Towards an Initial Quota for the Queensland Mud Crab Fishery

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Queensland Government

This publication has been compiled by A.R. Northrop, M.F. O'Neill and J.B. Robins of the Department of Agriculture and Fisheries. Department of Agriculture and Fisheries.

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Definitions and Acronyms

Biomass ratio	The estimated biomass divided by the initial unfished biomass. Also known as a depletion level. Biomass refers to exploitable legal sized crab.
DAF	Department of Agriculture and Fisheries (Queensland).
GOC	Gulf of Carpentaria (Queensland side).
Mud Crab	Unless otherwise specified, this refers to Giant Mud Crab – *Scylla serrata.*
NRIFS	National Recreational and Indigenous Fishing Survey. This was conducted in the year 2000.
Pre-recruits	Male mud crabs that have not yet grown to minimum legal size.
RFISH	A series of recreational fishing surveys conducted by DAF between . Carried out in 1997, 1999, 2002 and 2005
SWRFS	State Wide Recreational Fishing Survey. Carried out in 2010 and 2013.
TAC	Total Allowable Catch, recommended harvest for all fishing sectors.

Executive Summary

Mud crabs in Queensland (principally *Scylla serrata*) are captured by baited pots, and they are found mostly in estuaries and adjacent foreshores. Their populations are spatially variable and separated between the east coast and the Gulf of Carpentaria.

Amongst other mud crab species in this *Scylla* genus, *S. serrata* are considered fast growing (Meynecke et al., 2010). Longevity is believed to be up to four years (Knuckey, 1999). Males grow to the minimum legal size of 15 cm carapace width within two years (Doohan et al., 2003).

No previous stock assessment has evaluated the sustainability of mud crab harvests in Queensland. This stock assessment is new, using the modified catch-MSY method of Haddon et al. (2018) from Martell and Froese (2013).

The model used data from 1988/89 to 2017/18. This comprised of annual commercial harvests, and an estimate of recreational harvest derived from state-wide phone-diary surveys.

Recent reported commercial harvests (2017/18) were around 890 t from the east coast and 144 t from the Gulf of Carpentaria. The reported commercial harvest was suspected to be biased based on previous analyses (Brown, 2010; Wang et al., 2012). For this reason, Fisheries Queensland requested adjustment to reduce annual commercial harvests. The adjustment assumed 30 per cent over-reporting since the investment warning in 2003. Model results were sensitive to the adjustment.

Recreational harvests were estimated around 331 t from the east coast and 15 t from the Gulf of Carpentaria. As a fraction of total combined harvest, recreational harvests were calculated at 27 per cent for the east coast and 12 per cent for the Gulf of Carpentaria.

For the east coast in 2017/18, the model suggested that exploitable biomass was 62 per cent (between 37 per cent and 69 per cent) of unfished exploitable biomass (i.e. before fishing began). For the Gulf of Carpentaria in 2017/18, the exploitable biomass was estimated at 61 per cent (31 per cent–72 per cent).

In order to maintain the stock at the Sustainable Fisheries Strategy (SFS) longer term target of 60 per cent of unfished biomass by 2027, the recommended total allowable catch (TAC) is between 1 000 t and 1 100 t for both the recreational and commercial sectors on the east coast. A total harvest across sectors of 1 000 t would provide a greater certainty (94%) of maintaining the 60 per cent of unfished biomass target by 2027. Given the commercial harvest proportion was around 73 per cent, this equated to a commercial total allowable catch of around 730 t for the east coast.

The recommended TAC for the Gulf of Carpentaria was between 100 t and 120 t. A total harvest across sectors of 110 t would provide greater certainty (91%) of maintaining the 60 per cent of unfished biomass target by 2027. Given the commercial harvest proportion was around 88 per cent, this equated to a commercial total allowable catch of 97 t for the Gulf of Carpentaria.

The suggested harvest levels would ensure that no more than approximately five per cent of model scenarios were below the limit reference point of 20 per cent unfished exploitable biomass for mud crabs.

The recommendations considered the biological sustainability of the stock. Other objectives, such as social and economic, were not addressed in the analysis. However, they are important considerations when setting limits on harvests.

Region	Estimated Biomass compared with unfished Biomass	Reported commercial harvest (tons), accounting for a 30% estimate of over reporting 17/18	Estimated recreational harvest (tons)	Recommended total allowable catch (tons)	Recommended total allowable commercial catch (tons)
East Coast	62%	685	331	1000	730
Gulf of Carpentaria	61%	110	15	110	97

1. Background

The “Queensland Government’s Sustainable Fisheries Strategy 2017-2027” has set out a number of actions by which Queensland fisheries would be managed. A fundamental action of the Strategy was to set catch limits by 2027 to achieve “maximum economic yield” or 60 per cent biomass ratio. The choice of 60 per cent was derived from information on commercial profitability, the quality of fishing and stock resilience (DAF, 2017a).

There are many management “levers” that could be used to obtain particular levels of biomass. One such lever is that of a quota-based management system. An annual catch limit is set for the year referred to as the TAC (Hilborn and Walters, 2013).

The mud crab fishery has not been quota managed in the past, and Fisheries Queensland is currently investigating the feasibility of moving the fishery to an individual transferable quota (ITQ) system (DAF, 2018c). In this ITQ system, individual fishers are allocated a share of the quota, and are able to trade in their share (Hilborn and Walters, 2013).

The aim of this project was to model various TAC scenarios to assist Fisheries Queensland to set an initial annual TAC, and through an allocation process, set quotas for mud crabs in 2020.

The review of management procedures for mud crabs is a priority within the fisheries strategy. In recent years there have been localised depletions and high competition between fishers (DAF, 2018d).

Biology

Mud crabs are fast growing and short lived (Meynecke et al., 2010). Longevity is believed to be up to four years (Knuckey, 1999). Males grow to the minimum legal size of 15 cm carapace width within two years (Doohan et al., 2003).

Crab abundance can fluctuate from year to year depending on spawning-recruitment success. In association, annual mud crab harvests will vary between and within years dependent on seasonal catchability and levels of fishing effort.

Their distribution and availability for capture is also spatially variable. Mud crabs are found mostly in estuaries and adjacent foreshores and studies have recorded limited movements between estuaries after settlement (Alberts-Hubatsch et al., 2016).

The fishery

Queensland mud crabbing is seasonal, with high catches from November to May, and low catches from June to October (Brown, 2010). Commercial crabbers generally use smaller boats (less than six meters).

Baited “pots” are set to passively capture mud crabs. The pots are left in the water on the substrate and moved around throughout the season. The pots are hauled in by hand, checked and rebaited frequently, often daily or at each high tide (Brown, 2010).

Before the 1990s, mud crab pots used in the fishery were rigid. A transition period occurred during the 90s where most crabbers began using collapsible trawl mesh pots (McGilvray, 2018). However, some crabbers continue to use the rigid variety.

Crabs are most often sold live and by the kilogram. They are graded for sale depending on the stage of moult. At the time of writing, a commercial crabber interviewed was paid around $55 per kilogram for an “A” grade crab (full of meat) during Christmas, New Year and Chinese New Year. “B” grade crab (less filled) during this period averaged $30 per kilogram. Outside of the high demand periods, the prices paid to the crabber ranged from $20 to $40 per kilogram.

These prices were considerably higher than those reported by Brown (2010) in 2008, even after indexing for inflation. Brown (2010) suggested a price of between $10 and $20 per kilogram, with an average of $16 per kilogram, depending on the time of year and quality.

Under current Queensland legislation, it is illegal to retain female mud crabs. It is also illegal to retain male crabs under the minimum legal size of 15 cm carapace width.

Logbook reviews

There have been two thorough reviews of the mud crab commercial logbook data, those of Brown (2010) and Wang et al. (2012).

Brown (2010) conducted a forensic analysis of the commercial logbook data. It was discovered that logbook catch rates were biased and compounded around the time of the investment warning in 2003. Brown (2010) found the number of pots operated and lifted, which is fundamental to calculating catch rates, were not accurately recorded.

Wang et al. (2012) stated that the reliability of commercial logbook data was very poor over the period that was investigated and made a number of recommendations to improve the data. This included the need to verify and validate the logbook data.

Both Brown (2010) and Wang et al. (2012) discovered “super-fishers”. These were individual crabbers that recorded impossibly high catches.

Report objectives

The aims of this investigation were to:

1. Simulate biomass ratios of mud crabs on the east coast of Queensland and the Gulf of Carpentaria.
2. Predict the impact of a variety of TAC scenarios on biomass ratios, and compare the results with the Sustainable Fisheries Strategy reference point of 60 per cent by 2027 biomass ratio target.

2. Method

Harvest information for both commercial and recreational crabbers was used as input into a modified catch-MSY model (Haddon et al., 2018). The model simulated biomasses within certain parameter settings. The model also generated future biomass predictions based upon hypothetical catch scenarios.

2.1. Data inputs

Commercial harvests

Commercial mud crab harvests from the 1988/89 to 2017/18 financial years were estimated from Fisheries Queensland's CFISH database (from logbooks).

Based on previous reports, commentary and conclusions (Brown, 2010; Wang et al., 2012), the commercial harvest data for mud crab was considered to have high uncertainty. In 2003 the Queensland Government issued an investment warning relating to the mud crab fishery. Just prior to the warning, reported harvest and effort increased considerably. One explanation for the increase was a perception that quota allocations would be based on previous catch histories, which catalysed over-reporting (Brown, 2010). For this reason, it was agreed by the Fisheries Queensland Crab Working Group, at the meeting held on 12 and 13 September 2018 (DAF, 2018b), to apply a "30 per cent over-reporting factor" (Barry, 2019) from 2003 in the data.

Recreational harvests

There were two main data sources to estimate annual recreational harvests of mud crabs from Queensland east coast and Gulf of Carpentaria waters.

- The Queensland recreational fishing surveys (RFISH). was conducted in 1997, 1999, 2002 and 2005.
- The National Recreational and Indigenous Fishing Survey (NRIFS) was conducted in 2000. The State Wide Recreational Fishing Survey (SWRFS) followed the NRIFS methodology in 2010 and 2013.

The strengths and weaknesses of these surveys are discussed in detail in Leigh et al. (2014). In short, RFISH contains biases (Lawson, 2015) and NRIFS and SWRFS were deemed more representative and were used to estimate the total recreational mud crab harvest.

2.2. Analysis

A modified catch-MSY (Haddon et al., 2018) was used to simulate biomass levels of mud crab. Queensland waters were split into east coast and Gulf of Carpentaria in line with proposed management units (DAF, 2018c). The R package *simpleSA* (Haddon et al., 2018) was used in the analyses.

The catch-MSY (Martell and Froese, 2013) uses a Schaefer (1954) surplus-production model at its core. A range for the initial depletion levels are specified, as well as the number of replicates (many thousands) to be tested within the range. Initial depletion is the ratio of the biomass of the stock in the year of first available data, and the biomass of the stock before crabbing began. Stock reduction analyses are then used (Kimura et al., 1984) for each replicate to generate an array of feasible trajectories of the stock biomass over the harvest period.

There were two technical concerns why catch rates were not used in a more formal stock assessment analysis (e.g. delay difference or surplus production), which explained the use of the simple modified catch-MSY methodology:

1. The catch rates derived from logbook data had biases. The harvest biases, and also the inaccuracies in recording the number of pot-lifts, represent significant impediments in calculating catch rates.
2. Standardised catch rates were tested in line with Haddon et al. (2018) to examine that a time-lagged negative correlation existed between harvest and catch rates, and one was not found.

Another reason for using a catch-MSY analysis, rather than a more customised model, was the relatively short timelines in which the Crab Working Group requested the model (requested at the 12 and 13 September 2018 meeting for the following meeting held on 12 and 13 December 2018). A customised approach would have taken much longer than this to fully develop.

Assumptions of the catch-MSY analysis were:

1. The potential range for carrying capacity between the maximum harvest and 60 times the maximum harvest (Haddon et al., 2018)
2. The intrinsic rate of growth, or resilience, parameter were set at a “high” level (0.6-1.5). A resilient stock is one that has high spawning success. Resilience was assumed to be high due to it being illegal to harvest females.
3. Initial depletion ranges were set at between 0.2 and 0.5 for East Coast, and between 0.2 and 0.8 for the Gulf of Carpentaria.
4. Commercial harvests are suspected to be over-reported (Brown, 2010; Wang et al., 2012). Fisheries Queensland and the Crab Working Group (Barry, 2019) requested that harvests from the year 2003 incorporate a 30 per cent over-reporting factor.

Future catch limits were tested to determine the likelihood of obtaining the target reference point of 60 per cent biomass by 2027 (DAF, 2017b). To enable risk assessment of various TAC limits, three catch limit scenarios were generated for the east coast, and five catch limit scenarios for the Gulf of Carpentaria. The proportion of biomass ratio trajectories that fell below the limit reference point of 20 per cent was also calculated.

Additional analyses were conducted to determine the model sensitivity to a lower resilience parameter and alternate initial depletion levels. Further, a lower 15 per cent over-reporting factor, as requested by the Crab Working Group was also modelled.

3. Results

3.1. East coast

Data for mud crab commercial harvest began in 1988. The east coast commercial harvest had a seven-year mean average of 1103 t over the 2010/11 to 2016/17 financial years (Figure 1). When accounting for 30 per cent over-reporting, the average commercial tonnage was estimated to be 850 t. The most recent year of data for recreational harvest (2013) was estimated at 331 t. This equated to 22 per cent of the total harvest in that year. With the 30 per cent over-reporting adjustment, the estimated proportion of recreational harvest increased to 27 per cent in that year.

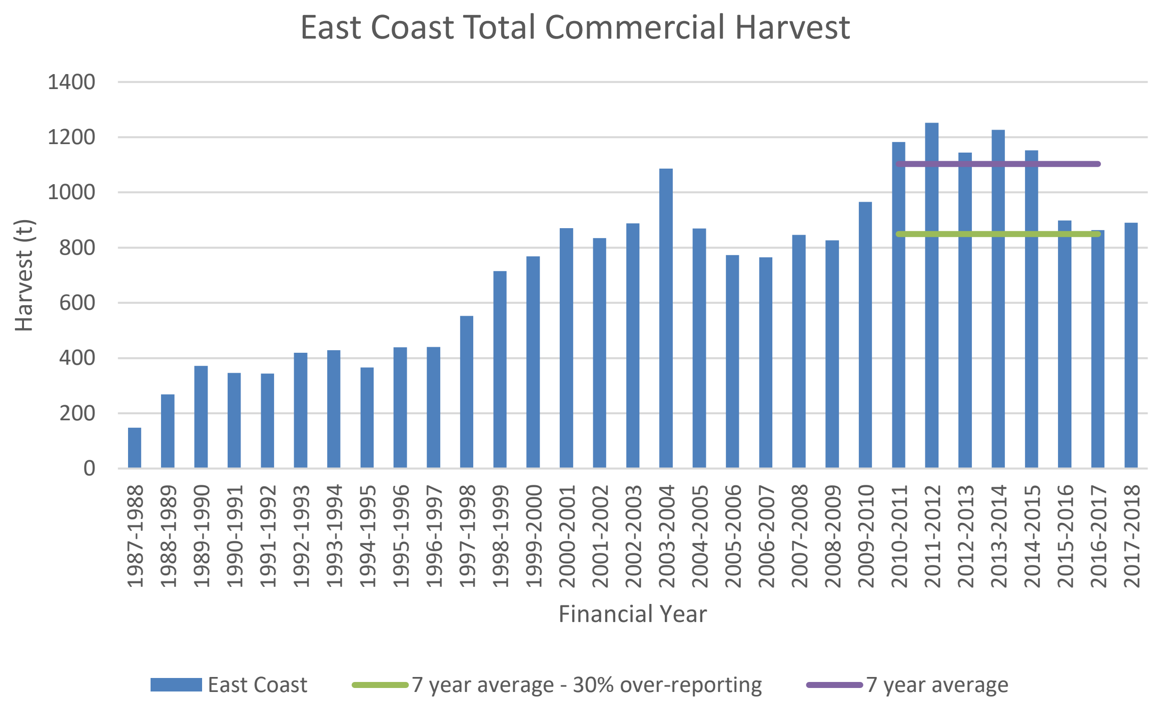

Figure 1 Commercial harvests for mud crab for the east coast of Queensland. The purple line represents the 7 year average, of 1103 t, from 2010/11 to the 2016/17 financial year. The green line represents the seven-year average but assumes that harvests are over reported by 30 per cent, resulting in an estimated annual average harvest of 850 t.

The modified catch-MSY (Haddon et al., 2018) and settings (section 2.2) were applied to the total harvest estimates to generate biomass trajectories (Figure 2). Results were that by the 2017/18 year, the mean biomass ratio was 59 per cent, with a median of 62 per cent, and this had relatively large uncertainty. No trajectories were below the 20 per cent limit reference point. Fifty-seven percent of trajectories were above the 60 per cent biomass target reference point. Table 1 summarises the results, and *Appendix A* gives further detail.

None of the future catch limit scenarios of 1000 t, 1100 t and 1200 t showed more than 10 per cent of trajectories falling below the limit reference point of 20 per cent biomass (Sainsbury, 2008). The 1000 t scenario showed the least probability of trajectories falling below the 20 per cent limit reference point, with 94 per cent of scenarios remaining above the 60 per cent target reference point. According to the model's simulations, the 1200 t would, on average, reduce the biomass over time until it stabilised at about 50 per cent. A catch limit of 1200 t had about 8 per cent of trajectories, where the stock would be below the 20 per cent limit reference point, and might be considered to be a higher-risk catch limit than the lower catch limits of 1000 t or 1100 t.

Table 1: Simulated TAC options for the East Coast, and their impact on future biomass ratios

			Mean Biomass Ratio	**Median Biomass Ratio**	**% of scenarios where biomass was less than limit reference point of 20%**	**% of scenarios above target reference point of 60%**
		2017/18	59%	62%	0	57%
Total TAC (recreational and commercial)	**1200 t**	**2019/20**	58%	62%	1%	62%
		2026/27	52%	57%	8%	33%
	1100 t	**2019/20**	61%	64%	<1%	70%
		2026/27	61%	65%	5%	82%
	1000 t	**2019/20**	63%	67%	<1%	76%
		2026/27	68%	71%	3%	94%

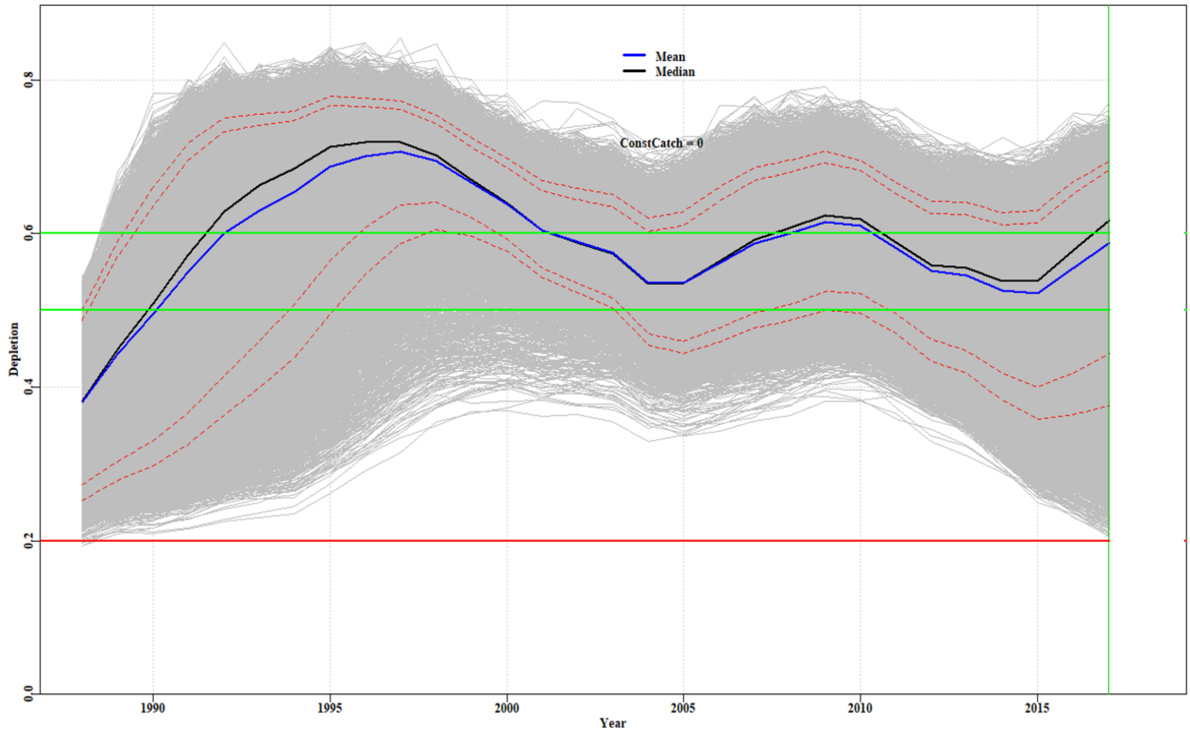

Figure 2 : Mud crab biomass trajectories for east coast waters of Queensland. The trajectories show the biomass ratios, labelled as depletion. The blue line represents the mean of the trajectories, the black line represents the median. The red dashed lines represent the 80th and 90th percentile bounds. The two green lines represent 50 per cent depletion/biomass levels (where MSY is obtained) and 60 per cent target biomass ratio. The red line represents the 20 per cent biomass limit reference level. Note year is financial year – for example 2015 represents the 2015/16 financial year.

3.2. Gulf of Carpentaria

For the Gulf of Carpentaria (Figure 3) the 7-year average harvest from 2010/11 to 2016/17 (financial years) was 152 t. However, when accounting for 30 per cent over-reporting, the estimated average harvest was 117 t. For recreational harvests, estimates of the recreational harvest in the Gulf for the years sampled were averaged, resulting in an annual harvest of approximately 15 t. This 15 t value was agreed to by consensus with Fisheries Managers and Biologists (Fisheries Queensland, 2018). This was also discussed by the Crab Working Group in December 2018 (DAF, 2018a), and most particularly by those crabbers representing the Gulf of Carpentaria. The proportion of recreational harvest was calculated as 9 per cent of the total harvest for the most recent data point. However, when accounting for 30 per cent over-reporting of commercial harvests, the estimated share was higher at 12 per cent.

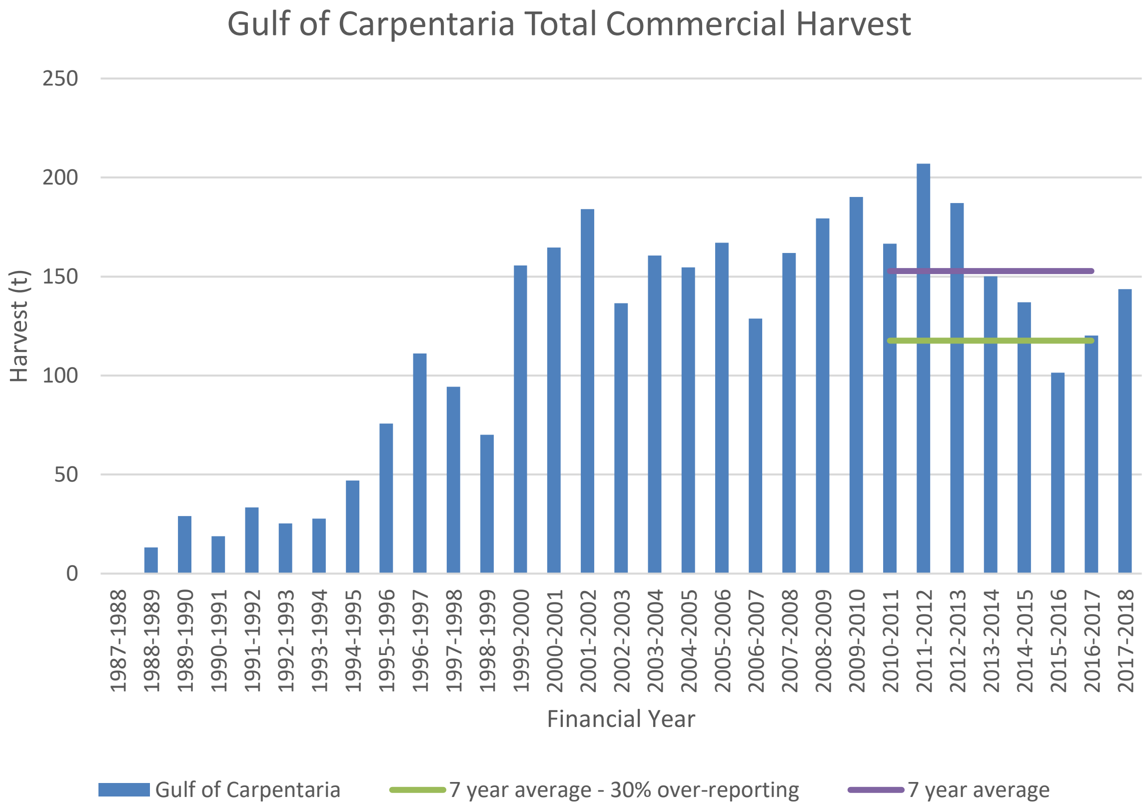

Figure 3 Commercial harvests for mud crab from Gulf of Carpentaria waters. The purple line represents the seven-year average, of 152 t, from 2010/11 to the 2016/17 financial year. The green line represents the seven-year average over the same period, but assumes that harvests are over-reported by 30 per cent, resulting in an estimated harvest of 117 t.

The modified catch-MSY was applied to the total harvest estimates in the Gulf of Carpentaria to generate biomass trajectories (Figure 4). By the 2017/18 year, the estimated mean biomass was 58 per cent, and the estimated median biomass was 61 per cent. Like results for the east coast, simulated biomass ratios had large uncertainty. No trajectories were below the 20 per cent biomass limit reference point. In total 53 per cent of trajectories were above the 60 per cent biomass target reference point.

To enable risk assessment of various catch limits, five catch limit scenarios were generated. These are shown in Table 2, with more detail in *Appendix B*. The 130 t and 140 t scenarios showed more than 10 per cent of trajectories below the 20 per cent limit reference point by 2026/27. The 100 t scenario showed the least probability of trajectories falling below the limit reference point, with 3 per cent of scenarios tracking below the 20 per cent biomass limit reference point. According to the model's simulations, 140 t would, on average, reduce the biomass average until it stabilised at about the 50 per cent biomass ratio.

Table 2: Simulated TAC options for the East Coast, and their impact on future biomass ratios

			Mean Biomass Ratio	Median Biomass Ratio	% of scenarios where biomass was less than limit reference point of 20%	% of scenarios above target reference point of 60%
		2017/18	58%	61%	0	53%
Total TAC (recreational and commercial combined)	**140 t**	**2019/20**	56%	61%	3%	53%
		2026/27	46%	55%	16%	17%
	130 t	**2019/20**	58%	63%	2%	60%
		2026/27	56%	64%	10%	70%
	120 t	**2019/20**	59%	65%	2%	64%
		2026/27	63%	69%	6%	85%
	110 t	**2019/20**	61%	66%	1%	68%
		2026/27	69%	73%	4%	91%
	100 t	**2019/20**	63%	68%	1%	71%
		2026/27	74%	77%	3%	95%

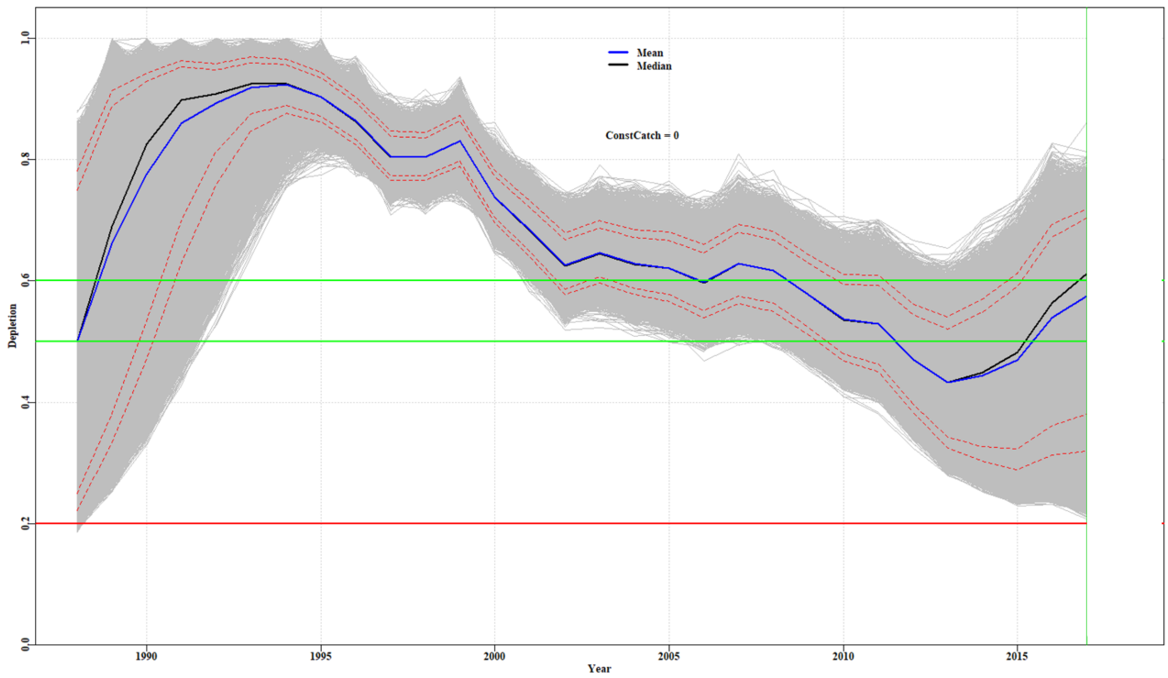

Figure 4 Mud crab biomass trajectories for the Gulf of Carpentaria. The trajectories show the biomass (depletion) ratio levels. The blue line represents the mean of the trajectories, the black line represents the median. The red dashed lines represent the 80th and 90th percentile bounds. The two green lines represent 50 per cent biomass ratios (where MSY is obtained) and 60 per cent biomass ratios. The red line represents the 20 per cent biomass limit reference level. Note year is financial year – for example 2015 represents the 2015/16 financial year.

Sensitivities of the assumptions were tested. The initial depletion range, the resilience range, and finally the choice of the 30 per cent over-reporting factor were explored. The model was not sensitive to the choice of the resilience parameter, nor to the choice of initial depletion. However, the effect of the over-reporting factor was pronounced, resulting in much higher catch limit recommendations. The results for a lower choice of over-reporting (15 per cent) are shown in *Appendix C* and *Appendix D*.

4. Discussion

Using the modified catch-MSY method, and with some realistic assumptions, we have produced harvest TAC estimates for the mud crab fishery in Queensland. Large uncertainties were nevertheless apparent and this is graphically illustrated in the ranges for biomass trajectories. The results quantified the risks of the biomass falling below the 20 per cent limit reference point as ‘low’ for the smaller harvest TAC projected (DAF, 2017a).

A range of possible TAC limits were tested. To obtain a mean/median of at least 60 per cent exploitable biomass by the 2026/27 financial year, with a low probability of tracking below the limit reference point, catch limits of less than 1100 t for the east coast and less than 120 t for Gulf waters is recommended. The choice of tonnages considered the biological sustainability of the stock. It was noted that the lower limits of 1000 t for the east coast and 110 t for Gulf of Carpentaria would provide greater certainty of maintaining the 60 per cent unfished biomass objective in the Sustainable Fisheries Strategy. Other considerations such as economic and social objectives should shape the setting of TAC.

The assessment was a data-limited approach given the known biases in the commercial logbook data. Better data is required to support improved analyses and predictions. The adjustment for over reporting considered intelligence received by Fisheries Queensland, and trends noted in the logbook data over a number of years. The model was sensitive to any adjustment (*Appendix C* and *Appendix D*). The reported commercial harvest for the east coast was 890 t in 2017/2018. With the 30% over-reporting adjustment, the commercial harvest assumed for the model was 685 t. The recommended TACC of about 730 tons was higher than what FQ believed was harvested in the last financial year. The reported commercial harvest for the GOC was 144 t for the 2017/18 financial year, the highest reported annual catch for the previous four years. With the 30% over-reporting adjustment, the commercial harvest assumed for the model was 110 t. The recommended TACC of about 97 tons was lower than what FQ believed was harvested in the last financial year. Better information on the extent of over reporting is required. Authenticated data would result in more certainty in the catch limits through improved analyses. Regardless, formal quota reporting procedures will help validate future logbook data, to provide the basis on which to improve mud crab assessments.

Experts believe that mud crab populations fluctuate based largely on environmental variables such as fresh water flows (Calogeras, 2003), rainfall and temperature (Meynecke et al., 2010). Future modelling should incorporate these environmental drivers into stock assessment modelling. The current Agri-Science Queensland project FRDC 2017-047 is working to provide additional knowledge for environmental drivers of mud crab abundance which could be used in the future to improve this stock assessment model.

The mud crab fishery is known to have localised depletion as a consequence of spatially- and temporally-intense fishing mortality from commercial and recreational sectors (DAF, 2018d). For this reason mud crab stocks would best be monitored at regional if not local levels e.g., per estuary in order to manage the risk of localised depletion. However it is uncertain how such localised depletion affects recruitment in this species, particularly given its high fecundity, the protection of females in Queensland waters, and the wide dispersion from (presumed) offshore oceanic spawning. Improved monitoring of mud crab abundance (i.e., pre-recruits and females) would result in greater certainty in this regard, but it is clear that more research is needed to safeguard the sustainability of this valuable fishery. Currently there is no independent survey of mud crab abundance and little available data of the biomass levels of female mud crab. A pre-recruit survey for crabs less than 15cm carapace width carried out towards the end of the mud crab season would provide an index of abundance that would provide appropriate adjustments to annual catch limits for quota for the following year. It could also give an index of abundance for female mud crabs, if carried out at the appropriate time. This would assist by providing a greater understanding of stock recruitment dynamics. For example, a pre-recruit index has been used successfully to manage snow crabs in Newfoundland and Labrador (Mullowney et al., 2017).

More recent estimates of the recreational harvest is also required for management and assessment. The most recent data used to determine recreational harvest, and the proportion of recreational harvest, was from 2013. A new estimate made available in 2020 from SWRFS will be useful in future modelling.

These TAC recommendations apply at a whole-of-stock spatial scale (i.e., Queensland east coast or Gulf of Carpentaria waters). To improve fishery performance at finer spatial scales (e.g. per estuary), the dynamics of localised mud crab populations and sectoral fishing mortality dynamics need to be reflected in management procedures. Excessive harvests and fishing effort in selected estuaries, latency in commercial TAC and incorrect recreational bag limit settings may undermine objectives for sectoral catch sharing and building fishery catch rates.

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References

Alberts-Hubatsch, H., S. Y. Lee, J.-O. Meynecke, K. Diele, I. Nordhaus, and M. Wolff. 2016. Life-history, movement, and habitat use of Scylla serrata (Decapoda, Portunidae): current knowledge and future challenges. Hydrobiologia 763(1):5-21. (journal article) doi: 10.1007/s10750-015-2393-z

Barry, S. 2019. Personal Communication, email from Simon Barry (Crab Fisheries Manager) on 2 November 2011.

Brown, I. W. 2010. Taking Female Mud Crabs (Scylla Serrata): Assessment of Risks and Benefits. Fisheries Research and Development Corporation.

Calogeras, C. 2003. Understanding the issues involved in implementing a quota management regime and an assessment of its potential for use in the Northern Territory Mud Crab Fishery.

DAF. 2017a. Queensland Sustainable Fisheries Strategy, 2017-2027, State of Queensland.

DAF. 2017b. What is the sustainable fisheries strategy? https://www.daf.qld.gov.au/business-priorities/fisheries/sustainable-fisheries-strategy/what-is-the-sustainable-fisheries-strategy.

DAF. 2018a. Crab Fishery Working Group Communique - 12-13 December 2018.

DAF. 2018b. Crab Fishery Working Group Communique - 12-13 September 2018.

DAF. 2018c. Crab Fishery Working Group Communique - 13-14 June 2018.

DAF. 2018d. Discussion Paper: Reform of the Queensland crab (mud and blue swimmer) fishery. Department of Agriculture and Fisheries.

Doohan, M., M. Dunning, S. Helmke, C. Bullock, E. Jebreen, B. Zeller, L. Williams, J. Higgs, K. Clarke, and I. Brown. 2003. QUEENSLAND MUD CRAB FISHERY.

Fisheries Queensland. 2018. Personal Communication: Meeting held with Fisheries Managers and Biologists 3 December 2018.

Haddon, M., P. Burch, N. Dowling, and R. Little. 2018. Reducing the Number of Undefined Species in Future Status of Australian Fish Stocks Reports: Phase Two - training in the assessment of data-poor stocks. FRDC Project: 2017/102, CSIRO Oceans and Atmosphere.

Hilborn, R., and C. J. Walters. 2013. Quantitative fisheries stock assessment: choice, dynamics and uncertainty. Springer Science & Business Media.

Kimura, D. K., J. W. Balsiger, and D. H. Ito. 1984. Generalized stock reduction analysis. Canadian Journal of Fisheries and Aquatic Sciences 41(9):1325-1333.

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

Lawson, A. 2015. An investigative analysis of Queensland's statewide recreational fishing surveys. Identifying bias in self-reported catch and effort data, Department of Agriculture and Fisheries.

Leigh, G., A. Campbell, C. Lunow, and M. O'Neill. 2014. Stock assessment of the Queensland east coast common coral trout (Plectropomus leopardus) fishery. Brisbane, Australia: Queensland Government

Martell, S., and R. Froese. 2013. A simple method for estimating MSY from catch and resilience. Fish and Fisheries 14(4):504-514.

McGilvray, J. 2018. Personal communication, Mudcrab data summary.

Meynecke, J.-O., S. Y. Lee, M. Grubert, I. Brown, S. Montgomery, N. Gribble, D. Johnston, and J. Gillson. 2010. Evaluating the environmental drivers of mud crab (Scylla serrata) catches in Australia. Fisheries Research and Development Corporation.

Mullowney, D., E. G. Dawe, K. R. Skanes, E. Hynick, W. Coffey, P. O'Keefe, D. Fiander, D. Stansbury, E. Colbourne, and D. Maddock-Parsons. 2017. An Assessment of Newfoundland and Labrador Snow Crab (Chionoecetes Opilio) in 2015. Canadian Science Advisory Secretariat.

Sainsbury, K. 2008. Best practice reference points for Australian fisheries. Australian Fisheries Management Authority Canberra, Australia.

Schaefer, M. B. 1954. Some aspects of the dynamics of populations important to the management of the commercial marine fisheries. Inter-American Tropical Tuna Commission Bulletin 1(2):23-56.

Wang, Y.-G., M. O'Neill, I. Brown, and J. McGilvray. 2012. Assessment of the utility of Queensland commercial mud crab logbook data.

Appendix

Appendix A: Catch Limit Scenarios for East Coast of Queensland Catch-MSY model

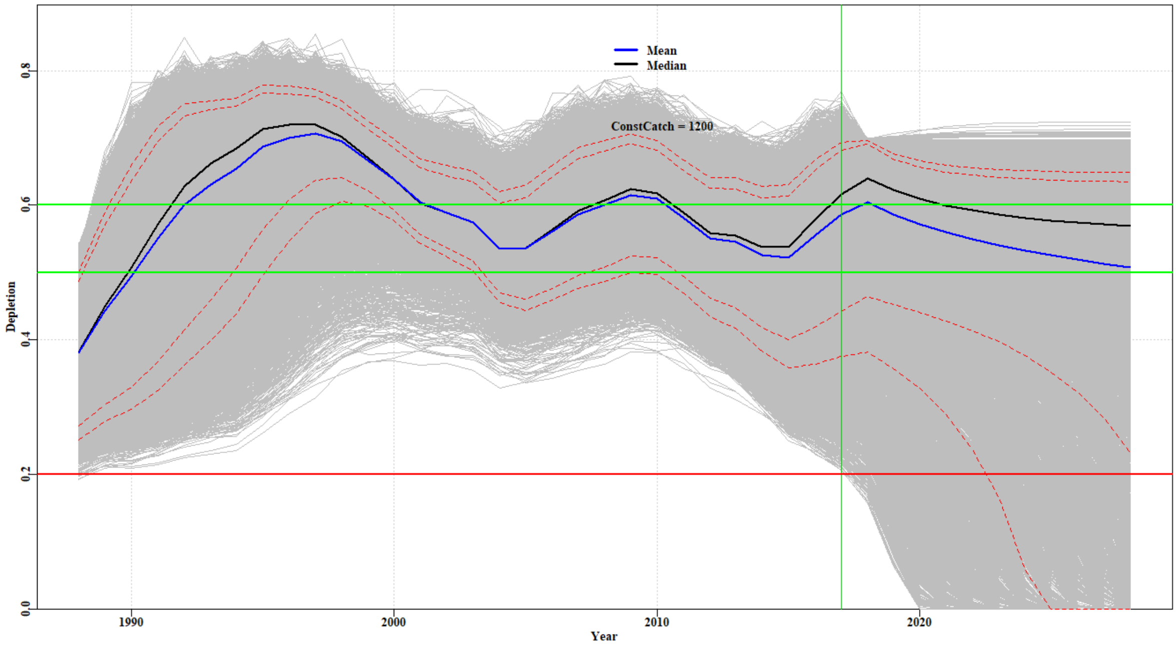

Figure 5: Mud crab biomass trajectories for the east coast with a constant catch limit of 1200 t. The trajectories show the biomass (depletion) ratio levels. The blue line represents the mean of the trajectories, the black line represents the median. The red line represents the 20 per cent biomass limit reference level. Note year is financial year – for example 2015 represents the 2015/16 financial year.

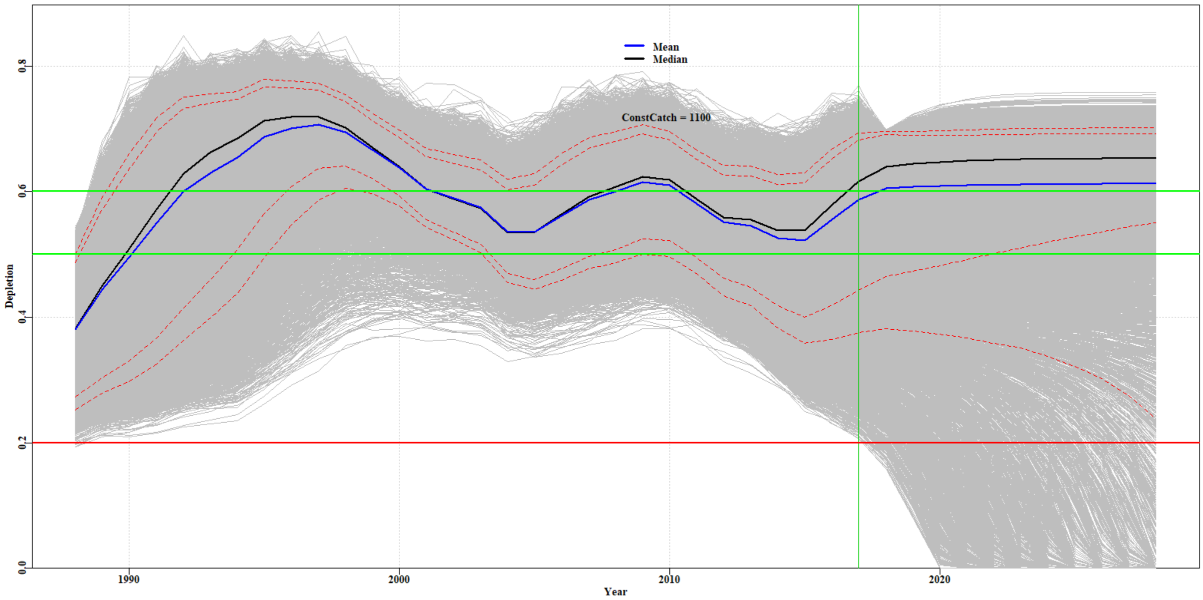

Figure 6: Mud crab biomass trajectories for the east coast with a constant catch limit of 1100 t. The trajectories show the biomass (depletion) ratio levels. The blue line represents the mean of the trajectories, the black line represents the median. The red dashed lines represent the 80th and 90th percentile bounds. The two green lines represent 50 per cent biomass ratios (where MSY is obtained) and 60 per cent biomass ratios. The red line represents the 20 per cent biomass limit reference level. Note year is financial year – for example 2015 represents the 2015/16 financial year.

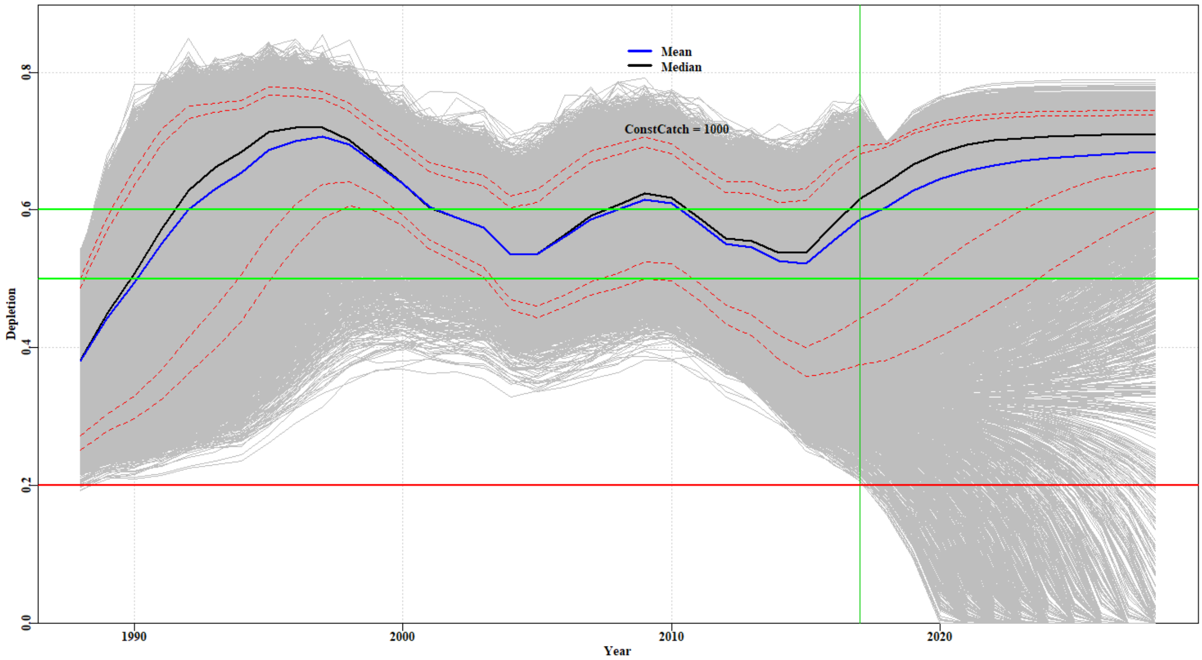

Figure 7: Mud crab biomass trajectories for the east coast with a catch limit of 1000 t. The trajectories show the biomass (depletion) ratio levels. The blue line represents the mean of the trajectories, the black line represents the median. The red dashed lines represent the 80th and 90th percentile bounds. The two green lines represent 50 per cent biomass ratios (where MSY is obtained) and 60 per cent biomass ratios. The red line represents the 20 per cent biomass limit reference level. Note year is financial year – for example 2015 represents the 2015/16 financial year.

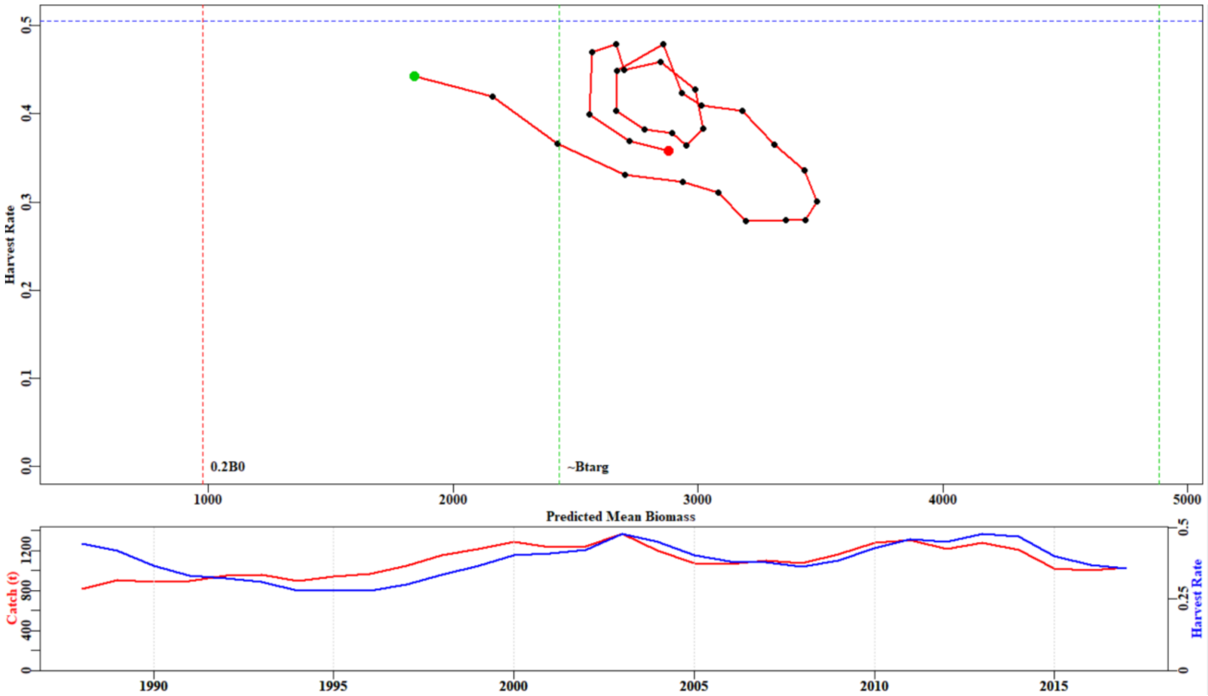

Figure 8: A phase plot of the mean predicted mud crab biomass for east coast waters and harvest rates from 1988/89 (green point) to 2016/2017 (red point) catch years. The axes for the bottom plot are identified through the colour of the axis titles.

Appendix B: Catch Limit Scenarios for Gulf of Carpentaria (Queensland) Catch-MSY model

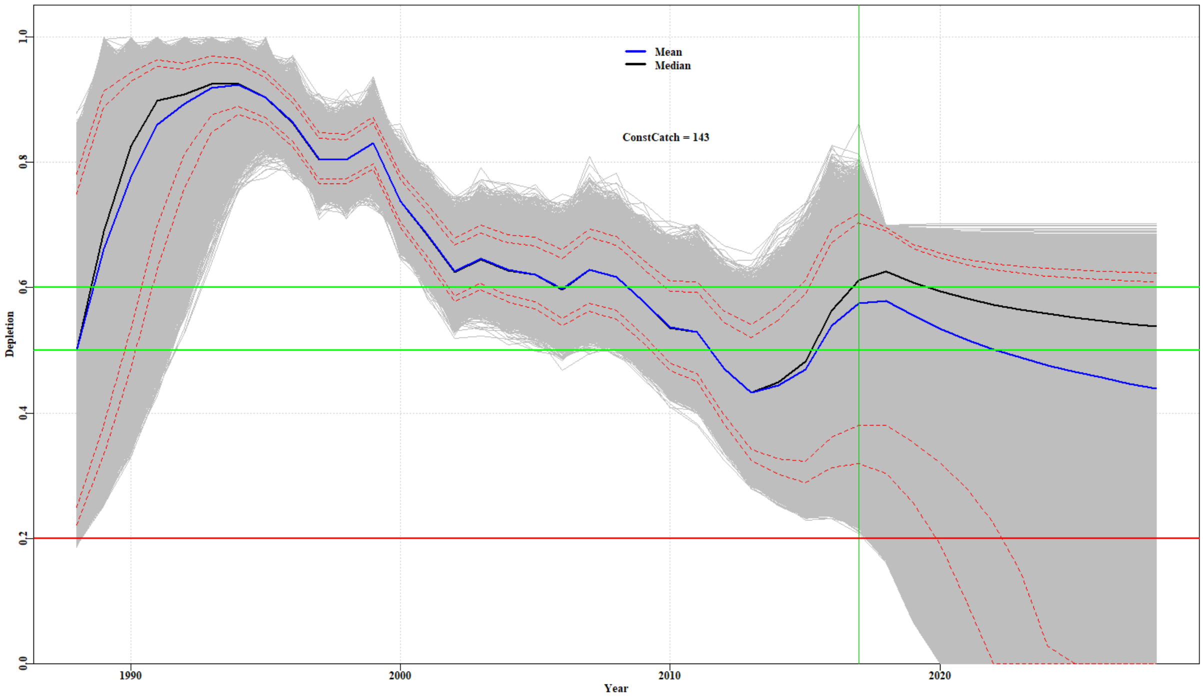

Figure 9 : Mud crab biomass trajectories for the Gulf of Carpentaria with a catch limit of 143 t. The trajectories show the biomass (depletion) ratio levels. The blue line represents the mean of the trajectories, the black line represents the median. The red dashed lines represent the 80th and 90th percentile bounds. The two green lines represent 50 per cent biomass ratios (where MSY is obtained) and 60 per cent biomass ratios. The red line represents the 20 per cent biomass limit reference level. Note year is financial year – for example 2015 represents the 2015/16 financial year.

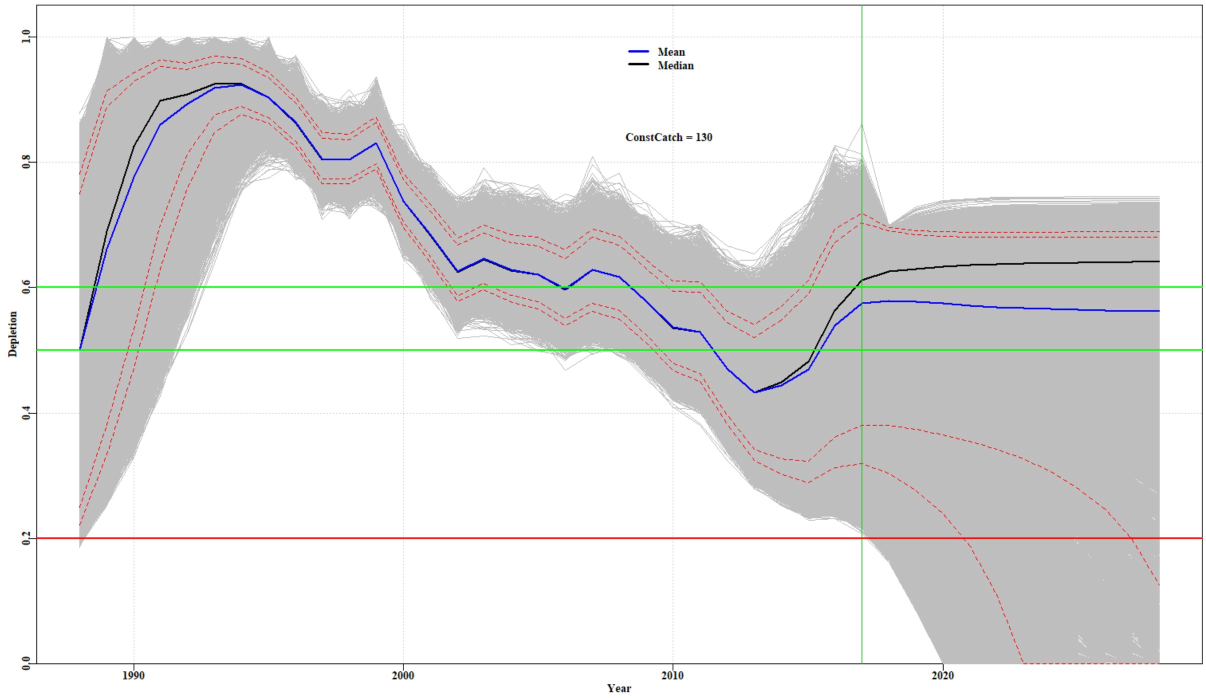

Figure 10 : Mud crab biomass trajectories for the Gulf of Carpentaria with a catch limit of 130 t. The trajectories show the biomass (depletion) ratio levels. The blue line represents the mean of the trajectories, the black line represents the median. The red dashed lines represent the 80^th and 90^th percentile bounds. The two green lines represent 50 per cent biomass ratios (where MSY is obtained) and 60 per cent biomass ratios. The red line represents the 20 per cent biomass limit reference level. Note year is financial year – for example 2015 represents the 2015/16 financial year.

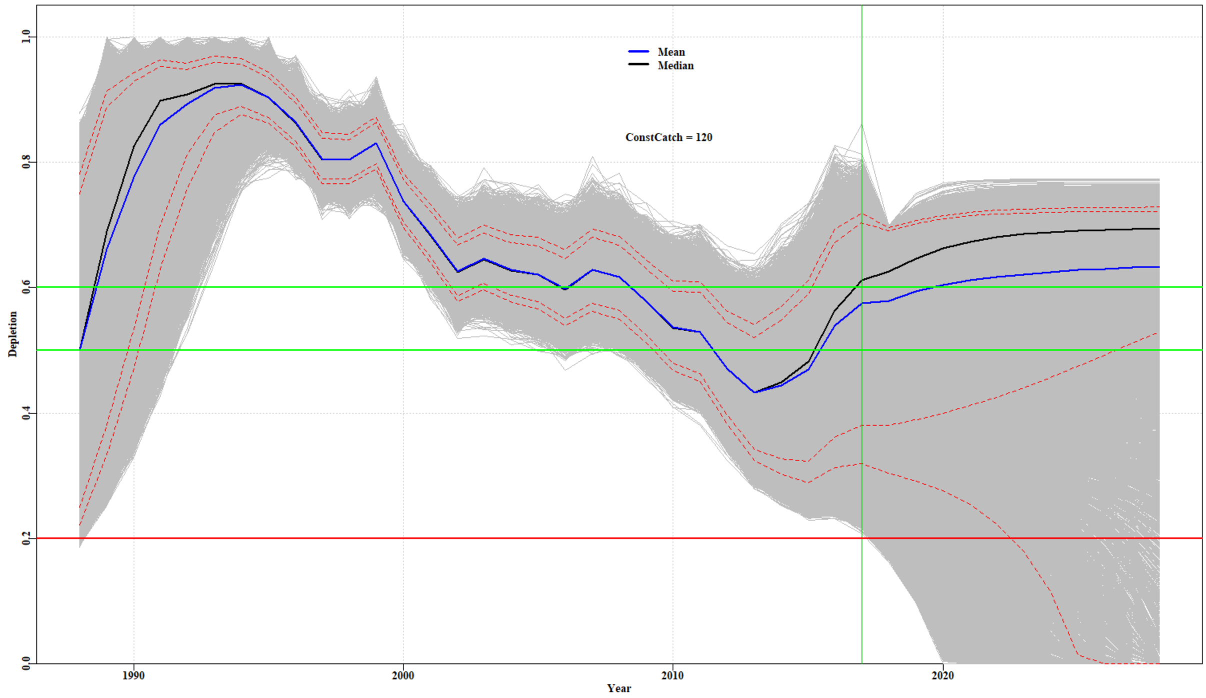

Figure 11: Mud crab biomass trajectories for the Gulf of Carpentaria with a catch limit of 120 t. The trajectories show the biomass (depletion) ratio levels. The blue line represents the mean of the trajectories, the black line represents the median. The red dashed lines represent the 80th and 90th percentile bounds. The two green lines represent 50 per cent biomass ratios (where MSY is obtained) and 60 per cent biomass ratios. The red line represents the 20 per cent biomass limit reference level. Note year is financial year – for example 2015 represents the 2015/16 financial year.

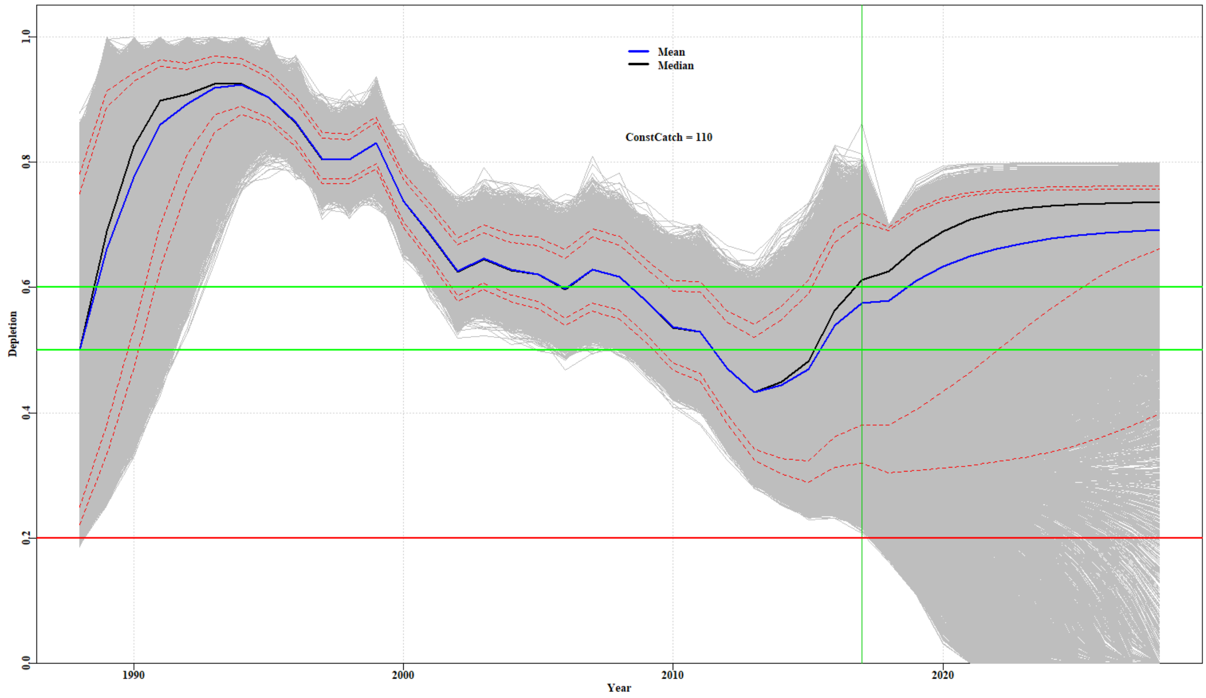

Figure 12 : Mud crab biomass trajectories for the Gulf of Carpentaria with a catch limit of 110 t. The trajectories show the biomass (depletion) ratio levels. The blue line represents the mean of the trajectories, the black line represents the median. The red dashed lines represent the 80th and 90th percentile bounds. The two green lines represent 50 per cent biomass ratios (where MSY is obtained) and 60 per cent biomass ratios. The red line represents the 20 per cent biomass limit reference level. Note year is financial year – for example 2015 represents the 2015/16 financial year.

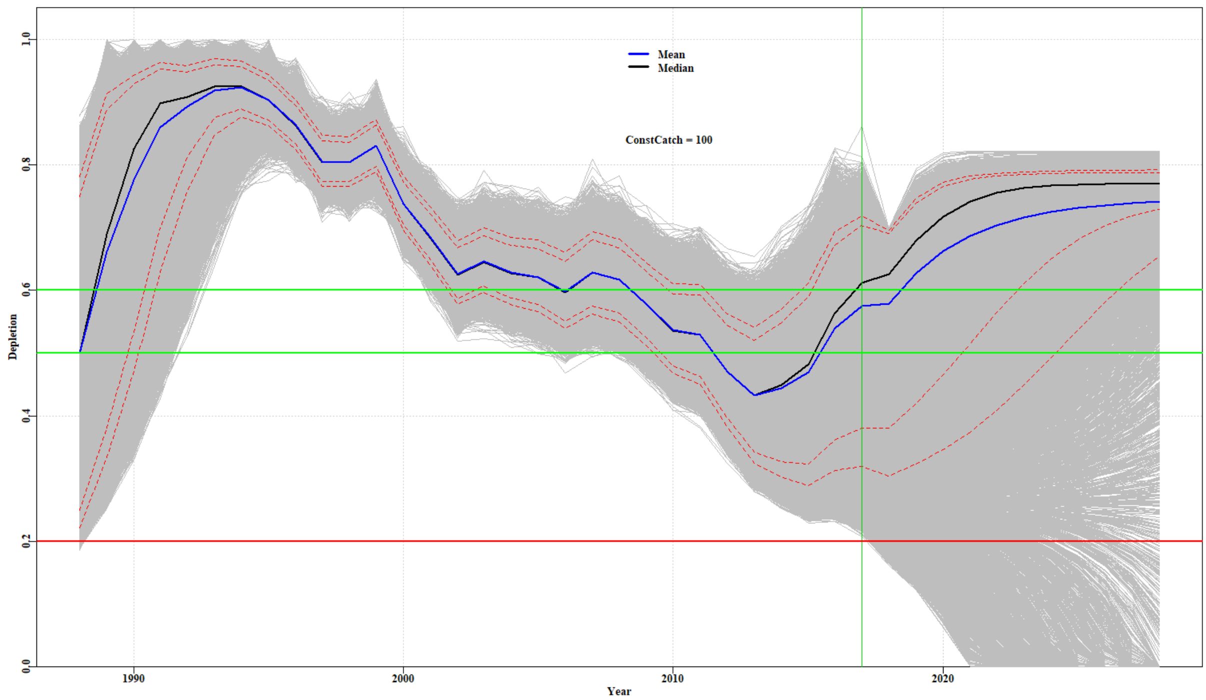

Figure 13 Mud crab biomass trajectories for the Gulf of Carpentaria with a catch limit of 100 t. The trajectories show the biomass (depletion) ratio levels. The blue line represents the mean of the trajectories, the black line represents the median. The red dashed lines represent the 80th and 90th percentile bounds. The two green lines represent 50 per cent biomass ratios (where MSY is obtained) and 60 per cent biomass ratios. The red line represents the 20 per cent biomass limit reference level. Note year is financial year – for example 2015 represents the 2015/16 financial year.

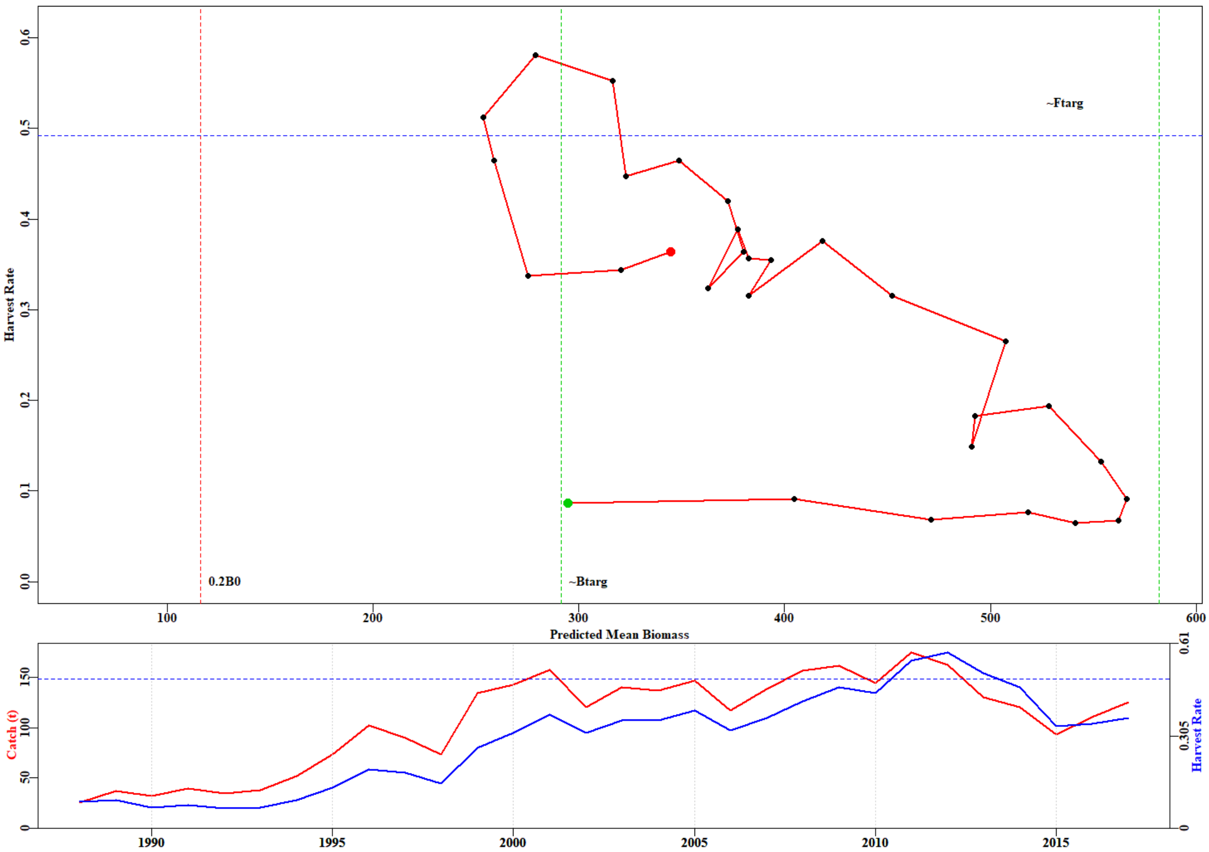

Figure 14: A phase plot of the mean predicted biomass and harvest rates for Gulf of Carpentaria mud crab from 1988/89 green point) to 2016/17 (red point) catch year. The axes for the bottom plot are identified through the colour of the axis titles.

Appendix C: Analysis of east coast mud crab assuming 15 per cent over-reporting.

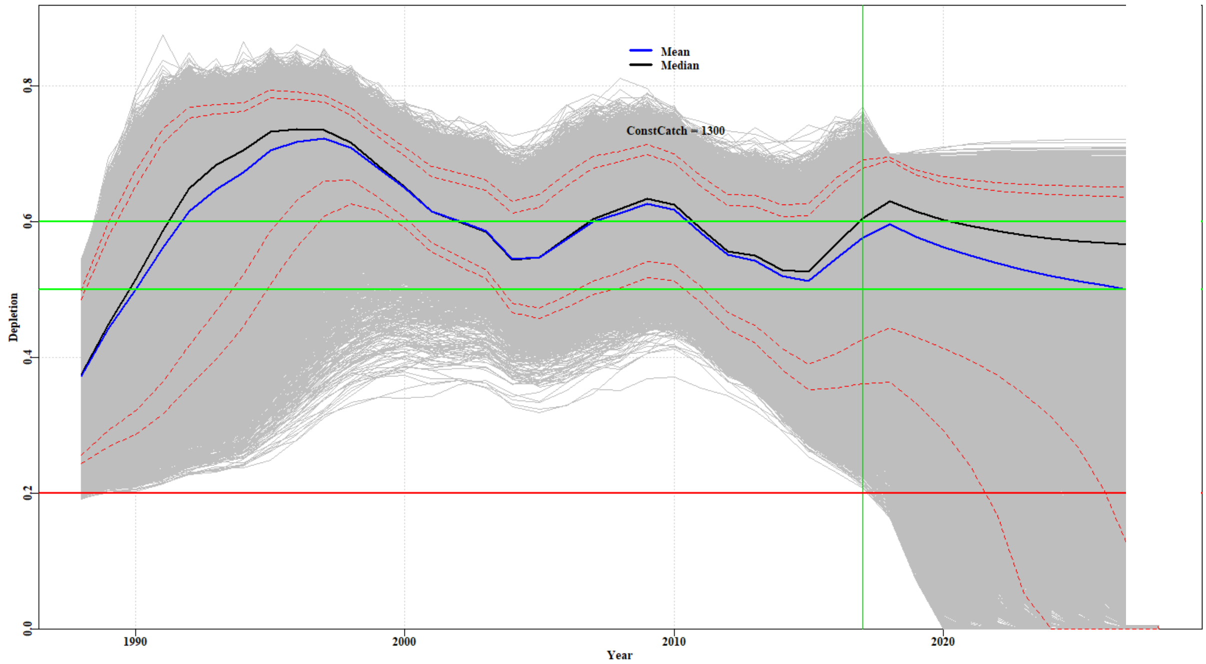

Figure 15: Mud crab biomass trajectories for a 15 per cent over-reporting assumption for the east coast with a catch limit of 1300 t. The trajectories show the biomass (depletion) ratio levels. The blue line represents the mean of the trajectories, the black line represents the median. The red dashed lines represent the 80th and 90th percentile bounds. The two green lines represent 50 per cent biomass ratios (where MSY is obtained) and 60 per cent biomass ratios. The red line represents the 20 per cent biomass limit reference level. Note year is financial year – for example 2015 represents the 2015/16 financial year.

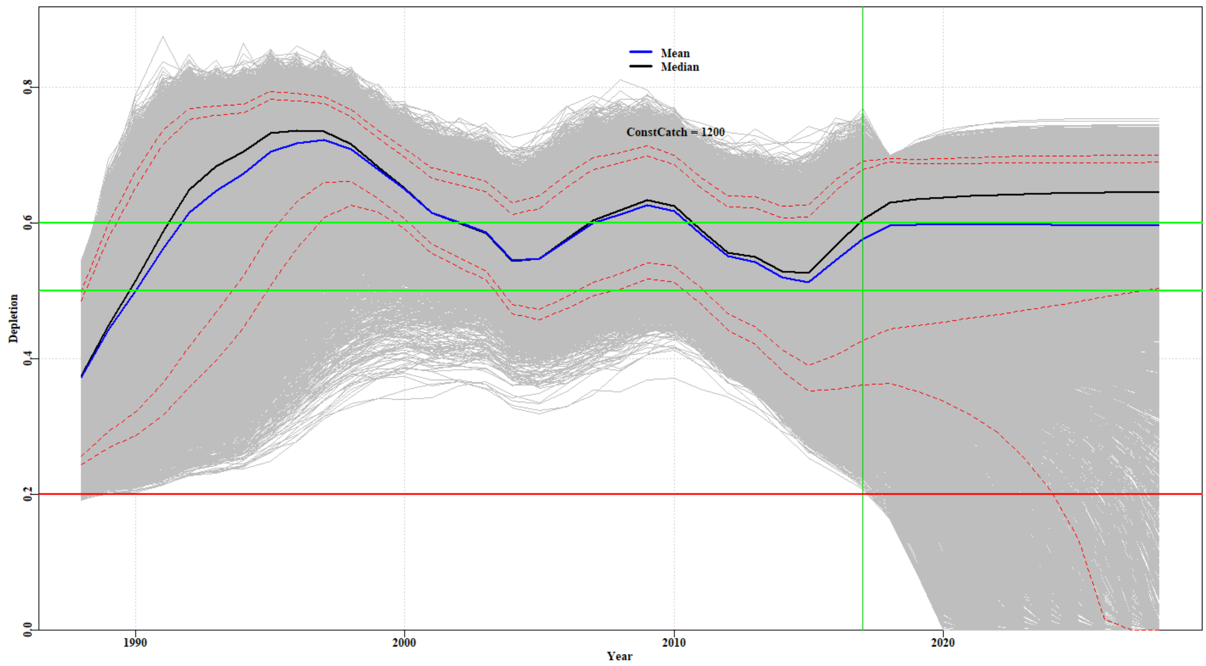

Figure 16: Mud crab biomass trajectories for a 15 per cent over-reporting assumption for the east coast with a catch limit of 1200 t. The trajectories show the biomass (depletion) ratio levels. The blue line represents the mean of the trajectories, the black line represents the median. The red dashed lines represent the 80th and 90th percentile bounds. The two green lines represent 50 per cent biomass ratios (where MSY is obtained) and 60 per cent biomass ratios. The red line represents the 20 per cent biomass limit reference level. Note year is financial year – for example 2015 represents the 2015/16 financial year.

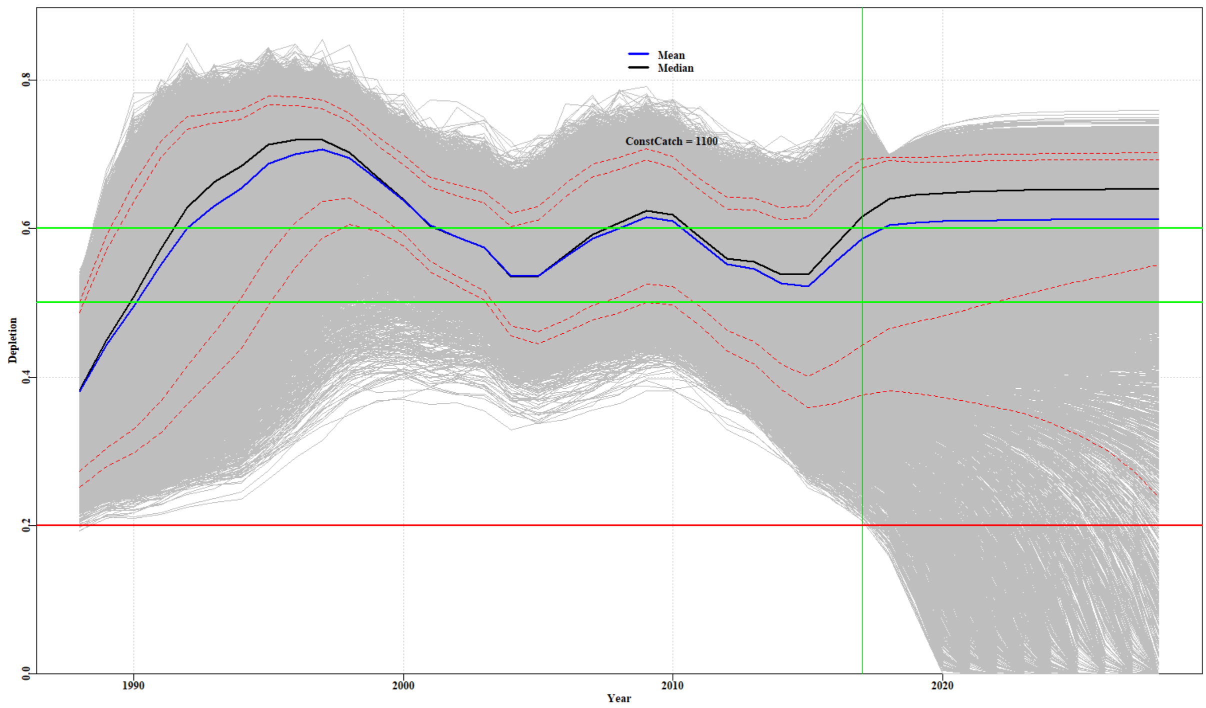

Figure 17: Mud crab biomass trajectories for a 15 per cent over-reporting assumption for the east coast with a catch limit of 1100 t. The trajectories show the biomass (depletion) ratio levels. The blue line represents the mean of the trajectories, the black line represents the median. The red dashed lines represent the 80th and 90th percentile bounds. The two green lines represent 50 per cent biomass ratios (where MSY is obtained) and 60 per cent biomass ratios. The red line represents the 20 per cent biomass limit reference level. Note year is financial year – for example 2015 represents the 2015/16 financial year.

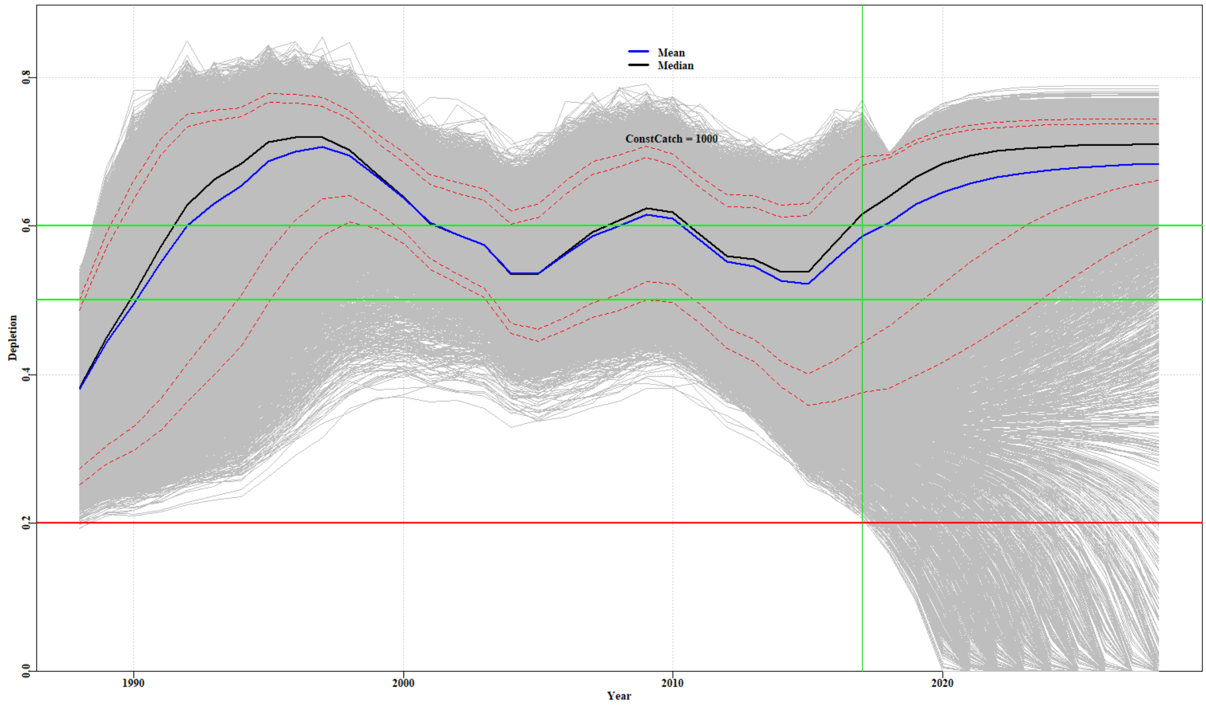

Figure 18: Mud crab biomass trajectories for a 15 per cent over-reporting assumption for the east coast with a catch limit of 1000 t. The trajectories show the biomass (depletion) ratio levels. The blue line represents the mean of the trajectories, the black line represents the median. The red dashed lines represent the 80^th^ and 90^th^ percentile bounds. The two green lines represent 50 per cent biomass ratios (where MSY is obtained) and 60 per cent biomass ratios. The red line represents the 20 per cent biomass limit reference level. Note year is financial year – for example 2015 represents the 2015/16 financial year.

Appendix D: Analysis of Gulf of Carpentaria (Queensland) assuming 15 per cent over-reporting

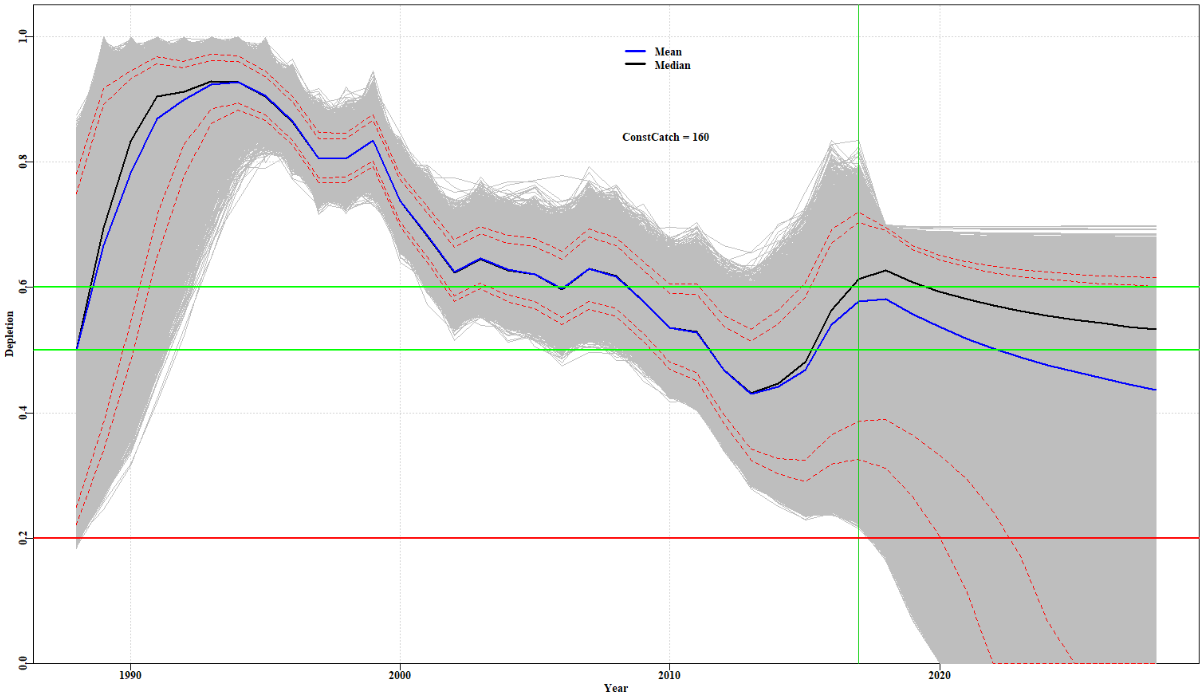

Figure 19: Mud crab biomass trajectories for a 15 per cent over-reporting assumption for the Gulf of Carpentaria with a catch limit of 160 t. The trajectories show the biomass (depletion) ratio levels. The blue line represents the mean of the trajectories, the black line represents the median. The red dashed lines represent the 80th and 90th percentile bounds. The two green lines represent 50 per cent biomass ratios (where MSY is obtained) and 60 per cent biomass ratios. The red line represents the 20 per cent biomass limit reference level. Note year is financial year – for example 2015 represents the 2015/16 financial year.

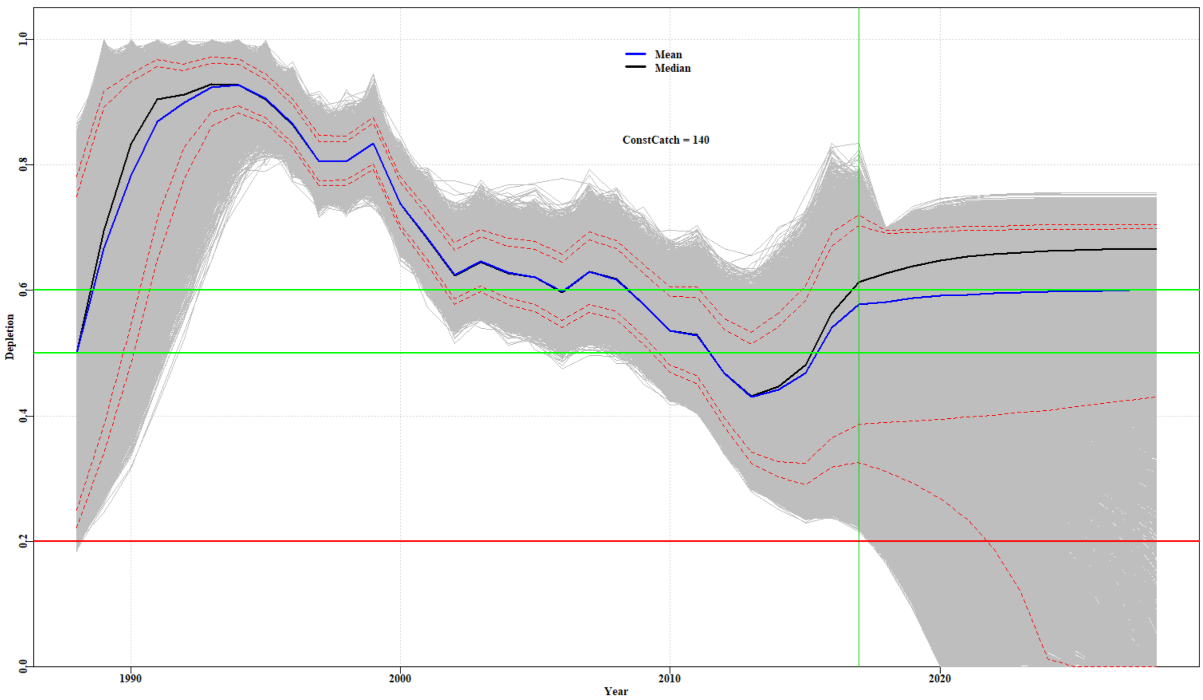

Figure 20: Mud crab biomass trajectories for a 15 per cent over-reporting assumption for the Gulf of Carpentaria with a catch limit of 140 t. The trajectories show the biomass (depletion) ratio levels. The blue line represents the mean of the trajectories, the black line represents the median. The red dashed lines represent the 80th and 90th percentile bounds. The two green lines represent 50 per cent biomass ratios (where MSY is obtained) and 60 per cent biomass ratios. The red line represents the 20 per cent biomass limit reference level. Note year is financial year – for example 2015 represents the 2015/16 financial year.

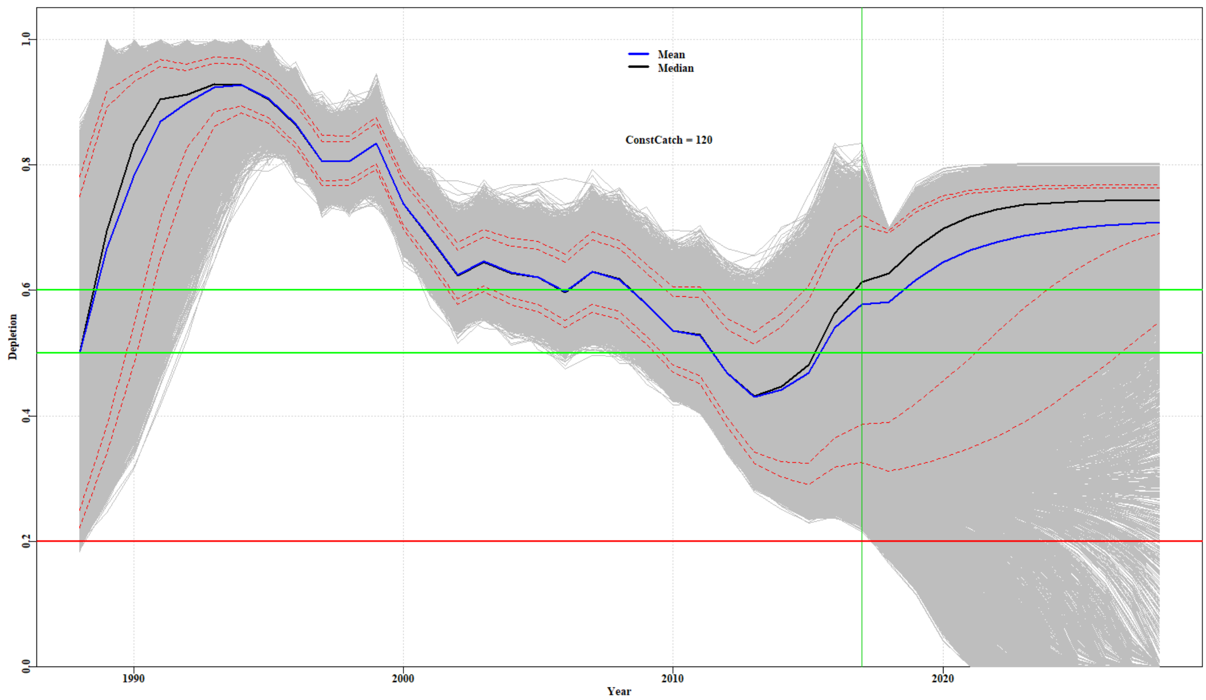

Figure 21: Mud crab biomass trajectories for a 15 per cent over-reporting assumption for the Gulf of Carpentaria with a catch limit of 120 t. The trajectories show the biomass (depletion) ratio levels. The blue line represents the mean of the trajectories, the black line represents the median. The red dashed lines represent the 80th and 90th percentile bounds. The two green lines represent 50 per cent biomass ratios (where MSY is obtained) and 60 per cent biomass ratios. The red line represents the 20 per cent biomass limit reference level. Note year is financial year – for example 2015 represents the 2015/16 financial year.