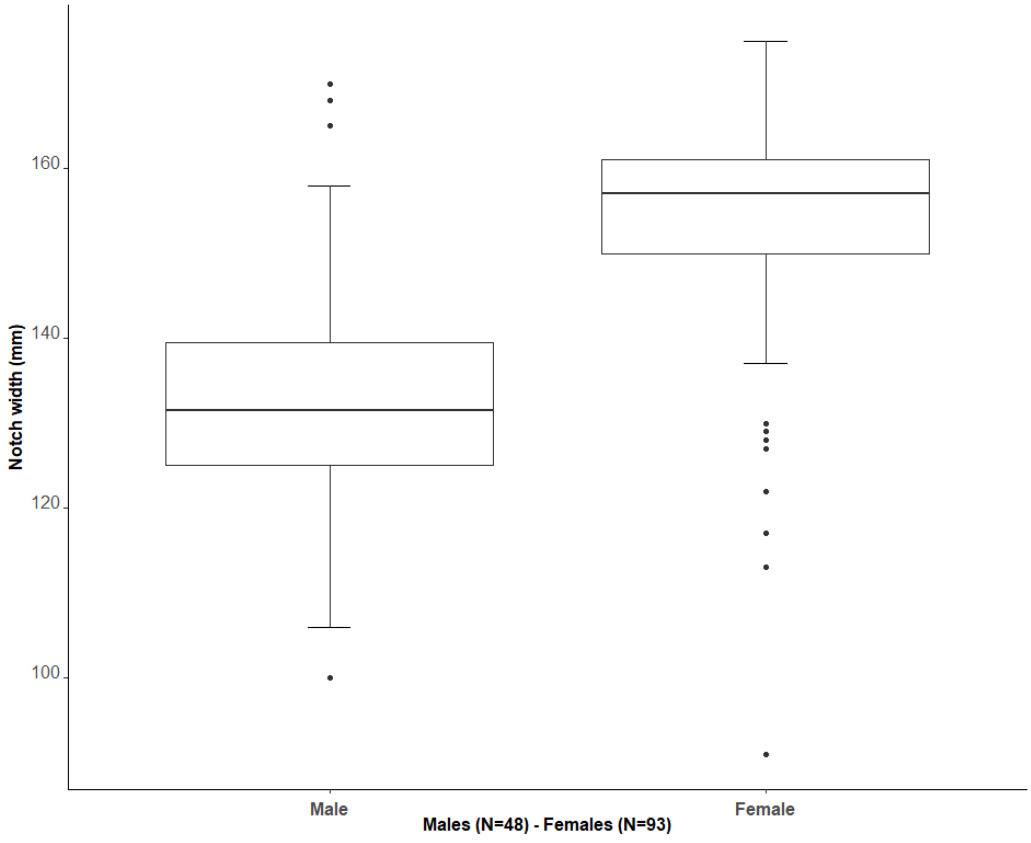


Figure 2: Notch width (mm) distribution of male and female mud crabs caught in March 2020. The box represents the middle 50% of ordered observations. Centre line is the median, the lower and upper edges correspond to the 25th and 75th percentiles. Whiskers extend from the box to the smallest and largest 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.

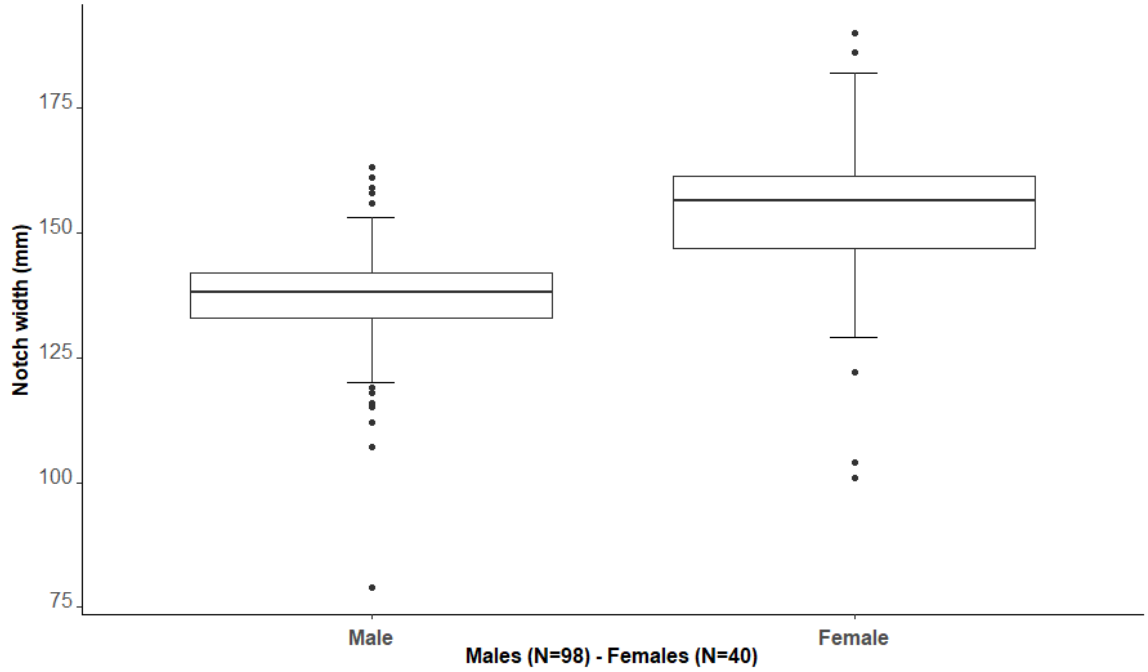


Figure 3: Notch width (mm) distribution of male and female mud crabs caught in June 2020.

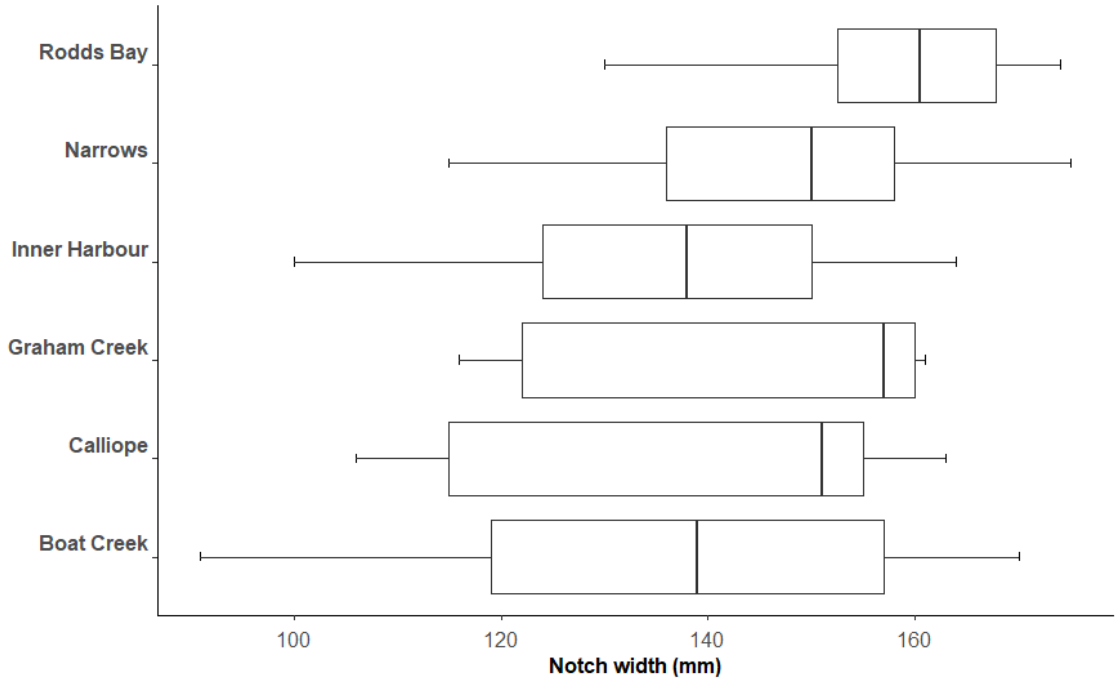


Figure 4: Notch width (mm) of mud crabs caught in March 2020, by zone.

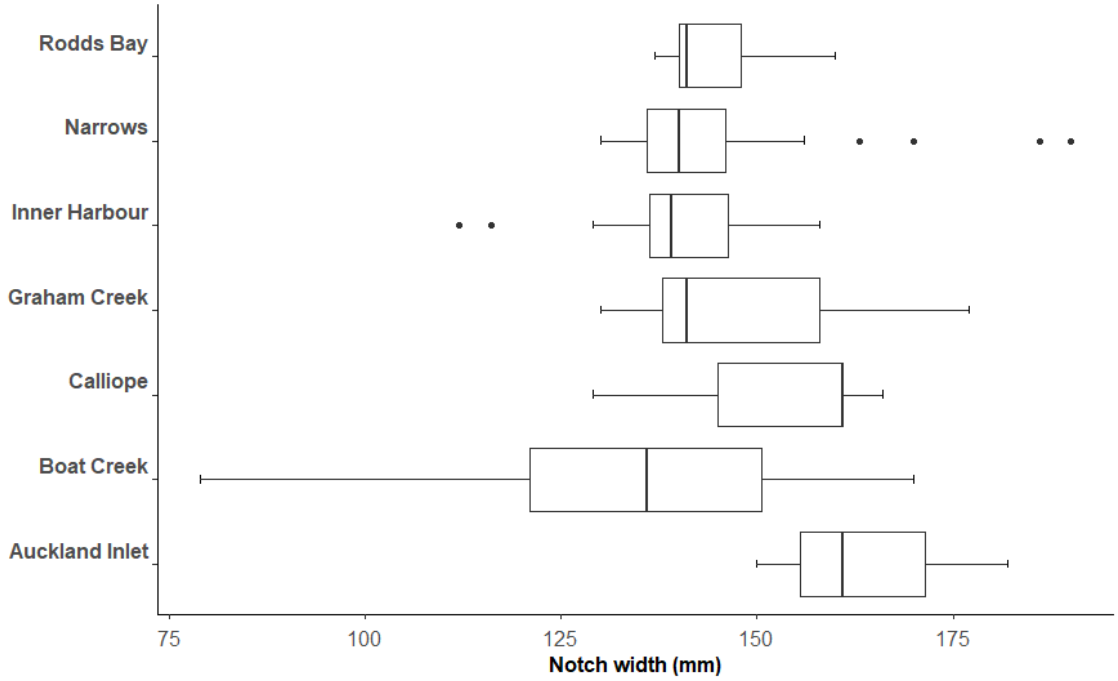


Figure 5: Notch width (mm) of mud crabs caught in June 2020, by zone.

In March 2020, for the fourth consecutive year, total catch per unit effort (CPUE) was again highest at the Narrows (4.65) and lowest at Auckland Inlet (0) (Table 6, Figure 6). In June 2020, CPUE was also highest at Boat Creek (2.39), closely followed by the Narrows (2.25) and, as in previous sampling years, again lowest at Auckland Inlet (0.15) (Table 7, Figure 7).

Table 6: Catch per unit effort in March 2020, by zone.

ZONE	ZONE NAME	# POTS	# MUD CRABS CAUGHT	CPUE
1	Narrows	20	93	4.65
2	Graham Creek	20	5	0.25
4	Boat Creek	7*	13	1.86
5	Inner Harbour	20	7	0.35
6	Calliope Estuary	20	9	0.45
7	Auckland Inlet	20	0	0
13	Rodds Bay	20	14	0.70

*Eight pots were submerged at Boat Creek and unable to be collected until the following low tide, so those pots are not included in the March dataset.

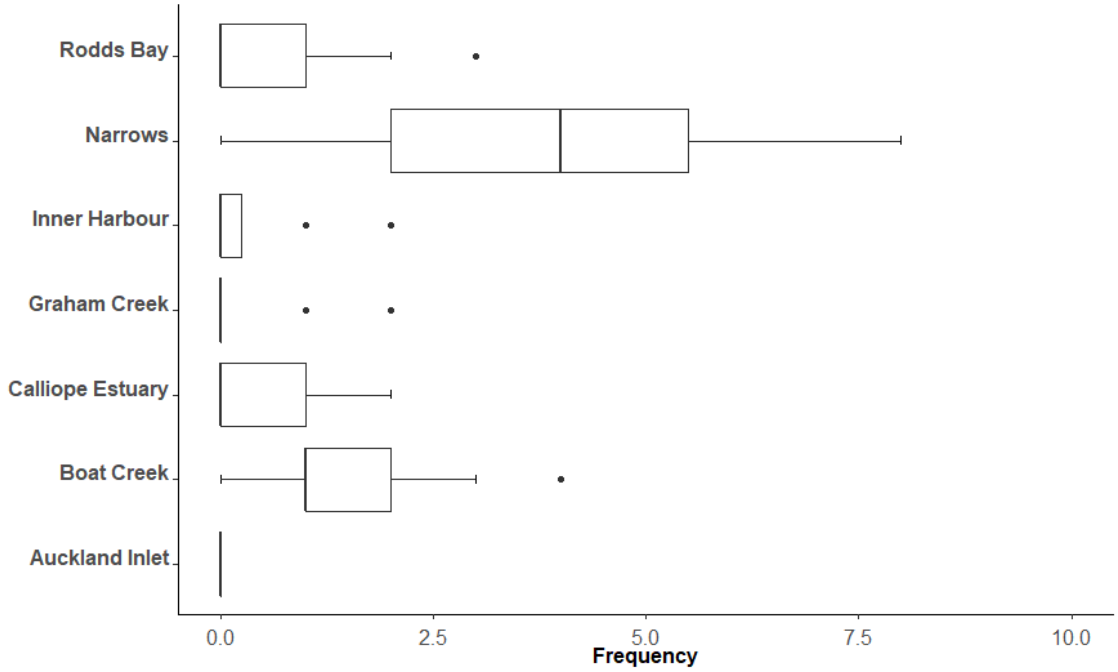


Figure 6: Number of mud crabs in each pot set in March 2020, by zone. No mud crabs were caught in Auckland Inlet.

Table 7: Catch per unit effort in June 2020, by zone.

ZONE	ZONE NAME	# POTS	# MUD CRABS CAUGHT	CPUE
1	Narrows	20	45	2.2500
2	Graham Creek	20	17	0.8500
4	Boat Creek	18	43	2.3889
5	Inner Harbour	20	16	0.8000
6	Calliope Estuary	20	10	0.5000
7	Auckland Inlet	20	3	0.1500
13	Rodds Bay	20	5	0.2500

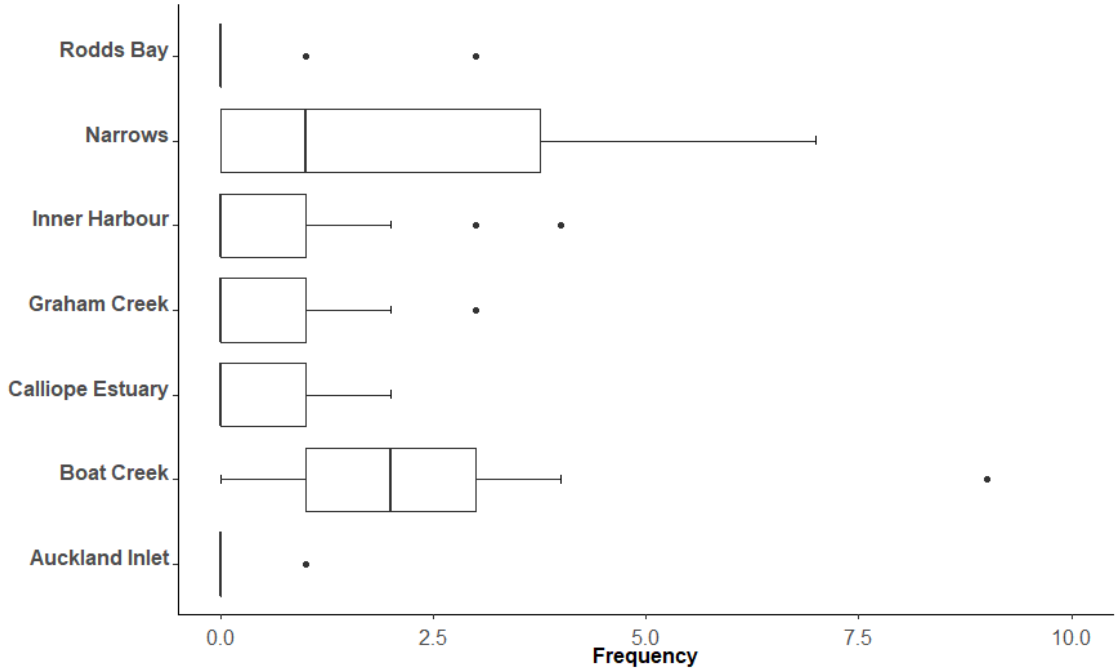


Figure 7: Number of mud crabs in each pot set in June 2020, by zone.

Sex ratio

In March and June 2020, many more oversized female crabs were caught than oversized male crabs in Gladstone Harbour. Sex ratios were therefore low across the harbour in both February and June (Table 8). A total of 113 mud crabs over the legal size limit of 150 mm carapace width (equivalent to 143 mm notch width) were caught in 2020, and only 34 were male, a similar result to previous years.

Table 8: Sex ratios of mud crabs with notch width > 143 mm, in March and June 2020, by zone.

ZONE	ZONE NAME	MARCH 2020 DATA			JUNE 2020 DATA		
		Males	Females	Sex ratio	Males	Females	Sex ratio
1	Narrows	3	58	**0.0517**	5	7	**0.714**
2	Grahams Creek	0	3	**0.0000**	2	5	**0.400**
4	Boat Creek	2	4	**0.5000**	7	8	**0.875**
5	Inner Harbour	0	2	**0.0000**	1	4	**0.250**
6	Calliope Estuary	1	4	**0.2500**	1	6	**0.167**
7	Auckland Inlet	/	/	**/**	1	2	**0.500**
13	Rodds Bay	3	10	**0.3000**	1	1	**1.000**

Rust lesions

Of the 141 mud crabs captured in March 2020, 16 had rust lesions. During this sampling event, crabs with lesions were caught at the Narrows (10 mud crabs), Boat Creek (3 mud crabs), Calliope Estuary (1 mud crab) and Rodds Bay (2 mud crabs). Prevalence was zero at Graham Creek and Inner Harbour (Table 9). In June 2020, 14 crabs with lesions were caught at the Narrows (4 crabs), Graham Creek (2 crabs), Boat Creek (2 crabs), Inner Harbour (1 crab), Calliope Estuary (3 crabs) and Rodds Bay (2 crabs). None of the 3 crabs caught at Auckland Inlet had any lesions (Table 9). These results are slightly higher than in previous years.

Table 9: Number and percentage of mud crabs caught in March and June 2020 with and without rust spot lesions, by zone. / = no data.

ZONE	ZONE NAME	MARCH 2020 DATA		JUNE 2020 DATA	
		# with lesions	% with lesions	# with lesions	% with lesions
1	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	/	/	0	0.00
13	Rodds Bay	2	14.29	2	0.40

Mud crab measure results by zone

The mud crab data set used to score each selected zone for the 2020 Gladstone Harbour Report Card included combined data from both March and June 2020. Results for each measure are provided by zone in Table 10.

Table 10: Calculated index values for 2020, for each of the three measures in each of the seven long-term monitoring sites. NC = not calculable (Auckland Inlet, < 5 crabs caught in 2020).

Zone	Zone name	Abundance (CPUE)	Prevalence of rust lesions	Sex ratio
1	Narrows	3.45	0.10	0.12
2	Graham Creek	0.55	0.09	0.25
4	Boat Creek	2.12	0.09	0.75
5	Inner Harbour	0.56	0.04	0.17
6	Calliope Estuary	0.48	0.21	0.20
7	Auckland Inlet	0.08	NC	NC
13	Rodds Bay	0.48	0.21	0.36

Indicator scores and grades

Scores and grades for the mud crab measures for the 2020 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 0.39 (D) has been calculated as the average of the three "Harbour Average" measure scores (following advice from the GHHP ISP), and an overall grade is provided for each zone. Only three mud crabs were caught in Zone 7 – Auckland Creek. Given the very small sample size (< 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.

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

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

Discussion

Indicator scores and grades

The Harbour Average was graded a D. The Harbour Average score is lower than in 2019, but the 2019 grade was the same.

The overall grades for the Mud Crab Indicator for each zone are as follows:

A: No zones.

B: Zone 4 – Boat Creek.

C: Zone 1 – Narrows.

D: Zone 2 – Graham Creek, Zone 5 – Inner Harbour, Zone 13 – Rodds Bay.

E: Zone 6 – Calliope Estuary.

Not Calculable (< 5 mud crabs caught): Zone 7 – Auckland Creek.

Changes in data collection and scoring methods from 2017 onwards

While the 2017 pilot year only included winter sampling (June/July), from 2018 onwards both summer and winter samples were collected, in February/March and June respectively. The inclusion of both summer and winter sampling allows for the detection of seasonal changes in the local mud crab population and provides a more representative assessment of the conditions in the harbour.

In June 2018 and February 2019, GHHP also commissioned CQUniversity to undertake mud crab surveys at Eurimbula Creek. In this creek in the Baffle Catchment, directly south of Gladstone Harbour (the same catchment as Rodds Bay), recreational and commercial crabbing is prohibited under Queensland legislation. This regulation, along with the generally good environmental condition of the creek, means that the population of mud crabs at Eurimbula Creek is in relatively pristine condition. The surveys that we conducted bore this out – if Eurimbula Creek was scored in 2018/19 using the GHHP mud crab indicator, the creek would have scored an A for abundance, A for prevalence of rust lesions, A for sex ratio and A overall (Flint et al., 2019). These results demonstrate the relevance of Eurimbula Creek as a reference site for mud crab surveys.

The primary reason for collecting data from Eurimbula Creek was to test the benchmark for the sex ratio measure. The sex ratio measure compares the number of male crabs over the legal size limit (150 mm carapace width, equivalent to 143 mm notch width) to female crabs over the (male) legal size limit. A benchmark for the sex ratio measure was originally established using international scientific literature from unfished mud crab populations in the 2017 pilot year and was adjusted in 2018 in response to results of a previously unavailable unpublished thesis from unfished estuaries in northern New South Wales. The results of the thesis (Butcher, 2004) aligned with results from a study in a small uncrabbed region in Moreton Bay, southern Queensland (Pillans et al., 2005). Both studies found a ratio of two male mud crabs to one female mud crab. The results from Eurimbula Creek confirmed the unfished sex ratio of two male to one female mud crab, so the benchmark used in 2018 was retained in 2019 and 2020.

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. This change was made as an alternative mechanism to allow for the inclusion of relevant and sufficient data on abundance in Auckland Inlet, in the overall Harbour score/grade.

Measure scores and grades

For comparison, the full set of scores and grades from 2017, 2018, 2019 and 2020 are provided in Appendix 1.

Scores and grades are slightly different in 2020 than in 2019. Zone 1 – the Narrows, scored a C in 2020 and 2019, compared to a B in both 2017 and 2018, but the difference throughout has been small (0.67 in 2017 and 2018, 0.63 in 2019, 0.60 in 2020). The grade for Zone 2 – Graham Creek is the same as in 2018 and 2019 (D). The grades for Zone 4 – Boat Creek has increased to a B in 2020, compared to a D in 2019 and C in 2018. In Zone 5 – Inner Harbour, a D grade has been maintained from 2019 to 2020 (in 2018 this zone was graded C). The grade for Zone 6 – Calliope Estuary has fallen for the second consecutive year, from C in 2018 to D in 2019 and E in 2020. Zone 13 – Rodds Bay has remained the same as 2017, 2018 and 2019 with a score of D.

As in 2018 and 2019, an overall score for Zone 7 – Auckland Inlet was again incalculable in 2020 due to very low catches (n = 3, all caught in June 2020). 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.

Lower mud crab catches were achieved in most zones in 2020, except the Narrows and Boat Creek. Abundance can indicate pressures such as habitat availability, extraction (fishing) and recruitment limitation, although natural biological variation can also be a factor, so the lower grade is not necessarily a cause for concern based on a single year. However, over the four years that the mud crab indicator has been monitored, there has been a steady downward trend in abundance across the harbour, despite the use of a moving average benchmark. Some of the possible (non-anthropogenic) factors affecting catchability of mud crabs include moult state of crabs, reproductive cycles, lunar and diel cycles, temperature and water motion (Knuckey, 1999). It is possible that the times of year that crabs are active is gradually changing. Another possibility if this trend continues, is that suitable habitat has been reduced or overfishing has impacted recruitment. This should be assessed further once five years of data are available in 2021. It is relevant to note that the reference, unfished and high-quality site at Eurimbula Creek would have been graded an A for abundance in 2018/19.

The prevalence of rust lesions measure also scored slightly worse in 2020 than in 2019, falling from an A to a B grade in the Narrows, Graham Creek and Boat Creek, from an A to a D in Calliope Estuary and from a B to a D at Rodds Bay. In contrast, there was an improvement in grade from a B to an A at Inner Harbour. In 2018 this measure was graded A in all zones. 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. Because of the lower catch rates in 2020, some of the scores for rust lesions were based on relatively low numbers of crabs, so this trend may not indicate a cause for concern but will be monitored further in 2021.

In areas such as Queensland, where a sex-based fishery is enforced, differences between the sex ratio (the ratio of oversized males to females) that cannot be explained by biological factors, are most likely to be related to fishing pressure. The sex ratio measure scored an E in every zone except Boat Creek (D) in 2020, a similar result to 2019 (E in all zones) and 2018 when all zones except Boat Creek (D) also received E grades. It is also worth noting, as mentioned in Flint et al. (2017) that the pattern observed suggests that fishers are observing regulations regarding the release of females.

Shifts in sex ratio caused by high fishing pressure have implications for population dynamics and may also influence ecosystem processes through sex-biased behaviours such as burrow digging. Research is underway by a PhD student at CQUniversity to determine whether smaller males are as successful at mating as larger males.

In addition to the above measures, two potential indicators were identified by Flint et al. (2017) as potentially useful. Both would require additional research and/or monitoring costs. These two indicators were bioaccumulation of metals and recruitment to nursery grounds of juvenile crabs.

Of these, bioaccumulation is likely to be of higher interest and could be incorporated into the existing adult mud crab monitoring program. It requires lethal sampling of mud crabs to measure toxicant (e.g. metal) concentrations in the hepatopancreas, muscle tissue or gills, with additional costs for dissection and analysis. Bioaccumulation of toxicants can be a particularly relevant indicator for urban and industrialised areas such as ports and is measured using established methods.

Several historical studies have used mud crabs as bioindicators of contaminants including persistent organic pollutants (POPs) and metals (Mortimer, 2000), and pesticides (Negri *et al.*, 2009). In Gladstone, elevated metal (As, Cr, Cu, Fe, Hg, Mn, Ni, U, Zn) concentrations have previously been reported from the hepatopancreas mud crabs collected at two sites at Spillway Creek, in comparison to two additional sites in the same creek, and to sites in Wild Cattle Creek (Gladstone Harbour), Baffle Creek (south of Rodds Bay) and Ayr (North Queensland) (Andersen *et al.*, 2001). A subsequent study identified measurable concentrations of Fe and Se only, from ten metals tested in hepatopancreas tissues (Andersen *et al.*, 2003), with both recorded at concentrations below food safety guidelines.

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. The following recommendations are provided for 2021 onwards:

- Continue to monitor the mud crab indicator at the seven long term monitoring sites
- Consider increasing the number of zones sampled to include other estuaries in Gladstone Harbour (e.g. South Trees Inlet and Boyne Estuary)
- Consider testing bioaccumulation as a possible additional measure for future monitoring
- In 2021, attention should be paid to whether the declining trends in abundance and rust lesion scores continue. It would be beneficial to sample again at Eurimbula Creek to test whether similar trends are identified at this reference site.

References

Alberts-Hubatsch, H., Lee, S.Y., Meynecke, J.-O., Diele, K., Nordhaus, I., Wolff, M., 2016. Life-history, movement, and habitat use of Scylla serrata (Decapoda, Portunidae): current knowledge and future challenges. Hydrobiologia 763, 5-21.

Andersen, L., Lewis, S., Melzer, A., 2001. Fluoride and metals in Spillway Creek crustacea. Gladstone, Australia, p. 53.

Andersen, L., Norton, J., 2001. Port Curtis mud crab shell disease: nature, distribution and management. FRDC Project No. 98/210. Central Queensland University, Gladstone.

Andersen, L., Storey, A.W., Sinkinson, A., Dytlewski, N., 2003. Transplanted oysters and resident mud crabs as biomonitors in Spillway Creek. Gladstone, Australia, p. 30.

Brewster, A., 2015. Giving this Country a Memory: Contemporary Aboriginal Voices of Australia. Cambria Press, New York.

Butcher, P.A., 2004. Mud crab (Scylla serrata) and marine park management in estuaries of the Solitary Islands Marine Park, New South Wales. University of New England, Armidale, Australia.

Dennis, M.M., Diggles, B.K., Faulder, R., Olyott, L., Pyecroft, S.B., Gilbert, G.E., Landos, M., 2016. Pathology of finfish and mud crabs Scylla serrata during a mortality event associated with a harbour development project in Port Curtis, Australia. Diseases of aquatic organisms 121, 173-188.

Dumas, P., Léopold, M., Frotté, L., Peignon, C., 2012. Mud crab ecology encourages site-specific approaches to fishery management. Journal of Sea Research 67, 1-9.

Flint, N., Anastasi, A., De Valck, J., Chua, E., Rose, A., Jackson, E.L., 2017. Developing mud crab indicators for the Gladstone Harbour Report Card: Project ISP015-2017. CQUniversity Australia, Rockhampton, Australia.

Flint, N., Anastasi, A., De Valck, J., Jackson, E.L., 2018. Mud crab indicators for the Gladstone Harbour Report Card: Project ISP015-2018. CQUniversity Australia, Rockhampton, Australia.

Flint, N., Anastasi, A., De Valck, J., Jackson, E.L., 2019. Mud crab indicators for the Gladstone Harbour Report Card: Project ISP015-2019. CQUniversity Australia, Rockhampton, Australia.

GHHP, 2015. Technical Report, Gladstone Harbour Report Card 2015, GHHP Technical Report No.2. Gladstone, Australia.

Heasman, M.P., 1980. Aspects of the general biology and fishery of the mud crab Scylla serrata (Forskal) in Moreton Bay, Queensland.

Knuckey, I.A., 1999. Mud crab (Scylla serrata) population dynamics in the Northern Territory, Australia and their relationship to the commercial fishery. Northern Territory University, Darwin, Australia.

McIntosh, E.J., Poiner, I.R., Panel, I.S., 2014. Gladstone Harbour Report Card Framework recommendation. Gladstone Healthy Harbour Partnership, Gladstone, Queensland, p. 82.

Meynecke, J.-O., Grubert, M., Arthur, J.M., Boston, R., Lee, S.Y., 2012. The influence of the La Niña-El Niño cycle on giant mud crab (Scylla serrata) catches in Northern Australia. Estuarine, Coastal and Shelf Science 100, 93-101.

Mortimer, M.R., 2000. Pesticide and Trace Metal Concentrations in Queensland Estuarine Crabs. Marine Pollution Bulletin 41, 359-366.

Negri, A.P., Mortimer, M., Carter, S., Müller, J.F., 2009. Persistent organochlorines and metals in estuarine mud crabs of the Great Barrier Reef. Marine Pollution Bulletin 58, 769-773.

Pillans, S., Pillans, R.D., Johnstone, R.W., Kraft, P.G., Haywood, M.D.E., Possingham, H.P., 2005. Effects of marine reserve protection on the mud crab *Scylla serrata* in a sex-biased fishery in subtropical Australia. Marine Ecology Progress Series 295, 201-213.

The State of Queensland, 2019. QFISH database. Available online at: http://qfish.fisheries.qld.gov.au/query/8bfbdad5-effd-4c7f-9654-7a70f8081a33/table?customise=True

Williams, M.J., Hill, B.J., 1982. Factors influencing pot catches and population estimates of the portunid crab Scylla serrata. Marine Biology 71, 187-192.

Appendix 1 Scores and grades from 2017 – 2020

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)

* Sex ratio based on legal size limits.

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)

* Sex ratio based on legal size limits. NC = not calculable in 2018.

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)

* Sex ratio based on legal size limits. NC = not calculable in 2019.

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

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)

* Sex ratio based on legal size limits. NC = not calculable in 2020.