Stock assessment of Australian pearl perch (*Glaucosoma scapulare*) with data to December 2019

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Queensland Government

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Summary

This stock assessment indicates that biomass declined between 1880 and 2003 to 47% unfished biomass. Following a further period of decline since 2005, at the beginning of 2020 the stock level was estimated to be 22% unfished biomass.

Pearl perch, *Glaucosoma scapulare*, are endemic to sub-tropical offshore-waters along the east coast of Australia. Pearl perch form a single genetic stock in ocean waters between Rockhampton (23.20° S) in Queensland and Port Jackson (33.5° S) in New South Wales. The species live at least 25 years and have a maximum observed size of 75 cm total length. Sexual maturity is reached at 2–4 years of age (between 25 and 45 cm total length).

This assessment builds on a previous assessment that estimated the stock was at 10–40% of unfished levels in 2014. This stock assessment includes updates to input data and methodology.

This stock assessment was conducted on calendar years and included input data through to December 2019. All assessment inputs and outputs will be referenced on a calendar year basis.

This assessment used a single-sex, age-structured population model, fit to age and length data, constructed within the Stock Synthesis modelling framework. The assessment modelled the dynamics of the fishery across seven fishing sectors: 1) Queensland (Qld) charter line, 2) Qld commercial line, 3) Qld recreational, 4) New South Wales (NSW) charter line, 5) NSW commercial trap fishing, 6) NSW commercial line, and 7) NSW recreational.

The model incorporated data spanning the period 1984 to 2019 including daily logbook commercial catch collected by Fisheries Queensland (FQ; 1988—2019), logbook data collected by NSW Department of Primary Industries (DPI; 1997—2019), historic commercial catch from NSW DPI (1984–1997), logbook data collected by the Australian Fisheries Management Authority (AFMA; 2005–2019), charter logbook data collected by FQ (1988–2019), charter logbook data collected by NSW DPI (1997–2019), nine recreational telephone and diary surveys (six conducted by FQ, two conducted by NSW DPI and one conducted by the former Australian Department of Agriculture Fisheries and Forestry; 1999–2019), age and length data collected by FQ and NSW DPI (1999–2019) and boat registration data (1991–2016).

Over the last 5 years, 2015 to 2019, total retained catch averaged 66.9 tonnes (t) per year, including 41 t (61.3%) for Queensland and 25.9 t (38.7%) for New South Wales (Figure 1). The 2019 Queensland retained catch share has decreased slightly from the 5 year average (Table 1) which continues a trend of decreasing proportions seen since the 1990s and 2000s.

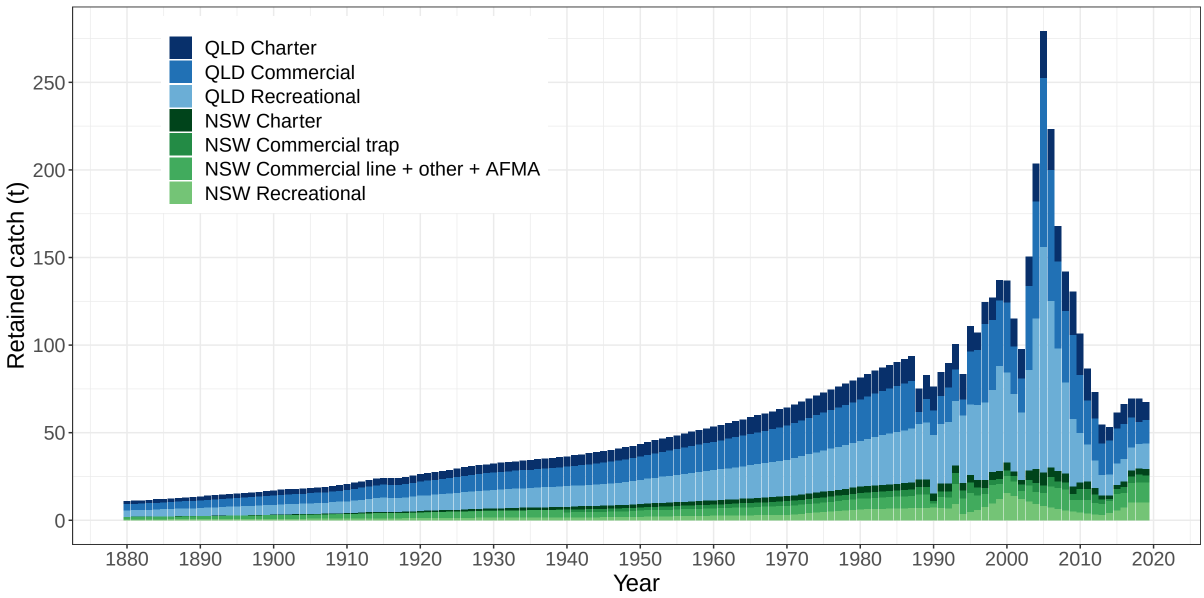

Figure 1: Annual estimated retained catch from commercial, recreational, and charter sectors between 1880 and 2019 for pearl perch

Queensland commercial and New South Wales commercial catch rates were standardised to estimate indices of pearl perch abundance through time. For Queensland commercial catch rates (Figure 2), the unit of standardisation was kilograms of pearl perch per 'operation-day', defined to be a single day of fishing by a primary vessel. Year, season, latitude and fishing operator were included as explanatory terms. For New South Wales commercial trap and line fishing (Figures 3 and 4), the unit of standardisation was kilograms of pearl perch per month. Year, calendar month, latitude, number of days fished and fishing operator were included as explanatory terms.

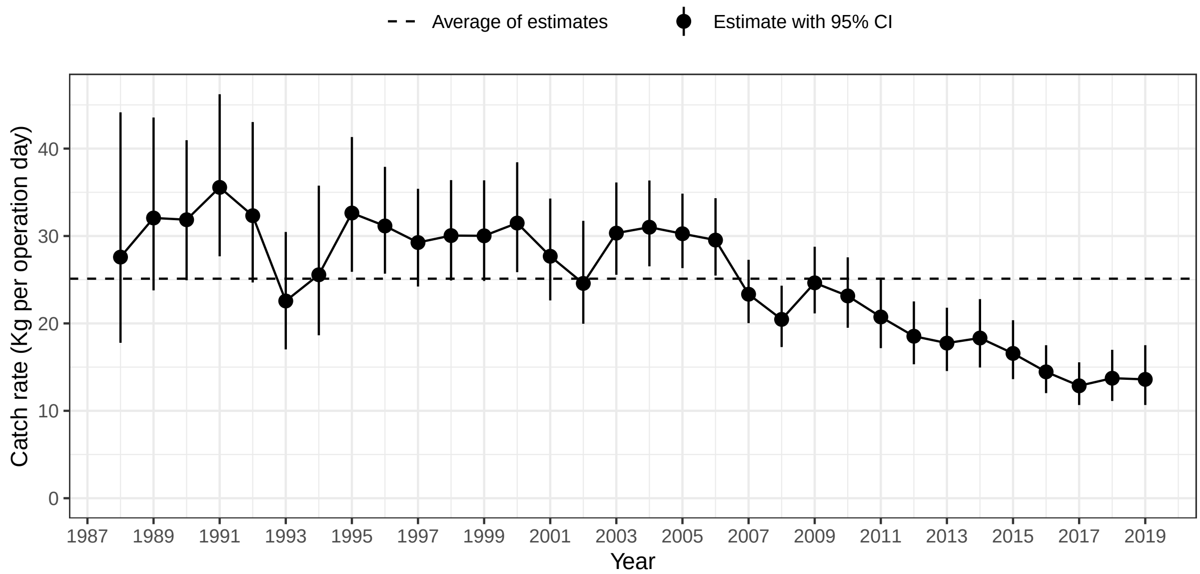

Figure 2: Annual standardised catch rates relative to average kg per day for Queensland commercial line-caught pearl perch between 1988 and 2019

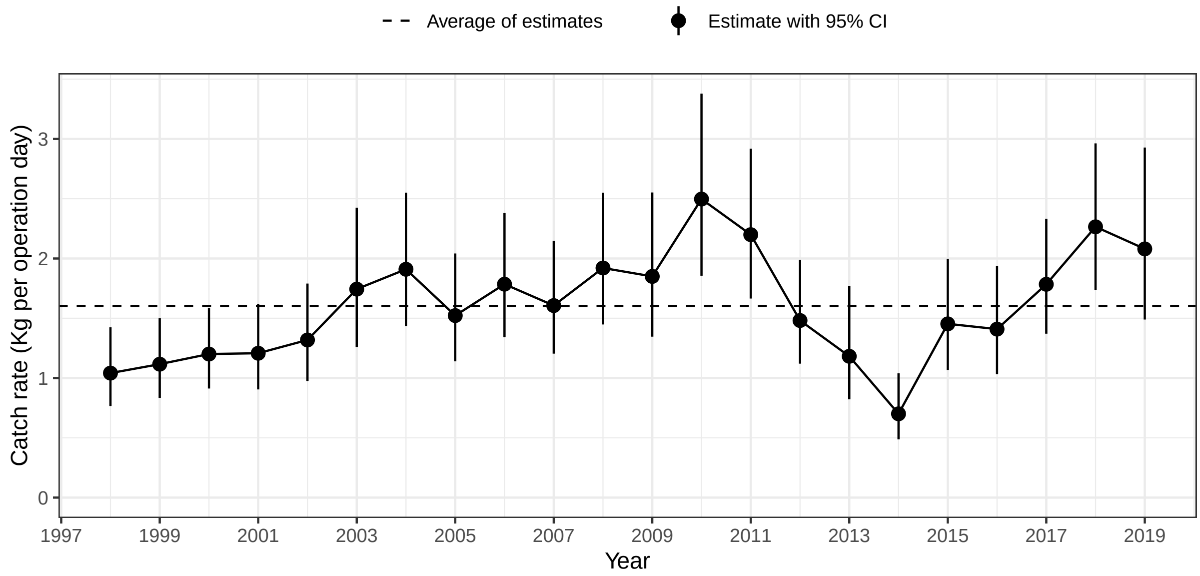

Figure 3: Annual standardised catch rates relative to average kg per day for NSW commercial trap-caught pearl perch between 1988 and 2019

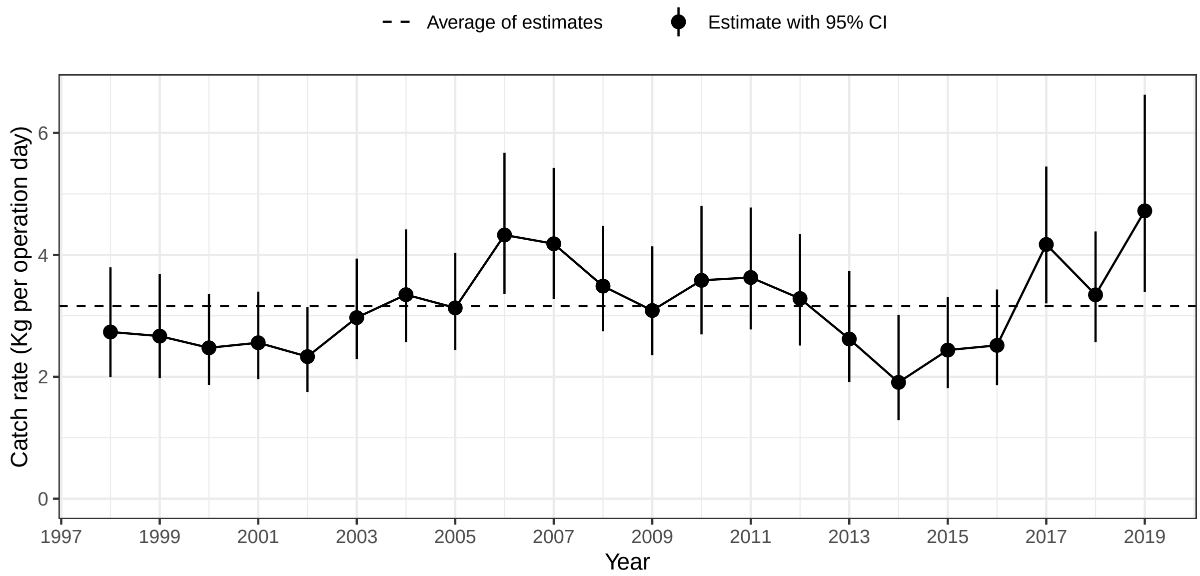

Figure 4: Annual standardised catch rates relative to average kg per day for NSW commercial line-caught pearl perch between 1988 and 2019

Sixteen scenarios were run, covering a range of modelling assumptions. Base case (Project Team recommended) results estimated spawning biomass to be 22% (14–46% range across scenarios) of unfished spawning biomass at the beginning of 2020 (Figure 5).

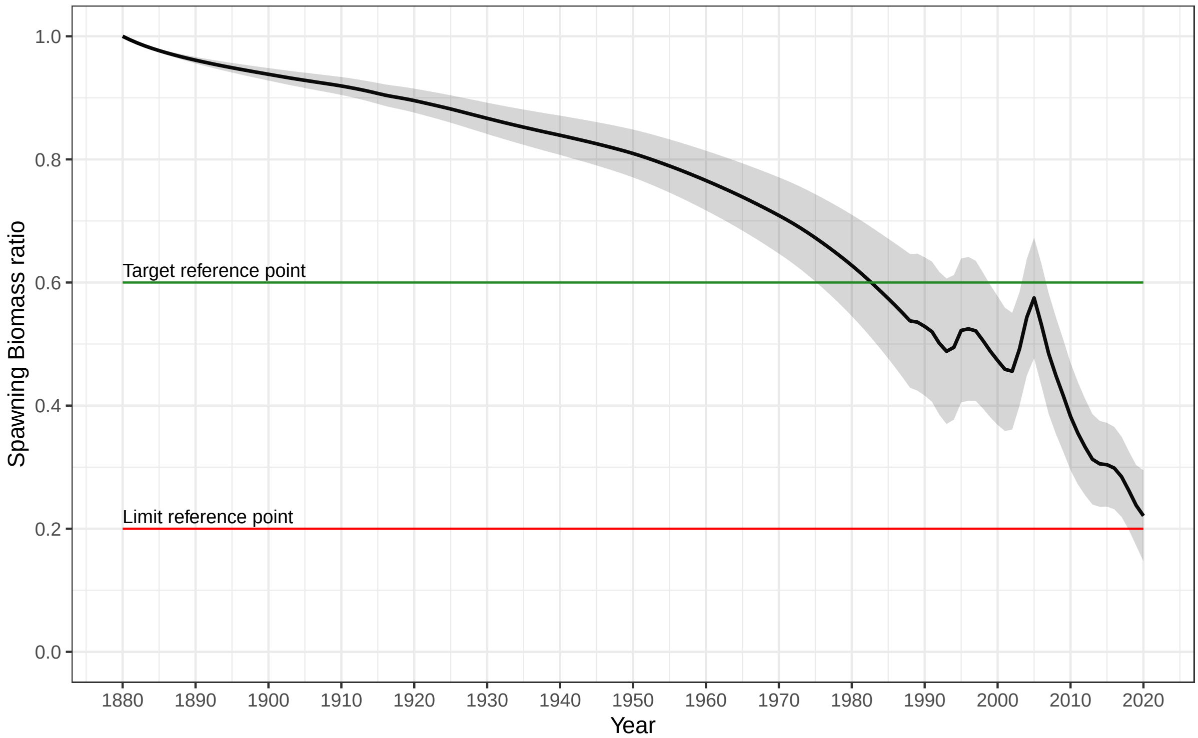

Figure 5: Predicted spawning biomass trajectory relative to unfished for pearl perch, from 1880 to 2020

The Sustainable Fisheries Strategy 2017–2027 sets out an objective for spawning biomass that aims to maximise economic yield, which in the absence of bio-economic modelling is represented by a proxy of 60%. The assessment recommends a biological catch of 1.24 t for 2020, with a retained component of 1.2 t (Table 1), to allow the stock to rebuild to 60% unfished spawning biomass. This will allow a longer-term biological retained catch of 62 t to be reached.

Table 1: Current and target indicators for Australian pearl perch

Indicator	Estimate
Biomass[◇] (relative to unfished) at the start of 2020	22% (14% to 46%)
Target biomass (relative to unfished)	60%
Biomass (relative to unfished) at MSY[⋆]	41%
MSY	74 t
Retained catch component of MSY	71 t
Retained catch in 2019	67.3 t
Queensland	38 t (56.4%)
New South Wales	29.3 t (43.6%)
Retained catch at 60% biomass target	62 t
RBC[†] for 2020 to achieve target	1.24 t
Retained component of RBC	1.2 t
Time to achieve target	> 20 years

[◇] Biomass is defined to be spawning stock biomass.
[⋆] MSY (maximum sustainable yield) is defined to be the maximum sustainable dead catch. That is, retained catch plus catch that dies following discarding.
[†] RBC (recommended biological catch) is the recommended catch according to the control rule. This is dead catch: retained catch plus catch that dies following discarding.

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Many sections of this report are reproduced from the comprehensive analysis carried out by Sumpton et al. (2017).

Glossary

AFMA	Australian Fisheries Management Authority. The Australian Fisheries Management Authority (AFMA) is the Australian Government agency responsible for the management of Commonwealth fish resources on behalf of the Australian community.
CI	confidence interval
fishing year	for pearl perch, fishing year is defined to be the same as calendar year
FL	fork length
fleet	a modelling term used to distinguish types of fishing activity: typically a fleet will have a unique curve that characterises the likelihood that fish of various sizes (or ages) will be caught by the fishing gear, or be observed by the survey
FP	fishing power, measures ‘a’ or ‘a group’ of fishing operations effectiveness in catching fish. More generally, fishing power refers to a measure of deviation in actual fishing effort from the standard unit of effort.
FRDC	Fisheries Research and Development Corporation
GLM	generalised linear model
ITQ	individual transferable quota
FM	Fisheries Monitoring Program (managed by Fisheries Queensland)
MLS	minimum legal size
MSY	maximum sustainable yield
NRIFS	the National Recreational and Indigenous Fishing Survey conducted by the Australian Department of Agriculture, Fisheries and Forestry
NSW	New South Wales
NSWDPI	New South Wales Department of Primary Industries
operation-day	a single day of fishing by a primary vessel, with year, month, region, number of dories and number of crew and combinations of these as example explanatory terms
Qld	Queensland
QFB	Queensland Fish Board
RBC	recommended biological catch, is the recommended catch according to the control rule. This is dead catch: retained catch plus catch that dies following discarding
REML	Restricted Maximum Likelihood (type of linear mixed model); method used to standardise catch rates
RFish	recreational fishing surveys conducted by Fisheries Queensland
SRFS	Statewide Recreational Fishing Survey
SS	Stock Synthesis
TL	total length

1 Introduction

Pearl perch, *Glaucosoma scapulare*, are endemic to sub-tropical offshore-waters along the east coast of Australia and are a valuable table fish popular with commercial and recreational fishers (McKay 1997). Pearl perch are considered to form a single genetic stock in ocean waters between Rockhampton (23.2° S) in northern Queensland and Port Jackson (33.5° S) in southern New South Wales (Roelofs et al. 2018; Stewart et al. 2013) (Figure 1.1).

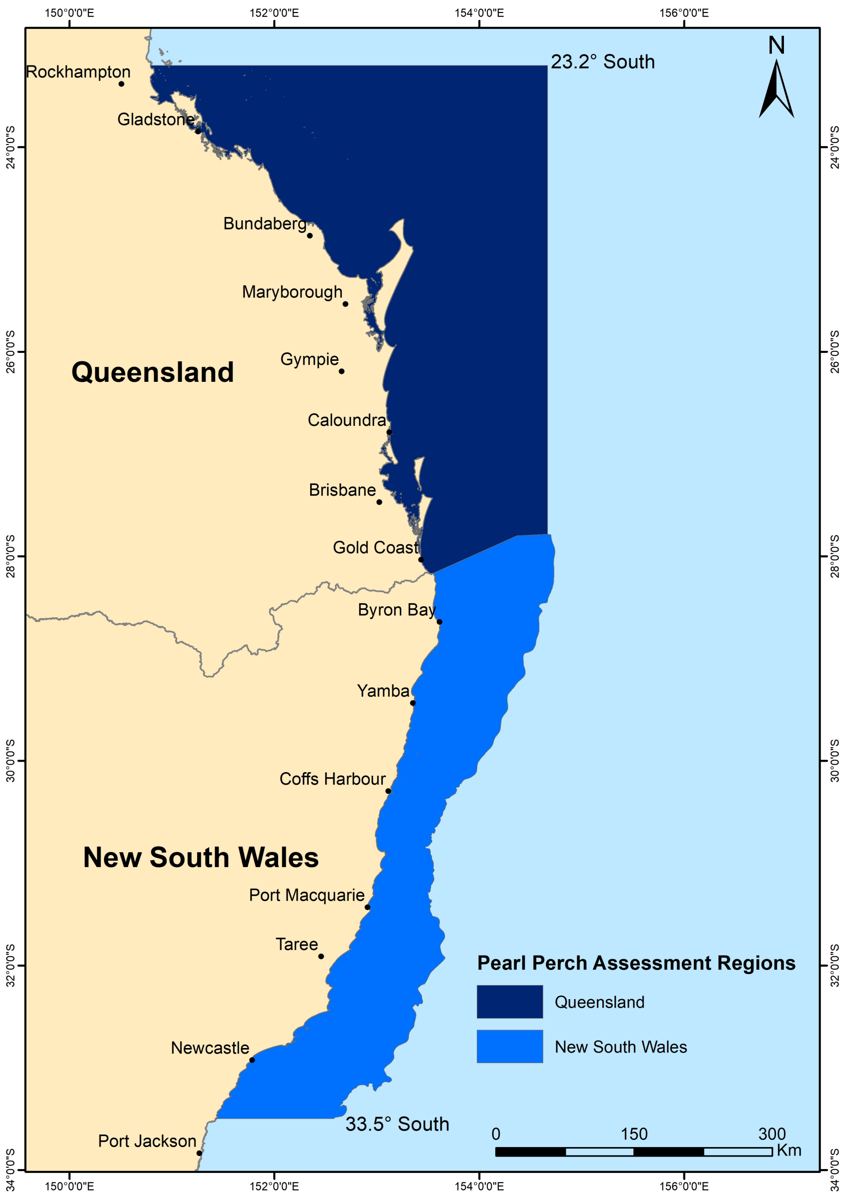

Figure 1.1: Pearl perch fishery in Queensland and New South Wales

Pearl perch have been observed in shallow rocky reef, deep rocky reef, deep gravel and deep sand habitats although predominantly occupy deep rocky reef habitats (Sumpton et al. 2017). They are generally found in waters deeper than 30 m, with observer data showing the majority of catch in Queensland waters occurring at depths between 100 m and 200 m (Sumpton et al. 2013a; Sumpton et al. 2013b;

Sumpton et al. 2017). Observer data from Sumpton et al. (2013b) also showed a significant correlation between the size of a pearl perch and the depth at which it is found, although the extent to this size/depth relationship is uncertain (Sumpton et al. 2013b). A study by Sumpton et al. (2013a) estimated post-release survival of line-caught pearl perch at about 90%. This survival was similar for legal (≥ 35 cm total length) and undersized (≤ 35 cm total length) fish (Sumpton et al. 2013a).

Very little is known about pearl perch migratory behaviour. A tagging study by Sumpton et al. (2013a) suggests that pearl perch movement is predominantly localised with only a few small fish moving substantial distances between release and recapture, although data were limited to 50 recapture observations (Sumpton et al. 2013a).

Female pearl perch mature at around 3 years of age at lengths 25–27.5 cm total length (Sumpton et al. 2013a). Sumpton et al. (2013a) determined natural mortality estimates ranged between 0.20 and 0.38. Pearl perch juveniles(i.e. fish younger than 3 years of age) are restricted to oceanic offshore areas (Sumpton et al. 2013a).

The maximum observed age from pearl perch catches is 25 years (Queensland Fishery Monitoring data). Sumpton et al. (2013a) determined pearl perch to be fully recruited to the fishery at around age 5 or 6. The maximum observed length from pearl perch catches is 75 cm total length. There is evidence that pearl perch grow faster in Queensland waters than they do in New South Wales waters (Stewart et al. 2013).

Historically, pearl perch were secondary targets for demersal line fishers, with snapper the most commonly caught reef-associated species. However, decreasing snapper bag limits and catch rates has seen pearl perch retained catch increasing in recent decades (Sumpton et al. 2013a). In addition, the uptake of new technologies such as GPS and sonar in recent decades has likely increased vessel efficiency, leading to increases in fishing power (Sumpton et al. 2013a).

In eastern Australia, some exemptions apply to Indigenous fishers catching pearl perch as part of the *Fisheries Act 1994 (Qld)*, *Fisheries Management Act 1994 (NSW)* and the *Native Title Act 1993 (Cth)*. The extent of Indigenous fishing activity on the fishery is unknown (Roelofs et al. 2018).

Fishery management measures have been legislated for the fishery in recent decades to lower fishing pressure and protect the resource for future use (Table 1.1). Current management measures in place for Queensland include a minimum legal size (MLS) of 38 cm total length, a recreational in possession limit of 5 fish and a 10 fish boat limit. Commercial restrictions include a total allowable commercial catch of 15 t. A seasonal closure (15 July to 15 August) was introduced in 2020. New South Wales management measures impose a MLS of 30 cm total length, a recreational bag limit of 5 fish and a requirement for escape panels in the ‘back’ of demersal fish traps.

Table 1.1: Management measures applied to pearl perch in Queensland and New South Wales waters

Date	Measure
Queensland	
1982	S35 permit: issued to recreational fishers who had caught more fish than they could use, and therefore were allowed to sell that portion of their catch that was deemed surplus to their requirements. *Fishing Industry Organization and Marketing Act 1982 (Qld) (FIOMA)*
1987	Offshore Constitutional Settlement (OCS) came into force
1988	Management of Demersal Reef Fish of the Superclass Pisces, other than Scombridae, caught by hand-line, drop-line, trolling-line or rod and line (including snapper and pearl perch) come under Queensland state jurisdiction via the Offshore Constitutional Settlement (OCS) *Arrangement between the Commonwealth and Queensland in relation to the Demersal Reef Fishery.*
1992	Moreton Bay Marine Park established
1993	Introduced MLS of 30 cm, recreational bag limit of 10 pearl perch per person *Fishing Industry Organisation and Marketing Amendment Regulation (No. 3) 1993, No. 235*
1994	removal of S35 permit. *Fisheries Act 1994*
Dec 2002	MLS of 35 cm, recreational bag limit of 5 pearl perch per person *Fisheries Amendment Regulation (No. 4) 2002 No. 339*
Sep 2003	Investment warning
Jul 2004	LF04 logbook introduced which had provision for the reporting of pearl perch
2009	rezoning of Moreton Bay Marine Park (increase to no-fishing zones)
March/April 2011	total ban on snapper, pearl perch and teraglin catches by all sectors for 6 weeks
Sep 2019	Urgent measures to protect snapper and pearl perch "depleted" stocks enacted: 1 month seasonal spawning closure; commercial competitive TACC 15 t for pearl perch; size limit increase for pearl perch to 38 cm TL; removed charter fishing extended trip bag limits; recreational bag limit of 4 pearl perch per person. Declaration commenced 28 May 2019. *Fisheries Declaration 2019*
2020	first seasonal closure for snapper and pearl perch to spawn (15 July–15 Aug)
New South Wales	
Jan 1998	Solitary Islands Marine Park areas closed to fishing
1998	Jervis Bay Marine Park areas closed to fishing
Feb 1999	Lord Howe Island Marine Park areas closed to fishing
prior to 2000	recreational daily bag limit of 5 fish *Fisheries Management Act 1994*
Nov 2002	Cape Byron Marine Park closed to fishing
Dec 2005	Port Stephens-Great Lakes Marine Park areas closed to fishing
Jun 2007	Batemans Bay Marine Park areas closed to fishing
Sep 2007	MLS of 30 cm TL
2008	'escape' panels of 50 x 75 mm mesh in the 'back' of demersal fish traps were introduced.

The stock was previously assessed with data through to 2014 by Sumpton et al. (2017) and predicted an exploitable biomass 10% to 40% of virgin levels in 2014.

In 2019, the Queensland Department of Agriculture and Fisheries commissioned an update to the stock assessment for pearl perch. This assessment aims to determine the status of the eastern Australian (Queensland and New South Wales) biological stock. This report informs estimates of sustainable retained catch to ensure the fishery operates at sustainable levels, for commercial, charter and recreational fishing, and support the harvest strategy defined in Queensland's Sustainable Fisheries Strategy 2017–2027.

This assessment contains updates to data and methodology and updates include:

- Stock Synthesis software was introduced to model the population and estimate parameters. The previous assessment used a custom model coded in Matlab (Mathworks 2017).
- The assessment modelled dynamics of the fishery into fishing sectors. The previous assessment grouped Queensland and New South Wales charter and commercial data. No such groupings were used in the current assessment.
- Recreational catch was estimated outside of the model whereas the previous assessment input known recreational catch data points to the model and then recreational catch was estimated within the model.

2 Methods

2.1 Data sources

Data sources included in this assessment (Table 2.1) were used to determine catch rates, create total annual catch (combining commercial, charter and recreational catches) and length and age compositions. Preparation of data were compiled annually in calendar years to align with abundance and reproduction peaks.

Table 2.1: Data sources compiled for input to the population model

Data	Years	Source
Commercial catch	1988–2019	Logbook data collected by Fisheries Queensland
	1997–2019	Logbook data collected by New South Wales Department of Primary Industries, Fisheries
	1984–1997	New South Wales historical commercial catch records
	2005–2019	Logbook data collected by AFMA
Charter catch	1988–2019	Logbook data collected by Fisheries Queensland
	1997–2019	Logbook data collected by New South Wales Department of Primary Industries, Fisheries
Recreational catch	1997, 1999, 2002, 2005	RFish - Survey conducted by Fisheries Queensland (Higgs 1999; Higgs 2001; Higgs et al. 2007; McInnes 2008)
	2000	NRIFS - National survey using a different methodology (Henry et al. 2003)
	2010–11, 2013–14, 2019–20	SRFS - NRIFS methodology adopted by Fisheries Queensland (Taylor et al. 2012; Webley et al. 2015; Teixeira et al. 2021)
	2013, 2017	New South Wales survey using similar methodology to the NRIFS (West et al. 2015; Murphy et al. 2020)
Biological data	1999–2019	Department of Primary Industries and Fisheries (2007), Fisheries Queensland (2009), and Fisheries Queensland (2019) and New South Wales Department of Primary Industries, Fisheries
Human population	1901–2011	Australian human population for each Australian state and territory (ABS 2014)
Boat registrations	1991–2016	Queensland and New South Wales boat registrations obtained from Sumpton et al. (2017)

2.1.1 Commercial

Queensland commercial data were sourced from the Fisheries Queensland compulsory logbook records, which began in 1988. These data contained daily entries where fishers recorded their retained catch of pearl perch in kilograms and the geographic location of each catch available in 30 or 6 minute grids. In 2004, the LF04 logbook introduced specific reporting of pearl perch (Table 1).

New South Wales commercial data were sourced from logbook data: 1997–2009 (monthly data) and 2010–2019 (daily data). Both sources were in kilograms of fish by region and fishing method.

Historical commercial catch data were sourced from New South Wales historical records: 1984–1997 (provided monthly) in kilograms of fish by region.

Daily records of the retained catch of pearl perch were provided by AFMA and covered the period 2005–2019. AFMA data covered the main fishing waters of east coast latitudes south of 26° S inclusive and north of 40° S inclusive.

2.1.2 Charter

The commercial logbook databases included data from the charter fisheries from both Queensland and New South Wales. These datasets provided the operator identifier, the date, the location fished, retained and discarded catch by species and the number of guests on the trip.

2.1.3 Recreational

All recreational surveys provided estimates of the number of pearl perch retained and discarded per trip and combined this with demographic information to estimate annual totals at state and regional scales.

2.1.4 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 retained catch and discard for Indigenous communities followed similar procedures to those in the recreational component of the survey (Henry et al. 2003). Data collected for this survey was limited to northern Australia (above Cairns) and hence Indigenous fishing data were not used for this assessment.

2.1.5 Biological data

Fishery dependent length compositions of pearl perch were monitored in New South Wales since 1999 and age and length compositions in Queensland since 2006. Fish samples were summarised for commercial, charter and recreational catch of pearl perch along the east coast of Queensland, and commercial trap and line catch of pearl perch from New South Wales. These data were given in fork length.

Queensland fisheries monitoring apply a scaling factor to the raw length data. When 100% of a fisher's catch cannot be sampled (i.e. when time constraints or circumstance do not permit each pearl perch in a catch to be individually measured), a representative sub-sample of the catch is measured and the percentage of the total catch that is sampled (PCS) is recorded (Department of Primary Industries and Fisheries 2007; Fisheries Queensland 2009; Fisheries Queensland 2019). The raw length data are then scaled by the percentage of the catch sampled (100/PCS). The scaled length frequencies are then weighted according to the proportion of the total annual retained catch reported (or in the case of the recreational sector, estimated) for each region thereby ensuring that the derived length distribution is representative of the entire Queensland catch. The resulting total sample size from the scaling and weighting process are upweighted, and are scaled down considerably via the modelling process by Francis variance adjustments (see Section 2.6.3). The age-length key was further applied to the length data outside of Stock Synthesis to produce age distributions. This method of using the age-length key external to the model was done to align with the previous assessment (Sumpton et al. 2017).

Commercial length data from NSW between 1993 and 2003 represents the whole commercial catch regardless of method (method was not recorded). For modeling purposes, this was assumed to be entirely line based catch.

2.2 Catch estimates

Commercial, charter and recreational catch data (where available) were analysed to reconstruct the history of retained catch from 1880 until the end of 2019. A start date of 1880 was chosen to keep in line with the snapper stock assessment. This section describes how these data were reconstructed to create a history of pearl perch retained catch (Figure 1).

A graphical representation of data used in the reconstruction is shown in Figure 2.1.

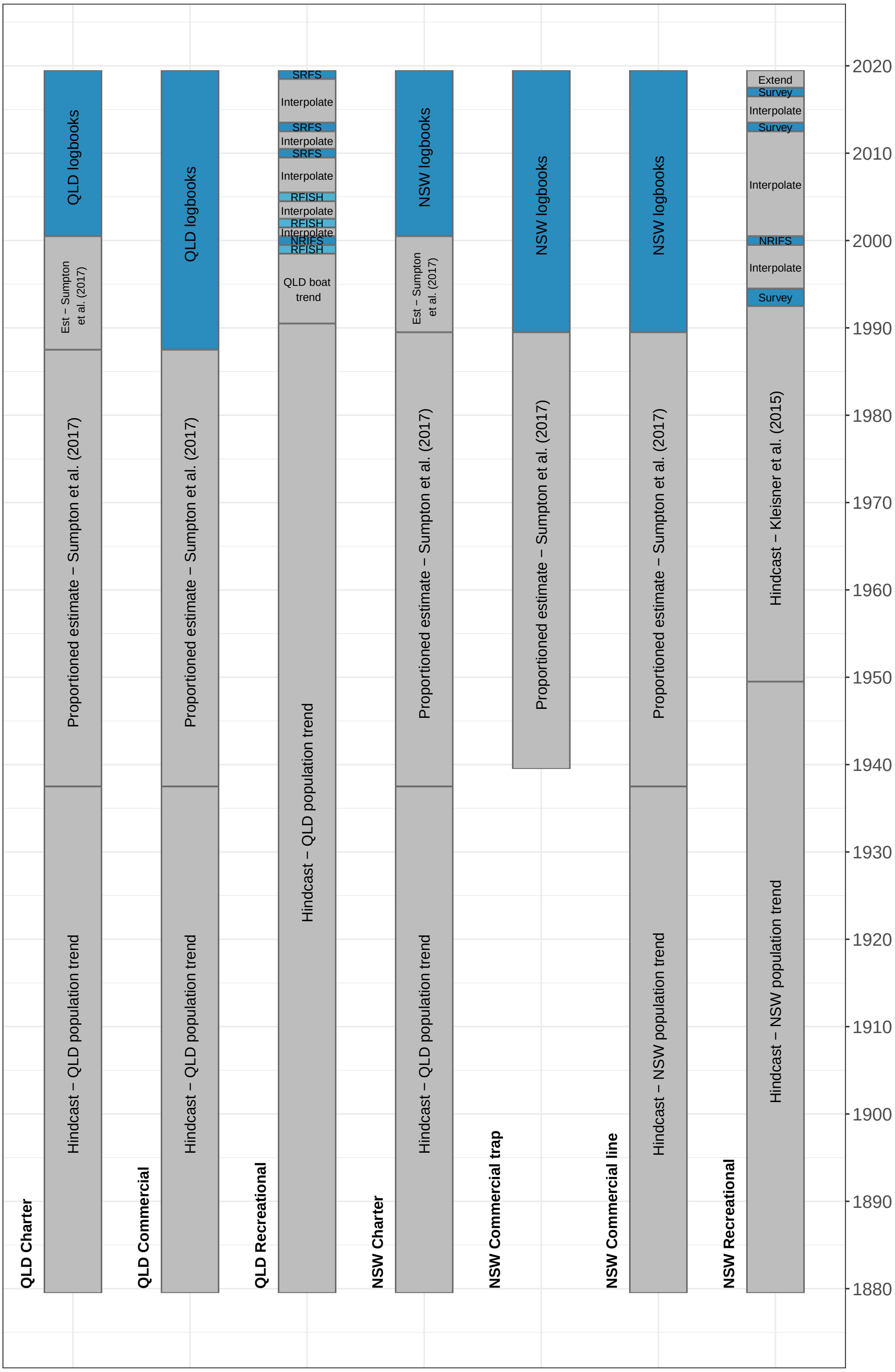

Figure 2.1: Data sources used for retained catch reconstruction of pearl perch for Queensland and New South Wales from 1880 to 2019

2.2.1 Commercial

Commercial retained catch estimates were calculated as follows:

1. Queensland

   1988–2019: Compile data sources into retained catch per calendar year using commercial logbook data.
   1938–1987: Charter and commercial fleets for Queensland and New South Wales grouped together were obtained from the past assessment estimate (Sumpton et al. 2017). A proportion was then taken from this data using the ratio of Queensland commercial to all fleet data from 1988–2014 (known data from past assessment).
   1880–1937: Hindcasting was performed by multiplying a vector of Queensland human population proportions by the derived average retained catch weight. This vector was created by taking the population number for each year and dividing by the population number in 1938 (ABS 2014). This vector was then multiplied by the retained catch generated for 1938 to create retained catch for the preceding years.

2. New South Wales

   1990–2019: Compile data sources into retained catch per calendar year using commercial logbook data.
   1988–1989: Obtained from past assessment estimate (Sumpton et al. 2017) and then proportioned over trap and line fleets.
   1938–1987: As for Queensland, fleets grouped together were obtained from the past assessment estimate (Sumpton et al. 2017). A proportion was then taken from this data using the ratio of New South Wales commercial to all fleet data from 1988–2014 (known data from past assessment). This was then further proportioned over trap and line fleets with the assumption that trap fishing commenced in 1940.
   1880–1937: Hindcasting was then performed by multiplying a vector of New South Wales human population proportions in a similar fashion to Queensland (ABS 2014).

2.2.2 Charter

Charter retained catch estimates were calculated as follows:

1. Queensland

   2001–2019: Compile data sources into retained catch per calendar year using charter logbook data.
   1988–2000: Obtained from past assessment estimate (Sumpton et al. 2017).
   1938–1987: Charter and commercial for Queensland and New South Wales fleets grouped together were obtained from the past assessment estimate (Sumpton et al. 2017). A proportion was then taken from this data using the ratio of Queensland charter to all fleet data from 1988–2014 (known data from past assessment).
   1880–1937: Hindcasting was then performed by multiplying a vector of Queensland human popu-

lation proportions in the same manner as the commercial hindcasting (ABS 2014).

2. New South Wales

   2001–2019: Compile data sources into retained catch per calendar year using commercial logbook data.
   1988–2000: Obtained from past assessment estimate (Sumpton et al. 2017).
   1938–1987: As for Queensland, fleets grouped together were obtained from the past assessment estimate (Sumpton et al. 2017). A proportion was then taken from this data using the ratio of New South Wales charter to all fleet data from 1988–2014 (known data from past assessment).
   1880–1937: Hindcasting was then performed by multiplying a vector of New South Wales human population proportions in the same manner as the commercial hindcasting (ABS 2014).

2.2.3 Recreational

Recreational retained catch estimates were calculated in four stages:

1. Scale RFish data.

   Queensland: 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). The RFish catch estimates were larger than would be expected based on the NRIFS and SRFS survey estimates and hence, the RFish estimates were adjusted. The RFish estimates from all years (1999, 2002 and 2005) were multiplied by the factor

   $$N_{2000}/\left(N_{1999}^{2/3}N_{2002}^{1/3}\right)$$

   where N_x represents numbers of fish in year x.

2. Convert numbers to weight.

   Queensland: Data provided were in numbers of fish retained. A weight multiplier per fish was used to convert these data (Table 2.2).

   Table 2.2: Average weights per fish for Queensland recreational pearl perch

Year	Weight	Source
1999–2002	1.2 kg	Higgs (1999), Higgs (2001), and Higgs et al. (2007)
2005	1.14 kg	McInnes (2008)
2010	1.19 kg	Taylor et al. (2012)
2013	1.13 kg	Webley et al. (2015)
2019	1.58 kg	Teixeira et al. (2021)

   New South Wales: Data for New South Wales were provided as a weight so no changes were necessary.

3. Hindcast.

Queensland: An average of the retained catch weights for the years 1999–2002 was taken for hindcasting.

Hindcasting to 1991 was performed by multiplying a vector of Queensland boat registration number proportions by the derived average retained catch weight (Sumpton et al. 2017). This vector was created by taking the number of registrations for each year and dividing by the number of registrations in 1999. Hindcasting to 1880 was then performed using a vector of Queensland human population proportions which was created in a similar fashion (ABS 2014).

New South Wales: Hindcasting to 1950 was performed using the methodology from (Kleisner et al. 2015). Participation rates sourced from Kleisner et al. (2015) and New South Wales human population numbers (ABS 2014) were used to create a vector of proportions relative to 1993. This vector was then applied to the average NSW recreational retained catch weight in 1993–1994.

4. Interpolate remaining years. This method follows Leigh et al. (2017).

   Queensland: Gaps were filled in the Queensland time series by loglinear interpolation of the available retained catch estimates. The retained catch for each interpolation year is given by

   $$C_{x+i} = C_x^{(d-i)/d} C_y^{i/d},$$

   where C_x and C_y represent the known retained catch for years x and y that we wish to interpolate between, the denominator $d = y - x$ and $i \in [1, (d-1)]$.

   New South Wales: The New South Wales time series gaps were filled in the same manner. In addition, for New South Wales, retained catch in each of the 2018 and 2019 years was assumed to be the same as the 2017 retained catch.

2.3 Abundance indices

Stock assessments for many fisheries rely on fishery-dependent catch and effort data to measure annual trends in the relative abundance of the stock (Hilborn et al. 1992). Where fishery-independent data through scientific surveys is not available, catch rates calculated from fishery-dependent catch and effort data are often relied upon and assumed to be proportional to underlying resource abundance (Cosgrove et al. 2014).

Queensland and NSW logbook data on commercial catches (kg whole weight for commercial) of pearl perch per fishing-operation-day were used as an index of legal-sized fish abundance. Methods for pearl perch catch rate standardisations were based broadly on the methods used in snapper (Wortmann et al. 2018) to align methods for rocky reef species.

The annual catch rate indices were calculated by year and latitude band. Each latitude's prediction was weighted by their total retained catch summed over all years. The latitude weightings w were scaled proportionally which satisfied $\sum_a w_a = 1$ and was kept constant over years. The spatial prediction methodology, of not changing weights through time, adhered to the concepts of Walters (2003), Carruthers et al. (2010) and Leigh et al. (2014).

R (version 4.0.2) was used to prepare data for the catch rate modelling. The statistical software package ASREML-R (version 4.1.0.130) was used to carry out the analyses. The standardisation approach used linear mixed (LMM) models. The LMM's used the REML algorithm allowing for model terms that can contain fixed and random effects.

2.3.1 Fishing power

The uptake rates of gears and technology (Sumpton et al. 2013b; Thurstan et al. 2016), and fishers perceptions on how advances in fishing technology had improved their catches over time, were combined in Wortmann et al. (2018) to calculate four time series of annual increases in fishing power for the rocky reef fishery. The effect of including fishing power lowers the catch rates, because in more recent years with modern gear and technology, it has become easier to find and catch fish than in earlier years. The effect of standardisation lowers catch rates in later years. The calculated series was used in the current analysis for the commercial catch rate standardisation. Four scenarios were tested:

1. no change in fishing power
2. reduced fishing power from the square root of the approximate fishing power (a scenario where fishing power was lower than what was approximated from the data)
3. approximate fishing power as estimated from the fisher knowledge data
4. high fishing power from the 75th percentile of the approximate fishing power (a scenario where fishing power was higher than what was approximated from the data)

For the trap catch rates, "reduced" fishing power is assumed for the catch rate standardisation as set out by the "Inter-Jurisdictional Snapper Workshop" held in 2017 (Appendix 12 of Wortmann et al. (2019)). For line catch rates in the base scenario, "approximate" fishing power was used in the calculation of catch rates. Other fishing power scenarios are considered in depth in section 2.6.4.

It was assumed that there had been no change in fishing power between 2016 and 2019.

2.3.2 Queensland commercial

Variables that were accounted for in the Queensland line catch rate model to model the number of kilograms retained per day were:

- Latitude band
- Year (region of the record combined with the year of the record)
- Seasonal variables as defined by Marriott et al. (2014). Trigonometric functions that used sine and cosine functions were used together to identify the seasonal patterns of catch rates corresponding to autumn, winter, spring and summer periods.
- Fisher (fisher license number)
- Fishing power as defined in Wortmann et al. (2018)

In July 2004, the LF04 logbook was introduced which had specific provision for the reporting of pearl perch. This resulted in a change in the way pearl perch was reported within the catch rate series. To mitigate the effect of this change in the catch rate standardisation, only the LMM was used.

This varied from that of other rocky reef species where the reporting of the species was consistent through the entire series (e.g. Wortmann et al. (2018)). The GLM component of the "two stage regression"—where the presence of an associated species, and the absence of pearl perch implied a zero catch of pearl perch, was not used for pearl perch in this assessment

2.3.3 New South Wales commercial

Trap and line data were separated and separate catch rate standardisations were run based on these fishing methods.

Variables that were accounted for in the New South Wales commercial catch rate model to model the weight of retained pearl perch per month (averaged to day for presentation purposes) were:

- Latitude Band
- Year (region of the record combined with the year of the record)
- Month
- Number of Effort Days in the month
- Boat

2.4 Discards and discard mortality

There are four techniques by which discards (and discard mortality) can be accounted for according to Punt (2019):

- Ignore them if minimal and not size-specific
- Add them to the catch; selectivity must account for them
- Model them as their own fleet
- Model a retention curve that interacts with selectivity and discard mortality

This assessment used a simple method and added them to the catch. This was due to the paucity of data available on discard ratios and discard lengths over time. Possible discard rate estimates (largely moment in time estimates) were available from the logbooks from a variety of sources for the various fleets:

- Queensland charter: 36% from Queensland Charter Logbooks)
- Queensland recreational: 63% from boat ramp surveys and diary surveys
- NSW charter: 57% from Gray et al. (2016)
- NSW commercial trap: 13% from Stewart et al. (2003)
- NSW commercial line: 13% from Macbeth et al. (2016)
- NSW recreational: 46% from Murphy et al. (2020)

Discard ratios for the Queensland commercial fishery are unknown, and were assumed to be the same as the NSW line fishery (13%). In all likelihood, the discard rates differ. But due to a dearth of reliable quantitative assessments of discards on the snapper commercial line fishery, particularly in Queensland, it was prudent to turn to the only available data on discard rates (i.e. that of the NSW line fishery).

Discarded catches were also subject to a fixed discard mortality of 10% across all sizes for all sectors (based on Sumpton et al. (2017)). The expected weight of the dead discards were added to the total reported retained catch for the year as input into the model.

All retained catch recommendations and values calculated by the model were then reduced by the total amount of dead discards, which equated to multiplying the output from the model by approximately 97% to obtain the actual retained portion of the catch.

2.5 Biological information

2.5.1 Length conversion

MLS restrictions imposed by fishery management use total length of fish. Scientific measurement of length data collected use fork length. The following formulae were used to relate total length (TL) to fork length (FL) of pearl perch, both measured in centimetres (Sumpton 1998):

$$FL = (TL + 0.415)/1.062 \tag{2.1}$$

2.5.2 Weight conversion

Fishery models are commonly structured by length (fork length) whereas commercial fishery catches are measured by weight. The following formula is used for converting total length TL, in cm to weight W, in kg (Sumpton et al. 2013a; Sumpton et al. 2017):

$$W = 3.96 \times 10^{-5}\ TL^{2.7528} \tag{2.2}$$

2.5.3 Growth

von Bertalanffy growth curve parameters were sourced from Sumpton et al. (2013a). These parameters were based on the relationship:

$$L_a = L_\infty(1 - e^{-\kappa(a-t_0)}) \tag{2.3}$$

where $L_\infty = 70.68$ cm, $\kappa = 0.156$ yr^{-1} and $t_0 = -0.502$ yr. As the L_∞ parameter was given in total length a conversion to fork length was required. Applying Equation 2.1, the value in fork length becomes $L_\infty = 70.46$. For use in the model, it was also necessary to reparameterise the von Bertalanffy equation to:

$$L_a = L_0 e^{-\kappa a} + L_\infty(1 - e^{-\kappa a}) \tag{2.4}$$

giving $L_\infty = 70.46$ cm, $\kappa = 0.156$ yr^{-1} and $L_0 = 5.31$ cm as model inputs.

2.5.4 Maturity

Maturity (m) was input to the model as a function of age where:

$$\begin{aligned} m_a = [&0.1949, 0.5123, 0.7866, 0.9240, 0.9748, 0.9914, 0.9968, 0.9987, 0.9995, \\ &0.9998, 0.9999, 0.9999, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1]. \end{aligned} \tag{2.5}$$

This vector of maturity at age was obtained from calculations performed in Sumpton et al. (2017).

2.5.5 Fecundity

Female batch fecundity (number of eggs) were based on the relationship estimated by Sumpton et al. (2013a) (Equation 2.6). This relationship was also used in the previous assessment (Sumpton et al. 2017). The parameters used were derived for total length measurements, however, due to a negligible difference between total length and fork length measurements and in the absence of parameters derived for fork length measurements, these parameters were considered acceptable.

$$W = 89.044\ FL^{2.2345} \tag{2.6}$$

2.6 Population model

An annual age-structured population model was fitted to the data to determine the number of pearl perch in each year and each age group using the software package Stock Synthesis (SS; version SS-V3.30.16). A full technical description of Stock Synthesis is given in Methot et al. (2019).

2.6.1 Model assumptions

For the base, assumptions for formulating inputs to the model included:

- The fishery began from an unfished state in 1880.
- The fraction of fish that are female at birth is 50% and remains so throughout an individual's life.
- Growth occurs according to the von Bertalanffy growth curve.
- The weight and fecundity of pearl perch are parametric functions of their size.
- The instantaneous natural mortality rate does not depend on age, size or sex.
- Deterministic annual recruitment is a Beverton-Holt function of stock size.

2.6.2 Model parameters

Parameters were estimated within the model where possible, to enable the best possible fit to available data. Uninformative priors were used. Other parameters were fixed at appropriate levels.

The natural logarithm of unfished recruitment ($\ln(R_0)$) was estimated within the model. This parameter was the natural logarithm of the number of recruits in 1880.

Stock recruitment steepness (h) was unable to be estimated within the model. Attempts to estimate this parameter resulted in h hitting the upper bound of 1. Hence h was fixed at 0.4 as a base case. This value is similar to values estimated in Sumpton et al. (2017) and is supported by a likelihood profile produced by the base case.

Parameters of the von Bertalanffy growth curve were fixed within the model including coefficients of variation.

Natural mortality rate (M) is the rate of the removal of fish from a population due to causes not associated with fishing (examples include predation or old age). M was estimated in the model, although scenarios where M was fixed at higher or lower levels were also trialled.

Logistic length-based selectivity parameters were estimated in the model for all line based fleets, separate selectivity curves were estimated for the Queensland and NSW fleets.

Recruitment deviations between 1988 and 2019 improved fits to composition data and abundance indices as variability in recruitment annually allowed for changes in the population on shorter time-scales than fishing mortality alone.

2.6.3 Model weightings

Data inputs were given equal weighting in the model. A Francis adjustment was applied to the age and length compositions within Stock Synthesis (Francis 2011). A nominal coefficient of variation (CV) of 0.1 was applied to the catch rates as described in Punt (2019) (example in Tuck (2014), as additional variance is calculated by Stock Synthesis. An automatic adjustment was made to each catch rate coefficient of variation and shown in the estimates tables.

2.6.4 Sensitivity tests and alternate scenarios

Sixteen additional model runs were undertaken to determine sensitivity to fixed parameters, assumptions and model inputs. Methodology was loosely derived from Burch et al. (2018).

Sensitivities were tested in five categories: Fishing power, natural mortality, steepness, catch rates, recreational catch and changing the start year of the model. Each component was varied from the base case to test the difference such a change would make:

- Three alternative fishing power scenarios were modelled; no change in fishing power, reduced fishing power and high fishing power
- Sumpton et al. (2017) fixed natural mortality at 0.289 with higher and lower values tested. This assessment estimated natural mortality with fixed levels of 0.2 and 0.32 tested
- Steepness values ranging 0.217–0.485 were estimated by Sumpton et al. (2017). A meta-analysis by Thorson (2020) provided values for the species at around 0.7. A likelihood profile was performed for the steepness parameter (Figure D.12). The profile indicated a best case for a steepness around 0.4, however certainty for this was low. For this assessment, steepness was fixed at 0.4 to maintain comparability with Sumpton et al. (2017) and values of 0.3, 0.5, 0.6, 0.7 and 0.8 were also tested
- As Queensland and New South Wales catch rates showed differing trends (in recent years in particular), scenarios were performed where only Queensland or only New South Wales catch rates were used
- Sensitivity to recreational dead catch estimates were investigated by testing scenarios with recreational catches reconstructed from survey data ± 1.96 times the standard error (se)
- The model simulation was changed from starting in 1880 in an unfished state, to starting in 1988 with an assumed equilibrium fishing mortality

Scenarios and their differences from the base case are shown below in Table 2.3.

Table 2.3: Scenarios tested to determine sensitivity to parameters, assumptions and model inputs

Model	Fishing Power	M	h	Catch Rates	Dead Catch	Start Year
base	approximate	est	0.4	All	reconstructed	1880
1	**none**	est	0.4	All	reconstructed	1880
2	**reduced**	est	0.4	All	reconstructed	1880
3	**high**	est	0.4	All	reconstructed	1880
4	approximate	**0.2**	0.4	All	reconstructed	1880
5	approximate	**0.32**	0.4	All	reconstructed	1880
6	approximate	est	**0.3**	All	reconstructed	1880
7	approximate	est	**0.5**	All	reconstructed	1880
8	approximate	est	**0.6**	All	reconstructed	1880
9	approximate	est	**0.7**	All	reconstructed	1880
10	approximate	est	**0.8**	All	reconstructed	1880
11	approximate	est	0.4	**QLD**	reconstructed	1880
12	approximate	est	0.4	**NSW**	reconstructed	1880
13	approximate	est	0.4	All	**low recreational**	1880
14	approximate	est	0.4	All	**high recreational**	1880
15	approximate	est	0.4	All	reconstructed	**1988**

2.6.5 Forward projections

Stock Synthesis's forecast sub-model was used to provide forward projections of biomass and future catch targets, following a harvest control rule defined by Fisheries Queensland (2021).

The harvest control rule, has a linear ramp in fishing mortality between 20% spawning 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_{B60}). Below 20% spawning biomass, fishing mortality remains set at zero, and above 60% spawning biomass fishing mortality remains set at F_{B60} (Figure 2.2). This shifting rate starts out small, which enables the stock to recover much more quickly and means that retained catches are not impacted for as long.

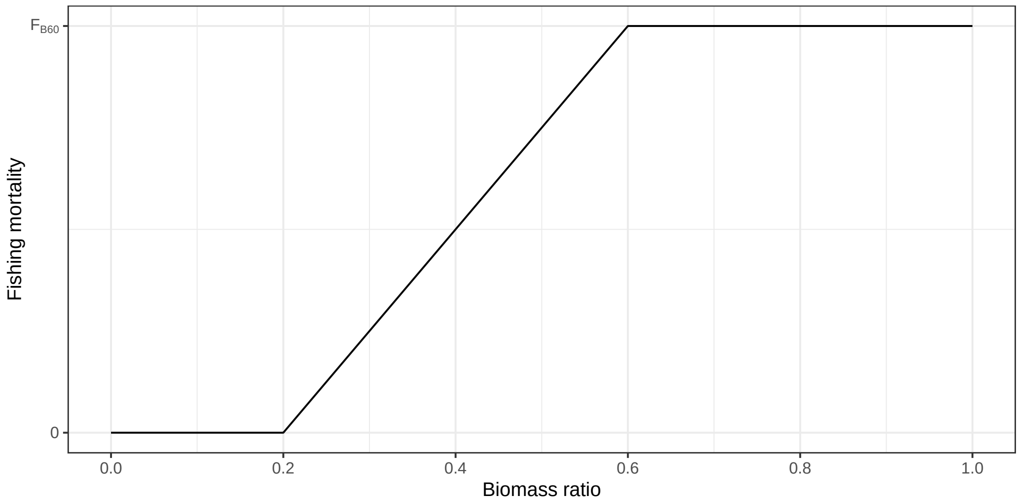

Figure 2.2: The harvest control rule (Fisheries Queensland 2021)

3 Results

3.1 Model inputs

Figure 3.1 summarises the estimated data used as input to the model.

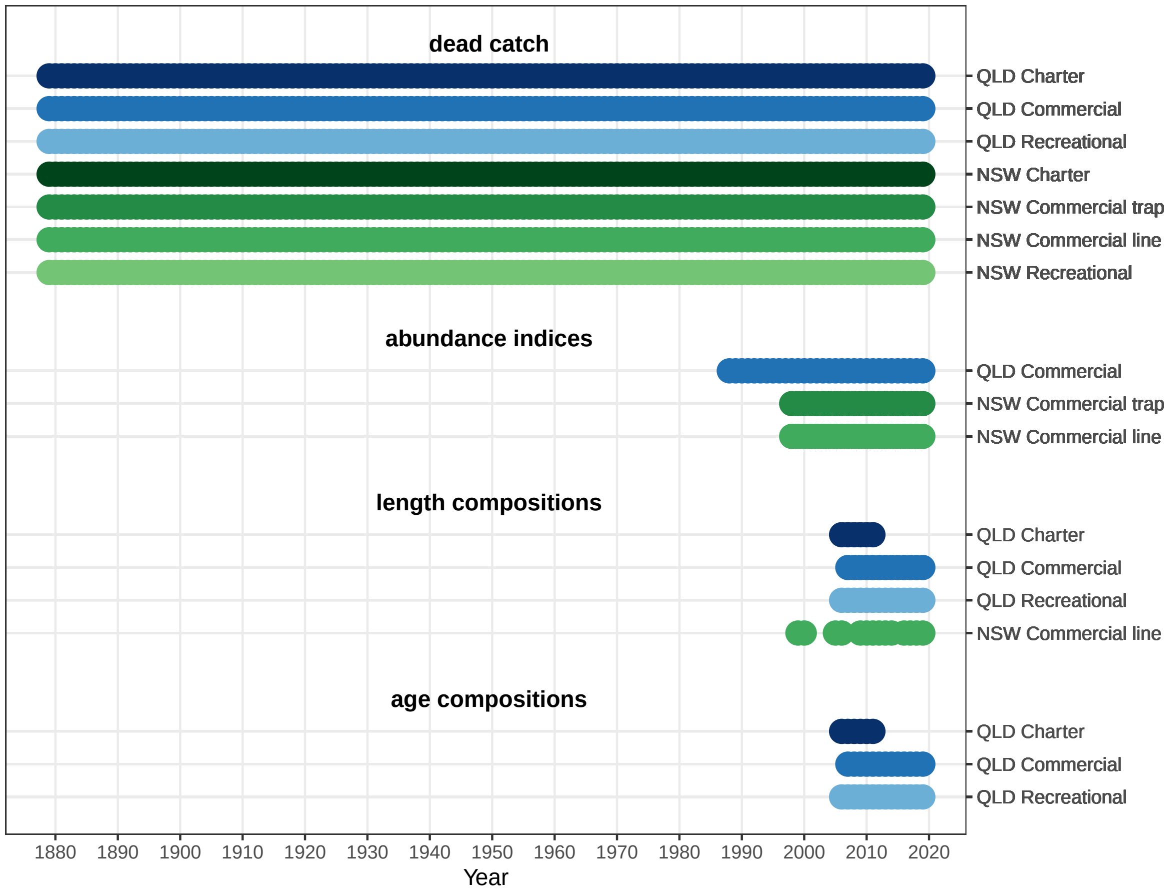

Figure 3.1: Data presence by year for each category of data type and sector for the pearl perch model

3.1.1 Catch estimates

The total retained catch consisted of catch from seven fleets: Queensland commercial, Queensland charter, Queensland recreational, New South Wales commercial line + other + AFMA, New South Wales commercial trap, New South Wales charter and New South Wales recreational (Figure 3.2). Retained catches show an increase from around 10 t at the beginning of the time series to a peak of just over 270 t in 2005, declining to around 50 t in 2014 and then a small increase to around 67 t in 2019. Of note is an increase in New South Wales catch share over the length of the time series.

Over the last 5 years (2015–2019) total retained catch averaged 66.9 t per year, including 41 t (61.3%) for Queensland and 25.9 t (38.7%) for New South Wales (Figure 1). The 2019 Queensland retained catch share has decreased slightly from the 5 year average which continues a trend of decreasing proportions seen since the 1990s and 2000s. Retained catch shares for 2019 are shown in Table 3.1.

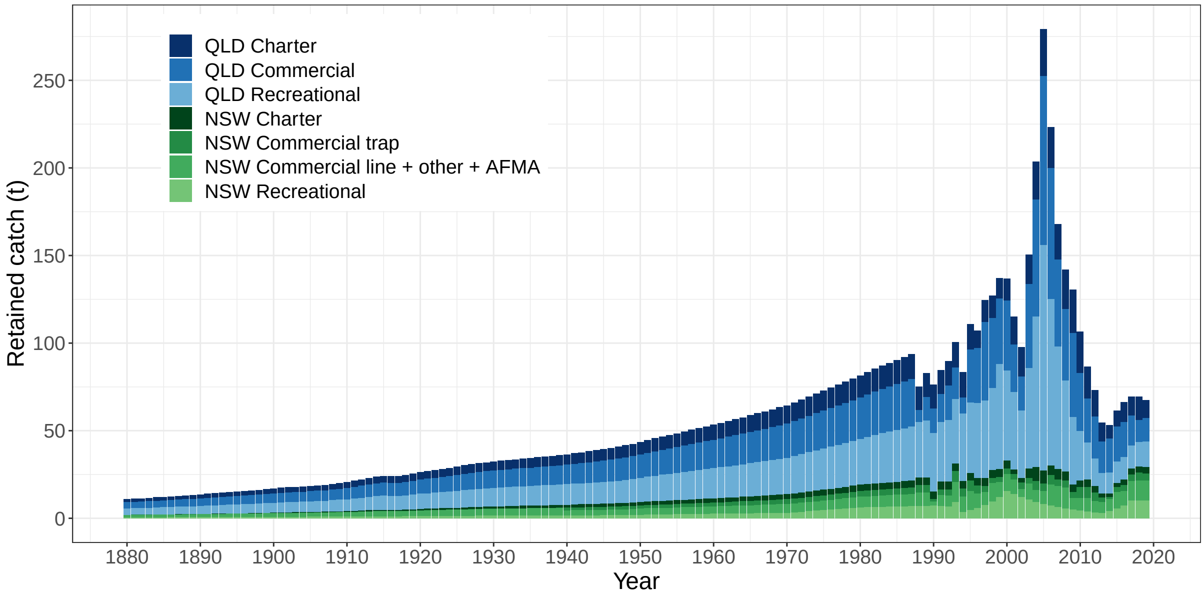

Figure 3.2: Annual estimated retained catch from commercial, charter and recreational sectors between 1880 to 2019 for pearl perch

Table 3.1: 2019 retained catch and retained catch shares for each fishing sector

Sector	Retained Catch	Share
Queensland	38 t	56.4%
Charter	10.1 t	14.9%
Commercial	13.6 t	20.3%
Recreational	14.3 t	21.2%
New South Wales	29.3 t	43.6%
Charter	3.9 t	5.7%
Commercial trap	4 t	6%
Commercial line + other + AFMA	11.4 t	17%
Recreational	10 t	14.9%

Mortality due to discarding was factored in by increasing the landed biomass input to the model (Section 2.4). Catch values increased by an average of 3%. A representation of dead catch input to the model is shown in Appendix A. All model output values involving future dead catch were therefore multiplied by 0.97 to yield actual retained catch estimates.

3.1.2 Standardised catch rates

Standardised catch rates were calculated to represent trends in abundance for the pearl perch stock. Three separate catch rate analyses were conducted: one for Queensland commercial line and one for each of New South Wales commercial trap and line (Figures 3.3, 3.4 and 3.5).

Queensland commercial line catch rates (Figure 3.3) show an overall decreasing trend since 1988. New South Wales commercial trap catch rates (Figure 3.4) show an increasing trend from 1998 to 2010, followed by a decrease to 2014 and then an increasing trend to 2019. New South Wales commercial line catch rates (Figure 3.5) show an increasing trend from 2002 to 2006, followed by a decrease to 2014 and then an increasing trend to 2019.

Diagnostic plots for catch rate analyses can be found in Appendix B.

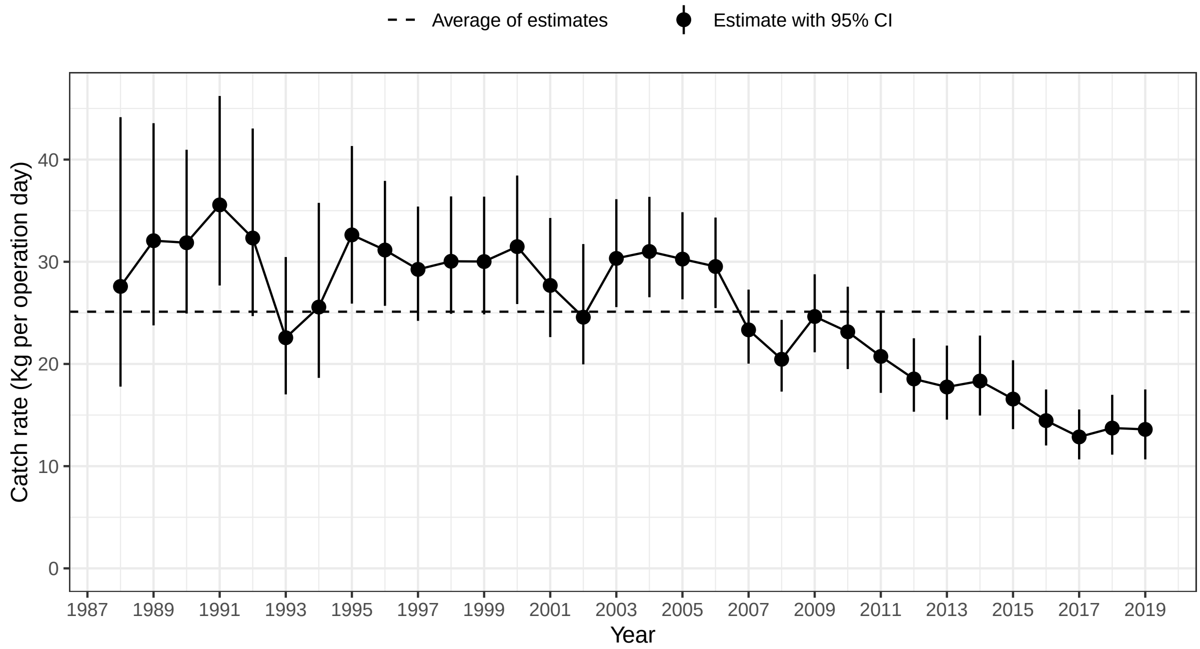

Figure 3.3: Annual standardised catch rates relative to average kg per day for Queensland commercial line-caught pearl perch between 1988 and 2019—with ”approximate” fishing power

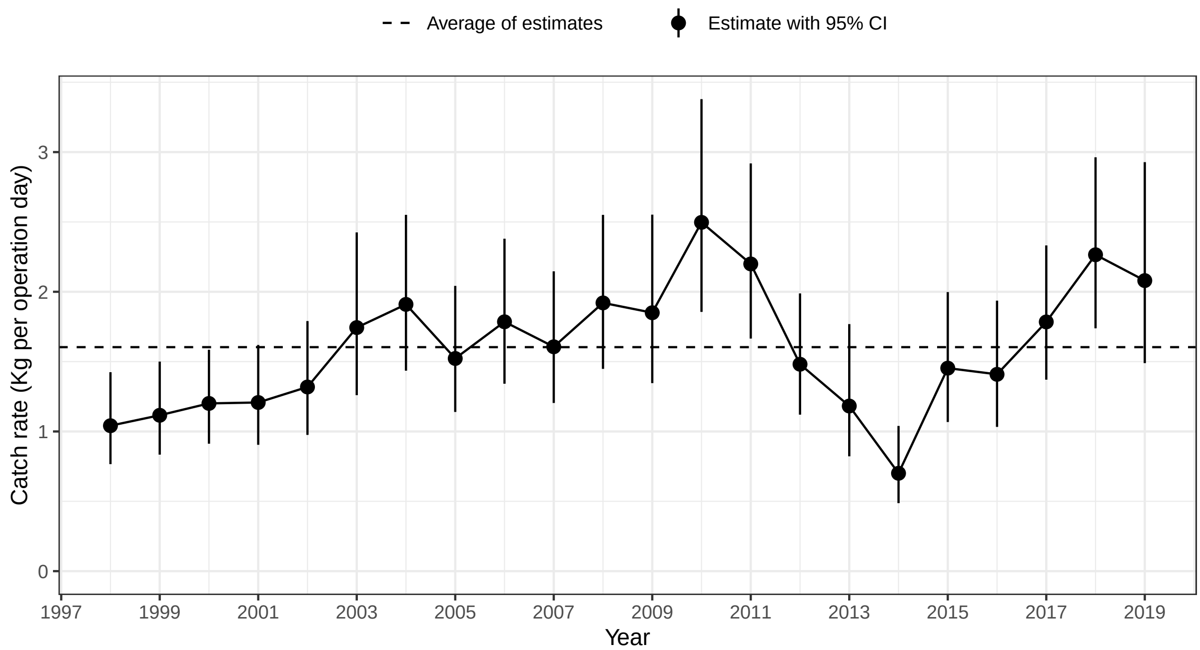

Figure 3.4: Annual standardised catch rates relative to average kg per day for NSW commercial trap-caught pearl perch between 1988 and 2019

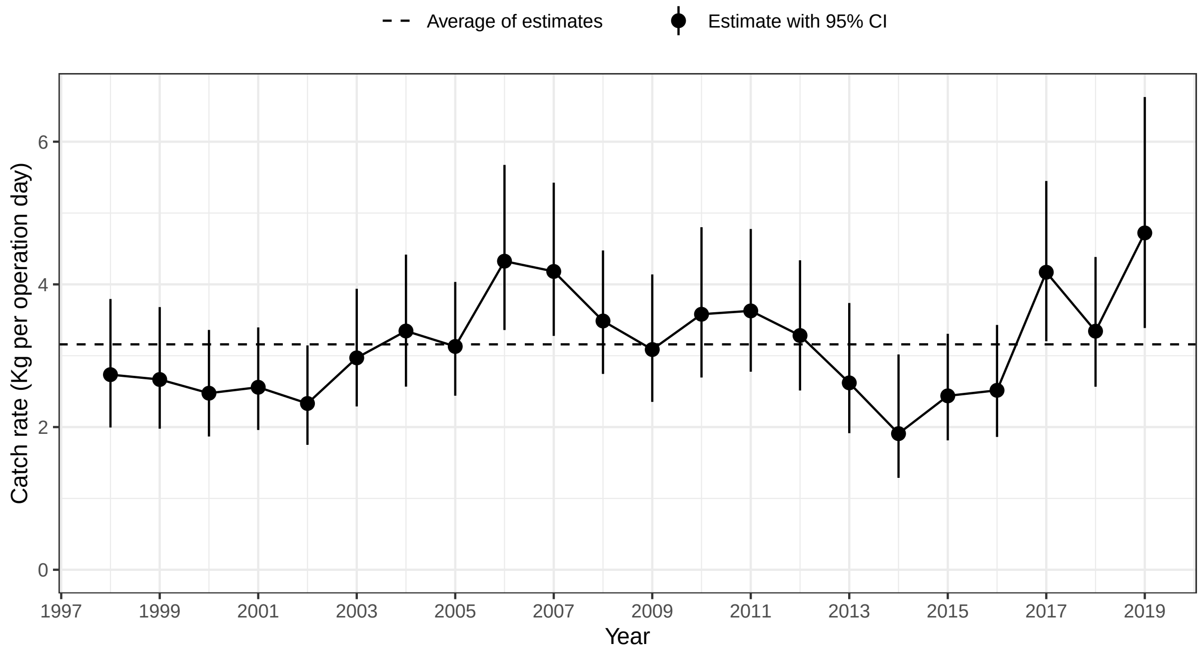

Figure 3.5: Annual standardised catch rates relative to average kg per day for NSW commercial line-caught pearl perch between 1988 and 2019—with ”approximate” fishing power

3.1.2.1 Fishing power

The effect of various fishing power weights applied to the commercial catch rates are shown in Figures 3.6 and 3.7.

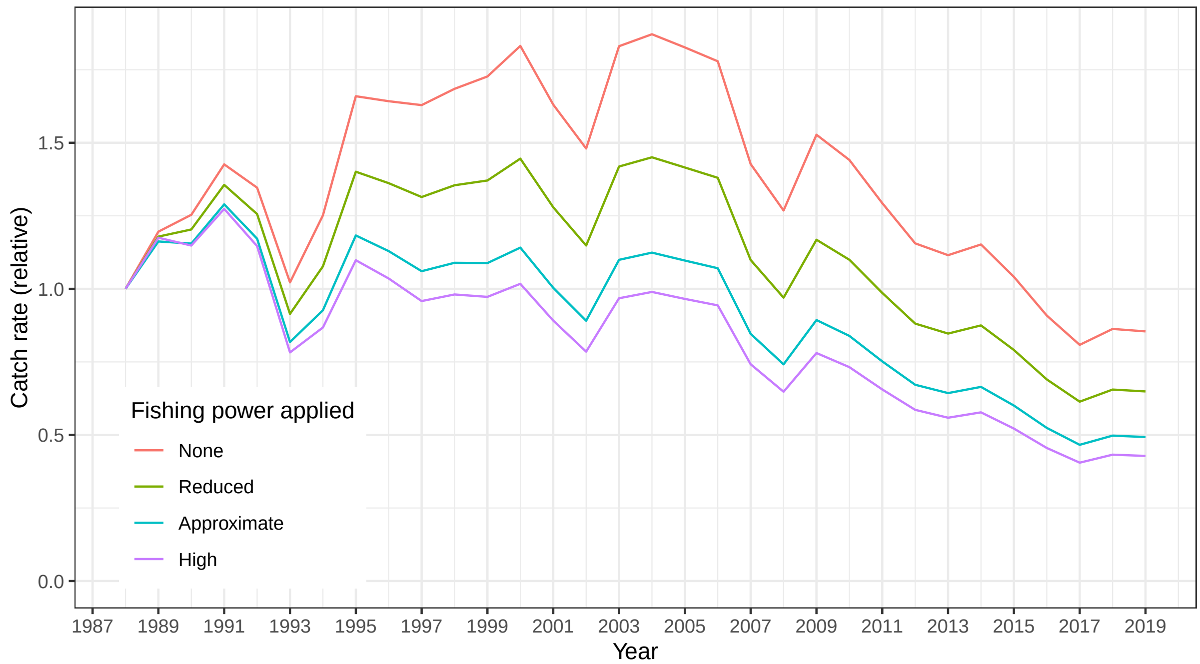

Figure 3.6: Comparison of the effect of fishing power on catch rates for the Queensland line fishery—For ease of comparison, values are relative to 1988

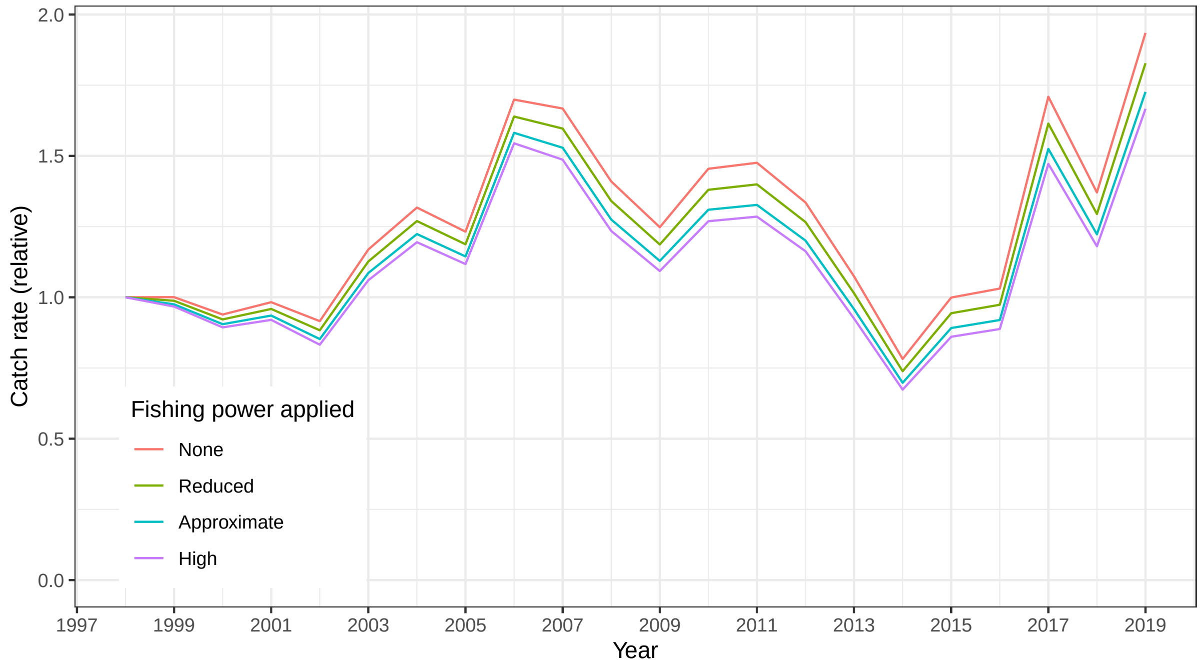

Figure 3.7: Comparison of the effect of fishing power on catch rates for the New South Wales line fishery—For ease of comparison, values are relative to 1988

3.1.3 Age and Length composition data

Age and length composition data (as well as their fit to the model), are shown in Appendices D.2.2 and D.2.3.

3.2 Model outputs

3.2.1 Model parameters

Several parameters were estimated for the base case model (Table 3.2). The full list of estimated parameters for the base and sensitivity runs is given in Section D.1.

Table 3.2: Estimated parameters for the pearl perch base population model

Parameter	Description	Value	Standard deviation
M	Natural mortality	0.282	0.02
$\ln(R_0)$	Logarithm of the number of recruits in 1880	6.587	0.21
σ_R	Variability of recruitment into the population	0.48	0.09
SD_q^{QLD}	Extra standard deviation in catchability for the Queensland commercial line fishery	0.01	0.02
$\text{SD}_q^{\text{NSW trap}}$	Extra standard deviation in catchability for the NSW commercial trap fishery	0.306	0.07
$\text{SD}_q^{\text{NSW line}}$	Extra standard deviation in catchability for the NSW commercial line fishery	0.243	0.06
L_{50}^{QLD}	Length at 50% vulnerability to QLD line fishing (cm)	30.461	0.25
L_{diff}^{QLD}	Difference between lengths at 95% and 50% vulnerability to QLD line fishing (cm)	3.977	0.36
L_{50}^{NSW}	Length at 50% vulnerability to NSW trap and line fishing (cm)	28.052	0.47
L_{diff}^{NSW}	Difference between lengths at 95% and 50% vulnerability to NSW trap and line fishing (cm)	2.427	0.7

Likelihood profiles can be used to determine whether parameters have been fixed at appropriate values. Integrated stock assessments use numerous data sources which may be in conflict with each other, but likelihood profiles provide a tool to determine these conflicts (Punt 2018). A likelihood profile was calculated to explore the assumption on steepness of 0.4 (Appendix D.6). This likelihood profile shows that a steepness of 0.4–0.45 is the most appropriate. The value of 0.4 was chosen for steepness as this was closer to values estimated in the last assessment (Sumpton et al. 2017).

3.2.2 Model fits

Good fits were achieved for all data sets, including abundance indices and length compositions (Appendix D.2). All models (including scenarios) converged at a value less than 0.0001, which is the default value for Stock Synthesis.

3.2.3 Selectivity

Selectivity of pearl perch was estimated within the model. Charter and commercial data within each state were very similar, so a “mirrored” selectivity function was used to represent them, making their selectivity curves identical (Figure 3.8).

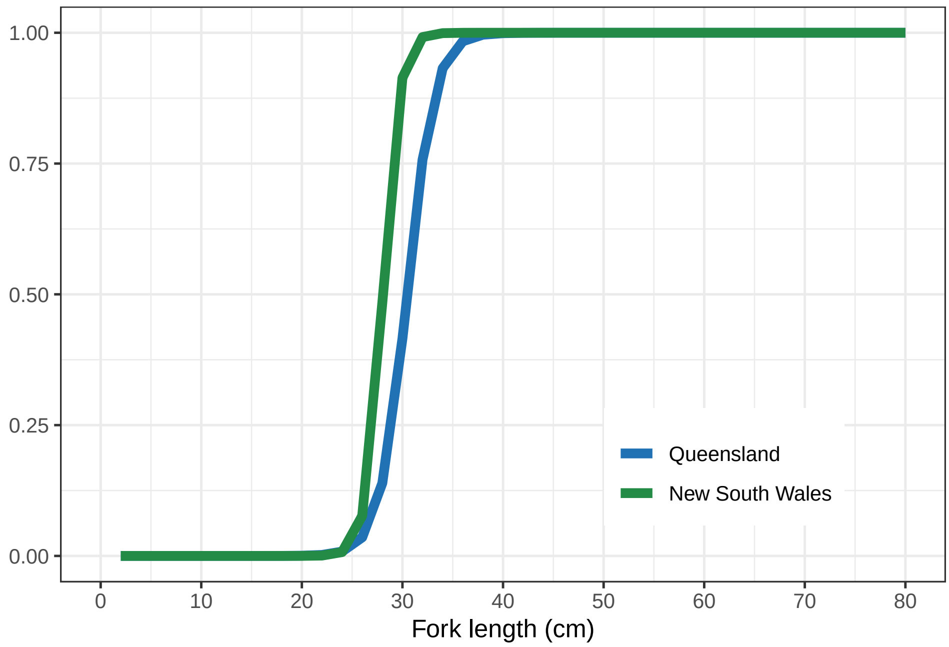

Figure 3.8: Model estimated length-based selectivity for pearl perch by state in 2019

3.2.4 Biomass

The spawning biomass trajectory through time was determined as a proportion relative to an assumed unfished spawning biomass in 1880 (Figure 3.9). The model has predicted that spawning biomass declined to around 46% in the early 2000s, increased to around 57% in 2005 and then declined sharply to around 22% of virgin spawning biomass in 2020[1] (with a confidence interval ranging 15% to 29%).

Predictions of recruitment variation from the late 1980s onwards are informed by biological data input to the model. Model estimates indicate peaks in recruitment in the early 1990s and the early 2000s followed by a period of low recruitment in recent years. Plots of recruitment deviations are available in Appendix D.4

The model prediction of a biomass peak in 2005 (Figure 3.9) coincides with high 2005 catches (Figure 3.2). This biomass peak is preceded by a prediction of high recruitment.

The relationship between the spawning biomass estimate and fishing mortality over time are presented in Appendix D.3.

[1] Stock Synthesis reports spawning stock biomass at the beginning of each year. Following this convention, the spawning stock biomass estimate is reported for 2020, the year after the input data end (2019).

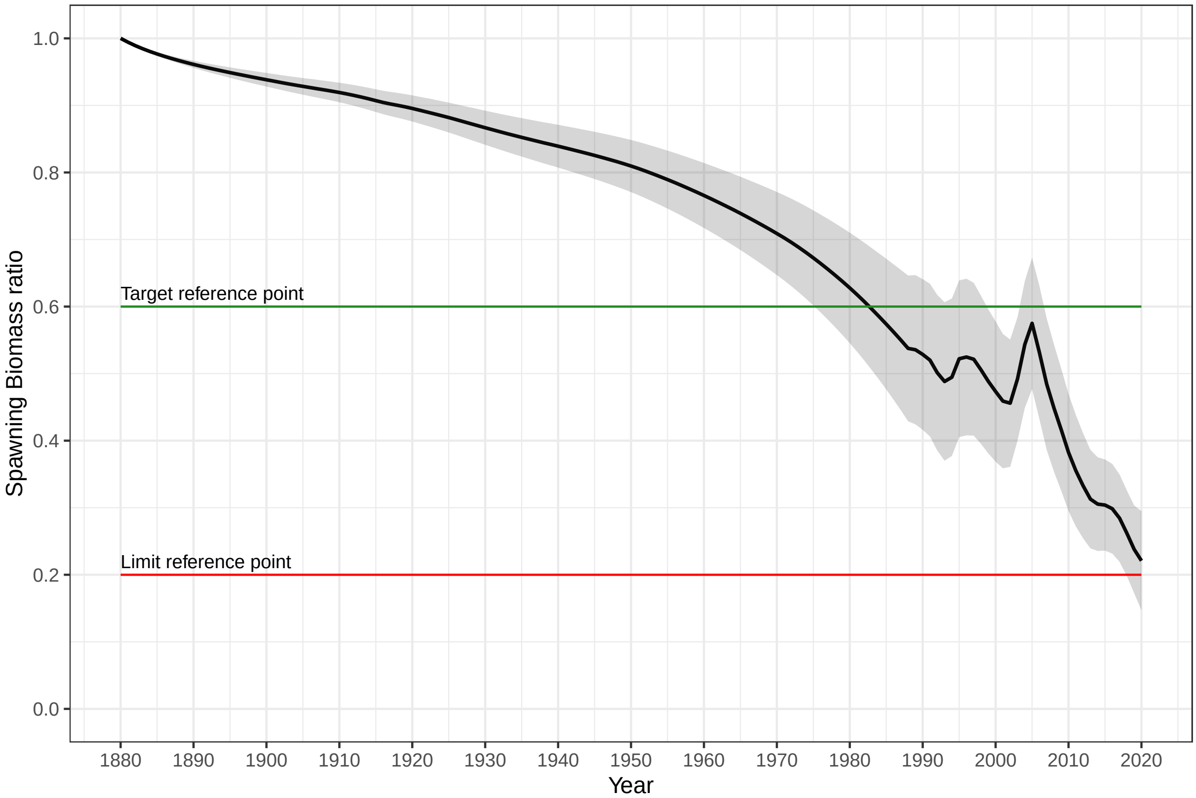

Figure 3.9: Predicted spawning biomass trajectory relative to unfished for pearl perch, from 1880 to 2020

3.2.5 Catch targets

Catch targets have been calculated to attain spawning biomass at the 60% target reference point for the base model, and a number of sensitivity test models, resulting in recommended biological catch (RBC).

Maximum sustainable yield (MSY) was estimated at 74 t per year (Figure 3.10). The retained catch consistent with a biomass ratio of 60% (a proxy for maximum economic yield) was estimated at 62 t across all sectors (Table 3.3).

The equilibrium yield informs on the productivity of the stock at different biomass levels (Figure 3.10).

Table 3.3: Current and target indicators

Indicator	Estimate
Biomass◇ (relative to unfished) at the start of 2020	22%
Target biomass (relative to unfished)	60%
Biomass (relative to unfished) at MSY⋆	41%
MSY	74 t
Retained catch component of MSY	71 t
Retained catch at 60% biomass target	62 t
RBC† for 2020 to achieve target	1.24 t
Retained component of RBC	1.2 t
Time to achieve target	> 20 years

◇ Biomass is defined to be spawning stock biomass.
⋆ MSY (maximum sustainable yield) is defined to be the maximum sustainable dead catch. That is, retained catch plus catch that dies following discarding.
† RBC (recommended biological catch) is the recommended catch according to the control rule. This is dead catch: retained catch plus catch that dies following discarding.

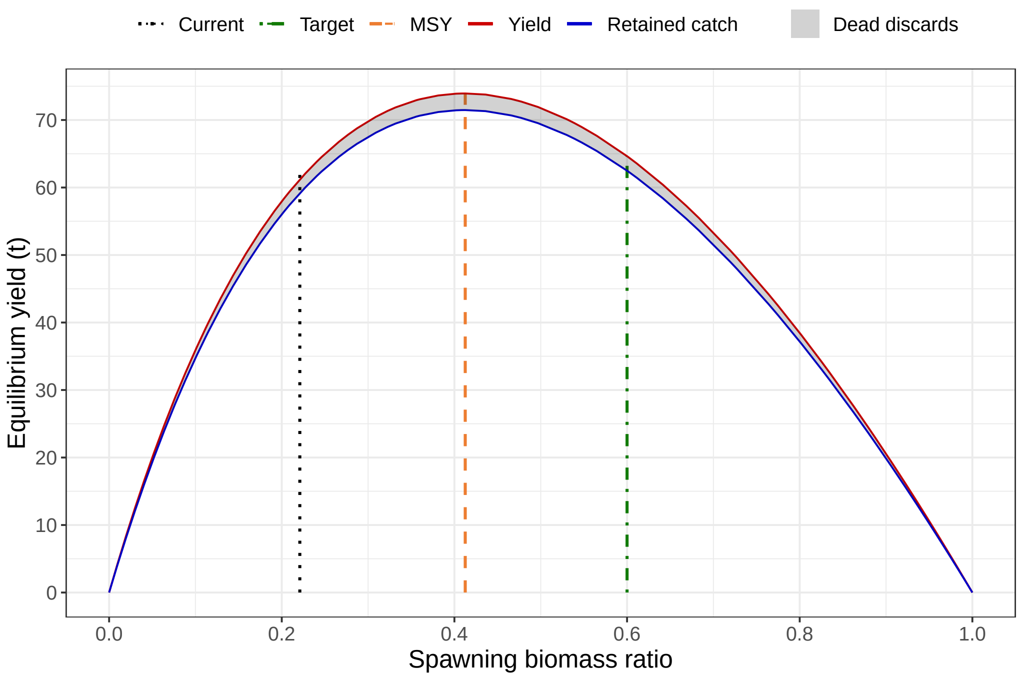

Figure 3.10: Equilibrium yield curve for pearl perch

The stock assessment shows the state of the stock is at low levels. Modelling estimates a retained component of RBC at about 1.2 t (0–6 t range) initially to allow stocks to rebuild. This retained catch could then be increased to 62 t over time.

These RBCs are the first in a schedule of projected recommended catch for Queensland's Harvest Strategy 2017–2027, using the harvest control rule. The schedule is presented here for the base case (Table 3.4).

Table 3.4: Estimated catch and biomass ratios of pearl perch for the base case to rebuild and maintain the stock at the target reference point of 60% unfished spawning biomass, following a harvest control rule (Fisheries Queensland 2021)

Year	RBC (t)	Retained Catch (t)	Biomass Ratio
2020	1.2	1.2	0.22
2021	3.2	3.1	0.25
2022	5.6	5.4	0.28
2023	8.3	8.0	0.30
2024	11.1	10.7	0.33
2025	14.1	13.7	0.35
2026	17.4	16.8	0.37
2027	20.7	20.1	0.39
2028	24.2	23.4	0.42
2029	27.7	26.7	0.44

3.3 Sensitivities

Table 3.5 and Figure 3.11 show the differences between model runs where sensitivities to fishing power, natural mortality (M), steepness (h), catch rates, recreational catch assumptions and model start year were tested. Results from these scenarios gave spawning biomass ratios ranging from 14% to 46% (and a confidence interval range of 11% to 63%)

Table 3.5: Summary of the pearl perch base case and scenario and sensitivity tests

Model†	$\ln(R_0)$ (std)	B_{1988}	F_{1988}	h	M (std)	B_{2020}	H_{60} (t)	RBC (t)	$-\ln L^{\star}$
base	6.587 (0.214)	0.54	0.0776	0.4	0.282 (0.024)	0.22	62	1	245.79 ***a***
1	6.559 (0.213)	0.45	0.1083	0.4	0.3 (0.026)	0.29	56	6	251.8
2	6.589 (0.22)	0.5	0.0903	0.4	0.293 (0.026)	0.26	60	3	247.51
3	6.578 (0.209)	0.55	0.0719	0.4	0.275 (0.023)	0.2	64	0	246.95
4	5.873 (0.021)	0.38	0.108	0.4	0.2 (fixed)	0.14	47	0	252.95 ***b***
5	6.926 (0.05)	0.62	0.0638	0.4	0.32 (fixed)	0.26	74	5	247.2 ***b***
6	7.013 (0.195)	0.52	0.0651	0.3	0.311 (0.022)	0.2	52	0	246.36 ***a***
7	6.345 (0.235)	0.54	0.0853	0.5	0.265 (0.026)	0.23	67	2	245.88 ***a***
8	6.188 (0.256)	0.55	0.0905	0.6	0.254 (0.028)	0.24	70	3	246.16 ***a***
9	6.08 (0.275)	0.55	0.0941	0.7	0.247 (0.03)	0.24	72	3	246.48 ***a***
10	6.184 (0.292)	0.6	0.0821	0.8	0.254 (0.03)	0.41	82	29	246.65 ***a***
11	6.547 (0.21)	0.52	0.0814	0.4	0.28 (0.024)	0.19	61	0	268.66
12	6.719 (0.242)	0.59	0.0662	0.4	0.291 (0.026)	0.46	69	34	283.72
13	6.172 (0.213)	0.52	0.0714	0.4	0.275 (0.024)	0.22	43	1	243.37
14	6.894 (0.215)	0.55	0.0806	0.4	0.288 (0.024)	0.22	83	2	246.25
15	6.524 (0.254)	0.64	0.0752	0.4	0.292 (0.026)	0.26	56	4	246.73

⋆ log-likelihood ($-\ln L$) values that are comparable contain identical superscripts (***a*** or ***b***) and lower values for the comparable likelihoods are indicative of a better fit

† scenarios are 1) no fishing power, 2) reduced fishing power, 3) high fishing power, 4) $M = 0.2$, 5) $M = 0.32$, 6) $h = 0.3$, 7) $h = 0.5$, 8) $h = 0.6$, 9) $h = 0.7$, 10) $h = 0.8$, 11) QLD catch rate only, 12) NSW catch rates only, 13) low recreational catch, 14) high recreational catch, 15) catch from 1988 with assumed equilibrium starting F

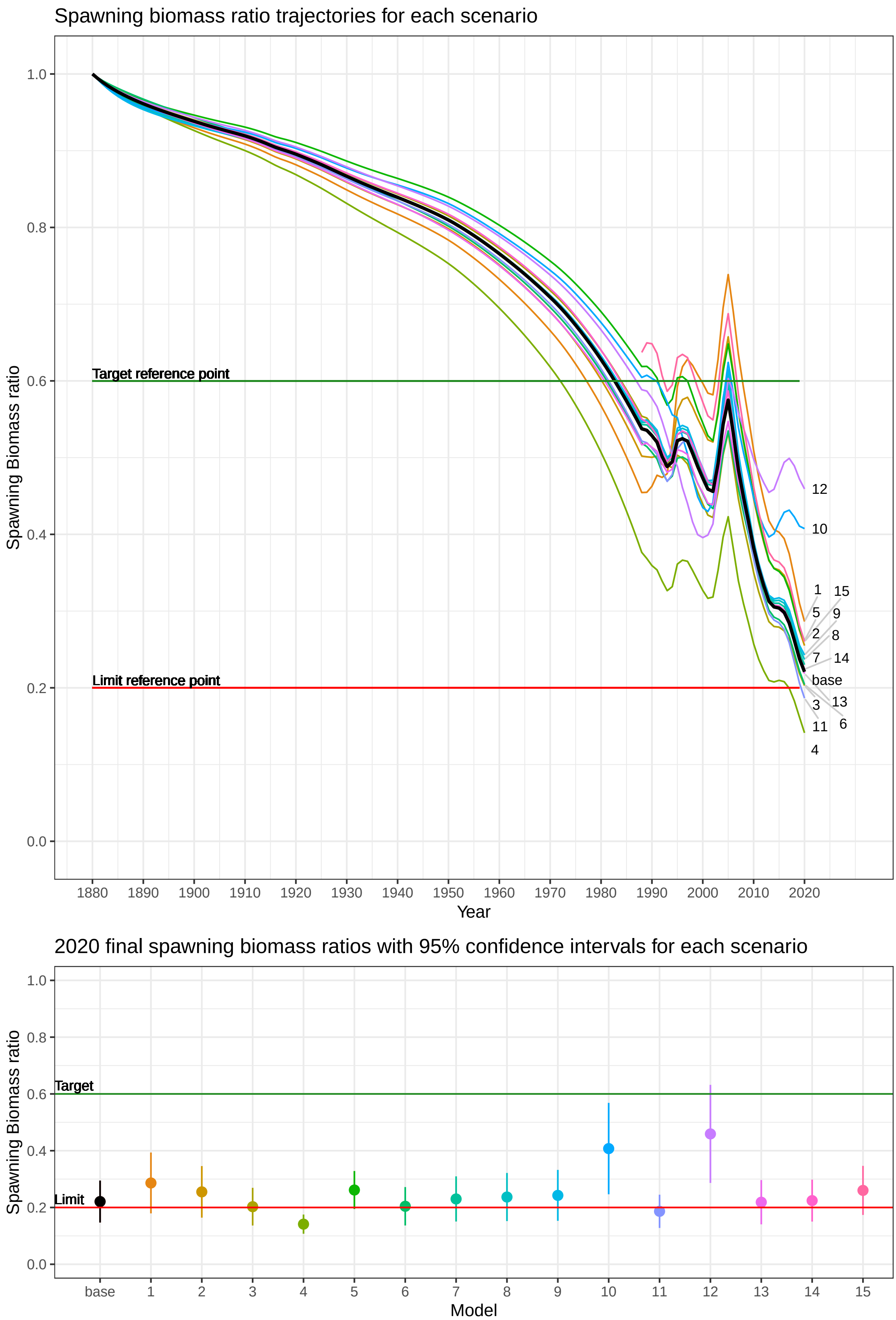

Figure 3.11: Spawning biomass ratio (relative to unfished) scenarios for pearl perch—scenarios are 1) no fishing power, 2) reduced fishing power, 3) high fishing power, 4) $M = 0.2$, 5) $M = 0.32$, 6) $h = 0.3$, 7) $h = 0.5$, 8) $h = 0.6$, 9) $h = 0.7$, 10) $h = 0.8$, 11) QLD catch rate only, 12) NSW catch rates only, 13) low recreational catch, 14) high recreational catch, 15) catch from 1988 with assumed equilibrium starting F

4 Discussion

The Queensland Sustainable Fisheries Strategy aims to build and maintain fisheries in the long term. The aim is to have a strategy in place to move to the target reference point of 60% unfished biomass (Department of Agriculture and Fisheries 2017).

Pearl perch catch has increased from the beginning of the fishery to 2005 and has fallen since then for the amount of fishing effort exerted. The increase in catch was more pronounced for Queensland than New South Wales. Retained catch has been 60–70 t per year across all waters and fishing sectors since 2014 (Figure 3.2).

Standardised catch rates showed differing trends in each state. For Queensland, a consistent decrease is evident. For New South Wales, trap and line sectors declined to a low in 2014, after which a recovery in catch rates is shown. The different signals in the New South Wales catch rates and the Queensland catch rates suggests that localised depletion in Queensland is likely to have occurred.

Results show that spawning biomass is currently at around 22% of virgin levels and requires rebuilding to target levels under the Queensland Sustainable Fisheries Strategy (Department of Agriculture and Fisheries 2017). MSY was estimated at 74 t per year and the yield consistent with maintaining a biomass ratio of 60% was estimated at 62 t across all sectors. The harvest strategy harvest control rule suggests a target of 1 t initially to begin rebuilding exploitable biomass to 60%. Forward projections of the model suggest that rebuilding would take around 20 years if retained catch is reduced to the recommended levels outlined in Table 3.4.

4.1 Performance of the population model

This stock assessment used an age and length-based model with an annual time step, with length-based selectivities for each state (Queensland and New South Wales). Data inputs included total dead catch (Queensland commercial, charter and recreational, and New South Wales commercial trap, commercial line, charter and recreational), standardised catch rates (Queensland commercial, New South Wales commercial trap and New South Wales commercial line), fishery-dependent length compositions and age data.

Overall, the model performed well, achieving good fits to the majority of data. The New South Wales catch rates however, did not fit as well as the Queensland catch rates. The model is heavily weighted and fitted to the Queensland catch rates. Queensland and New South Wales catch rates showed an opposing trend in the last five years in particular (Section 3.1.2). In order to investigate these outcomes, it was important to test the model with Queensland only catch rates and New South Wales only catch rates.

A number of sensitivities were tested to better understand which assumptions and parameters are most influential on the model (Section 3.3).

The likelihood profile on steepness h (Figure D.12) indicates a best steepness value of 0.4. This value is in alignment with values by Sumpton et al. (2017), hence a steepness of 0.4 was chosen as a base case for this assessment. Contrasting this is the meta-analysis by Thorson (2020) which provides values for the species at around 0.7, Additionally, it is important to note that all values in the likelihood profile show a likelihood change of less than 2 units and hence are all considered plausible. It was therefore considered important to test scenarios for steepness ranging 0.3–0.8 in increments of 0.1.

All steepness scenario values gave only a marginal change to the log-likelihood function. The difference in biomass ratio and catch targets were smallest for this parameter change with the exception of steepness equal to 0.8 (steepness equal to 0.8 showed the largest likelihood change on the likelihood profile).

Assumptions surrounding natural mortality and fishing power gave a spread of results ranging around 12% of the final spawning biomass ratio for each component tested.

The Queensland only catch rates scenario gave a lower final biomass and recommended catch. The largest change to the outcome during scenario testing was achieved with the New South Wales catch rates only scenario. Neither model fitted as well as the base case where all catch rates were present. Of the two catch rate scenarios, the use of Queensland only catch rates achieved a closer result to the base case final spawning biomass ratio. The New South Wales catch rate only scenario did not fit well to the catch rates even with the absence of the Queensland catch rates in the model. This is possibly due to the majority of the biological data being from Queensland.

Recreational catch scenarios tested showed a negligible difference in final biomass, however the catch target for the high recreational scenario was double that of the low recreational scenario.

The final scenario investigated starting the model in 1988 with an assumed equilibrium starting F. This investigation gave a similar value to the base case for the $\ln(R_0)$ and F_{1988} parameters. The comparative value for the biomass in 1988 however, was 10% higher. Results showed a 4% increase in the 2020 biomass and hence a higher RBC. Overall however, this scenario did not show a major difference to outcomes.

Model limitations of note include:

- The productivity parameter "steepness" (h) was fixed and a likelihood profile confirmed the model was unable estimate this parameter. The results indicated the model was not sensitive to this assumption with the exception of a very high steepness of 0.8 (Section 3.3).
- Regional variation in biological characteristics has not been taken into account.
- The extent of discarding in the commercial sector remains largely unknown, and the limited data that were available to support an estimate may not be reliable.

These limitations suggest further analysis and development will improve model performance (see Section 4.2.3).

4.2 Recommendations

4.2.1 Research and monitoring

Monitoring data in the form of fishery-dependent length and age data were advantageous to this assessment. In particular, data collected in recent years by fishery monitoring programs were of high quality. Continued monitoring of pearl perch age and length information that are representative of the fishery is important for the ongoing assessment and management of pearl perch.

Targeted research into the impacts of environmental changes on pearl perch would increase understanding and benefit future assessments and management of the fishery. FRDC 2019-013 is currently investigating the association of measures of abundance and environmental drivers. The decline in catch and catch rates in Queensland relative to New South Wales may support this.

4.2.2 Management

Stock biomass levels are currently below the target reference point of 60% of unfished spawning stock biomass. From the analyses it can be concluded that pearl perch is likely to be depleted past maximum sustainable yield.

Maximum sustainable yield was estimated at 74 t per year, and the retained catch consistent with a biomass ratio of 60% (a proxy for maximum economic yield) was estimated at 62 t for all sectors. The assessment, following the Queensland Sustainable Fisheries Strategy harvest policy, recommends low biological catches.

The recommended discount factor for this assessment is 0.91 based on a qualitative tier assignment process and Ralston et al. (2011) (σ is 0.36, P^* (risk aversion) is 0.4). Applying this gives a discounted 2020 retained catch of 1 t.

4.2.3 Assessment

Limitations with the performance of the current model have been discussed in this document. Specific recommendations for a future pearl perch assessment include:

- Age-at-length data input to future models would enable the estimation of fish growth parameters.
- Consider modelling discards using a retention curve. For best results, this would require length information of discarded fish.
- Consider using a spatial model. Catch rate and catch trends support the consideration of Queensland and New South Wales as separate regions.
- Consider a bridging analysis to show consistency between pearl perch stock assessments.
- Consider performing a MCMC analysis to increase confidence in model convergence.

4.3 Conclusion

This assessment has estimated the status of the eastern Australian pearl perch stock. Analysis suggests that spawning biomass has declined and is currently at around 22% (with scenarios ranging 14% to 46%) in 2020. The study presents biological catch levels that would be required under the Queensland Sustainable Fisheries Strategy to begin rebuilding the stock to levels consistent with 60% of unfished biomass.

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Appendix A Discards

Mortality due to discarding was factored in by increasing the landed biomass input to the model (Section 2.4). Catch values increased by an average of 3%. Final catch input to the model is shown in Figure A.1. All model output values involving future retained catch were therefore multiplied by 0.97.

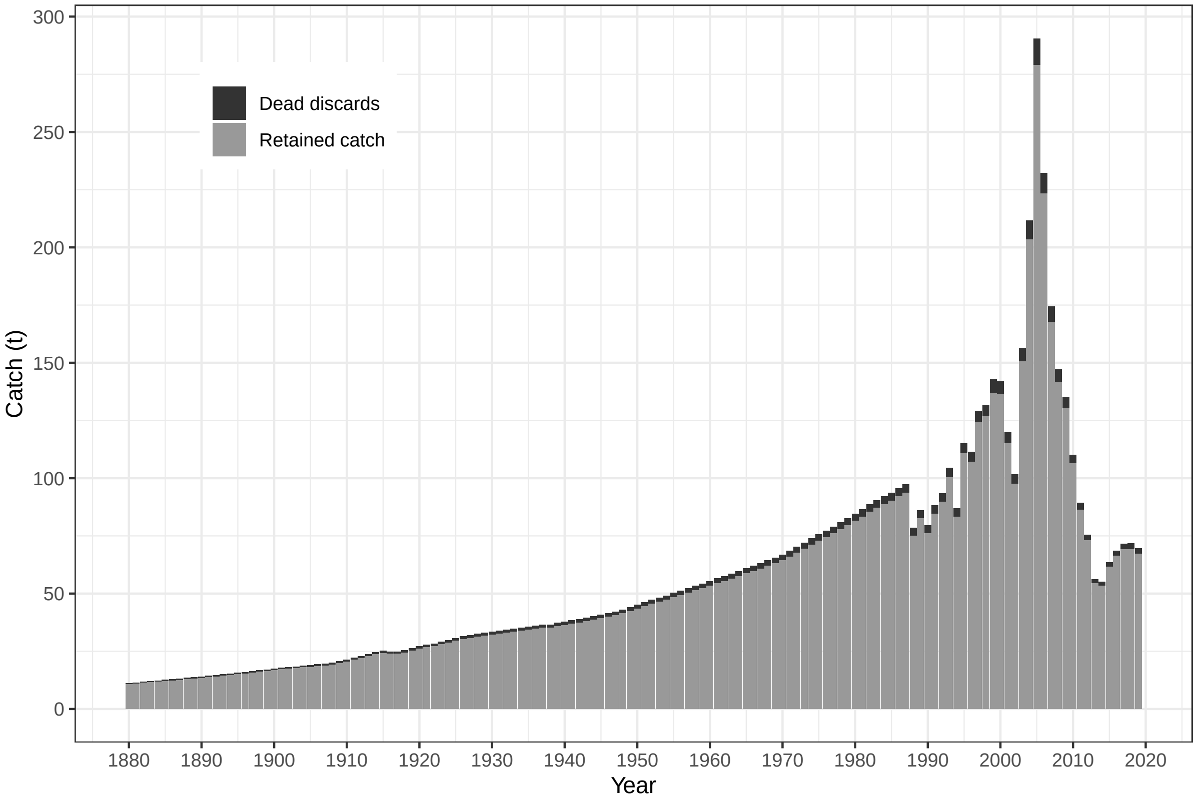

Figure A.1: Estimated total dead catch of pearl perch from 1880 to 2019

Appendix B Catch rate diagnostics

Figures B.1–B.3 show the LMM diagnostic plots. The plots were similar for all fishing scenarios. The top left shows the histogram of residuals, top right shows the fitted value plot, bottom left shows the qq plot, and bottom right shows the residuals by row labels. The catch rate diagnostics plots were tested for scenarios with no fishing power, reduced or increased fishing pressure and were found to be similar and therefore are not presented in this report .

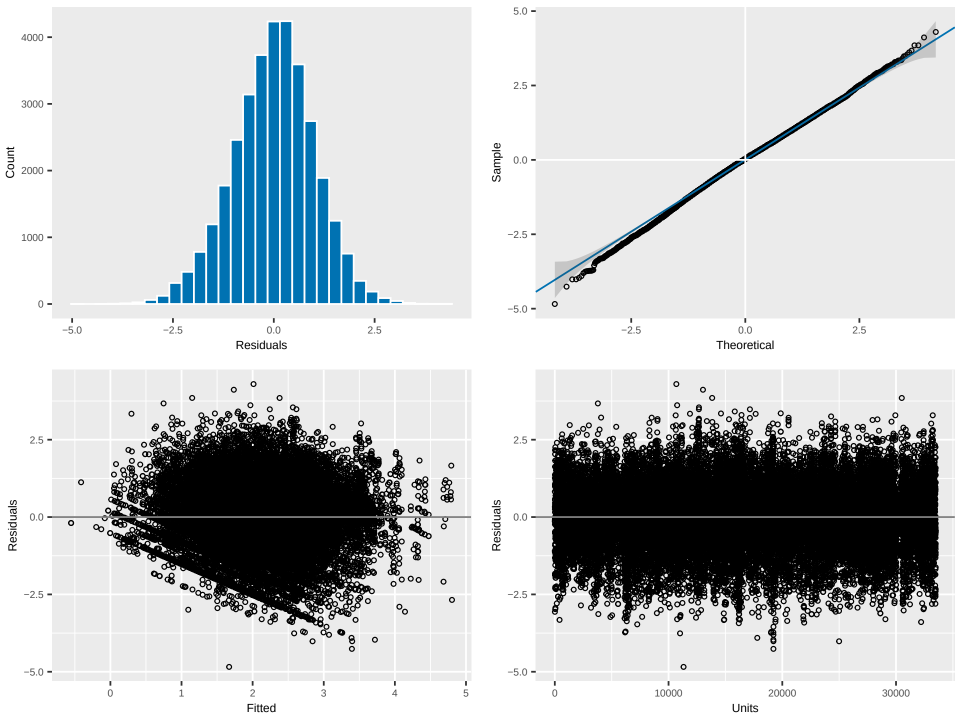

Figure B.1: Residual diagnostic plots of the linear mixed model for Queensland commercial line fishing assuming ”approximate fishing power” increases

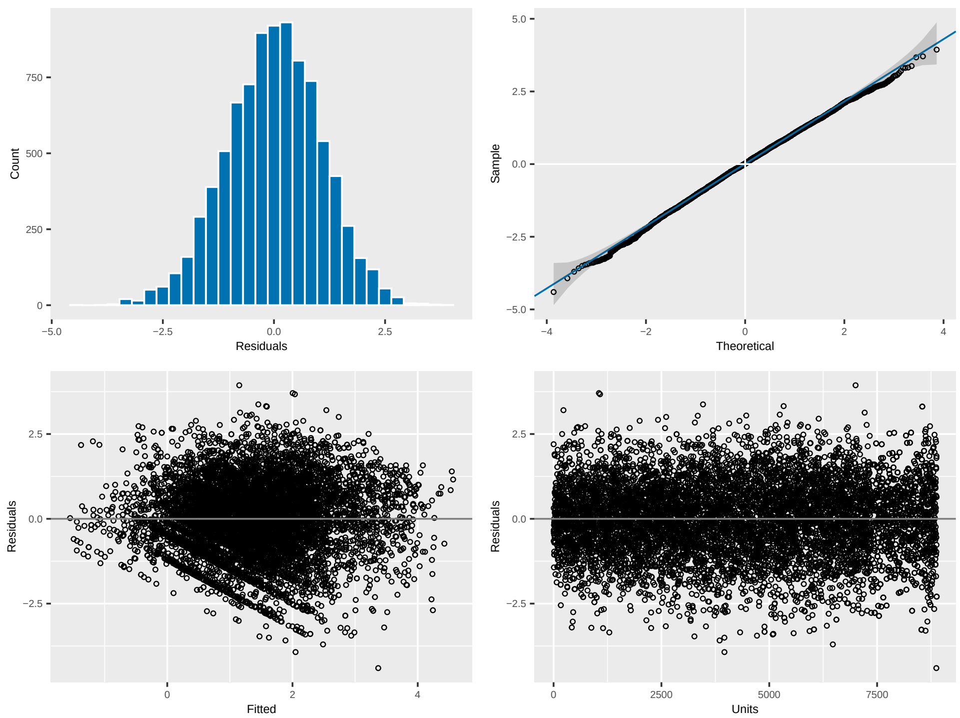

Figure B.2: Residual diagnostic plots of the linear mixed model for New South Wales fishing assuming ”approximate fishing power” increases

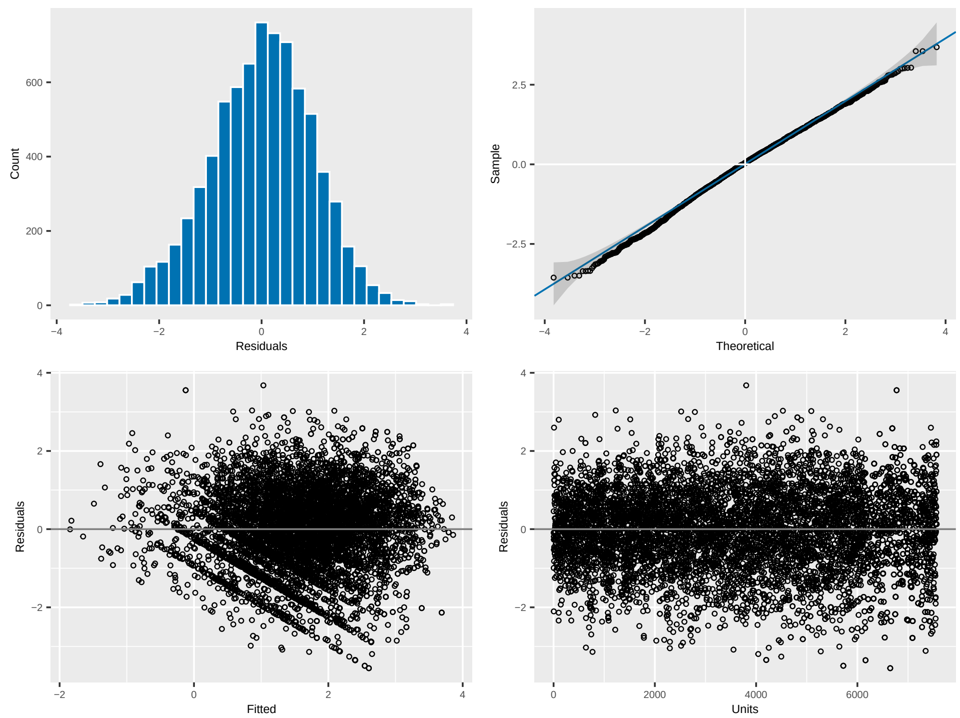

Figure B.3: Residual diagnostic plots of the linear mixed model for New South Wales trap fishing assuming reduced fishing power increases

Appendix C Biological data

C.1 Age and length sample sizes

These sample sizes are input to the model and form a starting point for data set weighting.

Table C.1: Raw sample sizes measured and aged input to the model for pearl perch

Year	Qld Age Data	Qld Charter Fishery (Length)	Qld Commercial Fishery (Length)	Qld Recreational Fishery (Length)	NSW Commercial Line (Length)
1999					515
2000					597
2005					395
2006	240	329		386	713
2007	190	1289	947	474	
2008	199	677	543	627	
2009	649	368	1383	404	606
2010	447	1576	1149	622	1472
2011	344	2525	614	591	1040
2012	409		892	564	922
2013	309		525	574	496
2014	466		1577	332	202
2015	321		763	646	
2016	353		1155	385	284
2017	328		582	375	437
2018	426		686	451	316
2019	438		1190	338	480

C.2 Biology

Age-based biological schedules input to the population model are shown in Figure C.1. The growth curve shown in Figure C.1(c) also shows the variance of fish growth input to the population model.

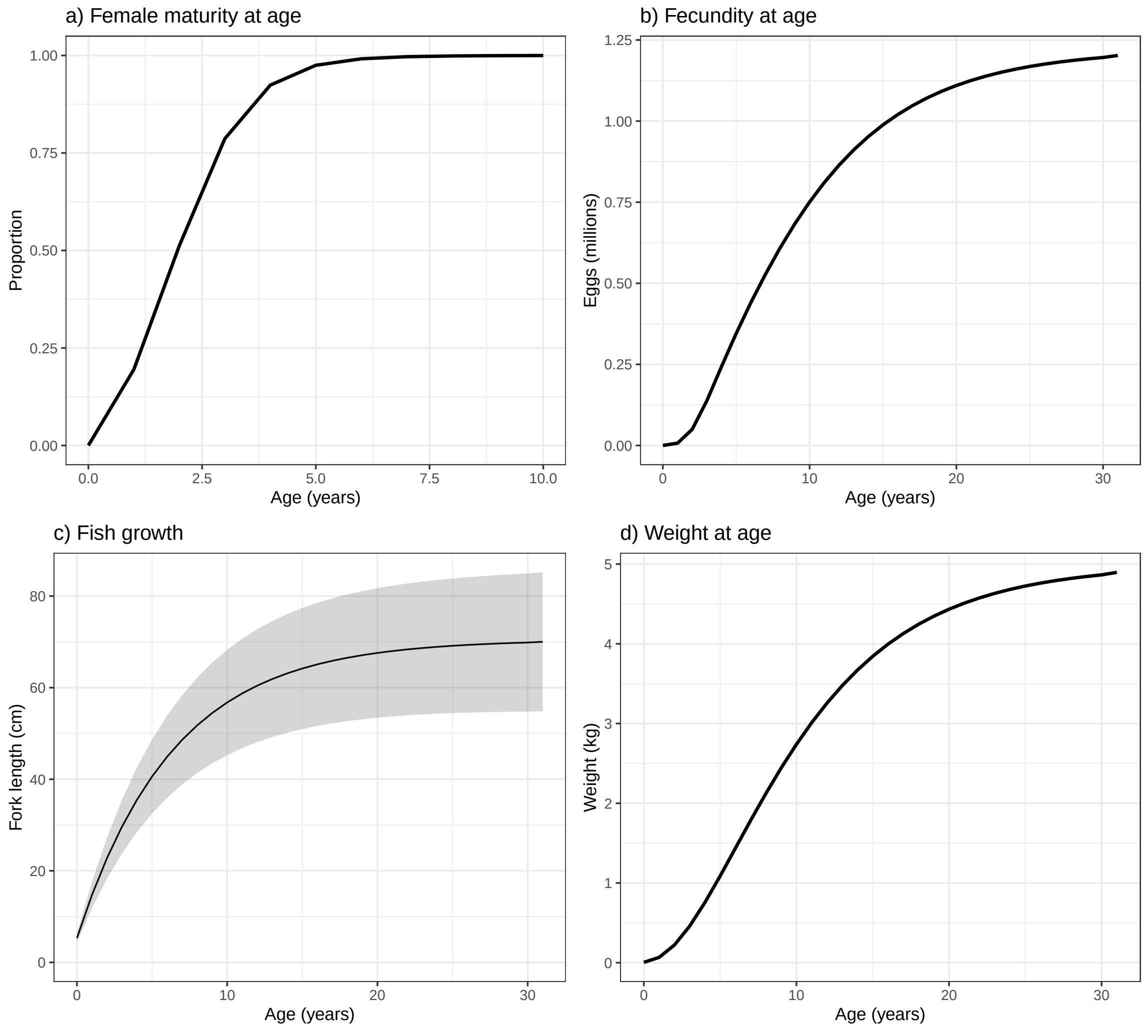

Figure C.1: Pearl perch age-based biological schedules for a) maturity, b) fecundity, c) growth and d) fish weight

Appendix D Model outputs

D.1 Parameter estimates

Table D.1 displays the base model setup for each parameter and its corresponding estimated values and outputs.

Table D.1: Parameter estimates for the base population model for pearl perch

Parameter	Estimate	Phase	Min	Max	Initial value	Standard deviation	Gradient
M	0.28	9	0.01	0.99	0.26	0.02	0.0000009
$\ln(R_0)$	6.59	1	3	31	6.26	0.21	-0.0000082
σ_R	0.48	4	0	2	0.52	0.09	-0.0000092
SD_q^{QLD}	0.01	4	0	0.5	0	0.02	-0.000001
$\text{SD}_q^{\text{NSW trap}}$	0.31	4	0	0.5	0	0.07	-0.0000011
$\text{SD}_q^{\text{NSW line}}$	0.24	4	0	0.5	0	0.06	0.0000003
L_{50}^{QLD}	30.46	2	15	50	30.42	0.25	0.0000041
L_{diff}^{QLD}	3.98	3	0.01	60	3.97	0.36	-0.0000007
L_{50}^{NSW}	28.05	2	15	50	28.04	0.47	0.000001
L_{diff}^{NSW}	2.43	3	0.01	60	2.42	0.7	0.0000005

D.2 Goodness of fit

D.2.1 Abundance indices

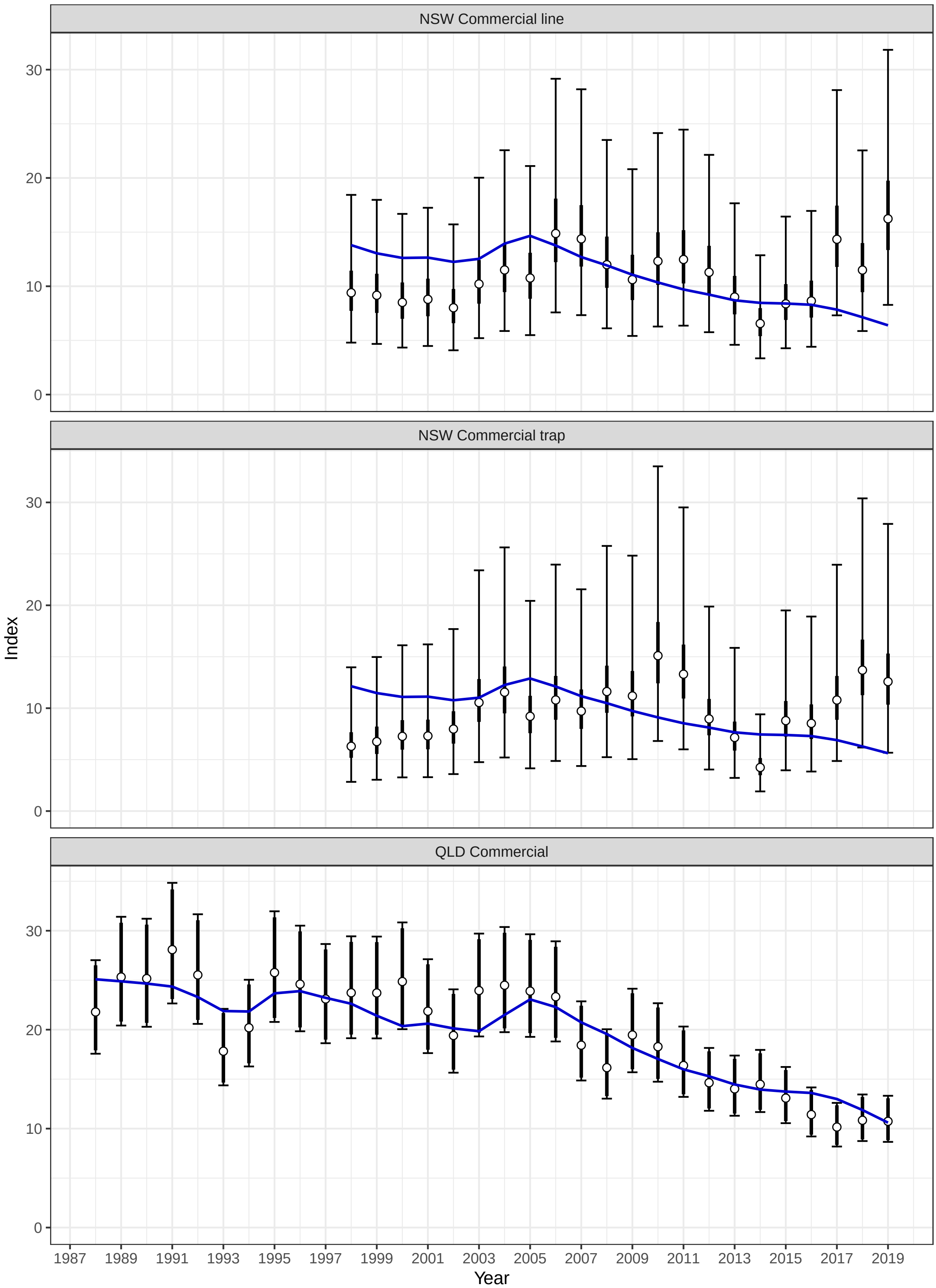

Figure D.1: Model predictions (blue line) to standardised catch rates (points) for pearl perch—thick black bars represent the standard error input into the model, while the thin error bars represent additional error estimated by the model

D.2.2 Length compositions

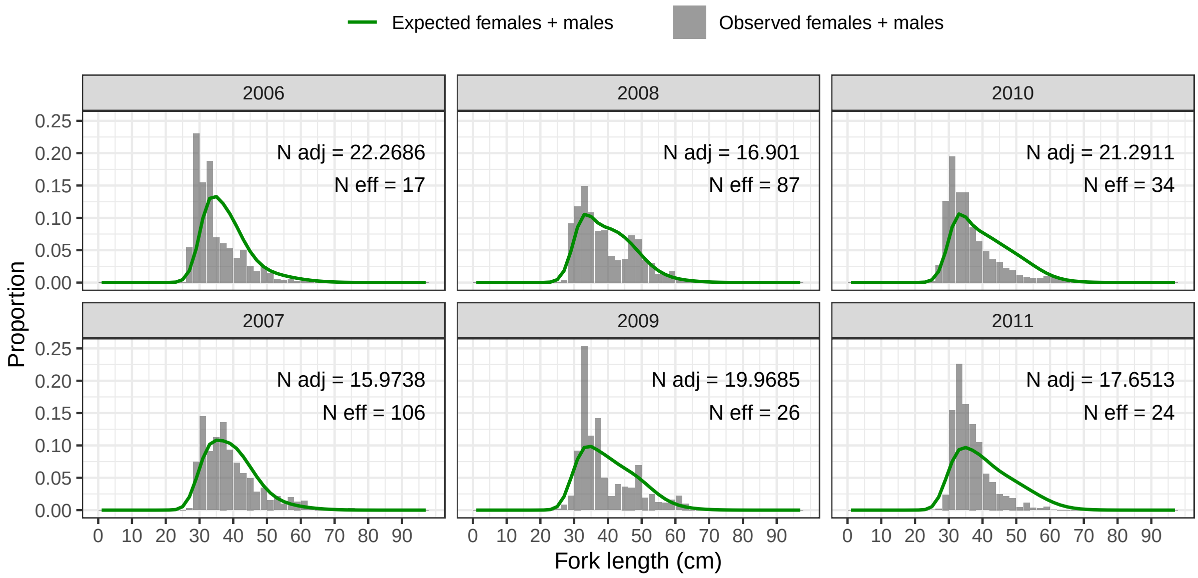

Figure D.2: Fits to length structures for the Queensland charter fleet for pearl perch—N adj. is the input sample size after data-weighting adjustment. N eff. is the calculated effective sample size used in the Francis tuning method

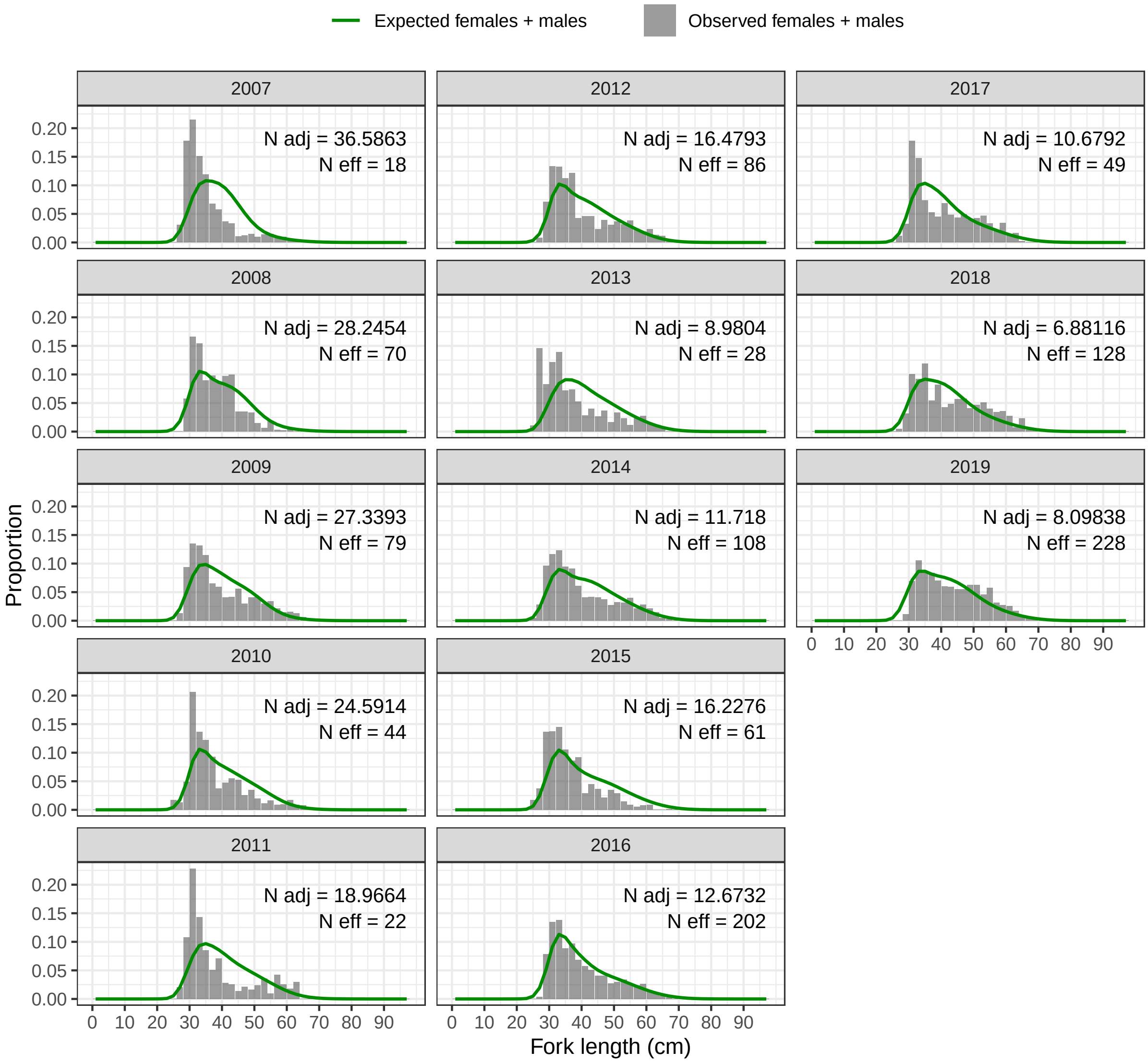

Figure D.3: Fits to length structures for the Queensland commercial fleet for pearl perch—N adj. is the input sample size after data-weighting adjustment. N eff. is the calculated effective sample size used in the Francis tuning method

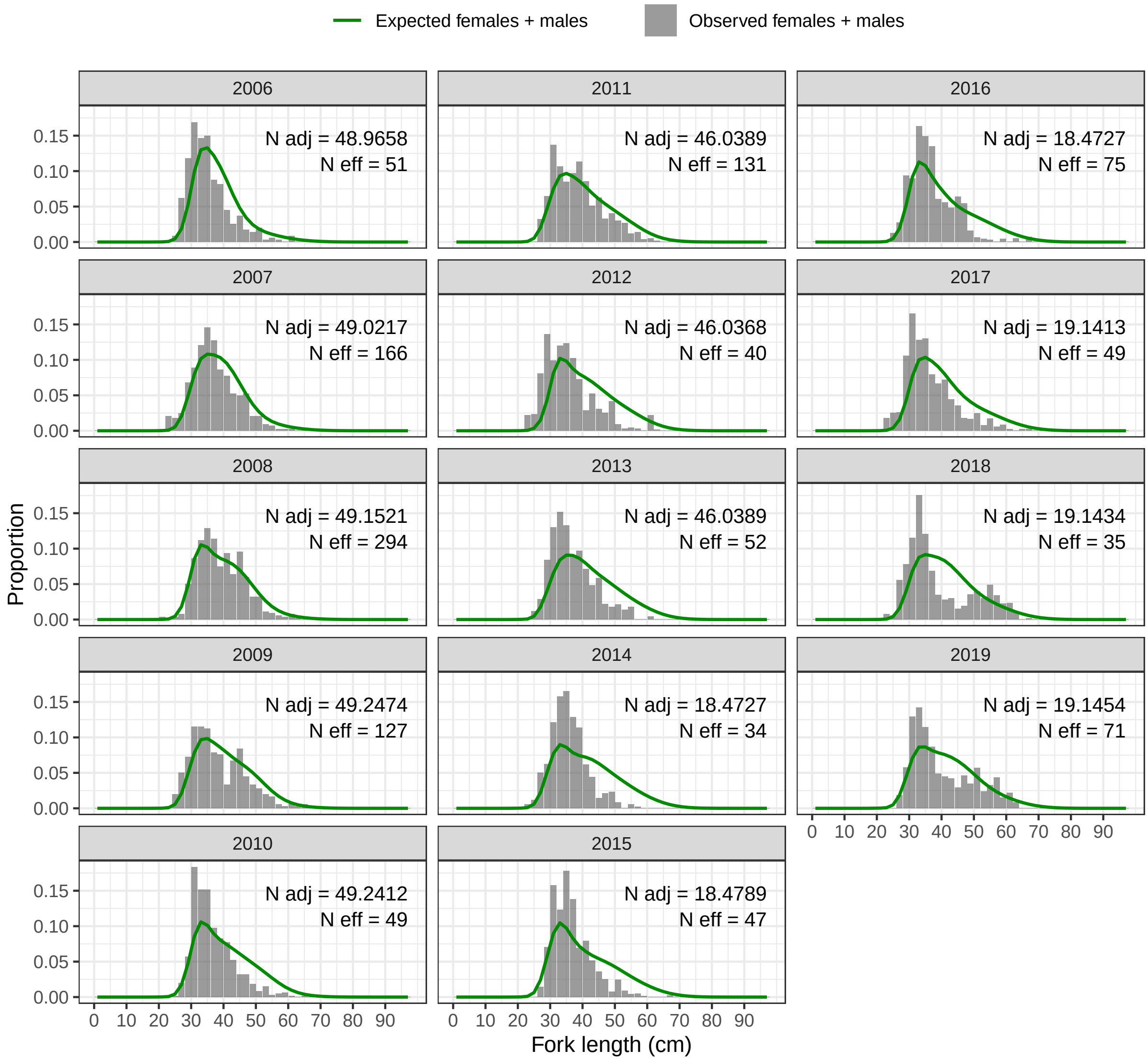

Figure D.4: Fits to length structures for the Queensland recreational fleet for pearl perch—N adj. is the input sample size after data-weighting adjustment. N eff. is the calculated effective sample size used in the Francis tuning method

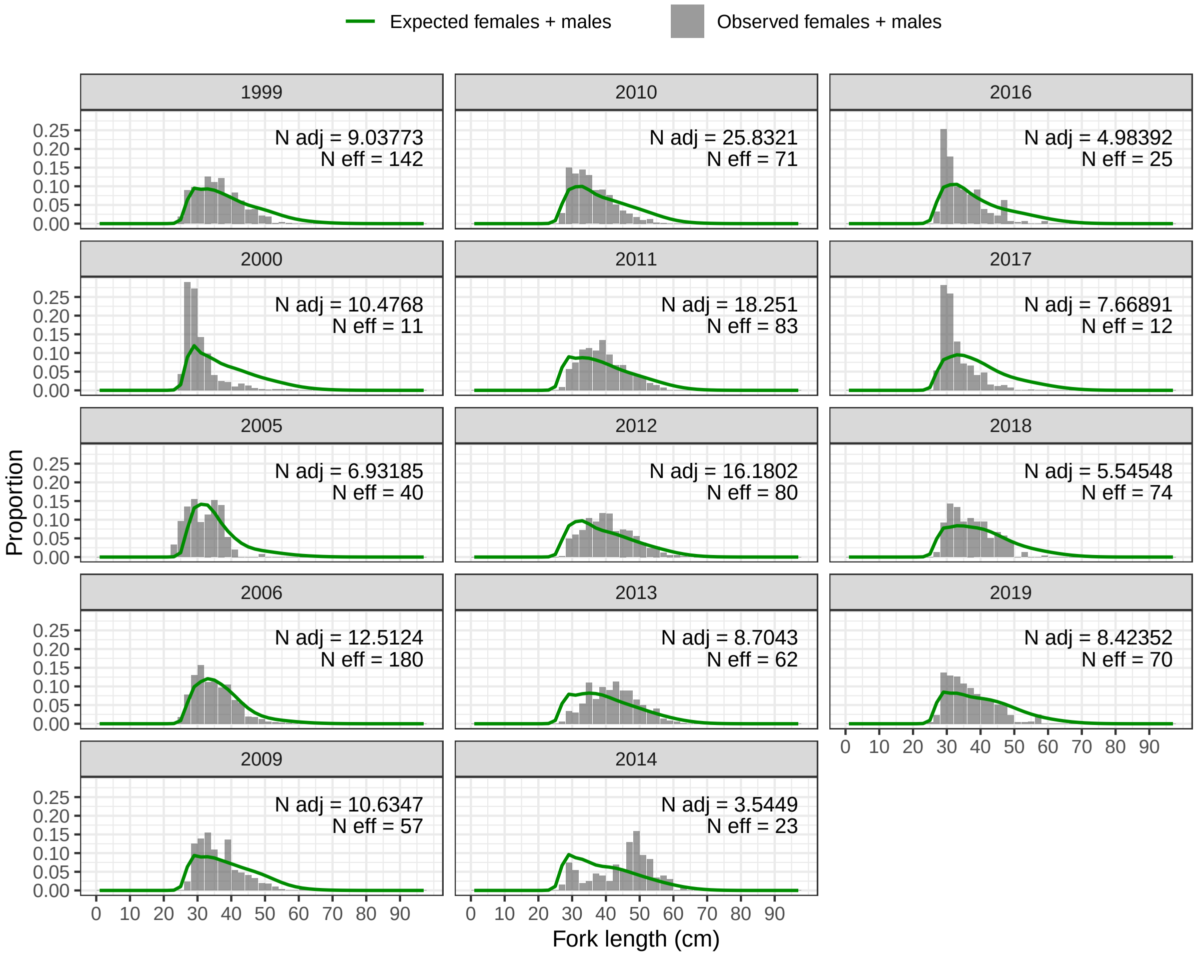

Figure D.5: Fits to length structures for the NSW commercial line fleet for pearl perch—N adj. is the input sample size after data-weighting adjustment. N eff. is the calculated effective sample size used in the Francis tuning method

D.2.3 Age compositions

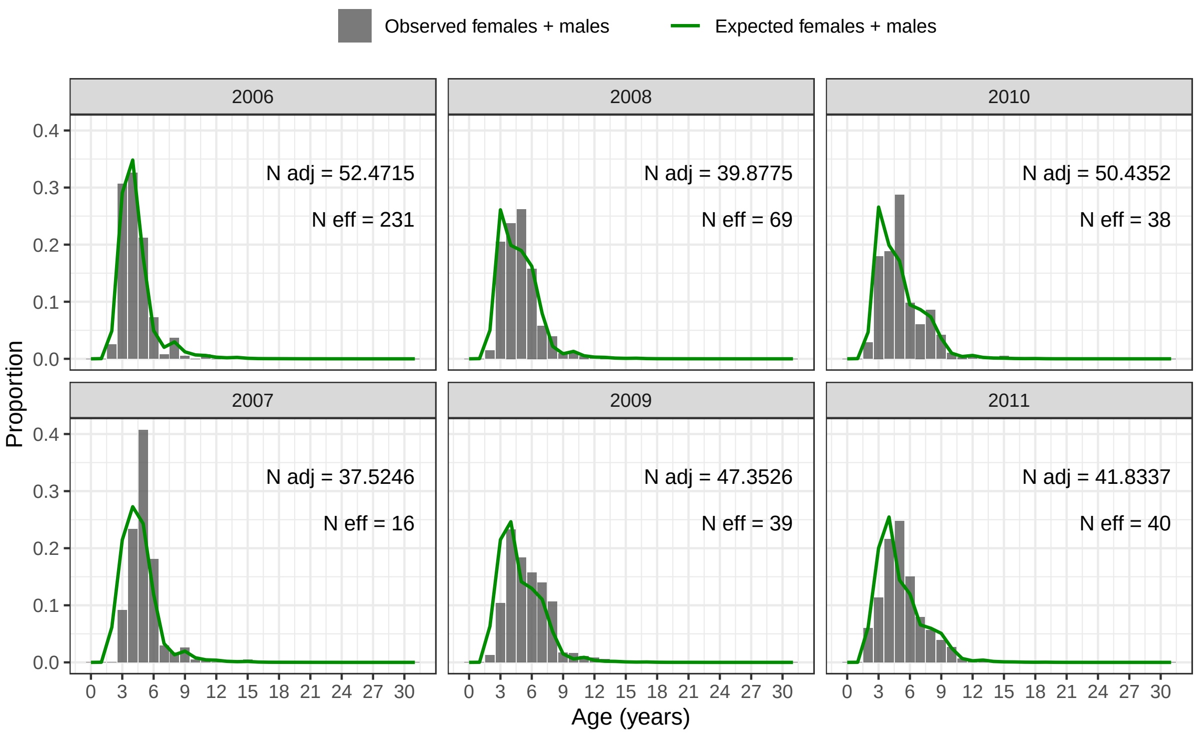

Figure D.6: Fits to age structures for the Queensland charter fleet for pearl perch—N adj. is the input sample size after data-weighting adjustment. N eff. is the calculated effective sample size used in the Francis tuning method

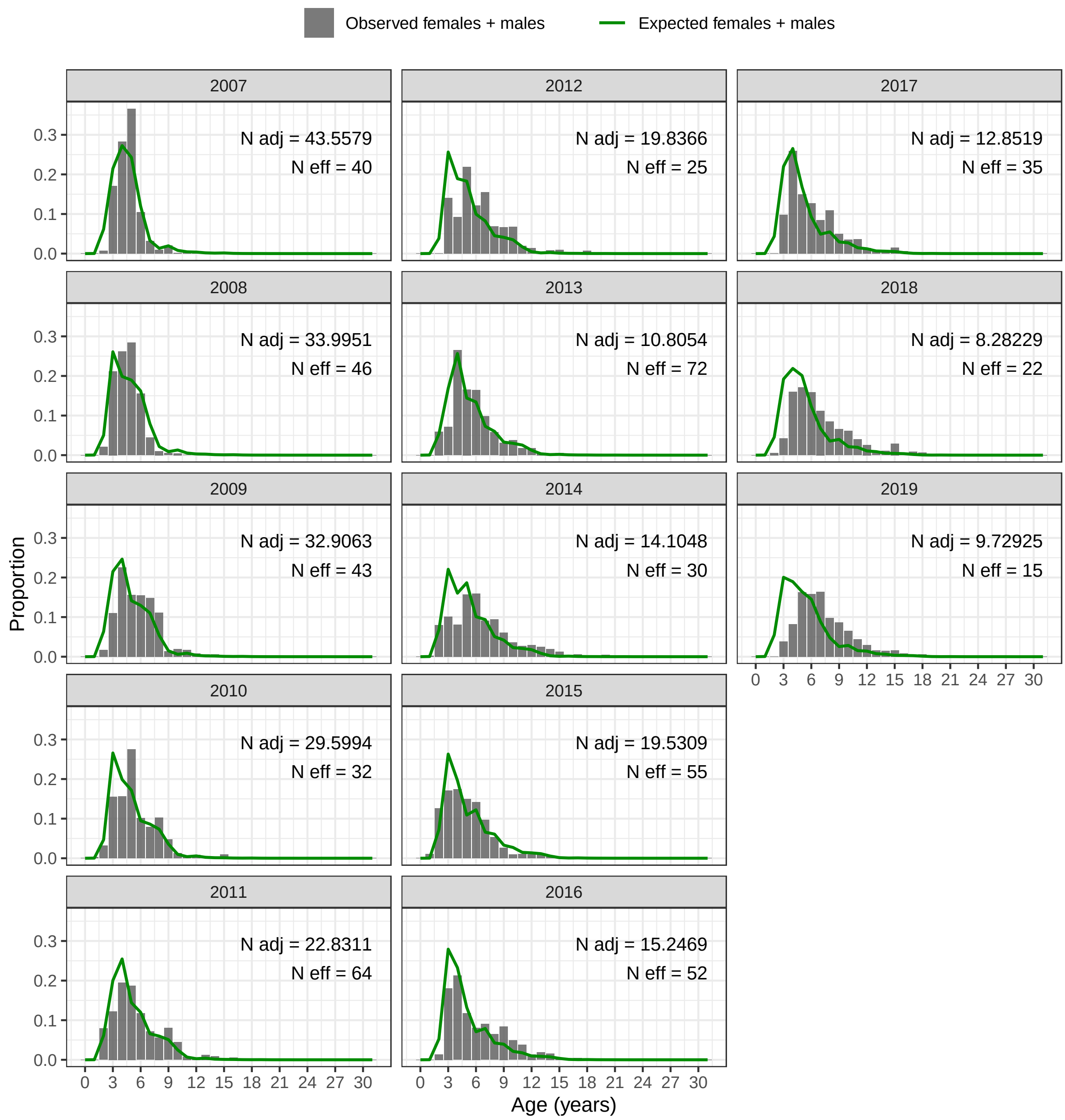

Figure D.7: Fits to age structures for the Queensland commercial line fleet for pearl perch—N adj. is the input sample size after data-weighting adjustment. N eff. is the calculated effective sample size used in the Francis tuning method

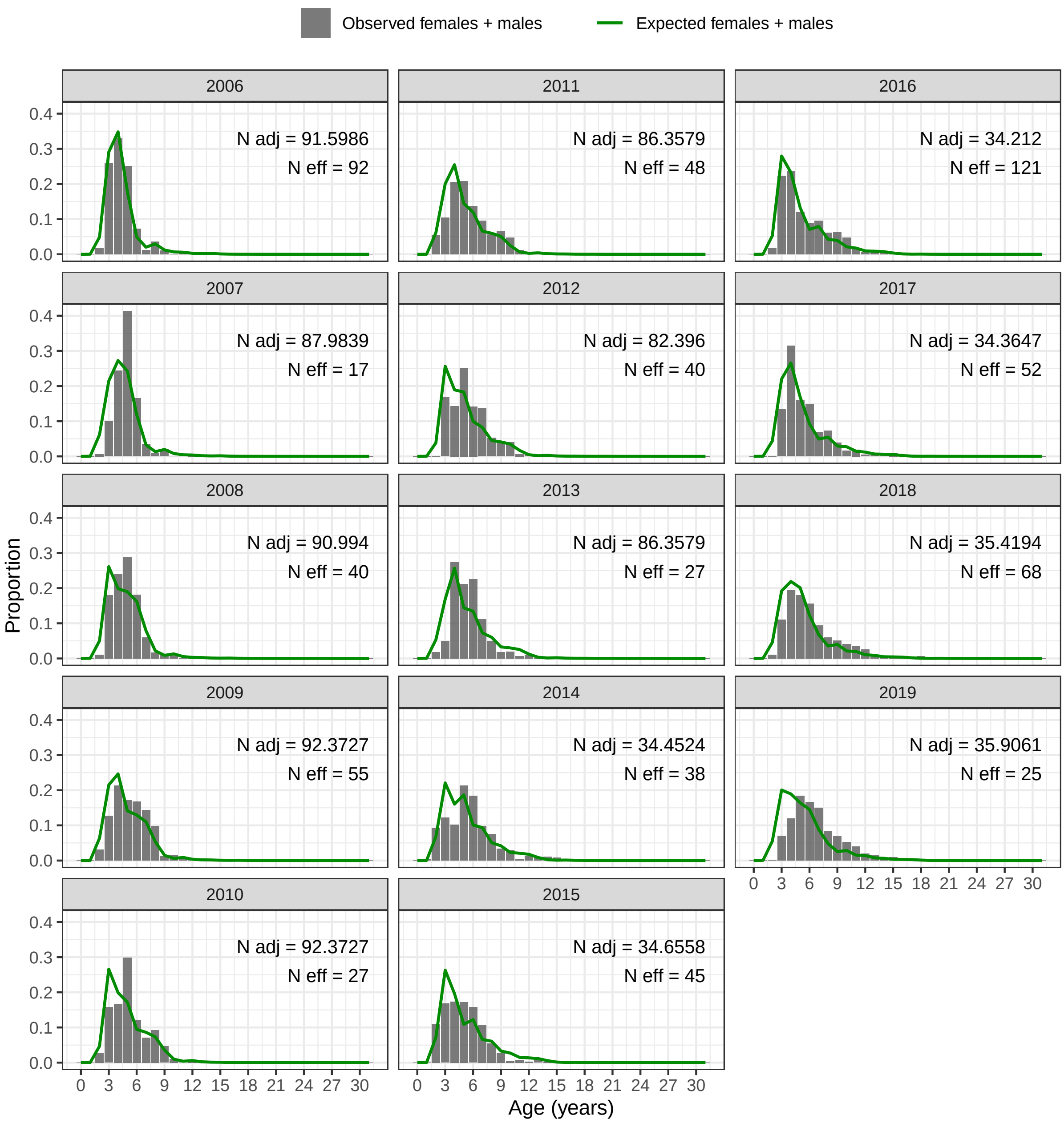

Figure D.8: Fits to age structures for the Queensland recreational fleet for pearl perch—N adj. is the input sample size after data-weighting adjustment. N eff. is the calculated effective sample size used in the Francis tuning method

D.3 Phase plot

The purpose of this stock assessment was to report on the health of the stock and provide information to support fishery management. Results were assessed and classified against fishery target and limit reference points outlined in the harvest strategy and harvest strategy policy for Queensland (Fisheries Queensland 2021).

Separate to this report and other Queensland government reporting, stock assessment results may be used and cited in the 'Status of Australian Fish Stocks' (SAFS) reports (Fisheries Research & Development Corporation 2020). The SAFS classification system applies different inferences and reference points.

The SAFS classification system was designed by the Status of Australian Fish Stocks Reports Advisory Group. The classification system evaluates the status of a stock based on the fishing mortality (F) and biomass (B) relative to a 20% biological limit reference point. The terms ‘sustainable stock’ and ‘stock status’ in the *Status of Australian Fish Stocks Reports 2020* refer specifically to the biological status against the limit reference point. The status of a stock is classified as sustainable, depleting, depleted, recovering, negligible or undefined.

Broader biological, economic or social considerations are not yet classified in SAFS. Reference points relating to these considerations may include maximum sustainable yield (B_{MSY}) or biomass at maximum economic yield (B_{MEY}). B_{MSY} generally ranges 35–40%, when catches from surplus production (the annual amount by which the fish population would increase from growth and recruitment) is maximized (Punt et al. 2013). B_{MEY} generally ranges 50–60%, minimising potential loss in profit (Punt et al. 2013).

A phase plot assists in defining SAFS stock status relative to limit reference points for biomass and fishing mortality (Fisheries Research & Development Corporation 2021). The plot tracks the annual stock biomass ratio relative to the unfished level, against the fishing mortality relative to the target reference point (Figure D.9).

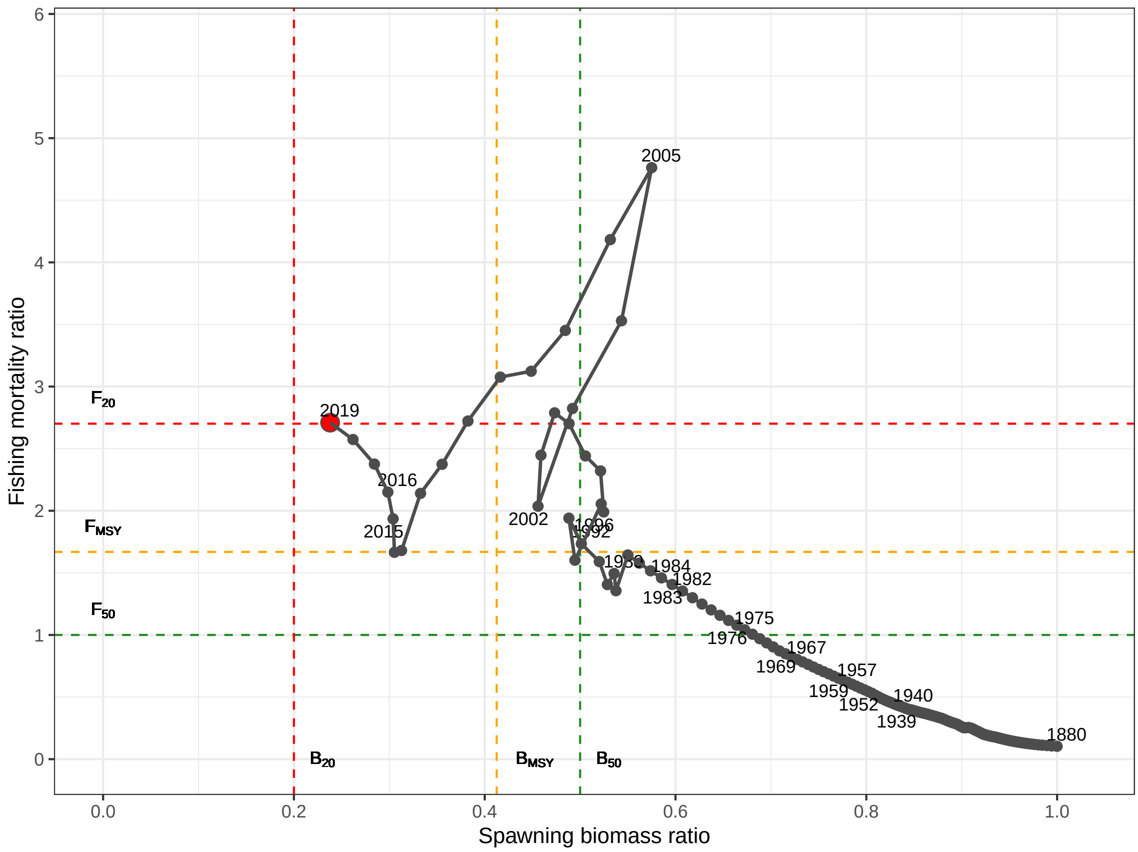

Figure D.9: Annual trajectory of fishing mortality relative to spawning biomass for pearl perch 1880 to 2019—final year indicated by red dot

D.4 Recruitment

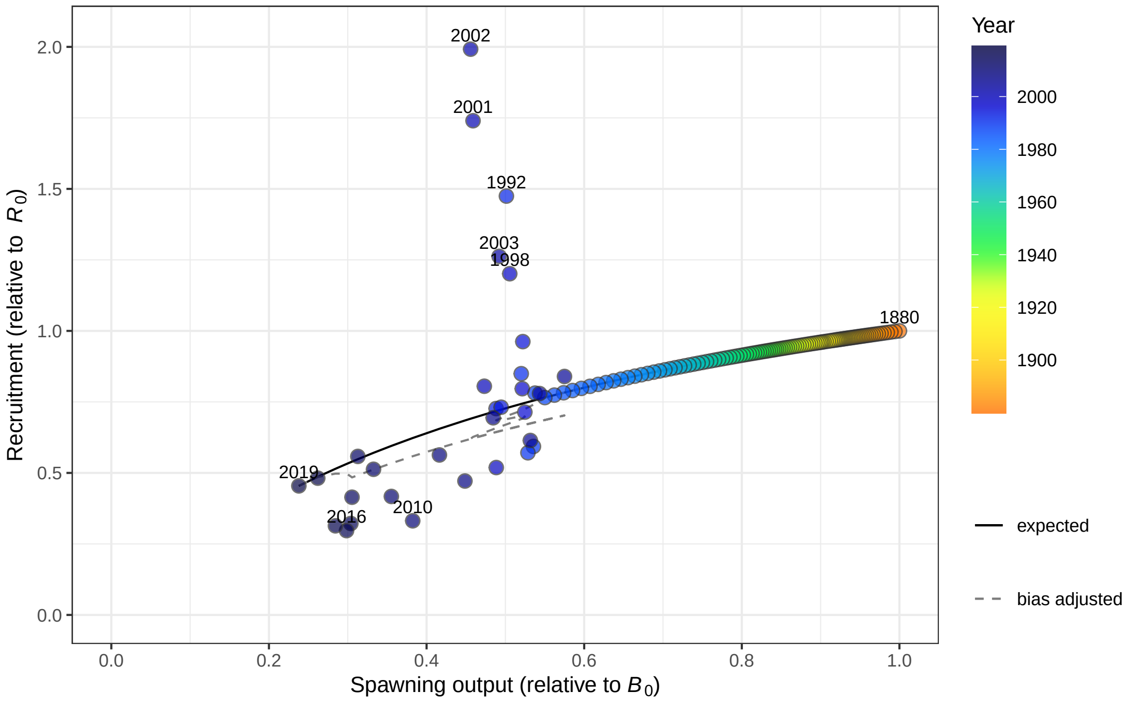

Figure D.10: Annual recruitment as a function of spawning output for pearl perch 1880 to 2019—labels are on first, last, and years with log deviations > 0.5)

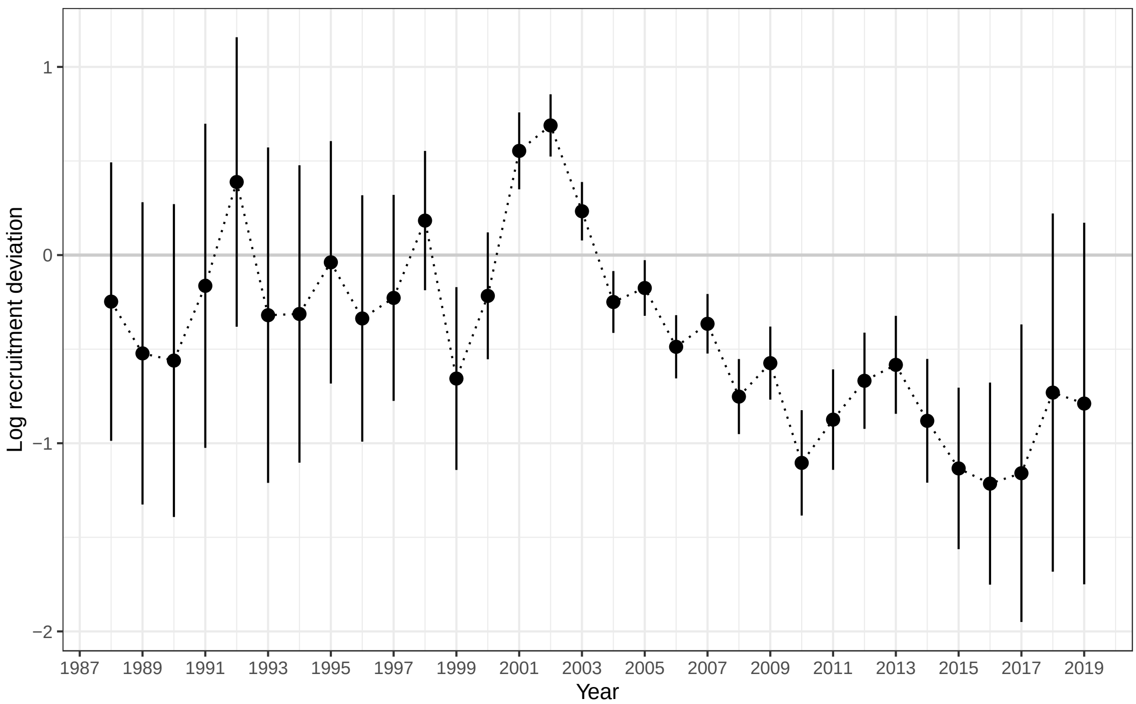

Figure D.11: Log recruitment deviations with 95% confidence intervals for pearl perch

D.5 Model likelihoods

Likelihood components for the base model further broken down into sub-components to allow insight into model behaviour are displayed below (Table D.2).

Table D.2: Log likelihood values for the pearl perch base model

Type	Likelihood	Lambdas
TOTAL	245.7910	
Catch	0.0000	
Equil_catch	0.0000	
Survey	-75.9911	
Length_comp	179.4450	
Age_comp	146.2200	
Recruitment	-3.8861	1
InitEQ_Regime	0.0000	1
Forecast_Recruitment	0.0000	1
Parm_priors	0.0000	1
Parm_softbounds	0.0033	
Parm_devs	0.0000	1
Crash_Pen	0.0000	1

D.6 Likelihood profile

A likelihood profile was performed to explore steepness and determine if the fixed value of 0.4 was appropriate. Values between 0.25 and 0.95 were explored (Figure D.12).

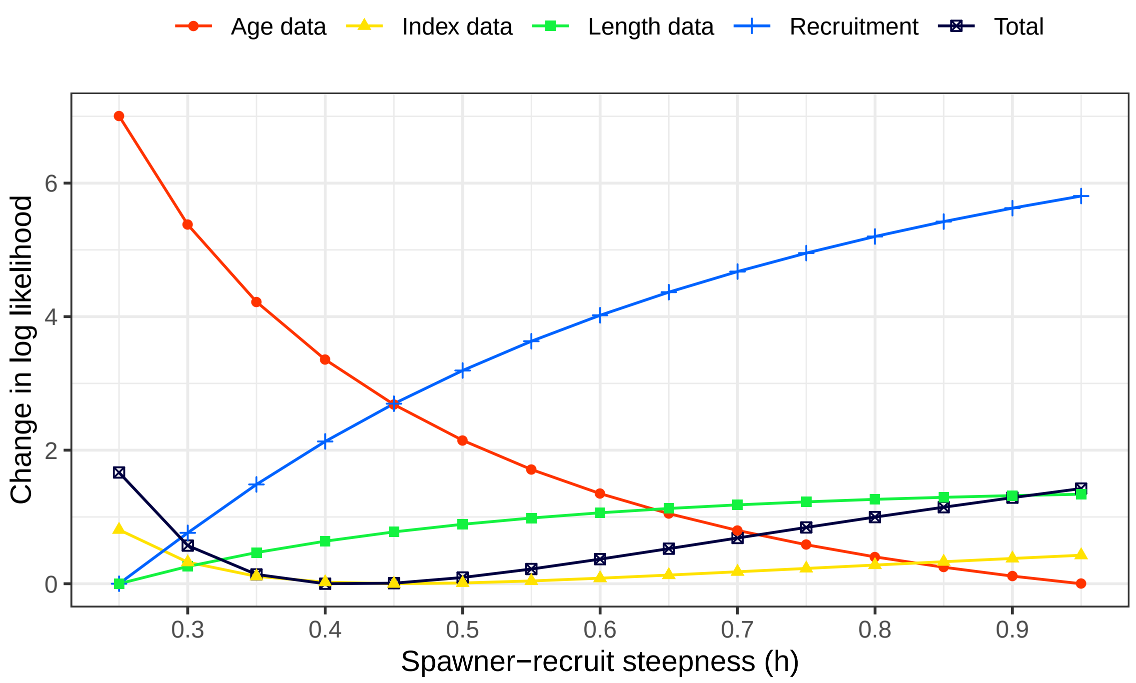

Figure D.12: Likelihood profile for the spawner-recruit steepness parameter h

A likelihood profile was performed to explore the $\ln(R_0)$ parameter and determine if the model estimated value of 6.59 was appropriate. Values between 4 and 20 were explored. Figure D.13 displays a small range of these values which contains the global minimum.

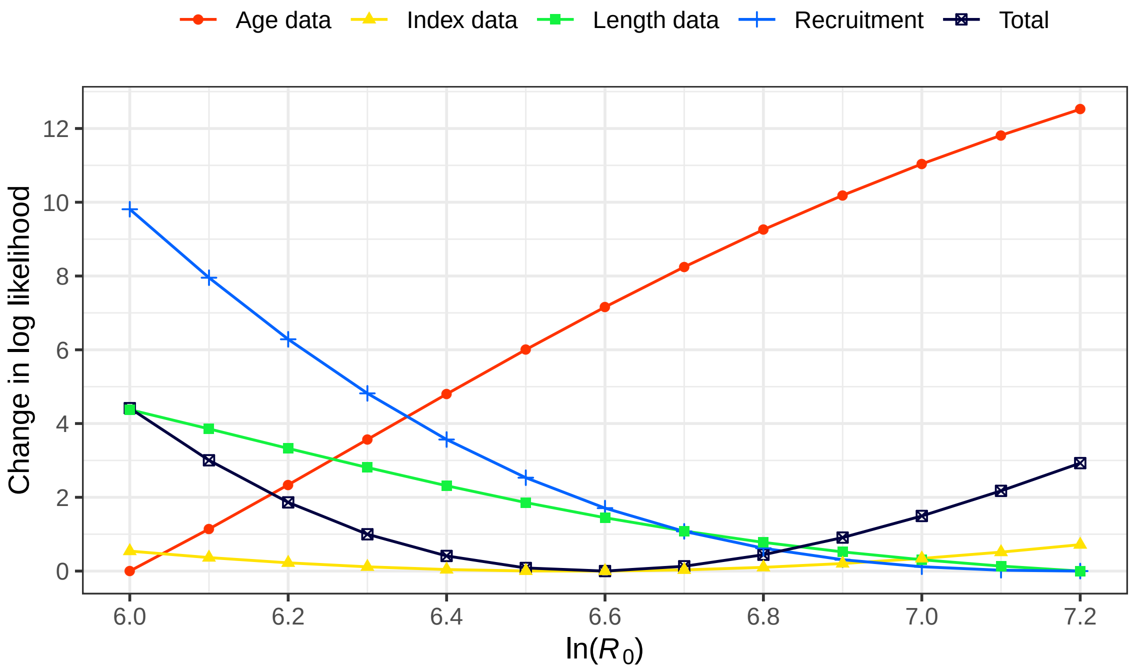

Figure D.13: Likelihood profile for the log of virgin recruitment parameter $\ln(R_0)$