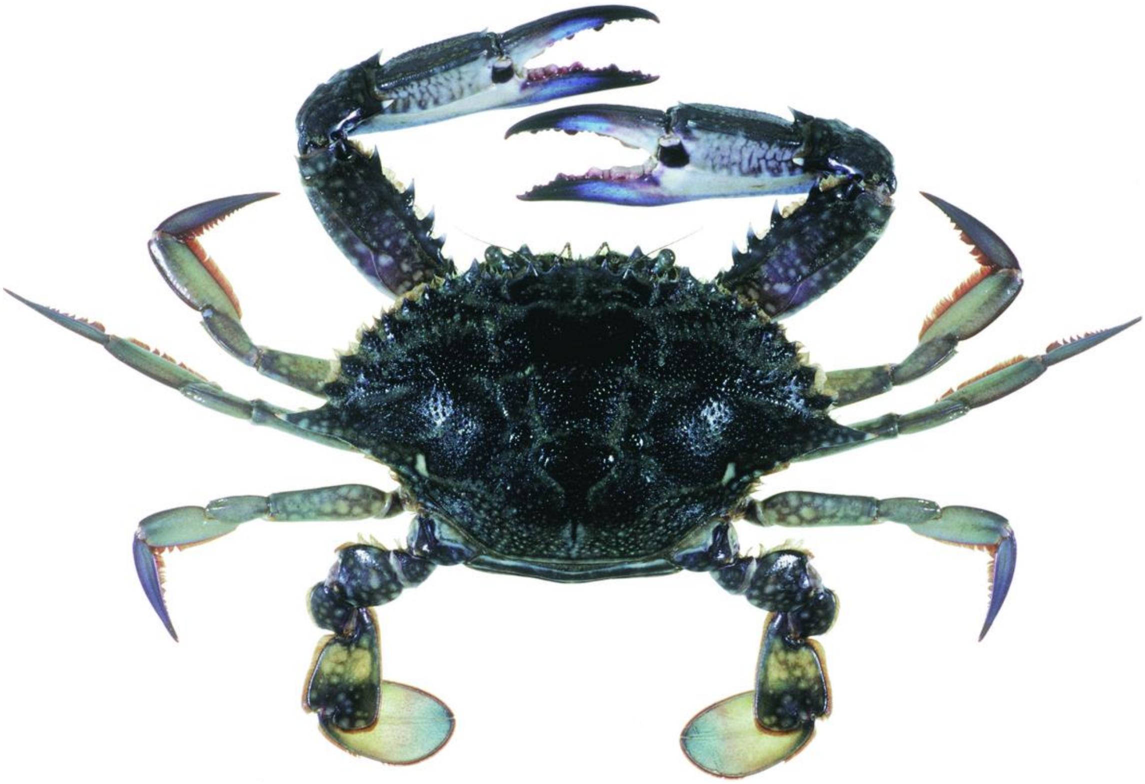

Stock assessment of Queensland east coast blue swimmer crab (*Portunus armatus*)

2020

Queensland Government

This publication has been compiled by R. Lovett, M. F. O'Neill and A. Garland., Fisheries Queensland, Department of Agriculture and Fisheries

Summary

Blue swimmer crabs are widely distributed in Australia. They are found along the western coast of Australia, across Australia's north and down the east coast to the New South Wales–Victoria border. They are also found in the warmer waters of the South Australian gulfs. They inhabit bays, estuaries and some offshore areas to depths of around 60 m (Kailola et al. 1993).

Blue swimmer crabs are mature from around 9 to 10 cm carapace width. They can live for around 3 to 4 years and can grow to a maximum size of approximately 20 cm (Sumpton et al. 2003). In Queensland, the current minimum legal size is 11.5 cm carapace width and harvest is restricted to males only.

Over the last five years, the Queensland east coast blue swimmer crab total harvest averaged around 394 tonnes (t) per year (Figure 1). During this time, average harvest shares were made up of 366 t commercial (from logbook data), and 28 t recreational (from recreational survey data). Indigenous and charter sector harvests were negligible with few data available; hence these sectors did not form part of this assessment.

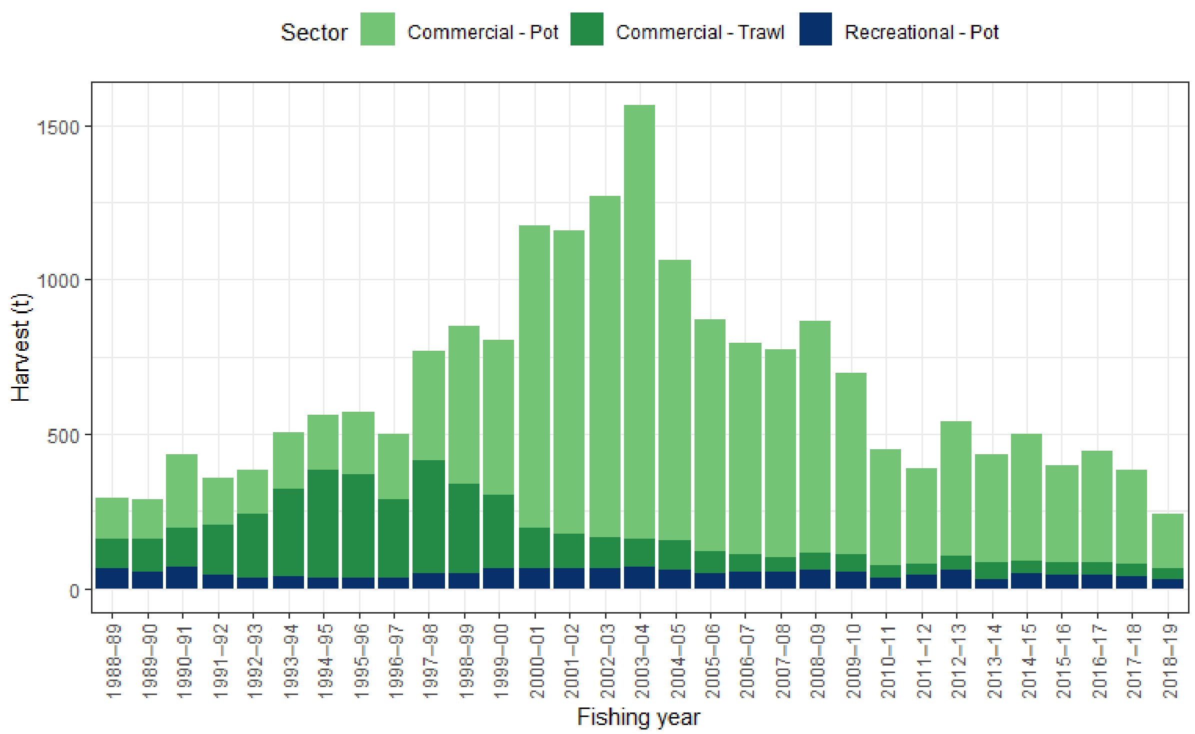

Figure 1: Blue swimmer crab harvest (retained catch) from commercial and recreational sectors for Queensland east coast from 1988–89 to 2018–19

Commercial catch rates were standardised to estimate an index of legal-sized male blue swimmer crab abundance through time (Figure 2). The blue swimmer crab catch rate (kg per 'fisher-day') was standardised to account for variation in catch associated with year, month, region, lunar phase, number of pots and combinations of these data.

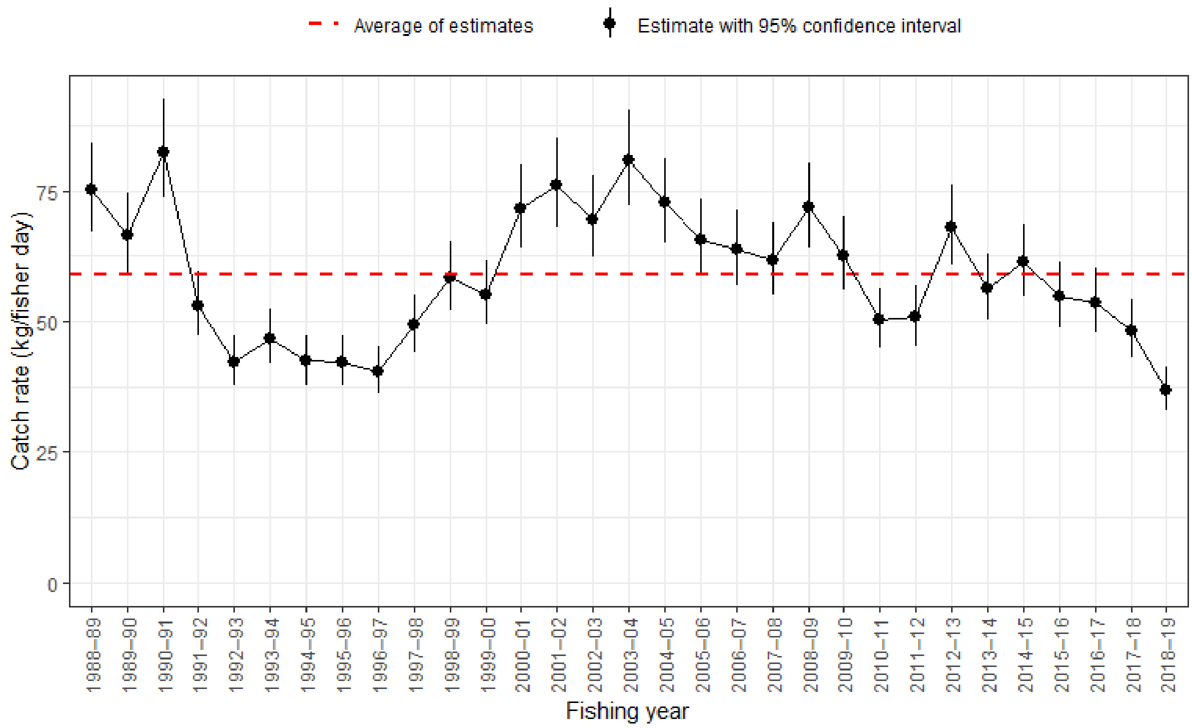

Figure 2: Annual commercial standardised catch rates for Queensland east coast blue swimmer crab fishery

A previous stock assessment for the southern component of the north eastern Australian (Queensland) biological stock was published in 2015. Results estimated exploitable (legal-sized male crab) biomass between 25 and 50 per cent of virgin unfished exploitable biomass.

This stock assessment used a length-structured model with a monthly time step. Data inputs included total harvests, standardised catch rates, and carapace width size compositions The data inputs were structured for Inshore Region (smaller crab) and Offshore Region (larger crab) size selectivity.

Model analyses suggested that exploitable biomass fell to around 33 per cent of unfished biomass in 2018–19 (Figure 3). Maximum sustainable yield (MSY) was estimated at 631–843 t per year and the yield consistent with maintaining a biomass ratio of 60 per cent was estimated at 415–557 t.

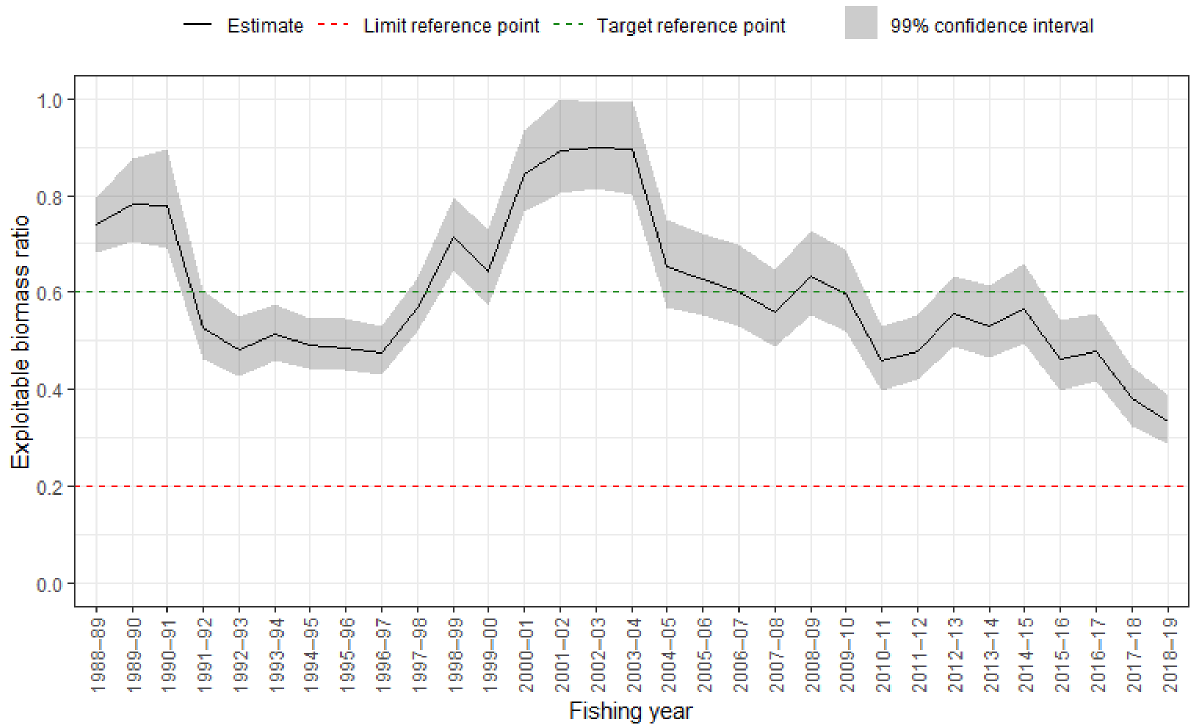

Figure 3: Annual exploitable biomass relative to virgin biomass for Queensland east coast blue swimmer crab

This report informs estimates of sustainable harvests to ensure the fishery operates at sustainable levels, for commercial and recreational fishing, and support the harvest strategy defined in Queensland's Sustainable Fisheries Strategy 2017–2027 (Department of Agriculture and Fisheries 2017). Results presented in this report reflect the quality and quantity of data available.

Recommended biological harvests were estimated for fishery management and harvest strategy goals and endpoints (Table 1). Estimates were based on the 2018–19 exploitable biomass. The blue swimmer crab harvest control rule recommends an initial harvest limit of 129 t to begin rebuilding the stock to levels consistent with 60% of unfished biomass.

Table 1: Description of current and target harvest indicators

Indicator	Estimate
Current exploitable biomass (relative to unfished) 2018–2019	33%
MSY exploitable biomass/unfished biomass (relative to unfished)	23%
Current harvest in 2018–19	240 t
Average 5 year harvest (2014–15 to 2018–19)	394 t
Harvest at MSY	722 t
Harvest at 60 per cent exploitable biomass	476 t
Initial harvest to build to 60 per cent biomass	129 t

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Acknowledgements

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In addition to the role of the project team, we would like to thank Carlie Heaven for the extraction and supply of the Queensland commercial harvest data, Daniella Teixeira and Jennifer Larkin for the supply and extraction of recreational data and Fishery Monitoring for the supply of biological size and abundance data.

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We would finally like to thank Eddie Jebreen and the project team for reviewing and providing comments on parts of the draft report.

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Glossary

Term	Definition
CI	confidence interval
Fishing year	1 July to 30 June
GLM	generalised linear model
Inshore Region	encompasses the entire Queensland east coast excluding the Offshore Region
LTMP	Long Term Monitoring Program
MLS	minimum legal size
MSY	maximum sustainable yield
notch-to-notch	Current method of measuring crab carapace width and in the document, carapace width is assumed to be notch-to-notch unless otherwise stated. Measurements are the distance between a point immediately forward of the base of the large lateral spine of the crab on one side of the crab and a point immediately forward of the base of the large lateral spine of the crab on the other side of the crab.
NRIFS	the National Recreational and Indigenous Fishing Survey conducted by the Australian Department of Agriculture, Fisheries and Forestry
Offshore Region	region defined by the previous stock assessment (Sumpton et al. 2015) and refers to the waters off the Sunshine Coast (see Appendix A)
RBH	recommended biological harvest
RFISH	recreational fishing surveys conducted by Fisheries Queensland
SRFS	recreational fishing survey conducted using NRIFS methodology by Fisheries Queensland
SFS	Sustainable Fisheries Strategy
tip-to-tip	Method of measuring crab carapace width prior to 13 Dec 2003. Measurements are across the greatest dimension of the carapace, but in cases where the carapace is missing or damaged shall be measured on the underside of the body on the one side, from the notch at the base of the junction of the claw (first pereiopod) with the body, to the notch at the base of the junction of the last walking leg (fourth pereiopod) with the body.

1 Introduction

Blue swimmer crabs are distributed in Australia from the south coast of Western Australia, north to the Northern Territory, across Queensland and down the east coast to the New South Wales–Victoria border. They are also found in the warmer waters of the South Australian gulfs (Kailola et al. 1993). They inhabit bays, estuaries and some offshore areas to depths of around 60 m.

There is extensive literature describing blue swimmer crab biology in temperate Australia (Meagher 1971; Penn 1977; Smith 1982; Potter et al. 1983). In Queensland, the earliest research into the fishery was conducted by Thomson (1951) who focused primarily on the commercial harvest. In the 1980s, further research was conducted which included information on the biology of blue swimmer crabs in Moreton Bay, Hervey Bay and waters off the Sunshine Coast (Potter et al. 1986, 1991; Weng 1992; Sumpton 1994; Sumpton et al. 1994a, 2003).

Tagging studies of blue swimmer crabs do not indicate any clear migration. However, tagging studies undertaken in Moreton Bay suggest a tendency for crabs to move into deeper waters as they increase in size (Sumpton et al. 1994b, 2003). Most tagged crabs were recaptured within two kilometres of their release site. Male and female blue swimmer crabs varied in abundance, with large males generally more abundant in deeper water and females tending to prefer shallower water, particularly on the top of sand banks (Potter et al. 1986).

Blue swimmer crabs are mature from around 9–10 cm carapace width (Sumpton et al. 2003). Mating can occur at any time during the year when the female crab is in the early post-moult (soft shell) condition (Clarke et al. 2004). Females may bear eggs throughout the year; however, the proportion of females bearing eggs are greatest during early spring (August–October). In Moreton Bay, peaks in the proportion of egg-bearing females occurred two or three months earlier than more temperate Australian populations (Smith 1982; Potter et al. 1983). This suggests temperature is an important factor in determining the timing of the reproductive cycle (Clarke et al. 2004).

Female crabs can produce a number of batches of eggs in one season, which can all be fertilised from the one mating. Juveniles settle out in shallow inshore areas at around 1.5 cm tip-to-tip carapace width. Blue swimmer crabs can live for 3–4 years and can achieve a maximum size of up to 20 cm carapace width (Sumpton et al. 2003; Clarke et al. 2004).

Blue swimmer crab has always been a culturally important species for coastal Indigenous communities and is targeted using a variety of methods. Blue swimmer crab is also currently targeted by commercial and recreational fishers using pots and are caught as a permitted by-product in commercial demersal trawls.

The commercial fishing history of blue swimmer crab in Queensland dates back to the early 1900s; however, little information about the fishery existed until records began to be kept by the Queensland Fish Board in the 1930s. The Brisbane Metropolitan Fish Market recorded an annual harvest of 32 000 crabs (just over 10 t) in 1937. Subsequent records show that by the 1960s, numbers had increased to an annual figure of over 400 000 crabs (around 140 t) (Thomson 1951; Sumpton et al. 2015).

Early fishing methods consisted of the use of long nets to tangle crabs close to the shore. In the early 1950s crab pots were also used, although these were technically an illegal apparatus at the time. Most of the catch at this time was taken from the western shores of Moreton Bay (Thomson 1951). *The Fisheries Act 1957* allowed the use of pots as a legal apparatus, however a license was required if crabs caught were to be sold. In December 1976, a 50 pot maximum was imposed (Sumpton et al. 2015).

The Queensland blue swimmer crab fishery primarily operates in southern Queensland. Before 1998, the majority of fishing was conducted inshore, in and around Moreton Bay. In 1998 commercial pot fishers began exploiting blue swimmer crab populations further offshore, in areas that were previously lightly fished. Fishing in Offshore Region (see Appendix A) waters peaked in 2003, when the Offshore Region harvest contributed approximately 70% to total harvest. A decline in trawl effort and harvest has been noted for the same period (Sumpton et al. 2015). By 2015, Offshore Region harvest had decreased and returned to levels slightly higher than those pre-expansion.

The impacts of trawl fishing on the blue swimmer crab population are unclear. A Moreton Bay study found that discards from trawlers contributed to 33% of the blue swimmer crab diet when trawling was underway (Wassenberg and Hill 1987). Hence, a reduction in trawl fishing could cause a decrease in the availability of food.

The stringing of pots (trotlining) occurred in Sunshine Coast offshore waters by some fishers producing harvesting efficiencies. This method was a rare occurrence in other regions. The effects of this method on the blue swimmer crab population are unknown due to a lack of data.

In 2018–19, there were a total of 279 licenses which commercially harvested blue swimmer crab along the Queensland east coast. Of those active licenses, 88 had a crab endorsement, and 193 had a trawl endorsement. There are currently 410 C1 symbols written on 343 authorities.

In Queensland, the current minimum legal size for blue swimmer crab is 11.5 cm carapace width. Legal take is male crabs only, and female blue swimmer crabs must be returned to the water. Table 2 outlines the management changes that have taken place in the Queensland blue swimmer crab fishery.

An assessment of the Queensland blue swimmer crab fishery was published in 2015 (Sumpton et al. 2015). This assessment was broad in scope and covered changes in fishery and population biology, parasitism and diseases, environmental influences and commercial fishery economics alongside population modelling and stock assessment. It primarily focused on blue swimmer crab in Hervey Bay, Sunshine Coast and Moreton Bay. Estimates of exploitable biomass ranged from 20% to 50% and spawning biomass ranged from 38% to 58% (Sumpton et al. 2015).

Research during the Sumpton et al. (2015) assessment concluded that key biological parameters were generally not different between Hervey Bay, Sunshine Coast and Moreton Bay, although crabs were generally significantly larger in offshore waters outside of Moreton Bay (see Appendix A). For this stock assessment, blue swimmer crab are analysed as one continuous stock along the Queensland east coast with Inshore and Offshore Region size selectivity components.

In 2019, the Queensland Department of Agriculture and Fisheries commissioned an update to the stock assessment for blue swimmer crab. This assessment aims to determine the status of the north eastern Australian (Queensland) biological stock. This report informs estimates of sustainable harvests to ensure the fishery operates at sustainable levels, for commercial and recreational fishing, and support harvest strategy defined in Queensland's Sustainable Fisheries Strategy 2017–2027 (Department of Agriculture and Fisheries 2017).

Table 2: Management changes applied to blue swimmer crab fishery in Queensland waters

Year	Fisheries Management and Legislation
1976	Minimum legal size 15 cm carapace width (tip-to-tip) and 5 cm body width. No take of females. Measurements are across the greatest dimension of the carapace, but in cases where the carapace is missing or damaged shall be measured on the underside of the body on the one side, from the notch at the base of the junction of the claw (first pereiopod) with the body, to the notch at the base of the junction of the last walking leg (fourth pereiopod) with the body. (*Fisheries Act 1976, No 80*)
1983	Issue of new non-trawl licenses ceased.
1984	Minimum legal size 15 cm carapace width (tip-to-tip), introduced a 3.7 cm body width. No take of females. (*Fishing Industry Organisation and Marketing Act and Another Act Amendment Act 1984, No 29*).
1984	Primary/tender boat license system introduced.
1988 (1 Jan)	Compulsory commercial logbook reporting began.
1995	Crabs may only be taken by using crab pots, collapsible traps, dillies or inverted dillies. Recreational: Not more than 4 crab pots, collapsible traps, dillies or inverted dillies alone or in a combination may be used at a time. Commercial: Not more than 50 crab pots, collapsible traps, dillies or inverted dillies alone or in a combination may be used at a time. (*Fisheries Act 1994; Fisheries Regulation 1995, Subordinate Legislation 1995, No 325*).
1999 (13 Jul)	Trawl license in possession limit of 100 for Moreton Bay or adjoining waters and 600 elsewhere. (*Fisheries Act 1994; Fisheries Regulation 1995, SL No 58 of 1999*).
2002 (1 Jan)	Trawl in possession limits for blue swimmer crabs reduced to 30 in Moreton Bay and 500 elsewhere (Sumpton et al. 2015).
2002 (12 Sep)	Investment warning.
2003 (13 Dec)	Minimum legal size change to 11.5 cm (notch-to-notch carapace width). Measurements are the distance between a point immediately forward of the base of the large lateral spine of the crab on one side of the crab and a point immediately forward of the base of the large lateral spine of the crab on the other side of the crab. (*Fisheries Act 1994; Fisheries Regulation 1995, SL No 214 of 2003*).
2008	Removal of latent effort in the line, crab, eel and beam trawl fisheries.
2008 (13 Jun)	Trawl license in possession limit of 100 for Moreton Bay or adjoining waters and 500 elsewhere. (*Fisheries Regulation 2008 1A*).
2010 (2 Apr)	Inverted dillies prohibited. (*Fisheries Regulation 2008 2I*).
2012	Entitlement to use an additional 50 to 100 pots under permit (Sumpton et al. 2015).
2014 (6 Mar)	Investment warning.
2014 (23 May)	Crabs may only be taken by using crab pots or dillies (crab apparatus). Recreational: Must not possess or use more than 4 crab apparatus at a time. Commercial: Must not possess or use more than 50 crab apparatus at a time. However, for fishers with a license that has C1 written on it more than once: Not more than 100 crab apparatus in possession or use at any one time. (*Fisheries Regulation 2008*)
2019 (1 Sep)	Recreational in-possession bag limit of 20 blue swimmer crabs per person (*Fisheries Declaration 2019*).

2 Methods

2.1 Data sources

Data sources included in this assessment (Table 3, Figure 4) were used to determine catch rates, create total annual harvests (combining commercial and recreational harvests) and size compositions. Data were used according to their quality, quantity and temporal-spatial resolution. Preparation of data was compiled monthly and in fishing (or financial) years to align with abundance and reproduction peaks.

Table 3: Data sources compiled for input into the population model

Data	Years	Source
Commercial	1988–2019	CFISH - Logbook data collected by Fisheries Queensland
Recreational	1997, 1999, 2002, 2005	RFISH - Surveys conducted by Fisheries Queensland (Higgs 1999, 2001; Higgs et al. 2007; McInnes 2008)
Recreational	2000–01	NRIFS - National survey using a different methodology (Henry and Lyle 2003).
Recreational	2010–11, 2013–14	SRFS - NRIFS methodology adopted by Fisheries Queensland (Taylor et al. 2012; Webley et al. 2015).
Fishery-dependent survey	1998–2001, 2013, 2014	Agri-Science Queensland
Fishery-independent beam trawl survey	2007–2015, 2017, 2018	Fishery Monitoring, Fisheries Queensland

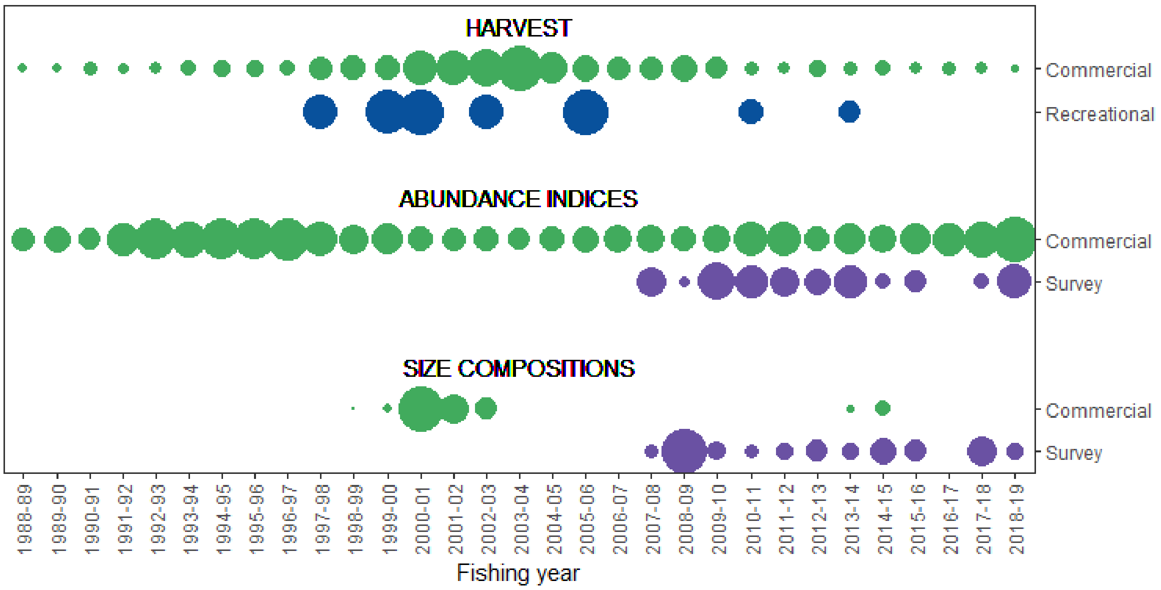

Figure 4: Data sources compiled for input into the population model. Circle sizes are proportional to total harvest for harvests; to precision for indices and to total sample size for size compositions

2.1.1 Commercial

Commercial harvest data were sourced from the Queensland Fisheries compulsory logbook records, which began in 1988. These data contained daily entries where fishers recorded their harvest of blue swimmer crab in numbers and/or kilograms, the geographic location of each harvest and the fishing method used (pot or trawl).

2.1.2 Recreational

All recreational surveys provided estimates of the number of blue swimmer crabs harvested and discarded per trip and combined this with demographic information to estimate annual totals at national, state and regional scales.

2.1.3 Indigenous

The National Recreational and Indigenous Fishing Survey in 2000 collected Indigenous fishing information on a national level by involving Indigenous communities in the gathering of fisheries statistics. Estimates of total harvest and discard for Indigenous communities followed similar procedures to those in the recreational component of the survey (Henry and Lyle 2003). Due to negligible harvests and only one year of data, Indigenous fishing data was not used as an input for this assessment.

2.1.4 Charter

Charter harvest data were sourced from the Queensland Fisheries records which began in 1988. These data contained daily entries in which fishers recorded their harvest of blue swimmer crabs in kilograms, the geographic location of each catch, and the catch method used. Very few reports were logged, and reported crab harvests were negligible. Hence, no charter data were assessed.

2.1.5 Historical

A potential source of historical commercial harvest data was the Queensland Fish Board annual catch data. These data were not used as an input to the assessment due to limited catch reporting (Sumpton et al. 2015).

2.1.6 Fishery-dependent survey

Blue swimmer crabs were sampled opportunistically from commercial pot harvest in northern and southern Moreton Bay, Hervey Bay and the Sunshine Coast waters during 1997–2001 and 2013–2014 (Sumpton et al. 2015). Methods have been described in previous reports and publications (Sumpton et al. 2003).

Sex and carapace width information consisted of tip-to-tip size compositions in 0.5 cm bins and are presented in Appendix D.1.

2.1.7 Fishery-independent beam trawl survey

Fisheries Queensland conducts a fishery-independent beam trawl survey in southern Queensland to determine the abundance of pre-recruits of eastern king prawn (*Melicertus plebejus*), snapper (*Chrysophrys auratus*) and blue swimmer crab (Fisheries Queensland 2016a, 2016b, 2019). This survey is used to inform stock assessment and management about recruitment variability of each of these species. The survey runs in November and December each year and has been conducted 13 times since 2006. Survey sites are located in key pre-recruit eastern king prawn, snapper and blue swimmer crab habitats between 24°30’S and 28°S (Bessell-Browne et al. 2020).

Carapace width size compositions of pre-recruit blue swimmer crabs obtained from the Fisheries Queensland fishery-independent beam trawl survey are presented in Appendix D.2. Blue swimmer crabs encountered during the survey were measured individually from notch-to-notch to the nearest 0.1 cm.

2.1.8 Boat ramp survey

Recreational boat ramp survey data provides numbers of blue swimmer crab harvested from 2016 to 2018. These data are not representative of recreational harvest but could be used to create an index of abundance for the recreational sector. Due to the limited span of fishing years currently available, an index was not calculated or used for this assessment but should be considered for the next assessment.

2.2 Harvest estimates

Commercial and recreational harvest data were combined to create a monthly time series of harvest used for input to the population model. While sufficient records for commercial harvests were available for the monthly time series, recreational data required some estimation to create a monthly time series of harvest.

Recreational surveys have an unspecified crab component for harvested crabs which have not been identified to species. A proportion of unspecified crab harvest has been added to the total recreational harvest for blue swimmer crab. This proportion was determined using the ratio of blue swimmer crab to all known crab species in the respective survey.

Surveys conducted in 2000–01, 2010–11 and 2013–14 had more effective follow-up contact procedures with diarists resulting in less dropout of participants compared to the other survey years using RFISH methodology (Lawson 2015). As such, there may be unknown biases in data from the RFISH surveys (Lawson 2015). Therefore, for surveys conducted in 1997, 1999, 2002 and 2005 using RFISH methodologies, estimates were adjusted using a ratio method (Leigh et al. 2017). These adjustments made the estimates of fish catches more comparable between surveys.

The annual recreational harvest of blue swimmer crab was then extrapolated by using the commercial catch rate and known recreational harvest points to encompass a broader range of years (1988–89 to 2018–19). The methodology for this extrapolation uses the relationship between effort (E), harvest (H) and catch rate (C)

$$E = H/C, \tag{1}$$

and followed the following steps:

1. For each known recreational harvest data point, calculate recreational effort from the commercial catch rate

$$E_y^{\text{Recreational}} = H_y^{\text{Recreational}} / C_y^{\text{Commercial}}$$

where $y \in [1997\text{–}98, 1999\text{–}00, 2000\text{–}01, 2002\text{–}03, 2005\text{–}06, 2010\text{–}11, 2013\text{–}14]$ (from the RFISH and adjusted NRIFS and SRFS as discussed above).

2. Calculate the average recreational effort

$$\overline{E}^{\text{Recreational}} = \frac{\sum_y E_y^{\text{Recreational}}}{n},$$

where n is the number of years y.

3. Using the average recreational effort and the commercial catch rate, calculate each recreational harvest data point that is missing

$$H_t^{\text{Recreational}} = C_t^{\text{Commercial}} \times \overline{E}^{\text{Recreational}},$$

where $t \in [1988\text{–}89{:}\,2018\text{–}19]$ and $t \neq y$.

The resulting interpolation assumed annual recreational catch rates to be the same as commercial catch rates, and average effort was constant.

This estimated annual recreational harvest was then divided into a monthly format by adopting the monthly pattern for each year in the monthly commercial pot caught harvest.

The population model had an Inshore Region component and an Offshore Region component. These components aligned with those used in the previous stock assessment, where Sunshine Coast was considered an Offshore Region (Appendix A). Recreational harvests were considered to be an Inshore Region activity and as such were added to the commercial Inshore Region harvest to provide a total Inshore Region harvest for Queensland east coast blue swimmer crab.

2.3 Abundance indices

2.3.1 Commercial catch rates

Monthly and annual catch rates were standardised for pot caught Queensland east coast blue swimmer crab using data based on commercial daily fishing records.

Observer-based fieldwork in the southern Queensland pot fishery, revealed that due to a legislative restriction of 50 pots, fishers were using more pots than reported in logbooks (Sumpton et al. 2003, 2015).

In order to address this overpotting-effort issue, it was necessary to develop an offset for the number of pots used by fishers operating in each region in each year. Fishery-dependent survey observations and pot data from commercial logbooks were analysed using a generalised linear model (GLM) and used to develop an appropriate offset for increased pot numbers, as described by Sumpton et al. (2015).

It is also considered that the use of trotlines in Offshore Region waters has had an effect on effort. Due to lack of information, this increase in efficiency has not been taken into account.

Data for the catch rate analysis used single catch observation for each fisher-day combination, with processing including:

- records for the same fisher fishing on the same day were combined into a single record
- when a fisher fished in multiple locations on the same day, all catch for that day was assigned to the location with the greatest individual catch
- minor numbers of records with missing data in required fields were omitted.

Seasonal patterns of blue swimmer crab harvest can alter due to preferential fishing for the higher valued mud crab at certain times of the year. To determine logbook records where blue swimmer crab was specifically targeted, mud crab data were also included in the above data processing rules. A mixture model was then performed to determine which records should be considered a ‘blue swimmer crab fishing day’ (see Appendix B). The results of this mixture model indicated that a ‘blue swimmer crab fishing day’ is when p (shown in Equation 2) is greater than 70%.

$$p = \frac{\text{blue}_{\text{wt}}}{\text{blue}_{\text{wt}} + \text{mud}_{\text{wt}} \times 2.7}. \qquad (2)$$

Additional catch rate data filtering included:

- records that were not considered to be on a ‘blue swimmer crab fishing day’ were omitted
- fishers who fished in only one year during the period of analysis were omitted

- fishers who fished for less than 30 blue swimmer crab days over their logbook history were omitted
- two sinusoidal variables were included to indicate lunar phases (lunar and lunar advanced by a quarter of a phase)
- a boat identifier term was created where fishers operating Hervey Bay were factorised separately to fishers operating in more southern waters (east and south of Fraser Island, see Figure 15).

Catch rates were standardised using a residual (or restricted) maximum likelihood (REML) model using GenStat statistical software (VSN International 2019). The methods for this procedure follow those found in O'Neill and Leigh (2006).

The daily catch for each vessel for the period 1 July 1988 to 30 June 2019 was log-transformed and analysed using a REML where interaction terms of fishing year x month, region, region x lunar and region x lunar advanced terms were added as fixed effects. Further, the boat identifier was added as a random term. The procedure for this followed similar steps outlined in Sumpton et al. (2015).

From the boat identifier term, parameters for each vessel were estimated by the REML, from which changes in fishing power of the vessels accessing the fishery were calculated as a function of fishing year and region. This allowed catch rates from each region to be standardised for the changes in fishing power. Annual fleet-vessel fishing power was calculated as described in Sumpton et al. (2015).

Resulting catch rates are presented in Section 3.1.2. In addition, catch rates were also calculated in the same manner for Hervey Bay, Moreton Bay and Sunshine Coast regions (see Appendix C) to provide consistency with catch rates presented in Sumpton et al. (2015).

2.3.2 Fishery-independent beam trawl survey

The standardised abundance index for pre-recruit blue swimmer crab generated from the fishery-independent beam trawl survey was calculated using data collected from Moreton Bay sites only (Bessell-Browne et al. 2020). Pre-recruits were considered to be all crabs less than 6.5 cm width in the month of November and all crabs less than 8.5 cm carapace width in the month of December (Bessell-Browne et al. 2020).

It should be noted that the index of abundance and corresponding size compositions are representative of the Moreton Bay portion of the Inshore Region. These data have been used as a proxy for the entire Queensland east coast Inshore Region.

2.4 Biological information

Extensive work was performed in Sumpton et al. (2015) to source biological parameters for use in population modelling. Most of these parameters have been used again for this assessment and are presented below.

Carapace width conversion:

Biological sampling used for this assessment was performed both before and after the change in minimum legal size and measurement style in December 2003. The fishery-dependent size composition data used in Sumpton et al. (2015) were measured tip-to-tip. These data were tallied in 0.5 cm bins making a conversion to notch-to-notch yield an inaccurate distribution. Blue swimmer crabs encountered during the fishery-independent beam trawl survey were measured individually from notch-to-notch to the nearest 0.1 cm. These data were able to be more accurately converted to a tip-to-tip measurement and then be placed in 0.5 cm bins. Hence, all size data used in the model conformed to the tip-to-tip measurement. This choice also enabled the use of much of the code from Sumpton et al. (2015). The following conversion equation from Sumpton et al. (2000) was used to convert notch-to-notch measurements to tip-to-tip measurements in mm:

$$\text{tip-to-tip} = (\text{notch-to-notch} + 16)/0.938. \tag{3}$$

Carapace widths for this assessment are usually referred to as size or lengths l in order to fit with standard conventions used in formulae. Hence it should be noted that the terms carapace width and length may be used interchangeably throughout this assessment.

Minimum legal size:

Minimum legal size (MLS) for blue swimmer crab is currently 11.5 cm carapace width and has been in force since December 2003. Prior to this, the MLS was 15 cm tip-to-tip carapace width using the old style of measurement. The population model takes account of MLS when calculating exploitable biomass, catch rates and survival. A binary matrix denoted $\Theta_{t,l}$ is used in the population model to determine at which length selected crabs are harvested and hence removed from the population. Note also that t in this instance represents either before or after the MLS change.

Crab weight:

The average weight w in kilograms at length l mm for sex s is given by the equation

$$w_{l,s} = a_s l^{b_s}/1000, \tag{4}$$

where $a_{\text{male}} = 0.00000855$, $b_{\text{male}} = 3.466$, $a_{\text{female}} = 0.0000931$ and $b_{\text{female}} = 2.984$ (Sumpton et al. 2015).

Spawning:

Blue swimmer crab female spawning was assumed to occur throughout the year with peak levels occurring during August–October (Sumpton et al. 2003). Spawning fractions for each month of the year (July–June) are represented by $\theta = [0.2,1,1,1,0.8,0.4,0.4,0.4,0.4,0.4,0.2,0.1]$.

Maturity:

A logistic maturity schedule by length (mm) was estimated using binomial regression and logit link, with parameters $\beta_0 = -23.57965$, $\beta_1 = 0.216872$ for female crabs and $\beta_0 = -13.51291$, $\beta_1 = 0.139929$ for male crabs (Sumpton et al. 2015).

Crab growth:

Due to the stepwise pattern of crustacean growth caused by moulting, it is difficult to assess the growth rate of crabs. Several techniques have been trialled, including modal progression analysis and tagging studies (Potter et al. 1986; Sumpton et al. 1994b). The current assessment employs a growth model used in Sumpton et al. (2015) based on techniques developed by Potter et al. (1986).

Using this technique, a growth transition matrix Ξ, allocated a proportion of crabs in carapace length-class l' at time $t-1$ to grow into a new length l over one time-month t. The transitions varied with crab sex s and month t, and assumed a gamma probability density function (Quinn and Deriso 1999; Haddon 2001). The growth model was based on the seasonal and non-seasonal estimates of crab growth. Key components of this method are shown below; however, for a full description of the method, the reader is directed to Sumpton et al. (2015), Appendix 1.

A generalised von Bertalanffy model is used where the change in length with respect to time is given by

$$l'(t) = [l_\infty - l(t)]\mathrm{z}(t) + \sigma(t)\epsilon(t), \tag{6}$$

where $\epsilon(t)$ is a zero mean error term and $\sigma(t)$ accounts for the heteroscedasticity of the error process. We fix the parameters $l_\infty = 19.5$ for females and $l_\infty = 22.5$ for males (Sumpton et al. 2015).

The annual growth rate $\mathrm{z}(t)$ was then integrated per time-month to produce a monthly growth rate $z(t)$ that models seasonality over a year. This seasonal growth rate is given by,

$$z(t) = k + \theta_1 \cos(2\pi t) + \theta_2 \sin(2\pi t), \tag{7}$$

where $\theta_1 = 0.49$, $\theta_2 = 0.4$ and $k = 0.882$ (Sumpton et al. 2015).

Recruitment:

Crab recruitment Λ_l is divided into proportions for each size class. The proportions were calculated from a lognormal distribution for length at recruitment, based on trawl monitoring data in fishing years 1984 and 1985 (Sumpton et al. 2015). The frequencies were the same for male and female crab with a 50% male/female split. Summary percentiles $[2.5,25,50,75,97.5]$ for the distribution were $[2.35,3.30,3.94,4.70,6.60]$ cm (Sumpton et al. 2015).

2.5 Population model

A population dynamic model was fitted to the data to determine the number of blue swimmer crab in each month and each carapace width group. Due to limited historic catch reporting prior to 1988, the model assumed the population was at a fished equilibrium at the start of the 1988–89 fishing year as assumed in the previous assessment (McGarvey et al. 2014; Sumpton et al. 2015). A 'fishing year' was defined as the period from 1 July to 30 June.

The fished equilibrium state was determined from each month's average harvest during the period 1988–89 to 1990–91. Model equations are given in Section 2.5.2. The model included Inshore and Offshore Region components with commercial (pot and trawl) and recreational fishing grouped together.

Initially models were attempted for the Moreton Bay and Sunshine Coast, and Hervey Bay regions separately. However, the Hervey Bay data were too limited. Hence a combined Queensland east coast model was employed to suit the needs of fishery management.

The model was coded in Matlab (MATLAB 2019) and consisted of maximum likelihood fitting for all analyses followed by Markov Chain Monte Carlo sampling (MCMC). The MCMC used parameter by parameter jumping following the Metropolis-Hastings algorithm described by Gelman et al. (2004). The MCMC was run in two stages: (1) first to estimate the parameter covariance matrix and to customise the jumping of parameter samples, then (2) simulate posterior parameter distributions with fixed covariance.

2.5.1 Model assumptions

The following assumptions were made when formulating the population model:

1. The fishery was in a fished equilibrium state prior to July 1988 with past fishing for each month of the year equivalent to that month's average harvest over the years 1988–89 to 1990–91.
2. Length refers to tip-to-tip carapace width.
3. Crab spawning was based on female crabs only and assumed to occur in varied fractions throughout the fishing year (Sumpton et al. 2003).

4. Fishing takes place in the middle of each month.
5. The weight of a crab was a parametric function of length and sex.
6. The proportion of mature crab depended on length.
7. Recruitment ratio of males to females was 50%.
8. The fishery-independent bream trawl survey index of abundance is representative of the entire Inshore Region Queensland east coast.

2.5.2 Population dynamics

The blue swimmer crab population model had a monthly time step and tracked numbers N and biomass B of crab by their sex s and length l (or carapace width), and included the processes of mortality, growth and recruitment in every month t.

The equations were:

Crab numbers:

$$N_{l,t,s} = \exp(-Z_{l,t-1,s}) \sum_{l\prime} \Xi_{l,l\prime,t-1,s} N_{l\prime,t-1,s} + 0.5 R_{l,t} \quad (8)$$

Spawning index — effective annual spawning biomass:

$$\tilde{E}_y = \sum_t \sum_l N_{l,t,1} m_{l,1} w_{l,1} \theta_t \times 10^{-3} \, , \quad (9)$$

where this index was calculated over female crabs only.

Recruitment pattern — normalised monthly proportion:

$$\phi_t = \exp[\kappa \cos(2\pi(t-\mu)/12)] / \sum_{t\prime=1}^{12} \exp[\kappa \cos(2\pi(t'-\mu)/12)], \quad (10)$$

where t indicated time-of-year months 1…12, μ and κ are estimated parameters representing the mode and concentration of the monthly recruitment pattern according to a von Mises directional distribution (Mardia and Jupp 2000)

Recruitment numbers — Beverton-Holt formulation:

$$R_{l,t} = \frac{4hR_0\tilde{E}_{y-1}}{E_0(1-h)+\tilde{E}_{y-1}(5h-1)} \phi_t \Lambda_l \exp(\eta_y) \, , \quad (11)$$

where y indicated the fishing year, Λ_l is the recruitment proportion for each length class (described in Section 2.4), $\exp(\eta_y)$ represent estimated recruitment deviations, R_0 represents virgin recruitment, and h is the Beverton-Holt steepness parameter (Beverton and Holt 1957). This steepness parameter h, is calculated from the estimated parameter ξ as follows:

$$h = r_{\text{max}}/(4 + r_{\text{max}})$$

$$r_{\text{max}} = 1 + \exp(\xi)$$

Virgin recruitment R_0 was estimated on the log scale using the parameter γ as follows:

$$R_0 = \exp(\gamma) \times 10^8 \quad (12)$$

Mid-month exploitable biomasses—forms 1 and 2:

$$B_{t,f}^1 = \sum_l N_{l,t,2} w_{l,2} v_{l,f} \Theta_{t,l} \exp(-M/2) \ \text{ and} \quad (13)$$

$$B_{t,f}^2 = B_{t,f}^1 \prod_f \sqrt{1-u_{t,f}} \, , \quad (14)$$

where f indicated the Inshore and Offshore Regions. This index was calculated over male crabs only as harvest of female crabs are prohibited. A form $B_{t,f}^3$ was also calculated for outputs only, standardised to the current MLS.

Survival:

$$\exp(-Z_{l,t,s}) = \exp(-M)\prod_f 1 - v_{l,f,s}\Theta_{t,l,s}u_{t,f,s}\ , \tag{15}$$

where commercial $u_{t,f}$ was calculated iteratively allowing for competing harvest rates on male crabs between fishing sectors.

$$u_{t,f} = \frac{C_{t,f}}{B^1_{t,f}\sqrt{1-v_{l,f'}\Theta_{t,l}u_{t,f'}}}\ , \tag{16}$$

where C was a fishing sectors monthly harvest (kgs). As harvest of female crabs are prohibited, $u_{\text{female}} = 0$.

Crab vulnerability to fishing:

$$v_{l,f,s} = \frac{1}{1+\exp(\delta(l^{50}_{f,s} - l))} \tag{17}$$

Logistic selectivity, where required, the schedule accounted for the minimum legal size of male crab. Note minimum legal size changed from 15 cm carapace width (tip-to-tip) to 11.5 cm carapace width (notch-to-notch) in December 2003. Note also that a common l^{50} was assumed for females, but was estimated differently for Inshore and Offshore Region male crab. This resulted in 3 vulnerability schedules.

Crab vulnerability to survey:

$$v_l^{\text{survey}} = \frac{\max\left[\frac{1}{d1}\left(\delta^{\text{survey}} + \frac{1-\delta^{\text{survey}}}{d2}\right), 0\right]}{\max_l\left[\frac{1}{d1}\left(\delta^{\text{survey}} + \frac{1-\delta^{\text{survey}}}{d2}\right)\right]} \tag{18}$$

$$d1 = 1 + \exp\left(-\log(19)\frac{l - l^{50}_{\text{rising}}}{l^{\text{diff}}}\right)$$

$$d2 = 1 + \exp\left(-\log(19)\frac{l - l^{50}_{\text{falling}}}{l^{\text{diff}}}\right)$$

Dome-shaped selectivity requiring four estimated parameters, where l^{50}_{rising} denotes length at 50% selection by the survey on the upward slope, l^{50}_{falling} denotes length at 50% selection by the survey on the downward slope, l^{diff} denotes the difference between the length at 50% selection by the survey and 95% selection and δ^{survey} denotes the asymptote past the dome.

Population indicators—catch rates by indicator:

$$c_t^f = q^f(t)B^2_{t,f} \tag{19}$$

$$c_t^{\text{survey}} = q_t^{\text{survey}}\sum_{s,l} N_{t,l,s}\, v_l^{\text{survey}}\Theta_{t,l}^{\text{survey}}, \tag{20}$$

where, $\Theta_{t,l}^{\text{survey}}$ is a binary choice for each length class and also limited to the months of November and December only in order to remain consistent with beam trawl survey methodology (Section 2.3.2). The Inshore Region f vulnerability schedule was used to fit to the single catch rate index.

Catchability:

$$q_f(t) = \exp(\log(q_f) + \varsigma_1\cos(t_{\text{seq}}) + \vartheta_1\sin(t_{\text{seq}}) + \varsigma_2\cos(2t_{\text{seq}}) + \vartheta_2\sin(2t_{\text{seq}})), \tag{21}$$

where, $t_{\text{seq}} = 2\pi\text{seqmonth}/12$. Fishery catchability by sector was based on a sinusoidal function to model monthly patterns using the variable 'seqmonth'. As the maximum water temperature was in February, (2 parameters seqmonth = 1 in March and = 12 in February. The equation was defined through the amplitude ς and peak timing of catchability ϑ parameters. Each sectors overall catchability

q_f was calculated as closed-form geometric mean of standardised catch rates divided by the mid-month biomass form 2 (Haddon 2001). Survey catchabilities were also calculated as a single closed-form geometric mean for the months of November and December.

Recruitment deviations

$$\eta = \zeta \mathrm{e} \tag{22}$$

ζ were the estimated parameters known as barycentric or simplex coordinates, distributed $NID(0,\sigma)$ with n = number of recruitment years – 1 (Möbius 1827; Sklyarenko 2011). These parameters ensure log deviations sum to zero with standard deviation σ, see Equation 25. The barycentric basis e was the $n \times n + 1$ coordinate basis matrix to scale the distance of residuals (vertices of the simplex) from zero (O'Neill et al. 2011, 2014). The resulting recruitment deviation vector η is of length $n + 1$. The barycentric basis e was constructed as follows;

$$\mathrm{e}_{i,j} = \begin{cases} \dfrac{-\sqrt{i/2(i+1)}/i}{\sqrt{n/2(n+1)}} & \text{for } j \leq i \\ \dfrac{\sqrt{i/2(i+1)}}{\sqrt{n/2(n+1)}} & \text{for } j = i+1 \\ 0 & \text{otherwise} \end{cases}$$

2.5.3 Matching predictions to data

Negative log-likelihood functions for calibrating population dynamics, parameter bounds and distributions are shown below (O'Neill et al. 2014).

Log standardized catch rates and recreational harvest (c):

$$\frac{n}{2}(\log(2\pi) + 2\log(\hat{\sigma}) + 1), \tag{23}$$

or simplified as $n\log(\hat{\sigma})$, where $\hat{\sigma} = \sqrt{\sum((\log(c) - \log(\hat{c}))^2)/n}$ and n was the number of months or years with catch rate or harvest data (monthly for commercial and observer catch rates; yearly for survey catch rates and recreational harvests). Equation 23 assumes a normal distribution (Haddon 2001).

Length (l) size-composition data:

$$-\sum\left(\log\left(\nu^{(\tilde{n}-1)/2}\right) - \left(\frac{1}{2}(\tilde{n}-1)\frac{\nu}{\hat{\nu}}\right)\right), \tag{24}$$

or simplified as $-\sum\frac{1}{2}(\tilde{n}-1)(\log\nu - \nu/\hat{\nu})$, where $\tilde{n}$ was the total number of size categories (l) with proportion-frequency > 0, $\hat{\nu} = (\tilde{n}-1)/2\sum\hat{p}\log(\hat{p}/p)$, $\nu = \max(2,\hat{\nu})$ specified sample size bounds, $\hat{p}$ were the observed proportions > 0 and p were predicted. Equation 24 uses an effective sample size (ν) in multinomial likelihoods (Leigh 2011; O'Neill et al. 2011).

Recruitment compensation ratio $r_{\max}$:

$$0.5\left(\frac{\xi - \log(4-1)}{\sigma}\right)^2 \times (\xi > \log(19)), \tag{25}$$

where $\sigma = 0.005$ defined the -LL penalty.

Annual log recruitment deviates η_y:

$$\frac{n}{2}(\log(2\pi) + 2\log(\sigma) + (\hat{\sigma}/\sigma)^2), \tag{26}$$

or simplified as $n\left(\log\sigma + \frac{1}{2}(\hat{\sigma}/\sigma)^2\right)$, where $\sigma = \min(\max(\hat{\sigma}, \sigma_{\min}), \sigma_{\max})$, $\sigma_{\min} = 0.1$ and $\sigma_{\max} = 0.4$ specified bounds, $\hat{\sigma} = \sqrt{\sum\eta_y^2/n}$ and n was the number of recruitment years y.

Vulnerability parameter penalty:

$$\frac{1}{2}\left(\frac{l^{50}_{\text{inshore,male}} - l^{50}_{\text{offshore,male}}}{\sigma}\right)^2 \quad \text{if} \quad l^{50}_{\text{inshore,male}} > l^{50}_{\text{offshore,male}}\,, \tag{27}$$

where $\sigma = 0.005$.

Recruitment pattern penalties:

$$\frac{1}{2}\left(\frac{\mu - 5}{\sigma}\right)^2 \quad \text{if} \quad \mu > 15 \text{ or } \mu < 0\,, \tag{28}$$

where $\sigma = 0.005$.

2.5.4 Model parameters

Parameters estimated in the model are described in Table 4 below.

Table 4: Descriptions of fixed and estimated parameters in the model

Parameter	Value	Description
$\boldsymbol{M}$	0.1	Natural monthly mortality rate allowing for 3–4 years maximum longevity (Sumpton et al. 2015).
$\boldsymbol{\xi}$	estimated	Used to determine Beverton-Holt steepness h, see Equation 11.
$\boldsymbol{\gamma}$	estimated	Used to determine R_0, see Equation 12.
$\boldsymbol{\mu}$	estimated	Mode of the monthly recruitment pattern, see Equation 10.
$\boldsymbol{\kappa}$	estimated	Concentration of the monthly recruitment pattern, see Equation 10.
$\boldsymbol{l^{50}_{f,s}}$	estimated	Length at 50% selection by fishing area. Only 3 parameters estimated. Inshore and Offshore Region for males and a shared parameter for Inshore/Offshore Region females, see Equation 17.
$\boldsymbol{\delta}$	estimated	Initial steepness of the vulnerability curve, see Equation 17.
$\boldsymbol{l^{50}_{\text{rising}}}$	estimated	Length at 50% selection by the survey on the upward slope, see Equation 18.
$\boldsymbol{l^{\text{diff}}}$	estimated	The difference between the length at 50% selection by the survey and 95% selection, see Equation 18.
$\boldsymbol{l^{50}_{\text{falling}}}$	estimated	Length at 50% selection by the survey on the downward slope, see Equation 18.
$\boldsymbol{\delta_{\text{survey}}}$	estimated	Asymptote for survey vulnerability, see Equation 18.
$\boldsymbol{\varsigma}$	estimated	Two parameters denoting catchability amplitude, see Equation 21.
$\boldsymbol{\vartheta}$	estimated	Two parameters denoting the peak timing of catchability, see Equation 21.
$\boldsymbol{\zeta}$	estimated	30 barycentric coordinates, see Equation 22.

2.5.5 Model uncertainty

Sensitivity analysis performed in the previous stock assessment showed that growth and natural mortality rates were two important factors effecting model outputs (Sumpton et al. 2015). This previous modelling illustrated the effects of changes in estimates of biomass ratios and maximum sustainable yields. Due to time constraints, there was no scope to repeat sensitivity testing in this assessment, given similar methods were employed. Instead, we focused on a core assessment based on the outcomes of sensitivity testing from Sumpton et al. (2015).

The population model found maximum likelihood estimates and then performed Markov chain Monte Carlo (MCMC) to provide random samples of possible parameter values. A total of 920 000 simulations were first run for the five annealing steps, and 4000 iterations of each parameter at each step. This was to form the parameter covariance matrix. For the following MCMC with fixed covariance, 4.6 million model runs assessed 100 000 iterations of each parameter, with every 50th simulation saved. There were 46 estimated parameters in total.

2.5.6 Forward projections

Model parameters determined were used to provide forward projections of exploitable biomass and future harvest targets, following a 20:60:60 harvest control rule (Department of Agriculture and Water Resources 2018). This rule (also known as a hockey stick rule), has a linear ramp in fishing mortality between 20% exploitable biomass, where fishing mortality is set at zero, and 60% exploitable biomass, where fishing mortality is set at the equilibrium level that achieves 60% biomass (F_{60}). Below 20% exploitable biomass fishing mortality remains set at zero, and above 60% exploitable biomass fishing mortality remains set at F_{60} (Figure 5). This shifting rate starts out small, which enables the stock to recover much more quickly and means that harvests are not impacted for as long. This rule can be augmented with a “buffer” to offset model uncertainty. A buffer is a discount factor applied to the control rule to account for risk under uncertainty. For this assessment, a buffer value of 0.82 has been chosen for some harvest scenarios following Commonwealth Harvest Strategy policy guidelines (Department of Agriculture and Water Resources 2018).

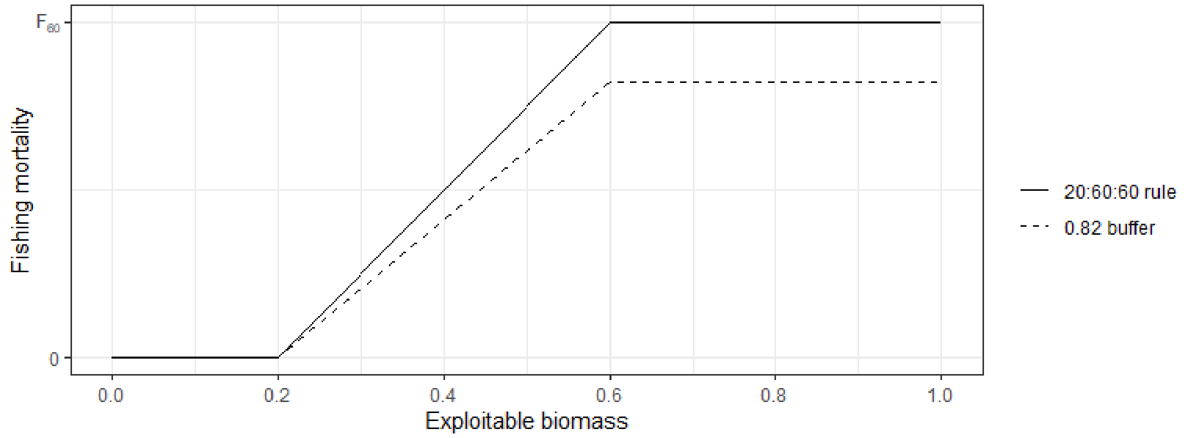

Figure 5: The 20:60:60 hockey stick harvest control rule.

3 Results

3.1 Model inputs

3.1.1 Harvest

Harvests for input to the population model were taken from commercial and recreational data. The total annual harvest is shown in Figure 6. This harvest consisted of recreational pot and commercial pot and trawl fishing methods. Harvests increased from the late 1980s to a peak in the early 2000s, declining again to just under 250 t in 2018–19.

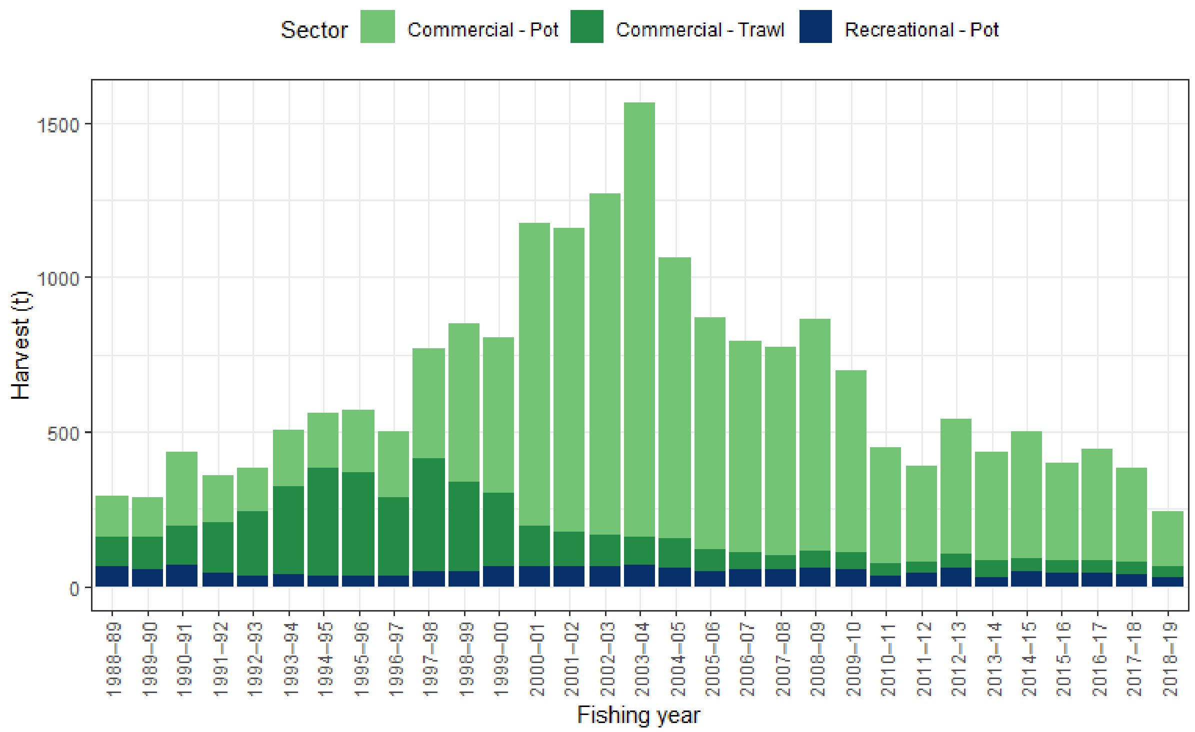

Figure 6: Estimated harvest (retained catch) from commercial and recreational sectors in Queensland east coast from 1988–89 to 2018–19

Data available from the seven recreational fishing surveys provided the basis for the recreational harvests from 1988–89 to 2018–19 (Figure 7).

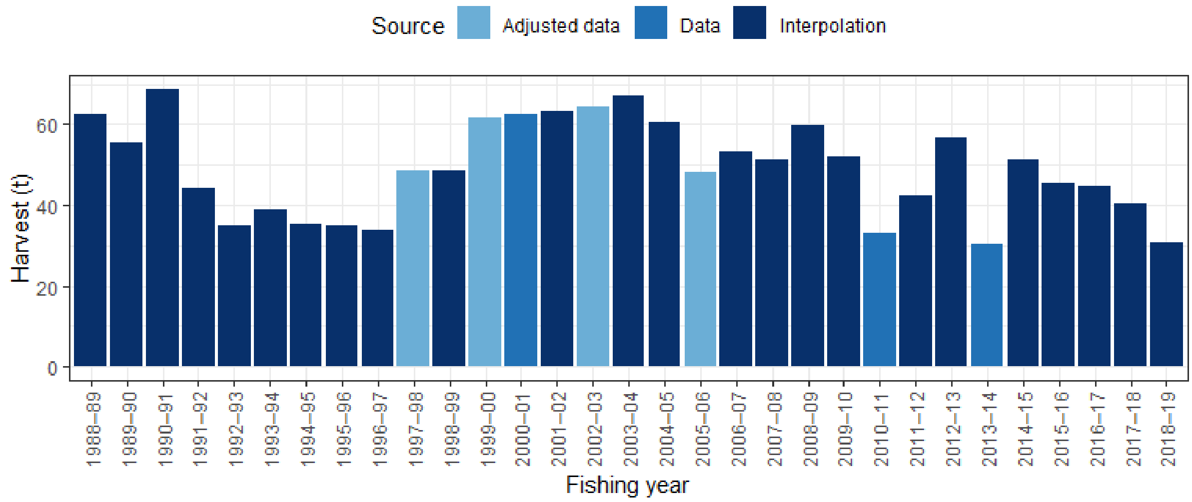

Figure 7: Estimated recreational harvests for blue swimmer crab 1988–89 to 2018–19

Model inputs were divided into Inshore and Offshore Region components as crabs caught from the Offshore Region were generally larger in size (Figure 8).

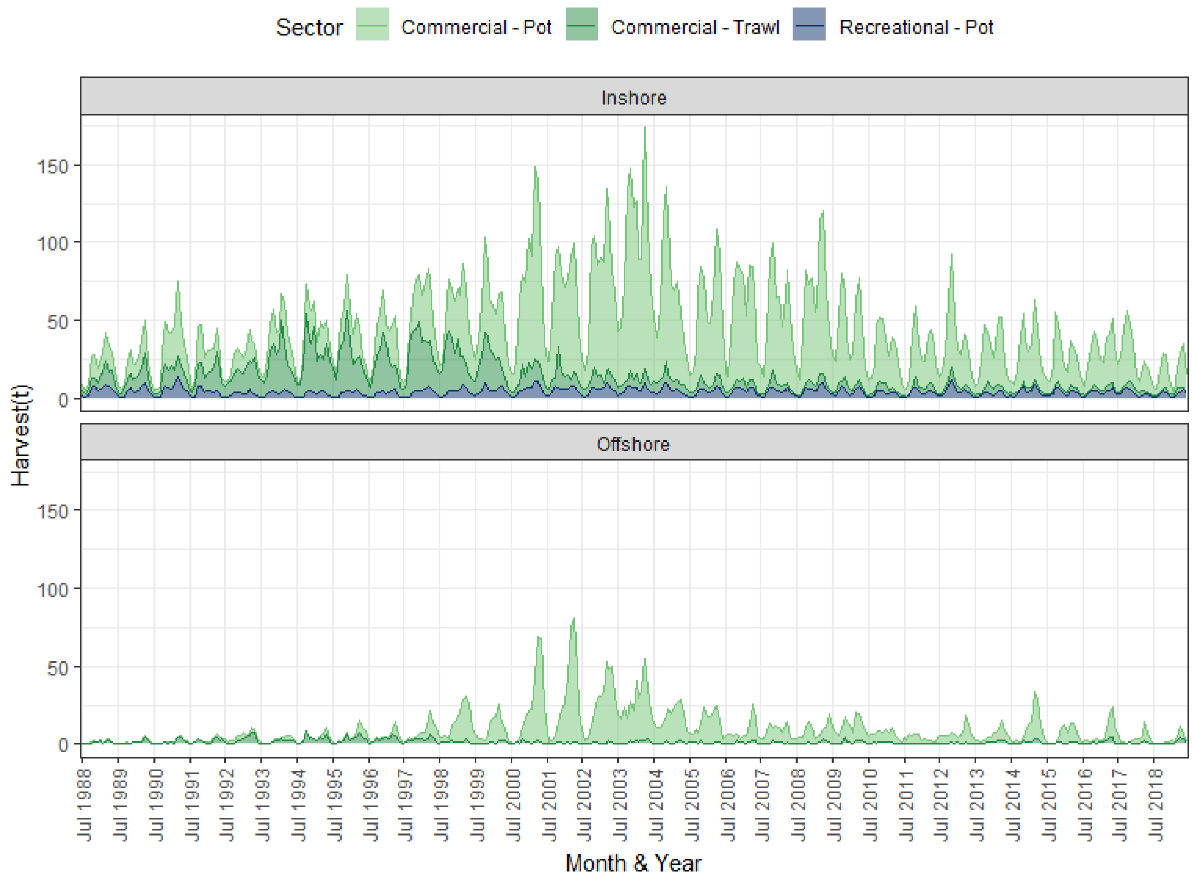

Figure 8: Queensland east coast blue swimmer crab monthly Inshore and Offshore Region harvest for the commercial pot, trawl and recreational pot sectors from July 1988 to June 2019

3.1.2 Abundance indices

Catch rates were calculated using commercial pot data; these catch rates were used to represent trends in abundance for the Queensland east coast blue swimmer crab stock. Figure 9 shows annual catch rates (used to display the annual trend) and monthly catch rates. This catch rate time series displays a similar trend with low abundance in the mid-1990s rising to a peak in the mid-2000s and then falling to the current day. Only monthly catch rates were used as a model input.

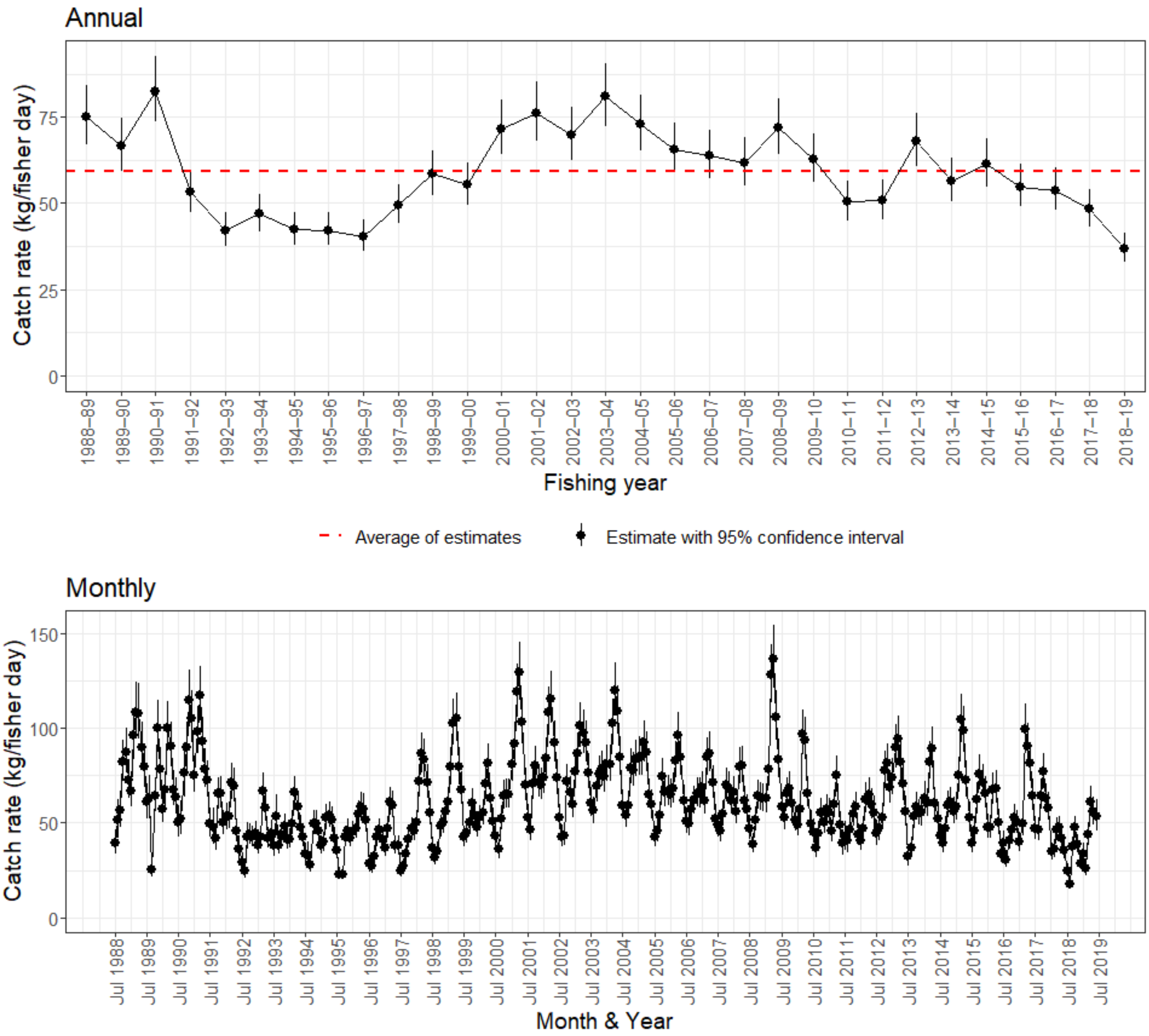

Figure 9: Annual and monthly commercial pot catch rates for Queensland east coast blue swimmer crab fishery

The fishery-independent beam trawl survey abundance index is measured by catch rates of the number of pre-recruit sized blue swimmer crabs per hectare (Figure 10). The index represents an abundance of pre-recruit blue swimmer crab from Moreton Bay and was used as a proxy for the Queensland east coast Inshore Region component of the population model. A higher abundance of pre-recruits is evident in the month of December compared to November. The survey data shows three obvious peaks abundance, in 2008, 2014 and 2017 separated by periods of relatively stable abundance.

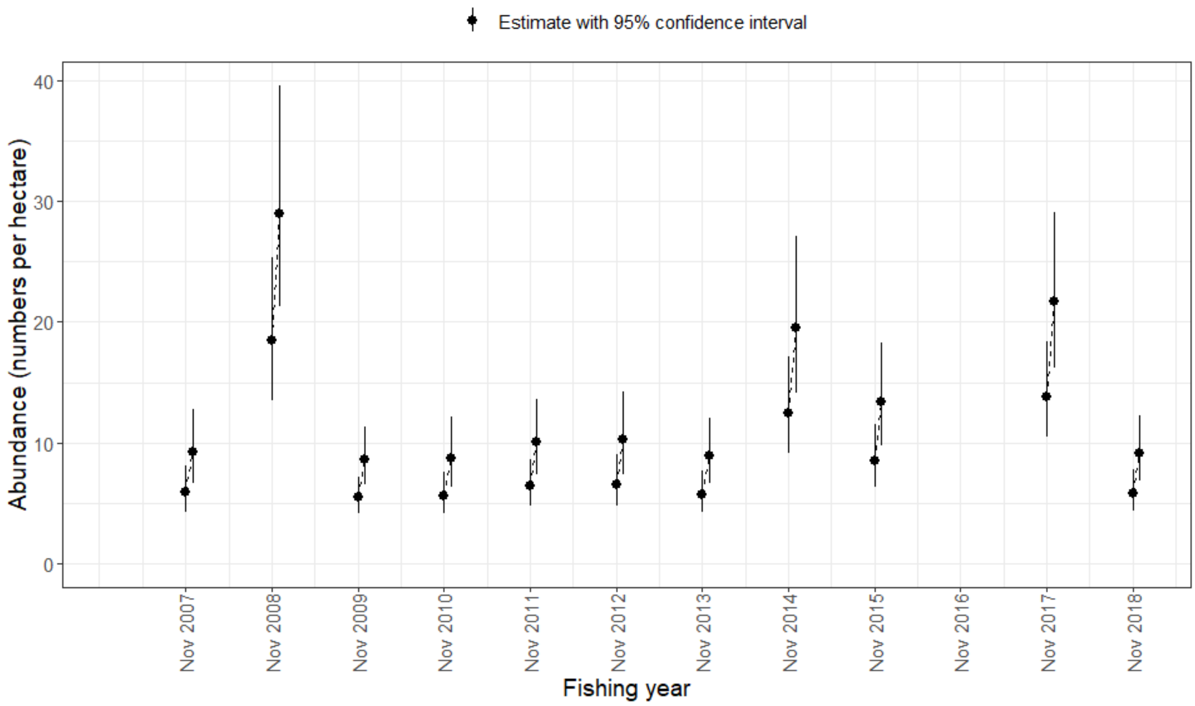

Figure 10: Fishery-independent beam trawl survey index of abundance for the months of November and December each year (Bessell-Browne et al. 2020). Note: a survey did not occur in 2016

3.2 Model outputs

Results from the stock model encompass available trends shown from the commercial catch, fishery-dependent size compositions and fishery-independent beam trawl survey index and size compositions.

3.2.1 Parameters

The results for the estimated parameters described in Table 4 are shown in Table 5 below. Parameter trace plots and estimated barycentric coordinates (used to calculate recruitment deviation values) are presented in Appendix E.

Table 5: Estimated model parameter values

Parameter	Description	Value	Standard error
$\boldsymbol{\xi}$	Used to determine Beverton-Holt steepness h.	-1.2958	0.1234
$\boldsymbol{\gamma}$	Used to determine R_0.	-1.5037	0.0511
$\boldsymbol{\mu}$	Mode of the monthly recruitment pattern.	7.4706	0.1155
$\boldsymbol{\kappa}$	The concentration of the monthly recruitment pattern.	0.2816	0.1089
$\boldsymbol{l^{50}}_{\textbf{inshore,male}}$	Length at 50% selection for Inshore Region males.	13.4312	0.1147
$\boldsymbol{\delta}$	Initial steepness of the vulnerability curve.	1.9707	0.1415
$\boldsymbol{l^{50}}_{\textbf{inshore \& offshore,female}}$	Length at 50% selection for females.	12.6101	0.1459
$\boldsymbol{l^{50}}_{\textbf{offshore,male}}$	Length at 50% selection for Offshore Region males.	14.2866	0.1174

l^{50}_{rising}	Length at 50% selection by the survey on the upward slope.	3.7228	0.1221
l^{diff}	Difference between the length at 50% selection by the survey and 95% selection.	0.7439	0.1442
l^{50}_{falling}	Length at 50% selection by the survey on the downward slope.	9.5566	0.1208
δ_{survey}	Asymptote for survey vulnerability.	0.2117	0.0749
ς_1	Catchability amplitude 1.	0.2703	0.0441
ϑ_1	Peak timing of catchability 1.	-0.1121	0.0591
ϑ_2	Peak timing of catchability 2.	0.1261	0.0395
ς_2	Catchability amplitude 2.	-0.1709	0.0442

3.2.2 Model fits

For the model to obtain the best fit and results, it was necessary to adjust the weighting (or importance) of each negative log likelihood value. The negative log likelihood for size compositions was weighted at 10%. Fits to the commercial catch rate, fishery-independent beam trawl survey abundance index and size compositions are shown in Appendix F.

3.2.3 Biomass estimates

The exploitable biomass trajectory through time was determined as a proportion relative to an assumed unfished biomass. Modelling included a warm-up phase with an assumed level of constant harvest prior to the 1988–89 fishing year, hence an initial depletion level was obtained. This assumed level of harvest was equal to the average level of harvest for each month over the period 1988–89 to 1990–91.

Figure 11 displays the trajectory of exploitable biomass over time since the 1988–89 fishing year. The model has predicted that exploitable biomass was initially depleted to around 75% of virgin biomass, fell to around 50% in the early to mid-1990s and then increased to around 90% in the early 2000s. Since this time, exploitable biomass has been steadily declining to around 33% in the current year. Note that exploitable biomass was calculated on the male legal crab population only. A monthly time series of exploitable biomass is included in Appendix G, noting within year biomass can vary significantly.

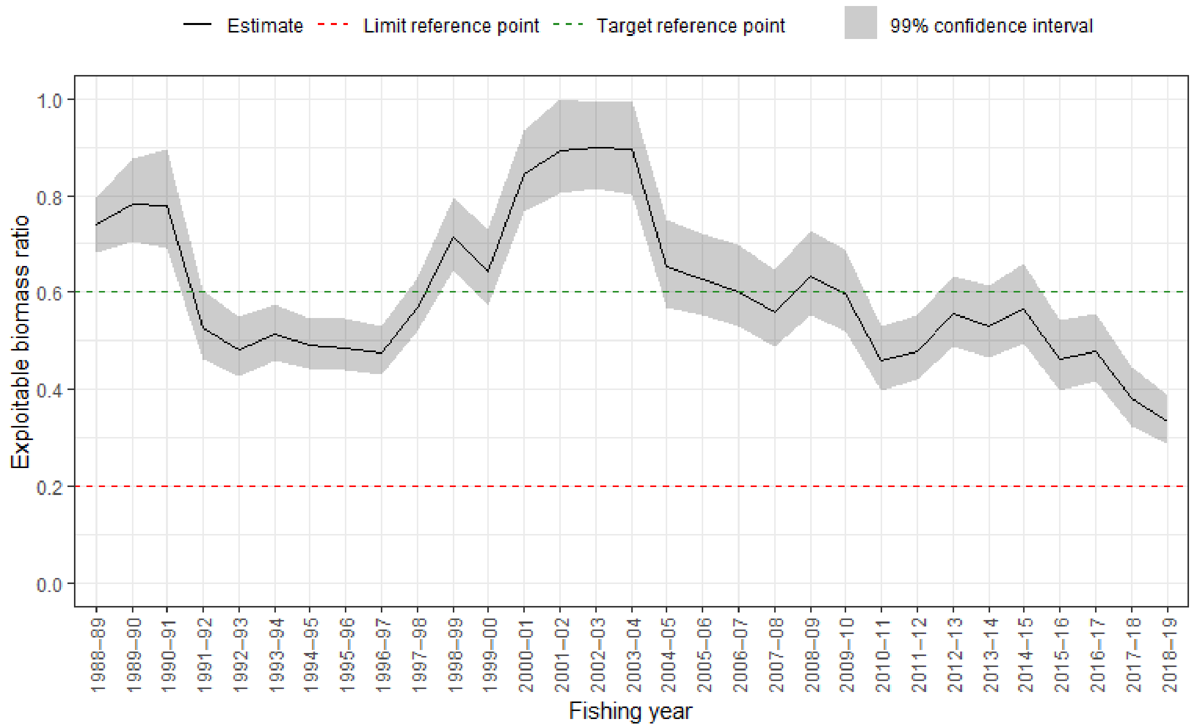

Figure 11: Annual exploitable biomass relative to virgin biomass for Queensland east coast blue swimmer crab

Spawning biomass (Figure 12) follows a similar trend to exploitable biomass; however, the proportion relative to virgin spawning biomass is higher due to the presence of the protected females.

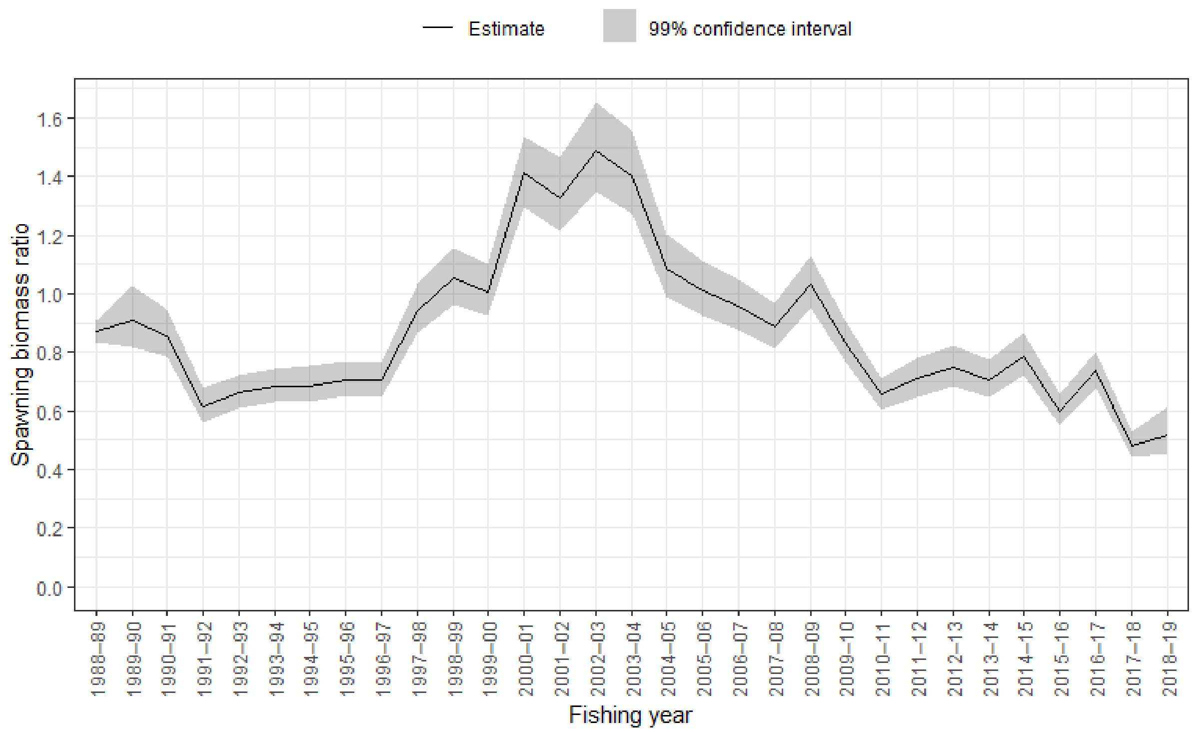

Figure 12: Predicted spawning biomass relative to virgin biomass for Queensland east coast blue swimmer crab

Figure 13 shows the trajectory over time of fishing pressure vs exploitable biomass. Fisheries Queensland aims to rebuild all fish stocks to an exploitable biomass of 60%. The population model also calculates the maximum harvest rate that would keep the exploitable biomass at an equilibrium of 60% once the desired 60% was achieved. This harvest rate, denoted F_{60} is also shown on the phase plot.

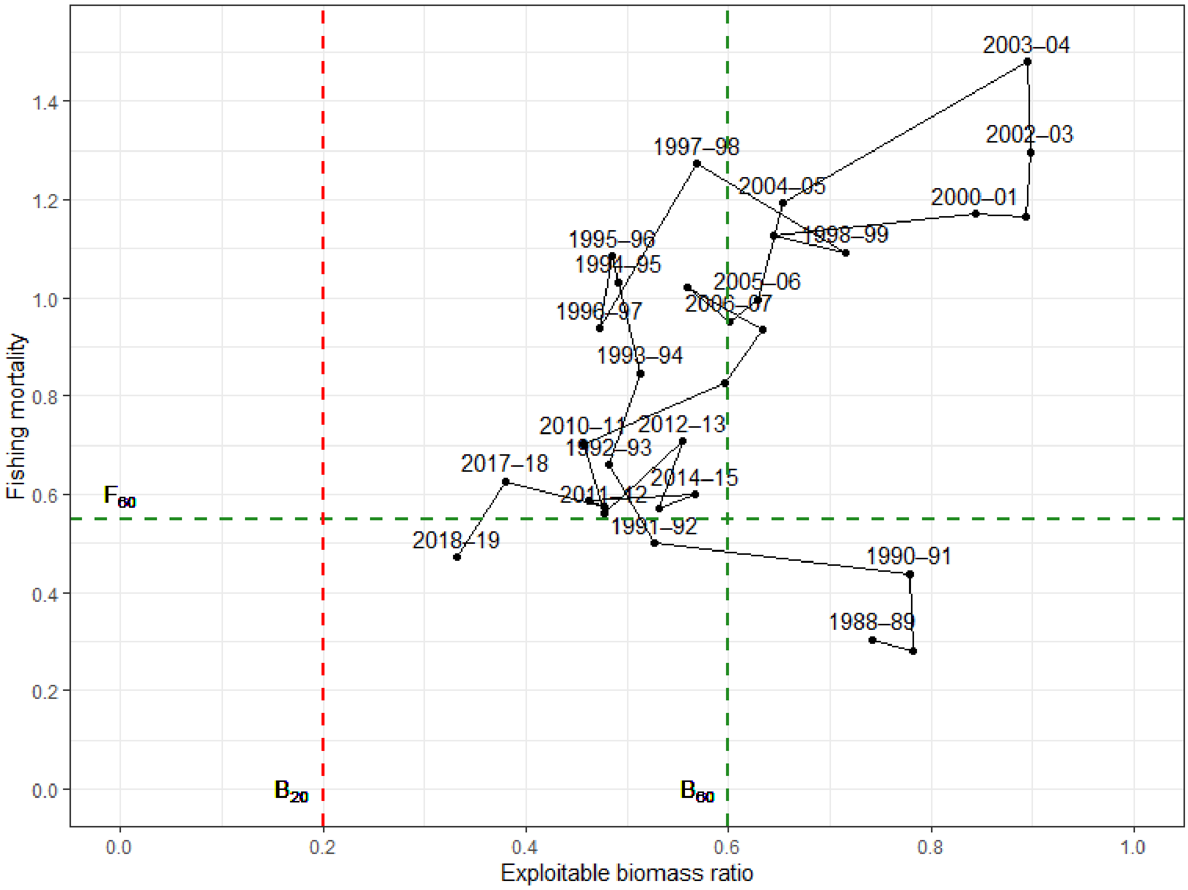

Figure 13: Phase plot of fishing pressure over time relative to the predicted exploitable biomass trajectory

3.2.4 Targets

Table 6 details current harvests and the harvest required to meet certain targets. Fisheries Queensland currently aims to use the 20:60:60 hockey stick harvest control rule where possible for determining harvest targets to rebuild biomass.

Table 6: Description of current and target harvest indicators

Indicator	Estimate
Current exploitable biomass (relative to unfished) 2018–2019	33%
MSY exploitable biomass/unfished biomass (relative to unfished)	23%
Current harvest in 2018–19	240 t
Average 5 year harvest (2014–15 to 2018–19)	394 t
Harvest at MSY	722 t

Harvest at 60 per cent exploitable biomass	476 t
Initial harvest to build to 60 per cent biomass	129 t

3.2.5 Projections

A forward projection using the hockey stick harvest control rule with no buffer shows a rebuilding of the fishery towards 60% (Figure 14). Deterministic recruitment was assumed for this projection. Initial years in this forecast are shown to vary rather than follow a smooth trajectory; this is due to the residual effect of predicted recruitment variation for years prior to the projection. It can be noted that this effect settles after the first four years of the projection. Further projections under different harvest scenarios are shown in Appendix H.

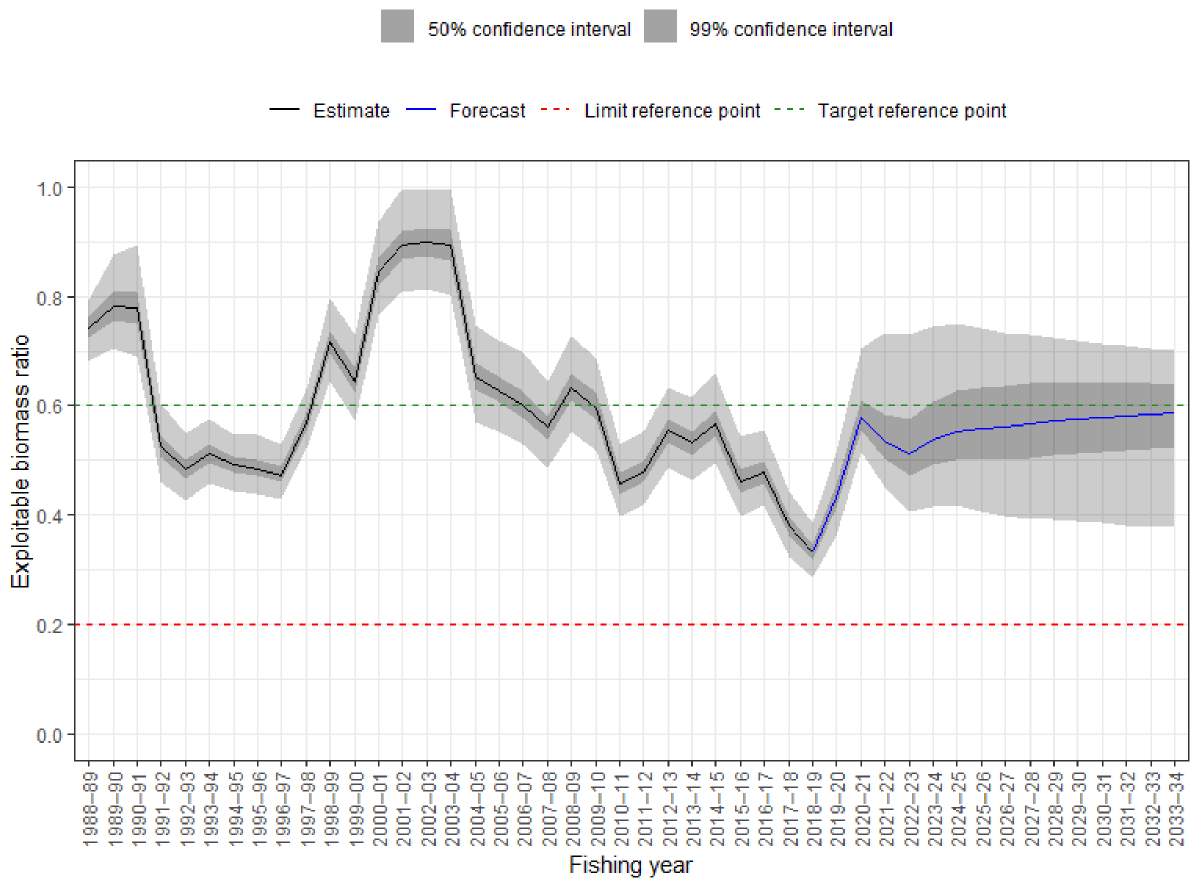

Figure 14: Forward projections of the exploitable biomass ratio under the hockey stick harvest control. Deterministic recruitment was assumed

4 Discussion

4.1 Stock status

Blue swimmer crab is a fast-growing species that occurs along the Queensland east coast. Average harvests over the last five years were around 394 t per year. Catch shares over this period were 366 t commercial and 28 t recreational.

In Queensland, current management restrictions include, harvesting of male blue swimmer crab only, a minimum legal size of 11.5 cm carapace width (measured notch-to-notch), and a recreational in-possession (bag) limit of 20 blue swimmer crabs per fisher. Additionally, recreational fishers must not possess more than four crab apparatus at a time, and commercial fishers must not possess more than 50 or 100 crab apparatus depending on the number of symbols attached to a license.

Management arrangements prohibit the take of female crabs, and a minimum legal size limit ensures that there is a window of protection for newly spawning stock and that a high proportion of males have an opportunity to mate before recruitment into the fishery.

Results show that current blue swimmer crab exploitable biomass is at 33% and requires rebuilding to target levels under the Queensland Sustainable Fisheries Strategy (Department of Agriculture and Fisheries 2017). This biomass estimate reflects the quantity and quality of data available. Difficulties in accounting for the effects of trotlines used in Sunshine Coast waters in the early 2000s when the fishery expanded, could have resulted in an overestimated biomass.

4.2 Performance of the population model

This stock assessment used a length-based model with a monthly time step, length-based selectivity and an Inshore and Offshore Region spatial component. Data inputs included total harvest (commercial and recreational), standardised catch rates (commercial pot), fishery-dependent size compositions and fishery-independent beam trawl survey size compositions and abundance.

To achieve the best fit to the data, fits-to-size compositions were down weighted to 10%. Overall, the model performed well, achieving good fits to the data with the caveats mentioned above. The fishery-independent beam trawl survey index of abundance did not fit as well as hoped; however, this is understandable given that it is conducted in Moreton Bay and likely not representative of the entire Inshore Region Queensland east coast.

Further statistical analysis is required to identify any potential stock recruitment relationships between the abundance index and the commercial fishery and the contribution of juvenile crabs from inshore Moreton Bay to fishing grounds further offshore.

Sensitivity testing was not performed due to time constraints, however, sensitivity testing in the previous assessment (Sumpton et al. 2015) was incorporated into decisions made for this assessment. MCMC sampling was performed supporting results obtained from this assessment.

4.3 Recommendations

The Queensland Sustainable Fisheries Strategy aims to build and maintain fisheries in the long term. The aim is to have a strategy in place by 2027 to move to the target reference point of 60% biomass (Department of Agriculture and Fisheries 2017). This assessment presents targets to rebuild the fishery to 60%.

4.3.1 Monitoring

Monitoring data in the form of fishery-dependent (commercial) size compositions and fishery-independent beam trawl survey (size compositions and index of abundance for pre-recruits) were advantageous to this assessment.

The difficulties in ageing blue swimmer crab mean that age data are not available. The fishery-independent beam trawl survey analysis of pre-recruits, and fills a gap by providing important information about the 0+ age group. Continuing data collection in the fishery-independent beam trawl survey will be useful for future stock assessments. Additionally, fishery-independent beam trawl survey data from Hervey Bay in 2017 and 2018, which were presently excluded until a longer time series is obtained, will help to create more robust data for future assessments.

Fishery-dependent (commercial) size compositions are from the early 2000s, the collection of current data would be useful for future assessments.

4.3.2 Management

Model indications are that the current blue swimmer crab exploitable (male legal crab) biomass for the Queensland east coast is at 33%. Under the Queensland Sustainable Fisheries Strategy, a rebuilding strategy needs to take place. The hockey stick harvest control rule suggests a target of 129 t initially to begin rebuilding exploitable biomass to 60%. Forward projections of the model suggest that rebuilding would occur in around 10 years.

4.3.3 Assessment

The fishery-independent beam trawl survey began collecting blue swimmer crab samples in Hervey Bay in addition to the existing Moreton Bay samples. This additional information could be used in future assessments to provide information about recruits and their abundance in the Hervey Bay region.

Future stock assessments of blue swimmer crab should also consider the use of Fisheries Queensland, fishery-dependent boat ramp survey data which could be used to model an index of abundance for the recreational sector.

4.4 Conclusions

This assessment has informed the status of the north eastern Australian (Queensland) blue swimmer crab stock. Analysis suggests that exploitable biomass has been declining since the mid-2000s and is currently at around 33% (for 2018–19). The study recommends an initial harvest limit of around 129 t to begin rebuilding the stock to levels consistent with 60% of unfished biomass. This is 60% of the unfished biomass target level, is specified in Queensland’s Sustainable Fisheries Strategy.

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Appendix A - Inshore and Offshore Regions

Sumpton et al. (2015) assessed blue swimmer crab for three regions (Figure 15). For the Sumpton et al. (2015) assessment, Sunshine Coast was considered an offshore component to the model. This offshore component was created to account for significantly larger crabs found in the region (Sumpton et al. 2015). The current stock assessment contained in this report follows the same protocol where grids attributed to Sunshine Coast in Figure 15 are considered an Offshore Region. All other areas where blue swimmer crabs are caught on the Queensland east coast are considered part of the Inshore Region for this assessment.

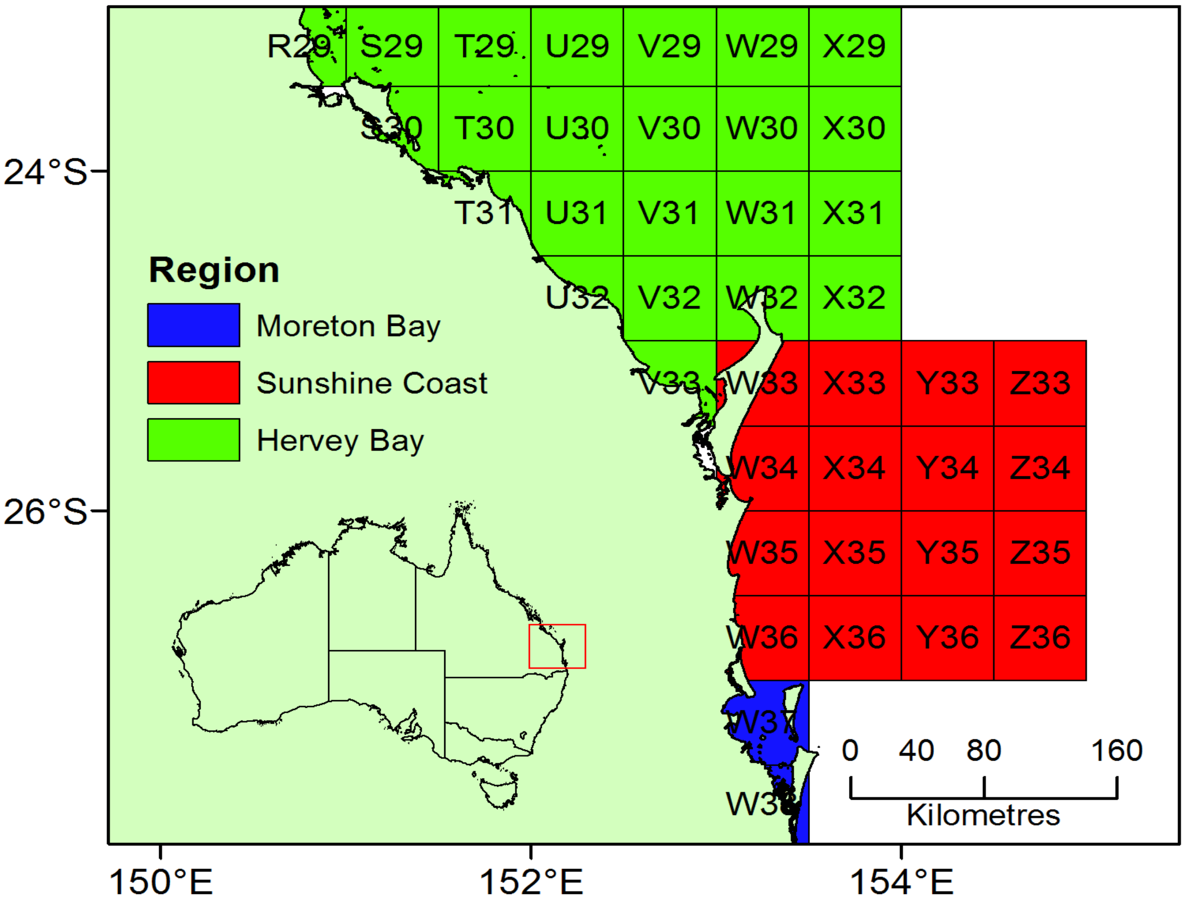

Figure 15: Commercial logbook CFISH reporting grid for both trawl and pot fisheries used in the Sumpton et al. (2015) assessment.(Image by Matthew Campbell © State of Queensland)

Appendix B - Selection of daily commercial catch rate data

Generally, the targeting of blue swimmer or mud crab occurs in different habitat areas. For example, blue swimmer crabs usually frequent sandier substrate habitats in estuaries, bays and offshore. Mud crabs typically occur in muddier substrates of estuaries and bays. However, spatial/ habitat of the species is sometimes shared and not always separate. Changes can occur with seasons and at a fine spatial scale, particularly around seagrass habitats, which both species inhabit.

The commercial logbook grids (30 × 30 minute) often do not capture the fine-scale spatial aspects of blue swimmer and mud crabs. Sometimes crab pots catch blue swimmer and mud crabs together. When this occurs, the target species is unknown.

The past way of inferring a targeted catch of blue swimmer crab was to select catches, where blue swimmer crab were ≥ 90% of the total harvest weight $\frac{\text{blue}_{\text{wt}}}{\text{blue}_{\text{wt}}+\text{mud}_{\text{wt}}} \geq 0.9$. This was a data-selection rule to ensure the catch rate data from the assumed targeting of blue swimmer crabs.

Herein, we check this 90% cut-off-rule to see if it might exclude some important data on blue swimmer crab harvests. For the examination, the methodology considered: Mixture-cluster analyses (McLachlan and Peel 2000; MathWorks 2020) of the blue swimmer crab proportions, compared to mud crabs. The mixture analyses assumed diagonal covariance matrices.

Analyses used all blue swimmer and mud crab catches-per-boat-day when both species were present, south of 23°S. In total, 98 213 (17%) out of all 571 362 daily catches of blue swimmer and mud crabs were analysed. Daily catches (by fisher) where only blue swimmer or mud crab were recorded were not analysed, as the inferred target was obvious. To help infer target species, blue swimmer and mud crab prices from the Sydney fish market determined the economic ratio of the crab species. Price data were only available for 2006–2014. Average crab prices were $23.45 for mud crab, and $8.69 per kg for blue swimmer crab. A 2.7 multiplier inflated mud crab weights to calculate blue swimmer crab ratios.

Figure 16 compares the co-occurrence of blue swimmer and mud crab based on the adjusted weight data. Generally, there was a tendency for the catches to lie close to the horizontal or vertical axes, though there were enough mixed co-occurrences towards the zero axes for lower sized catches. This simple summary suggested selecting blue swimmer crab data where the probabilities $\Pr(\text{blue}) > \Pr(\text{mud} \times 2.7)$, or easier $\text{blue}_{\text{wt}} > \text{mud}_{\text{wt}} \times 2.7$.

Analysis of the species proportions, $p_s = \frac{\text{blue}_{\text{wt}}}{\text{blue}_{\text{wt}}+\text{mud}_{\text{wt}}\times 2.7}$, suggested simple discrimination between blue swimmer and mud crabs was uncertain. Figure 17 illustrates that by fitting three clusters ($k = 3$), the AIC statistic improved significantly ($p < 0.05$). The target species was uncertain for proportions between about 0.2 and 0.7 (Figure 17d). Bootstrapping ($n = 500$) the mixture analysis suggested the percentage rule cut should be around 71% (95% confidence interval 66% and 76%); which was less than the original 90% rule.

Further work is required to refine the data-selection rule. Currently, with the above rules, some catch rate data will miss selection for analysis of either blue swimmer or mud crab. However, data-selection rules of either the 90%, 70% or 50% did not influence catch rate trends over the years 1988–2019 (Figure 18). Based on the formula $p_s = \frac{\text{blue}_{\text{wt}}}{\text{blue}_{\text{wt}}+\text{mud}_{\text{wt}}\times 2.7}$, the 70% rule increased the number of data to analyse by 6 703 rows and 21 682 for a 50% rule, compared to the original 90% equation.

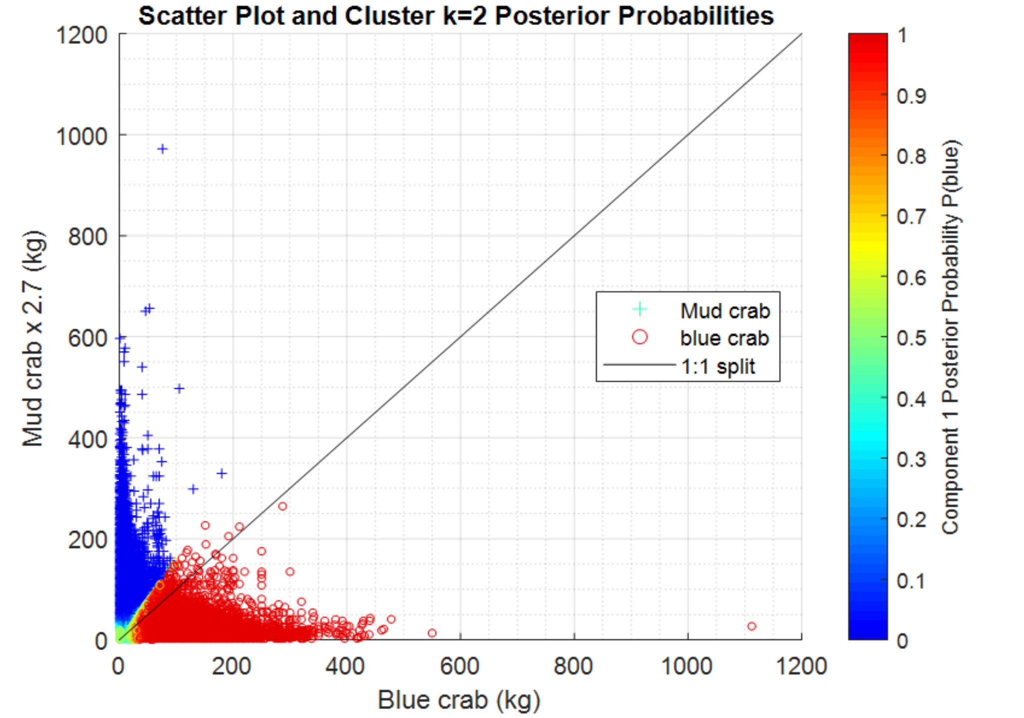

Figure 16: Summary of blue swimmer crab verses adjusted mud crab catches, and probabilities for inferring target species

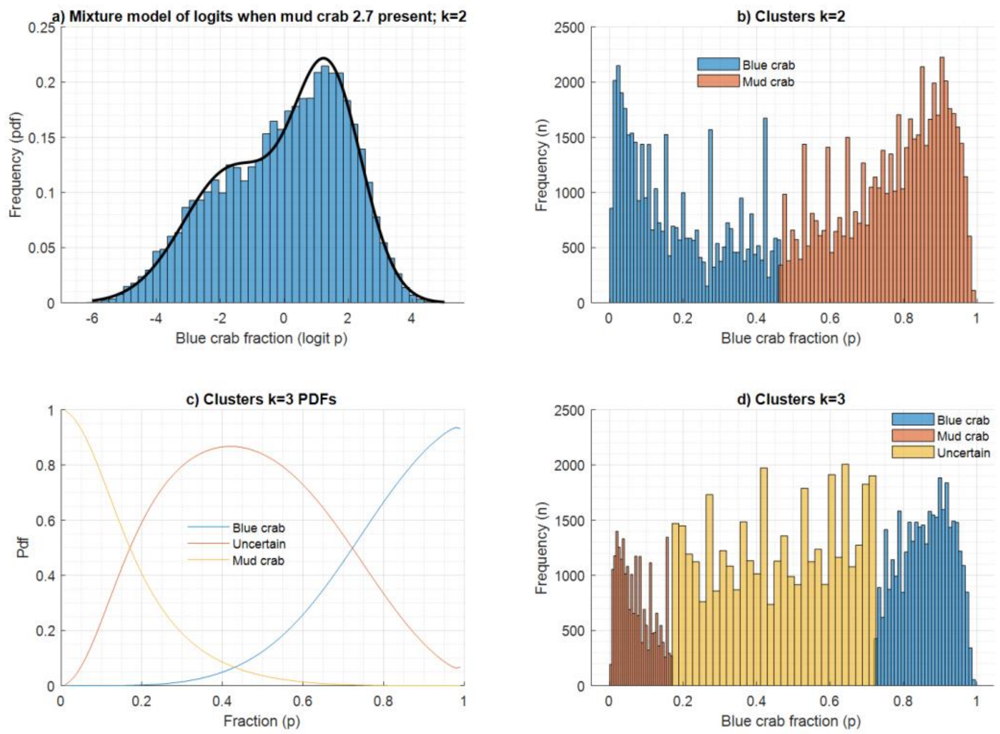

Figure 17: Mixture clusters of blue swimmer crab fractions for a) distribution of the logits with a fitted two component mixture, b) k=2 clustering of the blue crab fractions p, c) Pdfs for a $k = 3$ cluster, with the result summarised in subplot d)

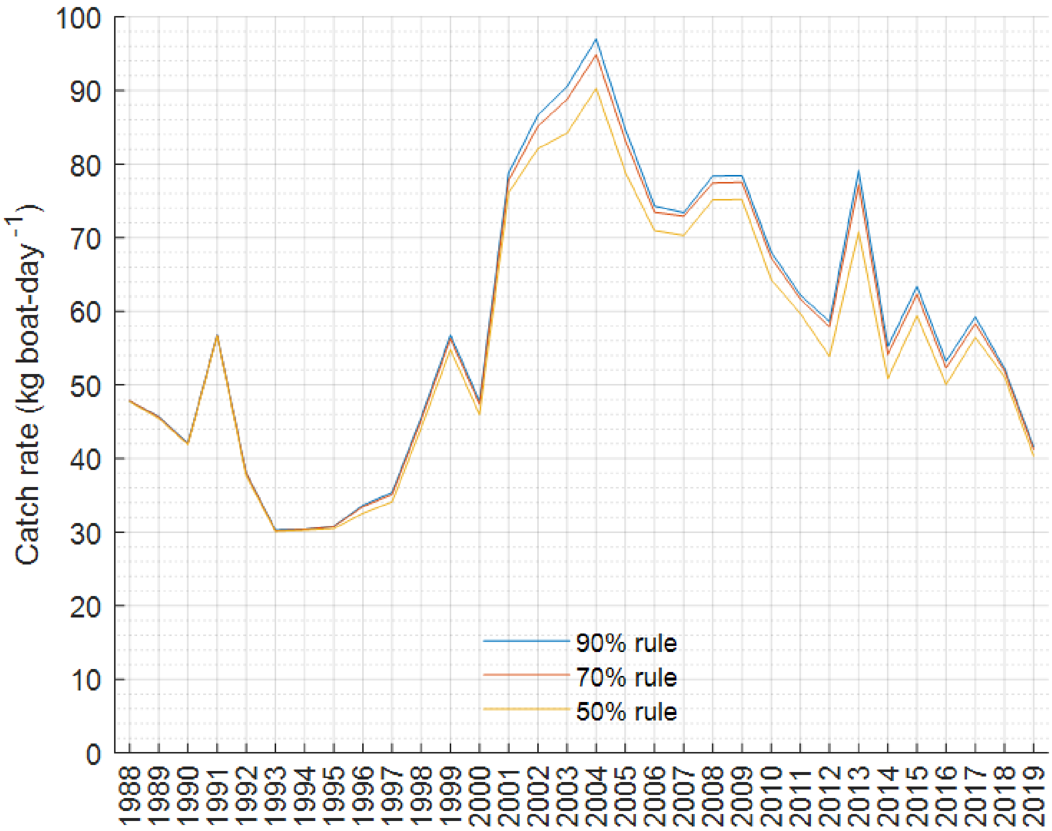

Figure 18: Annual nominal catch rates of blue crab by fishing year and data-selection rule

Another analysis method for inferring target species from the Northern Prawn Fishery was applied (Dichmont et al. 2001). This involved binomial GLMs for blue swimmer and mud crabs, based on defining a reasonable catch that exceeded the lower quartile for each species and year. The method's settings were not successful, with many records deemed both target catches of blue swimmer and mud crab.

Inferences from the mixture analyses suggest reducing the percentage rule cut-off using the second formula that considered crab price-values. This will increase the amount of data for analysis. The 70% rule was selected for this stock assessment.

Appendix C - Regional catch rates

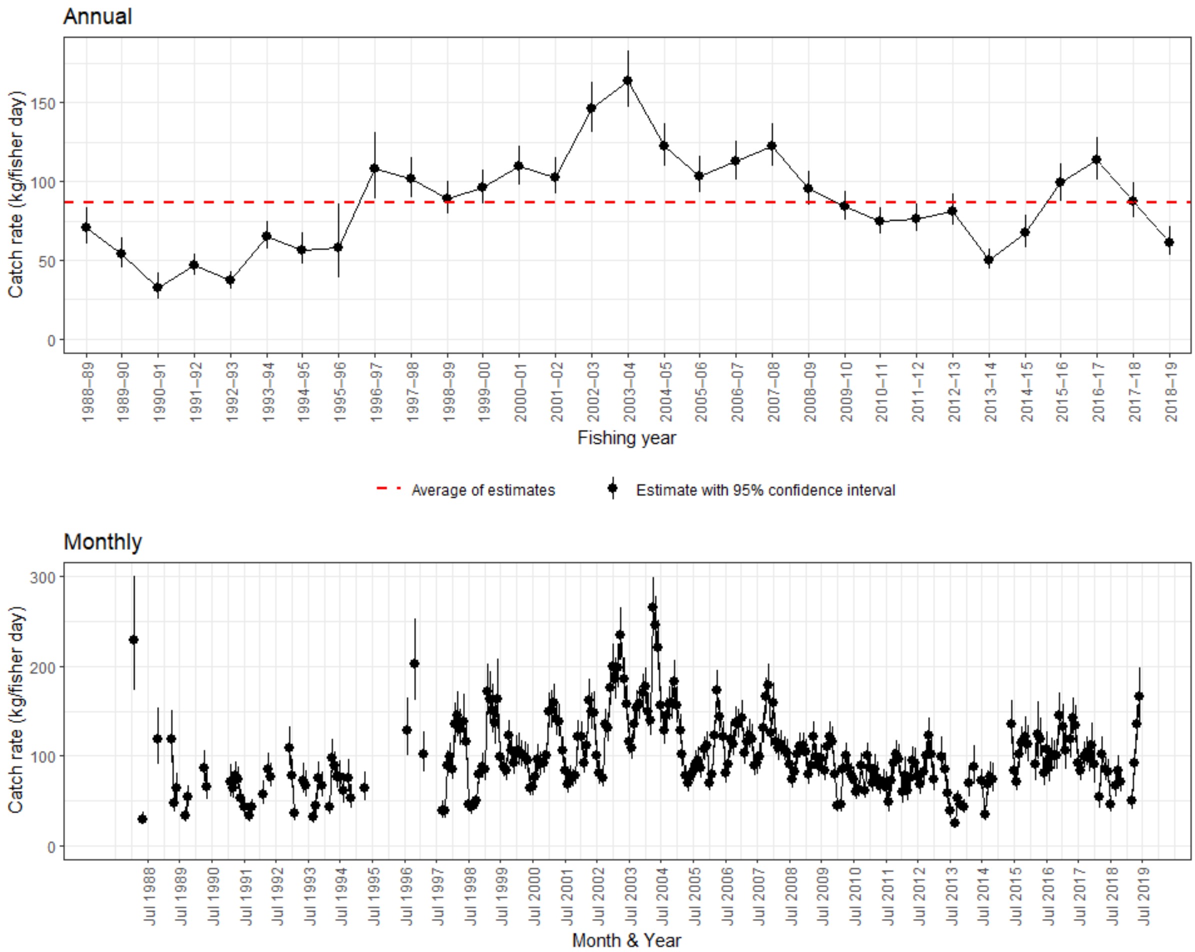

Figure 19: Annual and monthly commercial pot standardised catch rates for Hervey Bay blue swimmer crab fishery. Missing data represents months where less than 20 boat-days of effort were reported

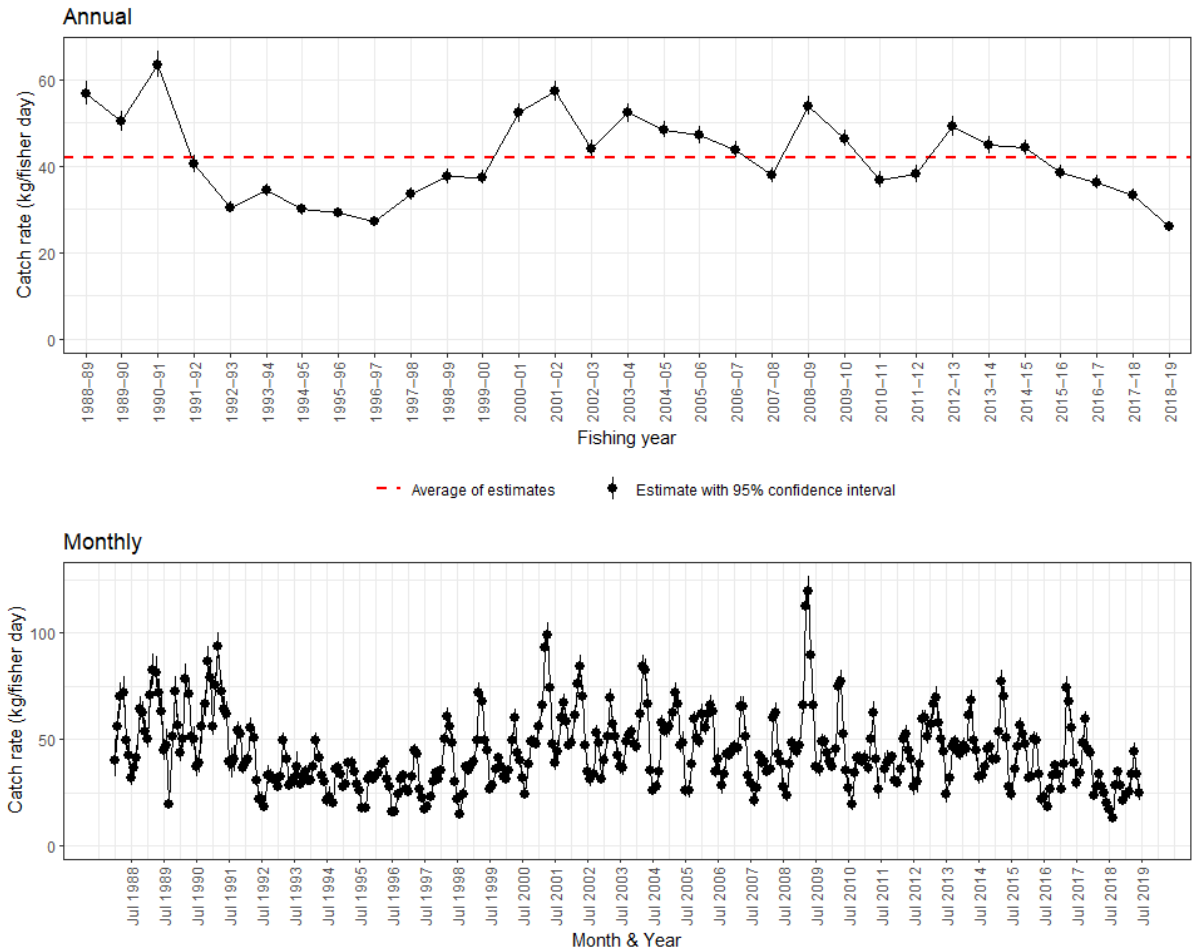

Figure 20: Annual and monthly commercial pot standardised catch rates for Moreton Bay blue swimmer crab fishery. Missing data represents months where less than 20 boat-days of effort were reported

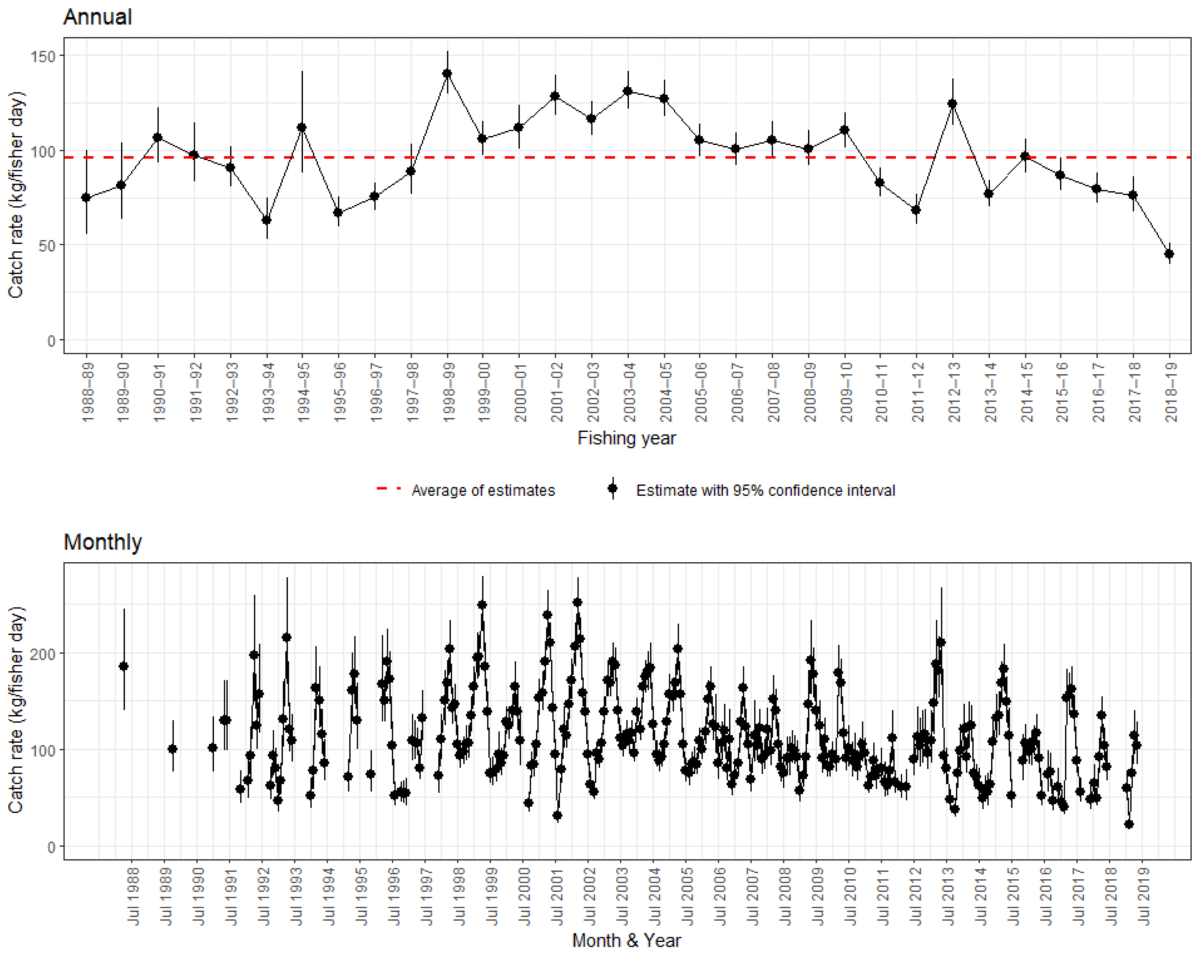

Figure 21: Annual and monthly commercial pot standardised catch rates for Sunshine Coast blue swimmer crab fishery. Missing data represents months where less than 20 boat-days of effort were reported

Appendix D - Size Composition

D.1 Commercial sampling

The carapace width of blue swimmer crabs were measured from samples taken opportunistically from commercial pot catches in northern and southern Moreton Bay (Inshore Region), Hervey Bay (Inshore Region) and the Sunshine Coast (Offshore Region) waters during 1997–2001 and 2013–2014 (Sumpton et al. 2015). Methods have been described by Sumpton et al. (2003). Carapace widths shown here are measured using the old tip-to-tip method (Figures 22 and 23).

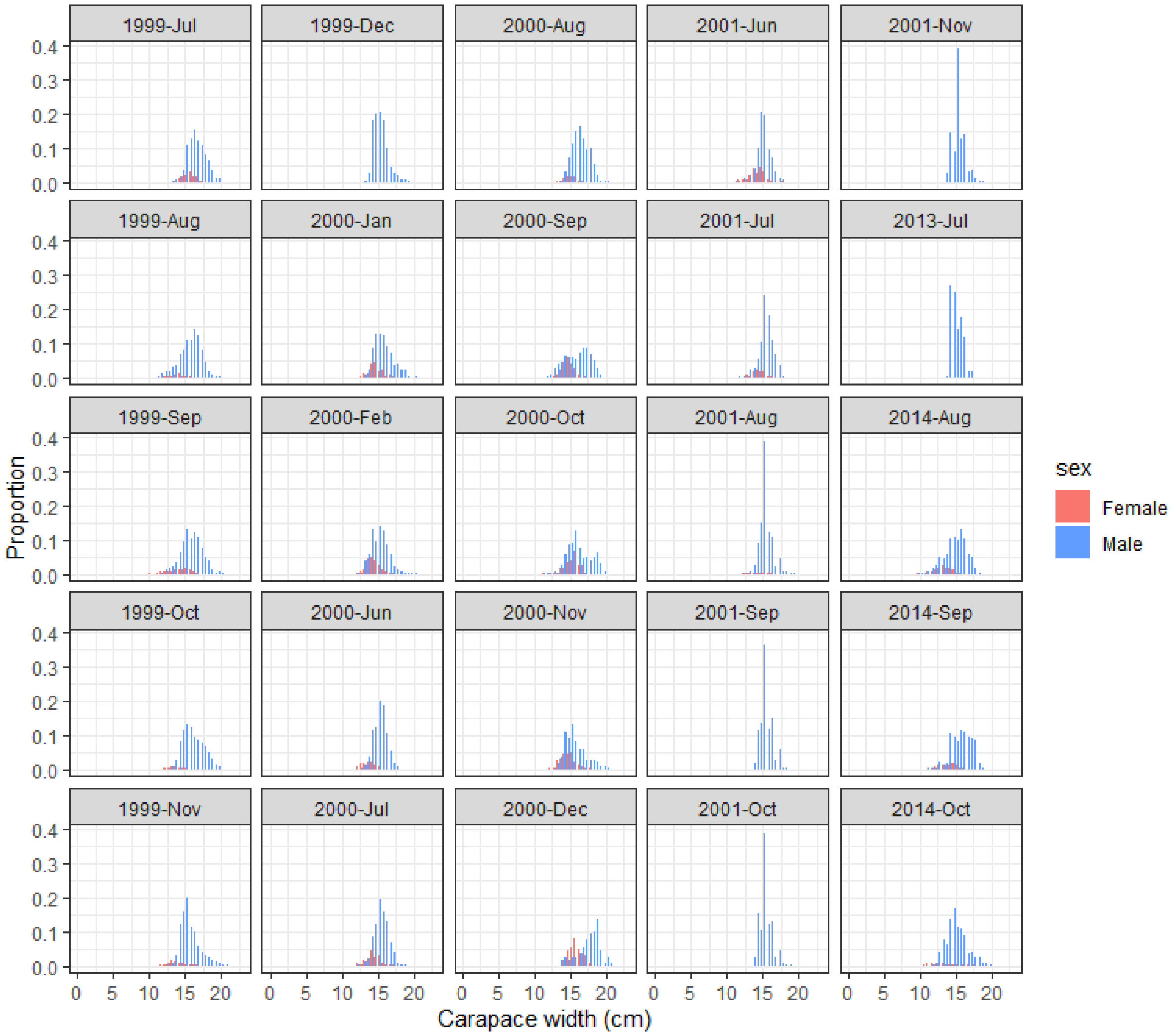

Figure 22: Fishery-dependent carapace width (tip-to-tip) size compositions for blue swimmer crab from the Queensland east coast Offshore Region commercial sector

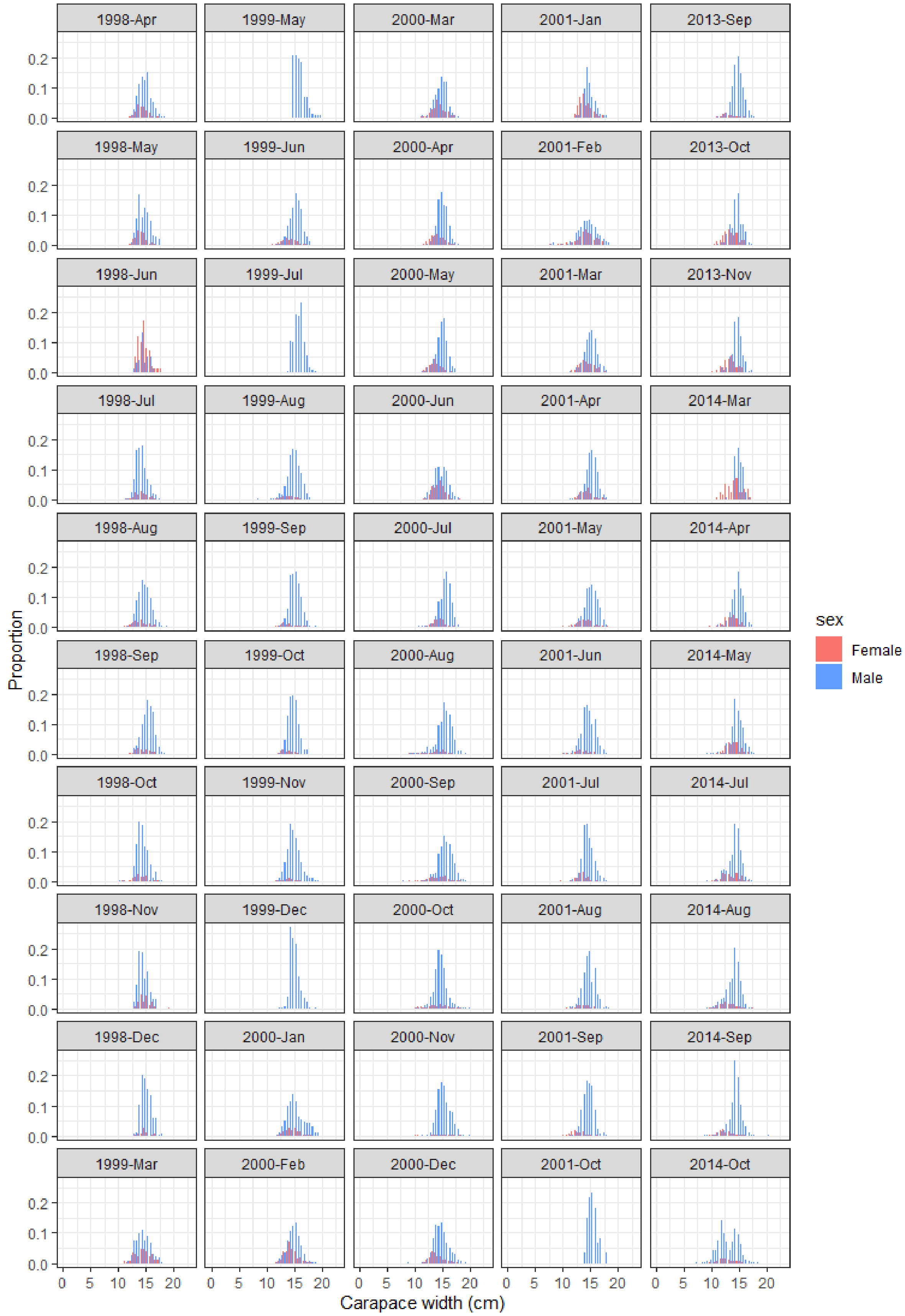

Figure 23: Fishery-dependent carapace width (tip-to-tip) size compositions for blue swimmer crab from the Queensland east coast Inshore Region commercial sector

D.2 Fishery-independent beam trawl sampling

Size compositions obtained from the Fisheries Queensland fishery-independent beam trawl survey (Figure 24) were used to fit to modelled survey samples for pre-recruits (0+ years old). Pre-recruits were considered to be all crabs less than 6.5 cm carapace width in the month of November and all crabs less than 8.5 cm carapace width in the month of December (Bessell-Browne et al. 2020) and are shown in the shaded section of each graph presented in Figure 24. As the sex distribution was unknown in 2010, carapace width compositions in 2010 were applied to both males and females as model inputs. Carapace widths shown here are measured using the current notch-to-notch method. These data and their corresponding cut off widths were converted to tip-to-tip measurements using Equation 3.

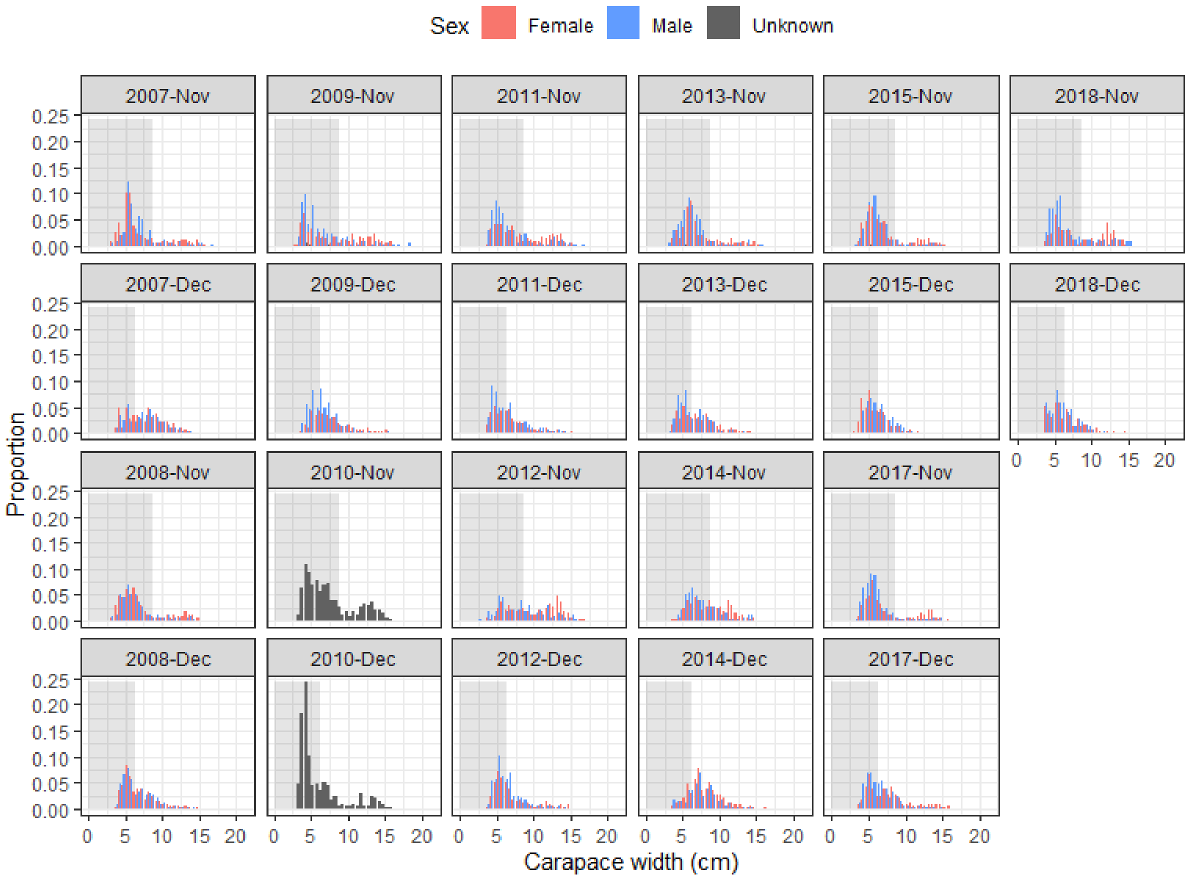

Figure 24: Carapace width (notch-to-notch) size compositions obtained from the Fisheries Queensland fishery-independent beam trawl survey conducted in Moreton Bay. Shaded sections indicate data used to inform pre-recruit abundance (less than 6.5 cm notch-to-notch carapace width in the month of November and less than 8.5 cm in the month of December) (Bessell-Browne et al. 2020)

Appendix E - Parameter analysis

Appendix E.1 below shows MCMC trace plots for each parameter or estimated value. Estimated barycentric coordinates (used to calculate recruitment deviations) with their credible intervals are displayed in Appendix E.2.

E.1 Trace plots

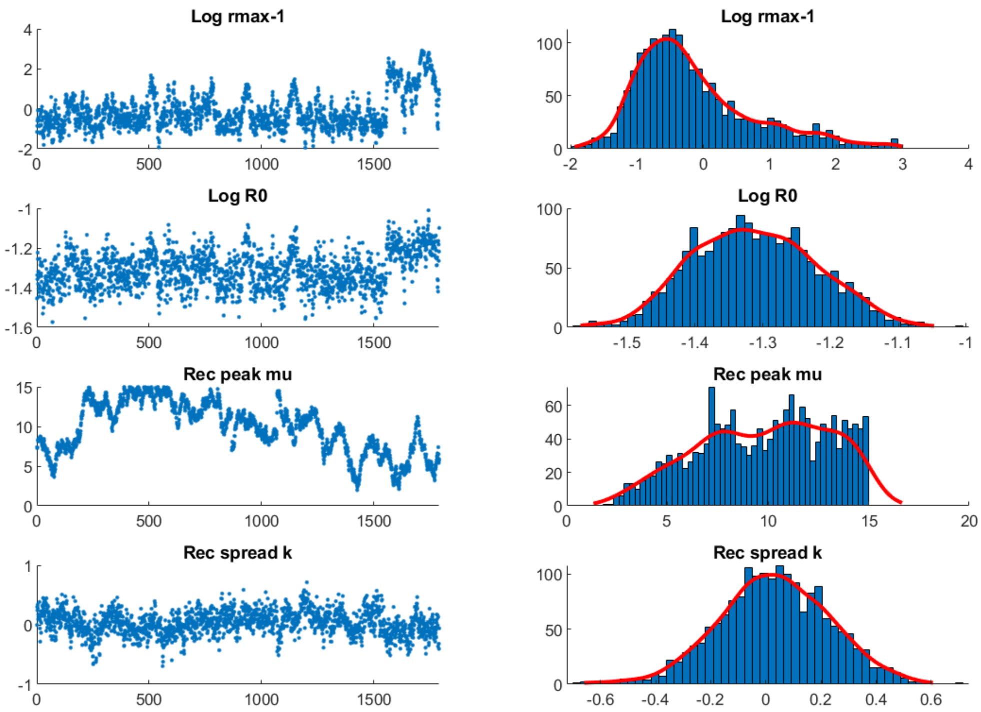

Figure 25: Trace plots and histograms for ξ (Log rmax-1), γ (Log R0), μ (Rec peak mu), κ (Rec spread k)

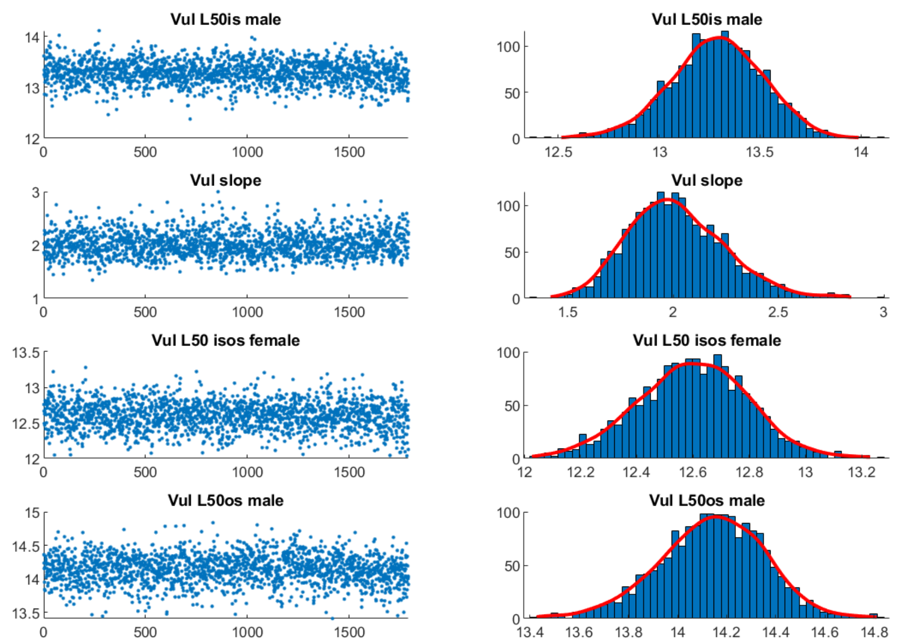

Figure 26: Trace plots and histograms for $l^{50}{}_{\text{inshore,male}}$ (Vul L50is male), δ (Vul slope), $l^{50}{}_{\text{inshore \& offshore,female}}$ (Vul L50 isos female), $l^{50}{}_{\text{offshore,male}}$ (Vul L50os male)

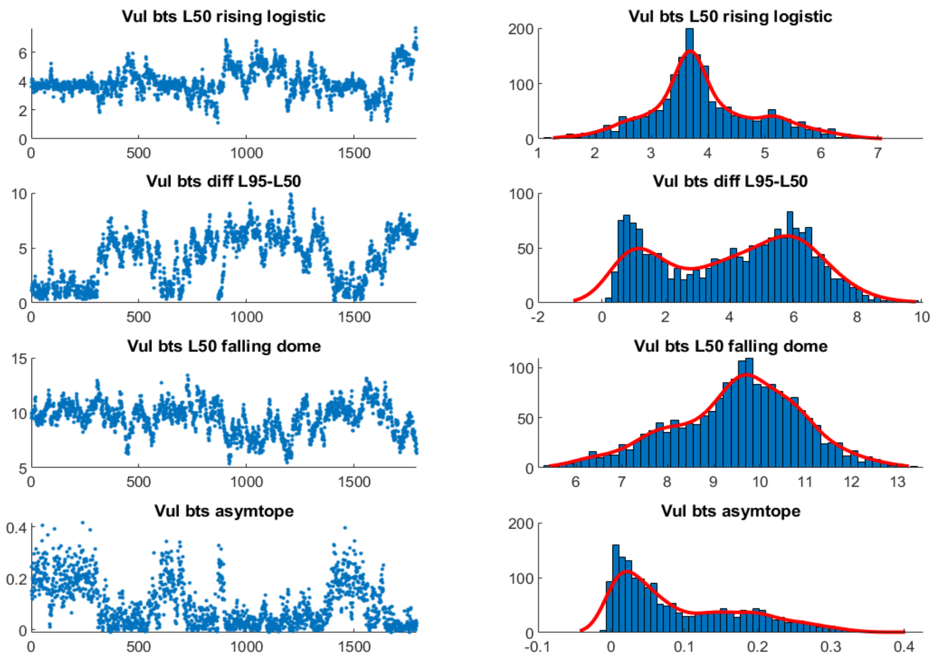

Figure 27: Trace plots and histograms for $l^{50}{}_{\text{rising}}$ (Vul bts L50 rising logistic), l^{diff} (Vul bts diff L95-L50), $l^{50}{}_{\text{falling}}$ (Vul bts falling dome), δ_{survey} (Vul bts asymptote)

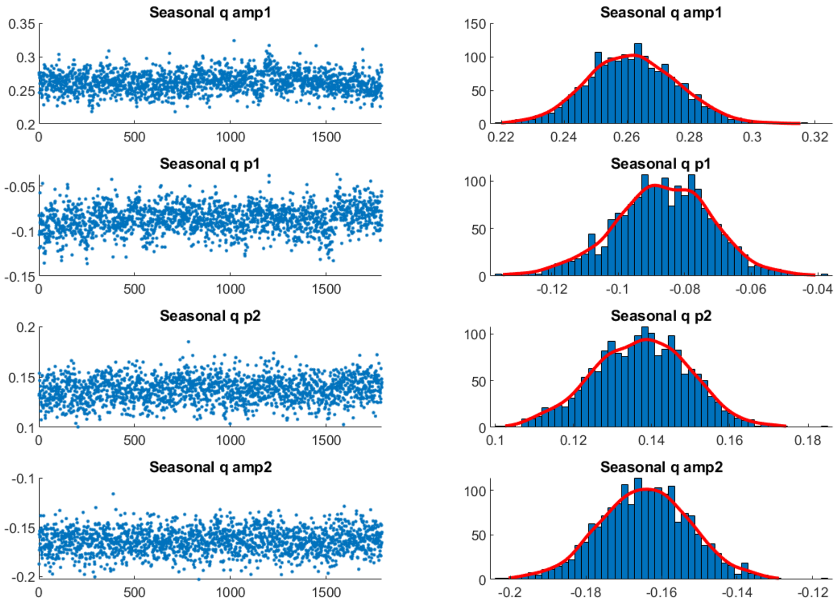

Figure 28: Trace plots and histograms for ς_1 (Seasonal q amp1), ϑ_1 (Seasonal q p1), ϑ_2 (Seasonal q p2), ς_2 (Seasonal q amp2)

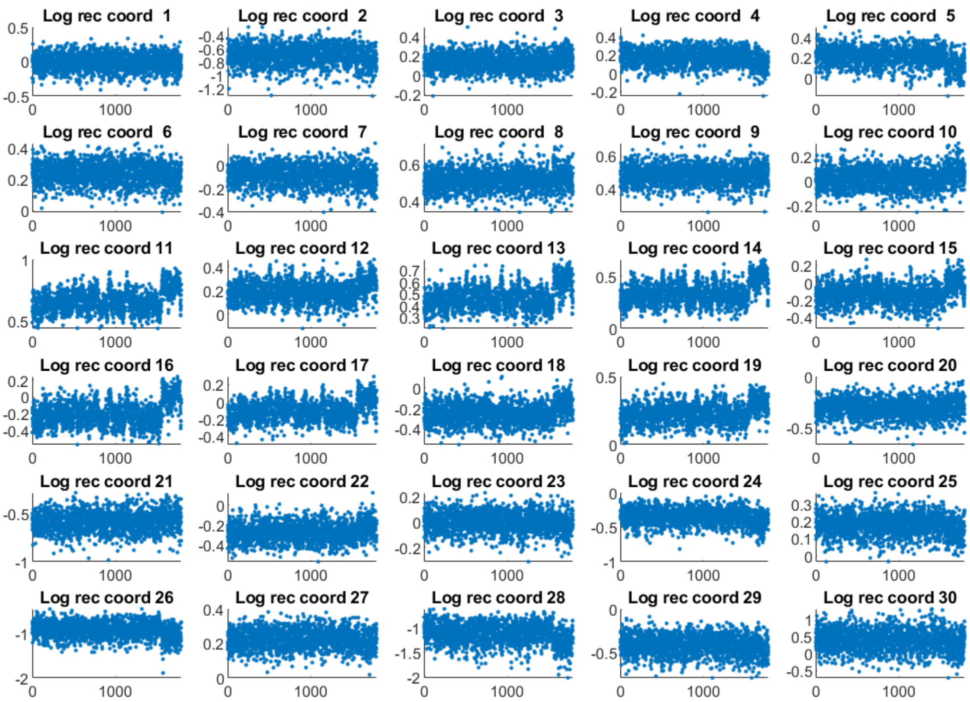

Figure 29: Trace plots for barycentric coordinates

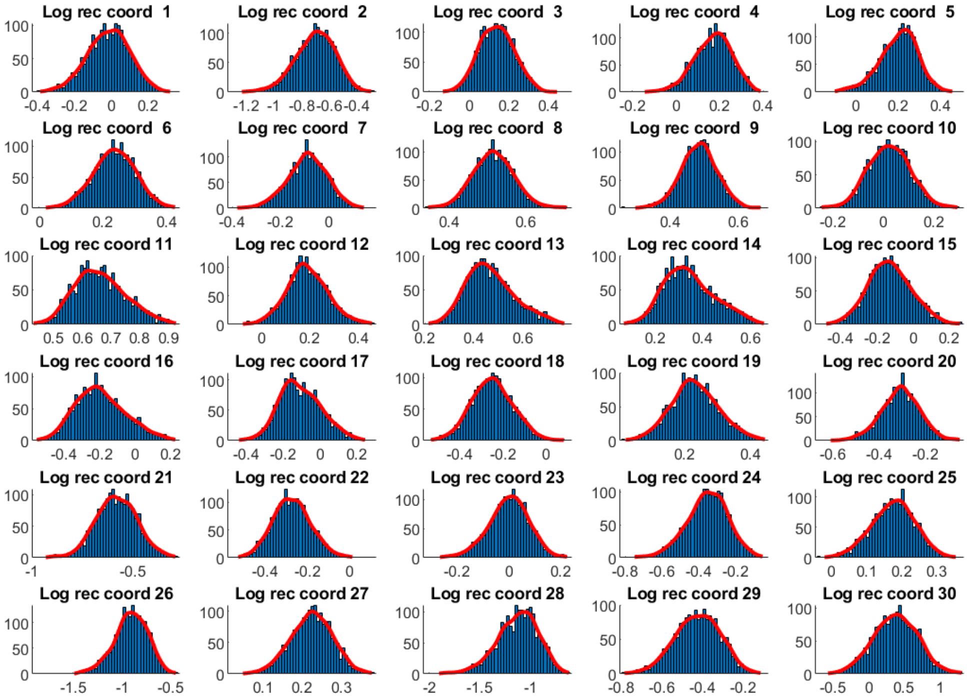

Figure 30: Histograms for barycentric coordinates

E.2 Barycentric coordinates

Table 7: Estimated barycentric coordinates ζ

Estimated value	Standard error	Median	lower CI	upper CI
0.0358	0.1008	-0.0100	-0.2462	0.2035
-0.5975	0.0993	-0.6974	-1.0067	-0.4497
0.1203	0.0987	0.1390	-0.0259	0.3132
0.2353	0.0846	0.1767	-0.0112	0.3244
0.2833	0.0800	0.2125	-0.0018	0.3654
0.2456	0.0802	0.2351	0.1033	0.3630
-0.0806	0.1027	-0.0869	-0.2631	0.0646
0.4855	0.0677	0.5158	0.4107	0.6283
0.4574	0.0714	0.4838	0.3754	0.5883
-0.0158	0.0987	0.0220	-0.1339	0.1906
0.5339	0.0712	0.6577	0.5138	0.8497
0.1488	0.0856	0.1837	0.0271	0.3657
0.3520	0.0726	0.4573	0.2988	0.6863
0.2243	0.0748	0.3324	0.1646	0.5678
-0.2403	0.0835	-0.1338	-0.3533	0.1169
-0.3757	0.0891	-0.2068	-0.4277	0.1052
-0.2486	0.0863	-0.1145	-0.3072	0.1244
-0.3233	0.0910	-0.2494	-0.4321	-0.0625
0.1382	0.0733	0.2279	0.0946	0.3778
-0.3224	0.0876	-0.3056	-0.4884	-0.1499
-0.6356	0.0983	-0.5817	-0.7766	-0.3812
-0.3495	0.0889	-0.2736	-0.4398	-0.0900
-0.0218	0.0884	0.0039	-0.1661	0.1378
-0.3021	0.0974	-0.3481	-0.5891	-0.1474
0.1863	0.0771	0.1793	0.0498	0.2910
-0.7843	0.1239	-0.9044	-1.2884	-0.6086
0.2289	0.0815	0.2252	0.1159	0.3232
-0.9616	0.1205	-1.1222	-1.5815	-0.7902
-0.4015	0.0977	-0.4170	-0.6460	-0.2148
0.3222	0.1402	0.3859	-0.2281	0.9783

Appendix F - Model fits

F.1 Catch rate fits

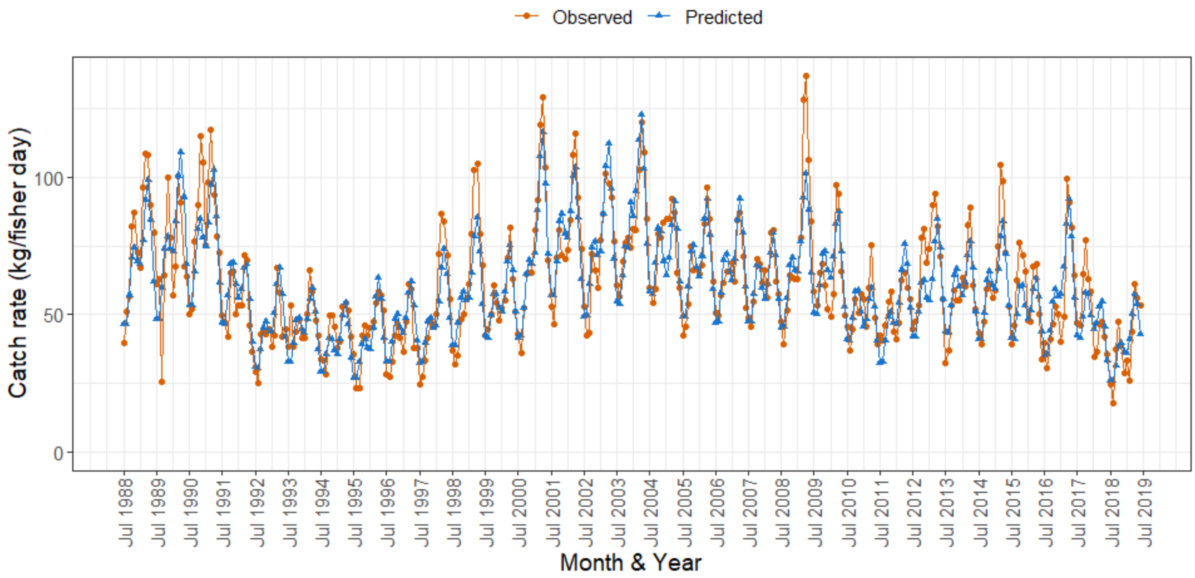

Figure 31: Model fit to the commercial catch rate for Queensland east coast

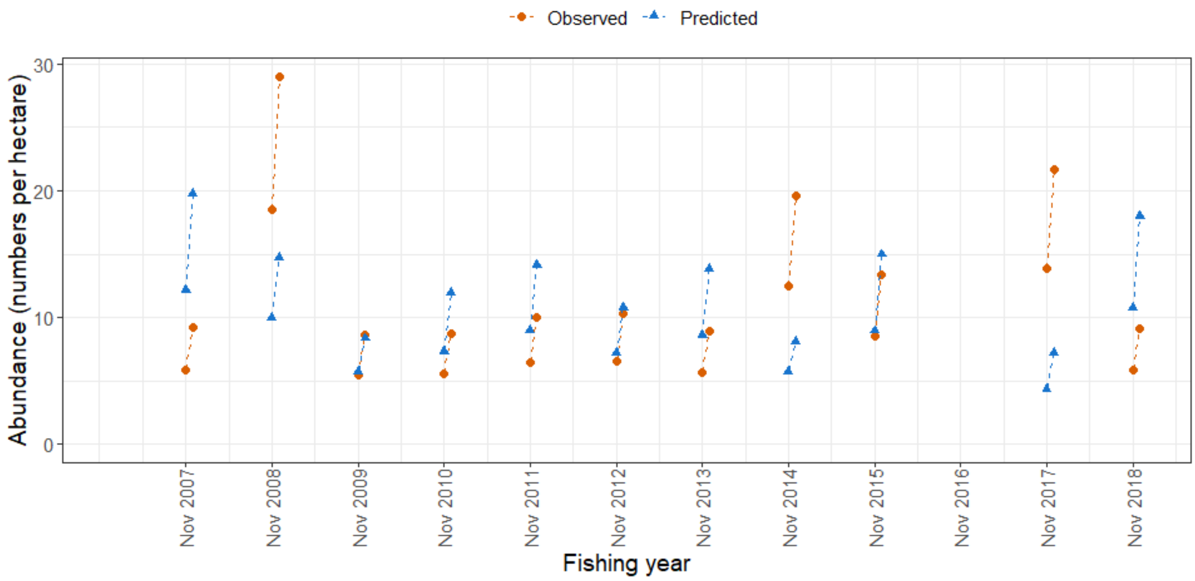

Figure 32: Model fit to the fishery-independent beam trawl abundance index for the months of November and December each year

F.2 Size composition fits

The effective sample size for each size composition has been adjusted to 10% of the original effective sample size as the model negative log likelihood has been set at 10% for these fits. Each of the fits (Figure 33, Figure 34 and Figure 35) display a satisfactory fit to the model.

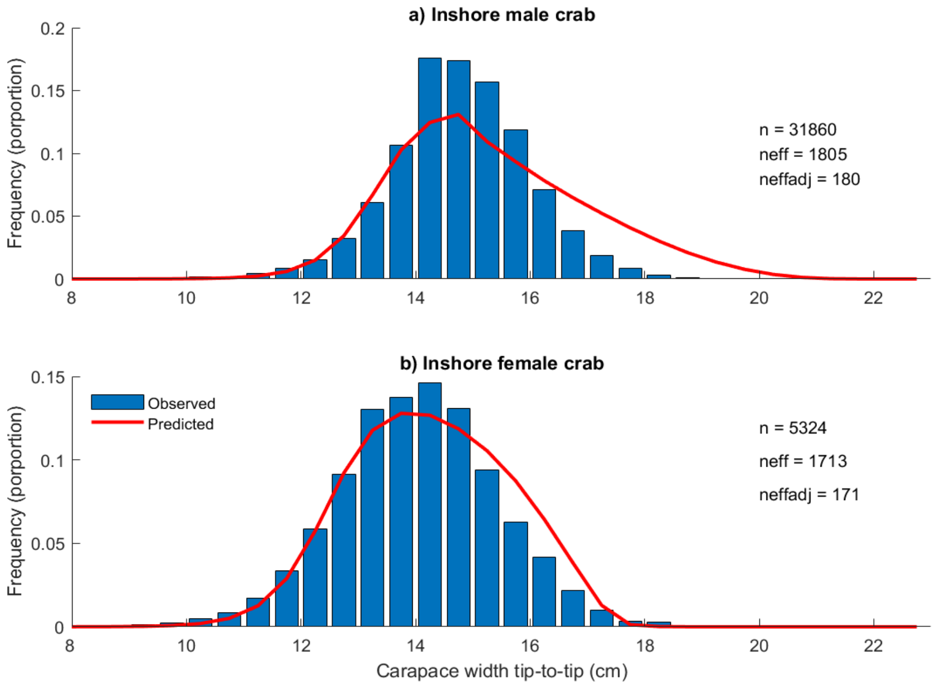

Figure 33: Distribution of observed (input) and predicted (model) size (carapace width) composition for fishery-dependent Queensland east coast Inshore Region. n is the number of samples input, neff is the effective sample size and neffadj is the adjusted effective sample size (as negative log likelihood fits were weighted at 10% to improve the model fit)

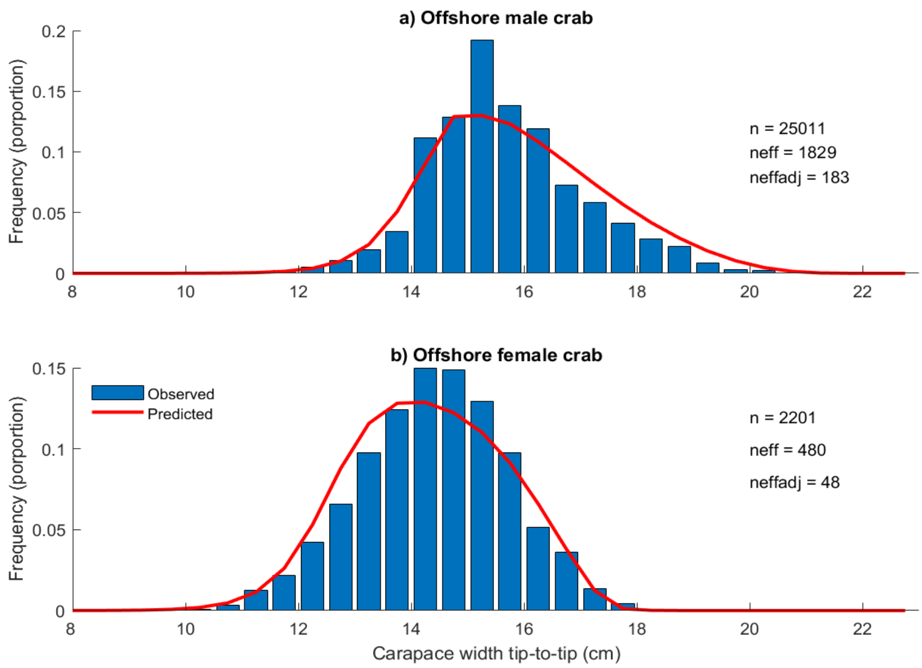

Figure 34: Distribution of observed (input) and predicted (model) size (carapace width) composition for fishery-dependent Queensland east coast Offshore Region. n is the number of samples input, neff is the effective sample size and neffadj is the adjusted effective sample size (as negative log likelihood fits were weighted at 10% to improve the model fit)

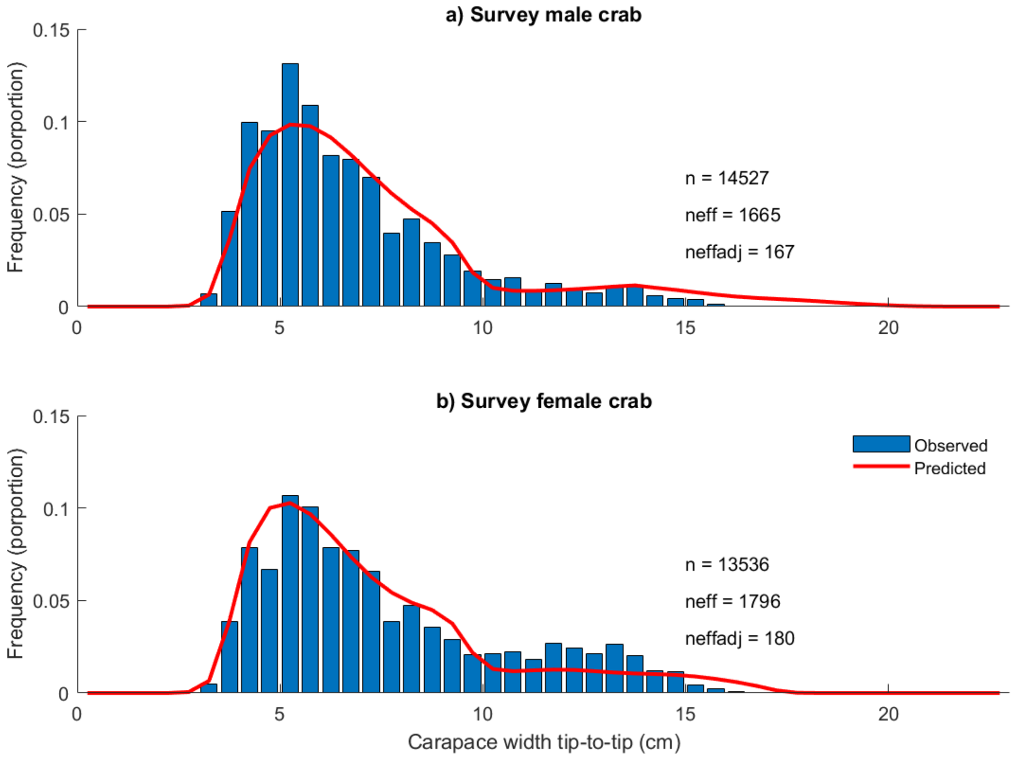

Figure 35: Distribution of observed (input) and predicted (model) size (carapace width) compositions for Fisheries Queensland fishery-independent beam trawl survey. n is the number of samples input, neff is the effective sample size and neffadj is the adjusted effective sample size (as negative log likelihood fits were weighted at 10% to improve the model fit)

Appendix G - Monthly exploitable biomass

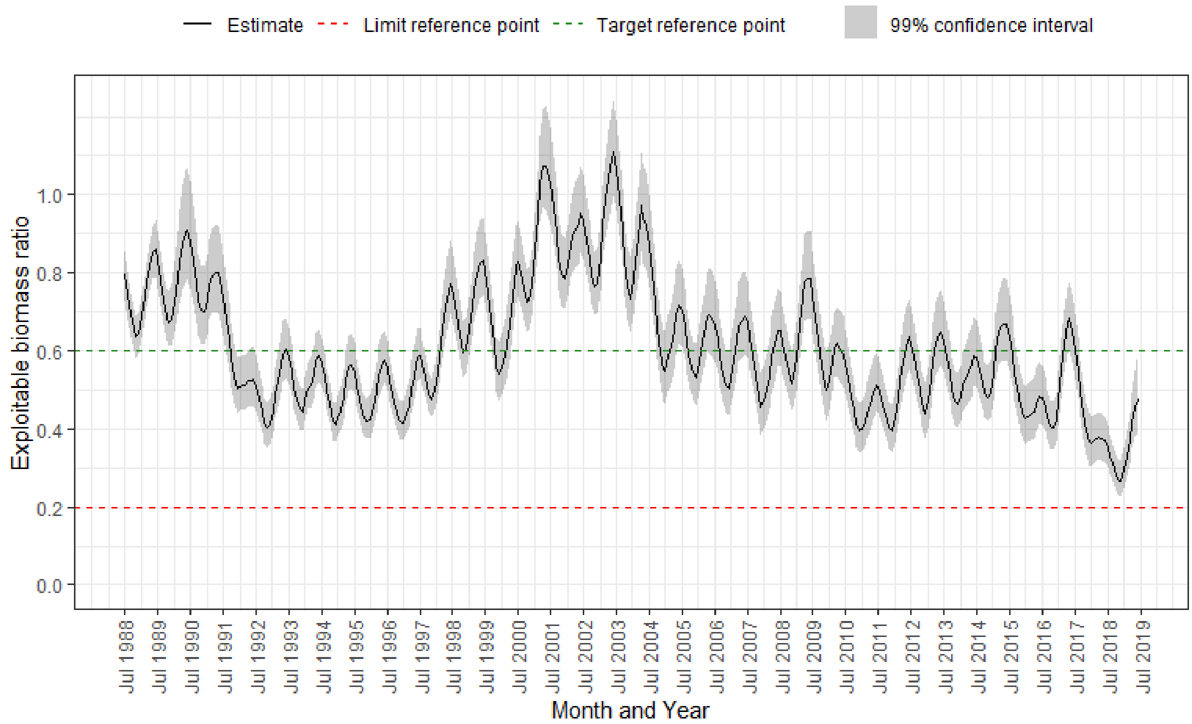

Figure 36: Monthly predicted exploitable biomass relative to virgin biomass for Queensland east coast blue swimmer crab

Appendix H - Projection scenarios

Forecast projections of different harvest scenarios (Figures 37, 38, 39, 40 and Table 8). Deterministic recruitment was assumed.

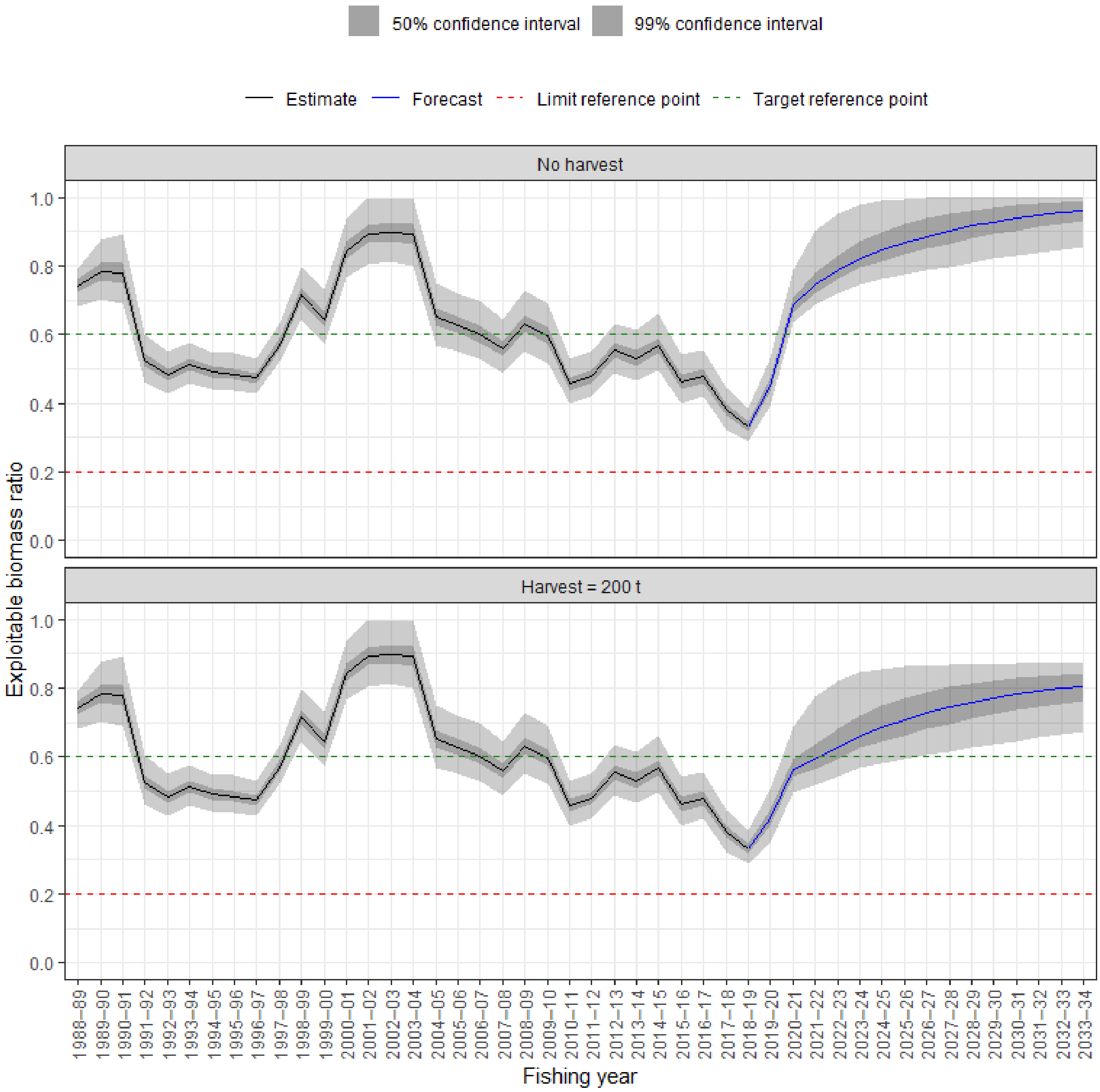

Figure 37: Forward projections of the exploitable biomass trajectory under harvest control scenarios: 0 t and 200 t constant harvest

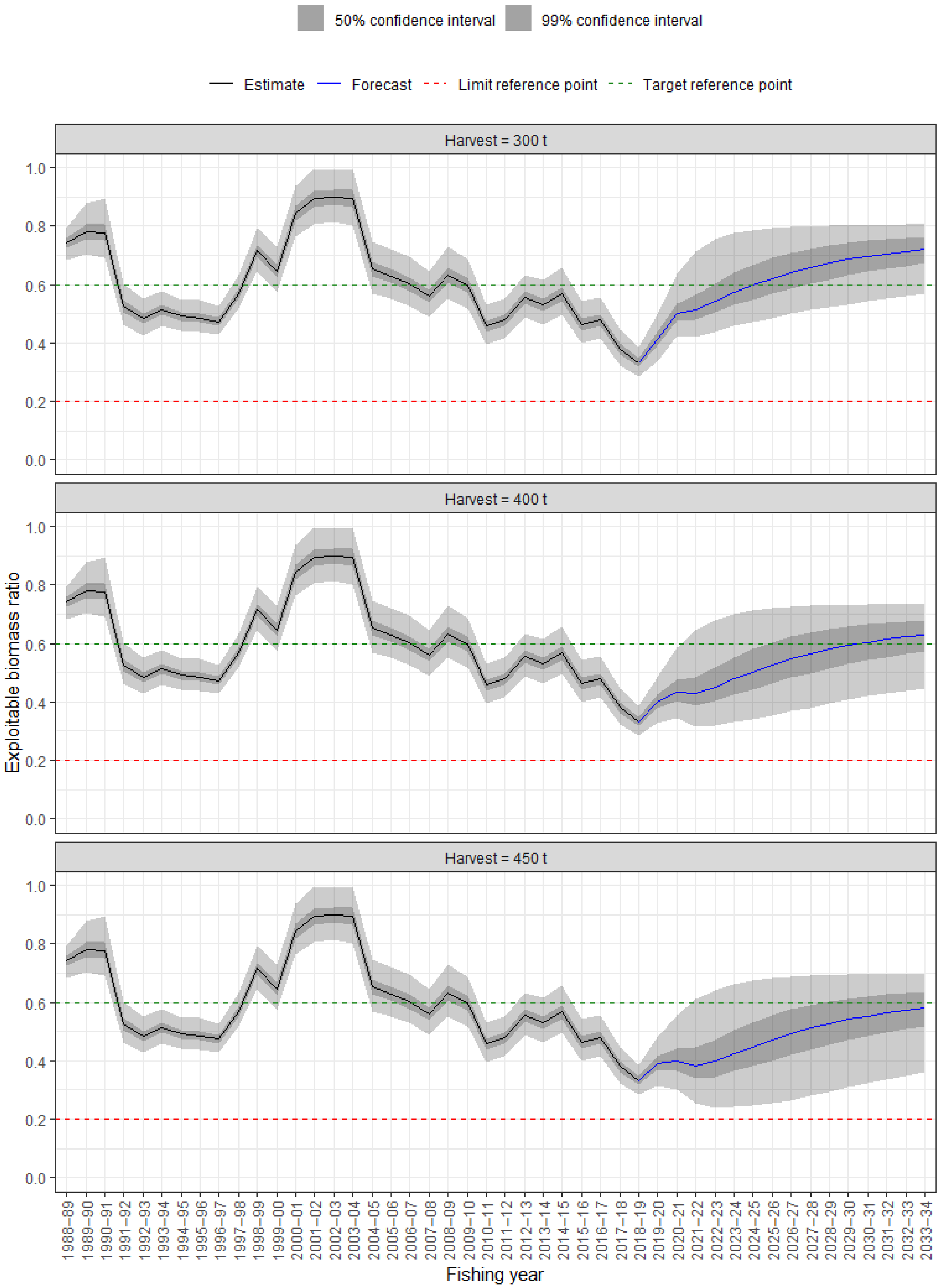

Figure 38: Forward projections of the exploitable biomass trajectory under harvest control scenarios: 300 t, 400 t and 450 t constant harvest

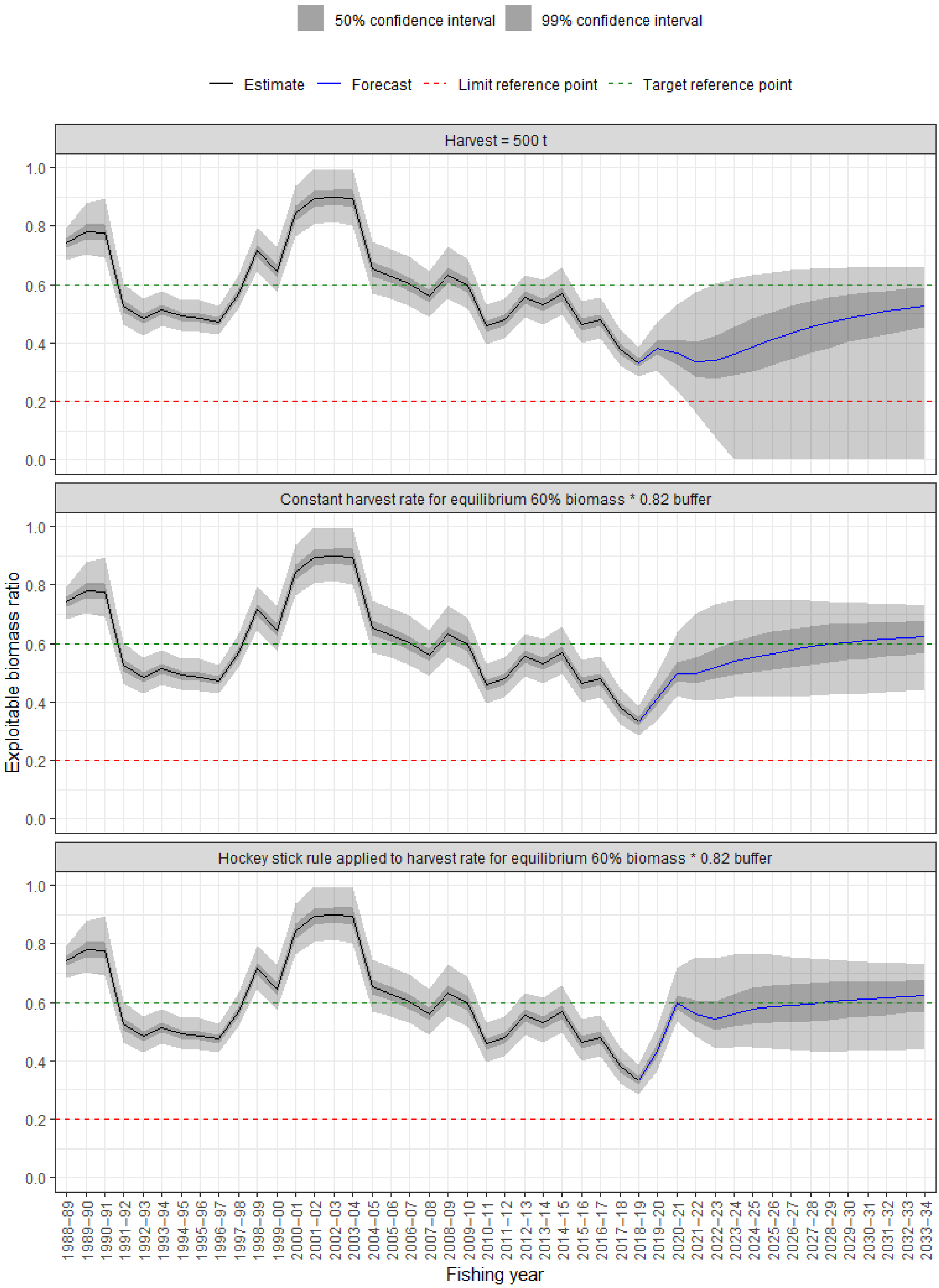

Figure 39: Forward projections of the exploitable biomass trajectory under harvest control scenarios: 500 t constant harvest, constant harvest rate for equilibrium 60% biomass × 0.82 buffer and hockey stick rule applied to harvest rate for equilibrium 60% biomass × 0.82 buffer

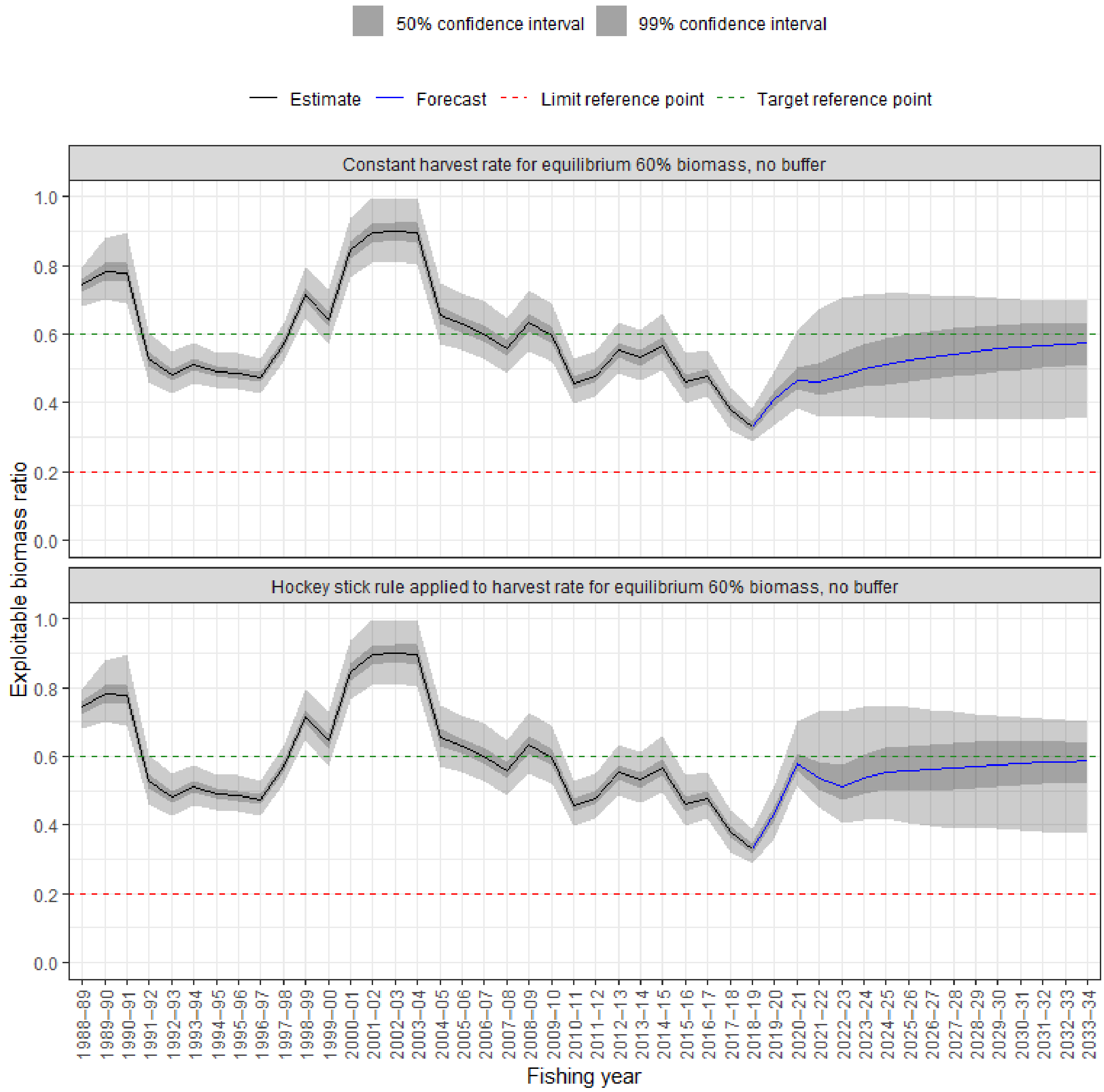

Figure 40: Forward projections of the exploitable biomass trajectory under harvest control scenarios: constant harvest rate for equilibrium 60% biomass and hockey stick rule applied to harvest rate for equilibrium 60% biomass, no buffer

Table 8: Annual harvests and resulting exploitable biomass ratios for each of the constant F_{60} and hockey stick harvest strategies without buffer

Fishing year	Harvest (t) for constant F_{60}	Exploitable biomass ratio	Harvest (t) for the hockey stick rule with F_{60}	Exploitable biomass ratio
2019–20	342.23	0.412	128.61	0.434
2020–21	368.04	0.498	268.22	0.597
2021–22	368.60	0.498	395.74	0.562
2022–23	385.48	0.518	345.72	0.542
2023–24	398.75	0.538	341.85	0.562