Stock assessment of the Australian east coast tailor (*Pomatomus saltatrix*) fishery

2020

Queensland Government

This publication has been compiled by R. Lovett, G. Leigh and L. Litherland of Fisheries Queensland, Department of Agriculture and Fisheries and J. Stewart of New South Wales Department of Primary Industries, Fisheries.

Enquiries and feedback regarding this document can be made as follows:

Email:	info@daf.qld.gov.au
Telephone:	13 25 23 (Queensland callers only)
	(07) 3404 6999 (outside Queensland)
	Monday, Tuesday, Wednesday and Friday: 8 am to 5 pm, Thursday: 9 am to 5 pm
Post:	Department of Agriculture and Fisheries GPO Box 46 BRISBANE QLD 4001 AUSTRALIA
Website:	daf.qld.gov.au

Interpreter statement

The Queensland Government is committed to providing accessible services to Queenslanders from all culturally and linguistically diverse backgrounds. If you need an interpreter to help you understand this document, call **13 25 23** or visit **daf.qld.gov.au** and search for 'interpreter'.

© State of Queensland, 2020.

The Queensland Government supports and encourages the dissemination and exchange of its information. The copyright in this publication is licensed under a Creative Commons Attribution 4.0 International (CC BY 4.0) licence.

Under this licence you are free, without having to seek our permission, to use this publication in accordance with the licence terms.

You must keep intact the copyright notice and attribute the State of Queensland as the source of the publication.

Note: Some content in this publication may have different licence terms as indicated.

For more information on this licence, visit creativecommons.org/licenses/by/4.0.

The information contained herein is subject to change without notice. The Queensland Government shall not be liable for technical or other errors or omissions contained herein. The reader/user accepts all risks and responsibility for losses, damages, costs and other consequences resulting directly or indirectly from using this information.

Contents

List of figures

List of tables

Summary

Tailor is found along the east and west coasts of Australia. On the east coast of Australia, tailor occurs along the coasts of southern Queensland, New South Wales and Victoria and is considered a single genetic stock. This stock assessment analyses the Queensland and New South Wales component of the east coast stock, as there was limited potential for tailor to migrate between Victoria and Queensland or northern New South Wales.

Tailor mature in their second year of life. In Queensland, the maximum observed age is 7 years and the maximum observed length is 112 cm total length. The current minimum legal size is 35 cm total length in Queensland and 30 cm total length in New South Wales. Tailor is a highly migratory species with an annual, close-inshore run of large schools from New South Wales, where the fishery peaks in April–June, to southern Queensland where the fishery peaks in July–September. Over summer the large schools appear to disperse to some extent as many of the fish make their way back south.

Over the last 5 years, 2015 to 2019, total harvest averaged 240 tonnes (t) per year, including 57 t (23.8%) by the Queensland commercial sector, 68 t (28.4%) by the New South Wales commercial sector, 59 t (24.5%) by the Queensland recreational sector, and 56 t (23.3%) by the New South Wales recreational sector (Figure 1). The 2019 harvest proportions varied only slightly from the 5 year average (Table 1).

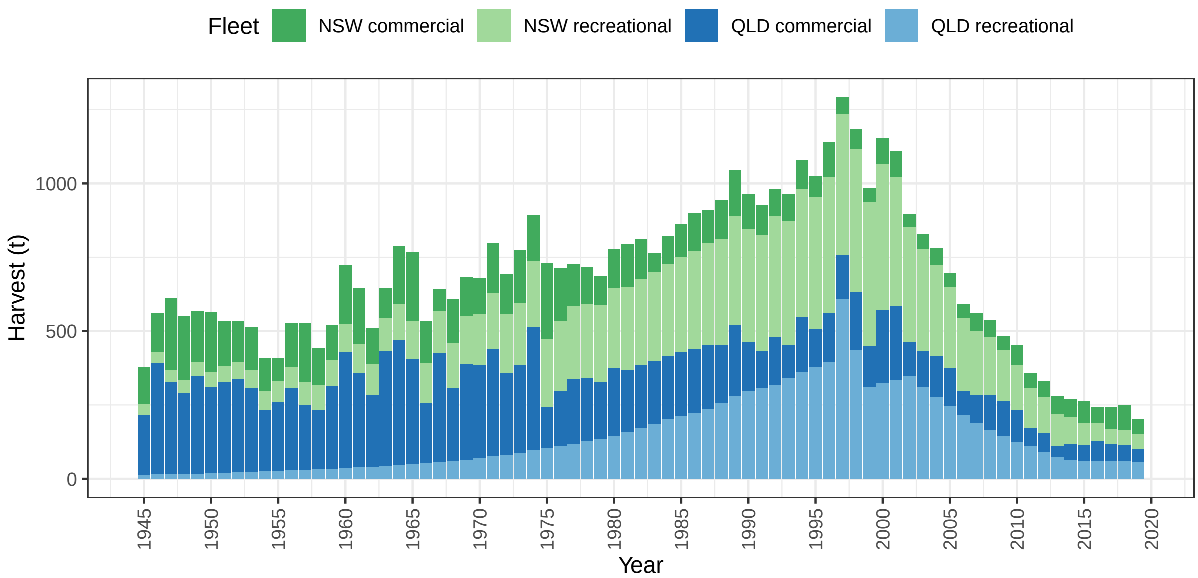

Figure 1: Tailor estimated harvest (retained catch) from commercial and recreational sectors for Queensland and New South Wales east coast from 1945 to 2019

Annual catch rates were standardised for tailor using data based on commercial daily fishing records. Three separate catch rate analyses were conducted: one for Queensland gillnet and one for each of New South Wales net and line (Figure 2). In addition, a fourth catch rate (Queensland fishing club) was sourced from Leigh et al. (2017). These catch rates were used to inform the model fleets Queensland commercial, New South Wales commercial, New South Wales recreational and Queensland recreational respectively.The schooling and movement behaviour of tailor in addition to limitations on units of fishing effort in logbooks may lead to overestimates in fish abundance and hence overestimate fishery performance.

Figure 2: Annual commercial standardised catch rates for Queensland and New South Wales tailor

A previous assessment for the Queensland and New South Wales component of the eastern Australian stock was published in 2017. Results estimated that the stock was at around 50% of virgin unfished exploitable biomass from the mid-1980s to 2012.

This stock assessment used the age-structured model from the previous assessment with an annual time step and included updates to the input data and methods. Incorporated data spanned the period from 1945 to 2019 including total harvests, standardised catch rates and length and age information. These data were divided into Queensland and New South Wales commercial and recreational sectors.

Model analyses suggested that spawning biomass was at around 51% of unfished biomass in 2019 (Figure 3).

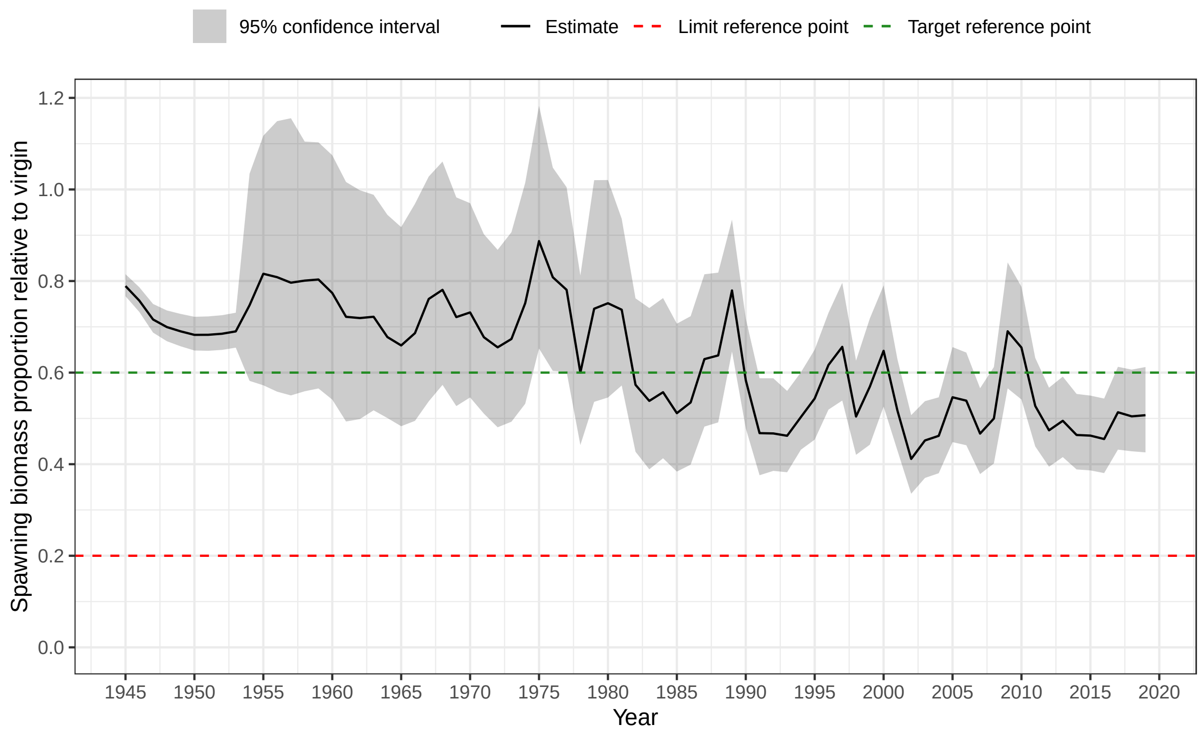

Figure 3: Annual spawning biomass relative to virgin spawning biomass for Queensland and New South Wales east coast tailor

This report provides estimates of sustainable harvests to ensure the fishery operates at sustainable levels, for commercial and recreational fishing, and supports the harvest strategy defined in Queensland's Sustainable Fisheries Strategy 2017–2027 (Department of Agriculture and Fisheries 2017).

Maximum sustainable yield was estimated at 857 t per year and the yield consistent with maintaining a biomass ratio of 60% was estimated at 685 t. However precautions should be taken, model analyses identified that recruitment has been low for the past 10 years leading to a difficulty in stock recovery even though fishing levels have been low during this time. A second scenario with continued low recruitment was also performed. This second scenario estimated maximum sustainable yield at 469 t per year and the yield consistent with maintaining a biomass ratio of 60% at 76 t should this low recruitment continue into the future.

Recommended biological harvests were estimated for fishery management and harvest strategy goals and endpoints with both recruitment scenarios (Table 1). Estimates were based on the 2019 spawning biomass. When deciding on future targets the effect of continued low recruitment should be kept in mind.

Table 1: Current and target indicators
Note: Estimate (average) refers to average recruitment and Estimate (low) refers to low recruitment where the average of the last 10 years recruitment was used

Indicator	Estimate	Estimate (average)	Estimate (low)
2019 spawning biomass ratio	51%		
Maximum sustainable yield spawning biomass ratio		35%	24%
Average 5 year harvest (2015–2019)	240 t		
2019 harvest	204 t		
2019 harvest shares:			
QLD commercial	45 t (22.3%)		
NSW commercial	52 t (25.5%)		
QLD recreational	57 t (28.0%)		
NSW recreational	49 t (24.1%)		
Harvest at maximum sustainable yield		857 t	469 t
Harvest at 60% spawning biomass		685 t	76 t
2020 harvest with harvest control rule		496 t	53 t

Acknowledgements

This work was overseen by a project team that consisted of the authors and the following scientists and managers: James Webley, Tyson Martin, Darren Roy, Ryan Keightley, Tony Ham, Ash Lawson, Michael O'Neill, Joanne Wortmann, Anthony Roelofs, Eddie Jebreen and Sue Helmke. The role of the project team was collaborative to share interpretation and decision making on information and review final results.

In addition to the role of the project team, we would like to thank Ash Lawson for the extraction and supply of the Queensland commercial harvest data, Daniella Teixeira for the supply and extraction of Queensland recreational harvest data, James Craig for the supply and extraction of New South Wales commercial, recreational and biological data and Queensland Fishery Monitoring for the supply of Queensland biological size and age data.

Additional thanks to Michael O'Neill and James Webley who alongside two authors, formed a small focus group to investigate harvest reconstruction. Some changes were made to harvest reconstruction methodology following advice from this group.

This report is an update of Leigh et al. (2017) and hence much of the text is reproduced here.

The authors would also like to acknowledge and thank the many fishers and scientists who have contributed to past and current research on tailor. We would finally like to thank the project team for reviewing and providing comments on parts of the draft report. This assessment was funded by the Department of Agriculture and Fisheries.

Glossary

Age	age within this report refers to Age group unless otherwise stated (see Appendix B)
Fishing year	1 January to 31 December
FL	fork length
FM	Fishery Monitoring Program
FMC	fishing method code
GLM	generalised linear model
Hyperstability	a bias that can occur in catch rates due to fisher knowledge of spatially and/or temporally predictable fish aggregation behaviour leading to generally stable catch rates even though fish abundance declines (O'Neill et al. 2018)
MCMC	Markov chain Monte Carlo
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
QLD	Queensland
RFish	recreational fishing surveys conducted by Fisheries Queensland
SAIGE	Stock Assessment with Individual Growth Equations
SRFS	Statewide recreational fishing surveys conducted by Fisheries Queensland
TL	total length

1 Introduction

Tailor, *Pomatomus saltatrix*, is widely distributed in subtropical and temperate waters around the world. It is the only species in its family Pomatomidae.

In Australia, tailor is found on the east and west coasts of Australia. On the east coast of Australia, tailor is considered a single genetic stock (Nurthen et al. 1992). The east coast stock extends from Wilsons Promontory (Victoria) to the northern tip of Fraser Island (Queensland). This stock assessment focuses on the New South Wales and Queensland component of the harvest (Figure 1.1).

Figure 1.1: Extent of the Australian east coast tailor fishery in Queensland and New South Wales

Tailor is a highly migratory species with a pronounced annual, close-inshore run of large schools from New South Wales, where the fishery peaks in April–June, to southern Queensland where the fishery peaks in July–September. Over summer the large schools appear to disperse to some extent as many of the fish make their way southward. Dispersal of pelagic eggs and larvae with prevailing currents, movement of juveniles into sheltered near-shore or estuarine habitats, and the seasonal migration behaviour of adults, facilitate a genetically homogenous population along the coastline (Zeller et al. 1996; Juanes et al. 1996; Miskiewicz et al. 1996; Ward et al. 2003). Extensive north–south migration of tailor also takes place in other parts of the world, including Western Australia (Lund et al. 1970; Wilk 1977; Haimovici et al. 1996; Shepherd et al. 2006; Lyman 1987, ch. 1–2; Smith et al. 2013, p. 7).

A general study of east coast tailor biology was undertaken by Bade (1977), including fecundity analysis on a small sample of fish. Zeller et al. (1996), Pollock (1984c) and Schilling et al. (2019) cover various aspects on life history of east coast tailor. Halliday (1990), Mann (1992), Morton et al. (1993), Miskiewicz et al. (1996), Brodie et al. (2018), Schilling et al. (2017), Schilling et al. (2018), and Schilling et al. (2020) further cover the movement and distribution of tailor (eggs, larvae, juveniles and adults) along the east coast. Juanes et al. (1996) compare early life history strategies for populations in different parts of the world. Pollock (1984b) and Broadhurst et al. (2012) cover catch-and-release mortality within the Australian east coast population and Ayvazian et al. (2002) in Western Australia.

Tailor mature in their second year of life and many enter the ocean-beach fishery during this year (Williams 2002, p. 164). Tailor does not exhibit sex change, segregation by sex or significant sex-specific differences in length-at-age. They are reported to be serial spawners and have an extended period of spawning from winter through to late summer but peaking in the spring (Miskiewicz et al. 1996; Zeller et al. 1996; Kellet 1998; Ward et al. 2003; Schilling et al. 2020). Multiple spawning groups occur along the east coast that appear to spawn at different times and locations depending on water temperature, the Eastern Australian Current and latitude (Miskiewicz et al. 1996; Juanes et al. 1996; Schilling et al. 2020). Similar spawning characteristics occur in other tailor populations including Western Australia, South America and North America (Haimovici et al. 1996; Robillard et al. 2008; Callihan et al. 2008; Smith et al. 2013).

The maximum observed age from the Australian east coast harvest is 7 years old (Fishery Monitoring data). A similar age range is observed in other southern hemisphere populations such as Western Australia and South America where the majority of fish are less than 7 years of age with only a few fish being up to 10 years old (Haimovici et al. 1996; Smith et al. 2013). The maximum observed length from the Australian east coast harvest is 112 cm total length.

In eastern Australia, Aboriginal artisanal fishing for tailor using spears and possibly hooks and scoop nets probably dates back many thousands of years (Williams 1982, p. 14; Pepperell 2009). After white settlement and before refrigeration became widespread, tailor was recognised as a potential food fish but, although present in fish markets year-round, was not strongly targeted (Pepperell 2009, pp. 59–60), perhaps because it destroyed fishers' nets or because the flesh begins to decompose quickly after capture (Stead 1906, pp. 153–157).

By the 1940s, commercial fisheries harvesting hundreds of tonnes per year for tailor had developed in Queensland and New South Wales. Records of harvest sizes from that time onward are held by state government agencies. Commercial fishing operates using seine nets which encircle schools of fish swimming off beaches; gillnets which mesh fish around the gills as they swim through; and tunnel nets which are set to capture fish as the tide recedes from suitable beach, sandbank and mud-bank locations.

Since 1997 a significant commercial line fishery for tailor has developed in New South Wales. Fishing for tailor generally occurs inshore and line fishing is primarily shore-based from ocean beaches or rocky headlands.

After the mid-1970s, consumers' taste changed, tailor had been commonly consumed in fish and chips, but this declined in importance relative to other forms of fast food. Also, tailor was no longer the standard fish for meals in Queensland hospitals, a major market of commercially caught tailor at the time

(Dichmont et al. 1999, p. 105). Commercial fishing crews now primarily focus on mullet during ocean beach fishing seasons.

The 1950s saw tailor fishing become increasingly popular due to developments such as waders, sidecast reels, and gangs of three or more hooks, lures, nylon fishing line, and improved access to bait (Claydon 1996). Development of the recreational tailor fishery was greatly facilitated by improved access to fishing locations and fishers were accessing virtually virgin fishing grounds as four-wheel drives and barges became commonplace. By the 1970s the recreational catch exceeded the commercial catch and by the 1980s tailor became one of the most commonly caught species in New South Wales and on Fraser Island (Pollock 1984c). Recreational fishing kept increasing until the mid-1990s. Ocean-beach gutters, especially on Fraser Island, became crowded with anglers.

Fishery management measures have been legislated throughout the history of the fishery 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 35 cm total length, a recreational in possession limit of 20 fish and a seasonal finfish fishing closure on part of Fraser Island. Commercial restrictions include net fishing restrictions (Queensland Department of Employment, Economic Development and Innovation 2009), seasonal and temporal closures and a total allowable commercial catch of 120 tonnes.

In New South Wales, current management measures include a MLS of 30 cm total length, recreational fishing licences, daily bag limits of 10 fish (with an in possession limit of 20 fish), commercial net fishing restrictions and daily trip limits. Both states impose gear and licence restrictions.

Table 1.1: Management measures applied to the tailor in Queensland and New South Wales waters

Date	Measure
Queensland	
1877	Minimum legal weight 6 ounces
1877–1974	Various measures relating to fishing gear and practices; e.g. mesh size, net length, allowed species, closed seasons, powers of inspectors
1887	Minimum legal weight 8 ounces (*Queensland Fisheries Act 1887*)
1914	Minimum legal size 10 inches total length (*The Fish and Oyster Act of 1914*)
1957	Minimum legal size 12 inches total length (*Fisheries Act 1957*)
16 Dec 1976	Minimum legal size abolished (*Fisheries Act 1976*)
8 Mar 1990	Minimum legal size 30 cm total length (*Amendment of Fisheries Organization and Marketing Regulations, 1990*)
1 Sep 1990	Seasonal fishing closure on Fraser Island between 400 m north of Waddy Point and 400 m south of Indian Head, for the month of September
1995	Closure to commercial net fishing of many beaches around populated areas; most of Moreton Bay (all of Moreton Bay at weekends); Great Sandy Strait at weekends; and the eastern (ocean beach) shore of Fraser Island from 1 April to 1 September (*Fisheries Regulation 1995*)

Table 1.1 – *Continued on next page*

Table 1.1 – *Continued from previous page*

Date	Measure
1 May 2002	Recreational bag limit (in-possession limit) 20 fish; 30 for fishers staying on Fraser Island for 72 hours or more; total allowable commercial catch of 120 tonnes for commercial fishers, except for incidental catch up to 100 kg per fisher per day.
1 Aug 2002	Seasonal fishing closure on Fraser Island extended to cover August and September
1 Sep 2003	Closure to commercial net fishing on Fraser Island between Tooloora Creek and the northern end of North Ngkala Rocks from 1 April to 1 September (already closed for the rest of the year in 1995)
20 Sep 2003	Closure to commercial net fishing on northern beaches of North Stradbroke Island from 20 September to 1 April
1 Mar 2009	*Marine Parks (Moreton Bay) Zoning Plan 2008* closed many areas near Brisbane to fishing where tailor were commonly caught
May 2009	Incidental catch for commercial fishers up to 30 kg per fisher per day
1 Mar 2010	Minimum legal size increased to 35 cm total length, recreational bag limit (in-possession limit) set at 20 (no variation for extended stay on Fraser Island)
New South Wales	
1902–1994	Various measures relating to fishing gear and practices; e.g. mesh size, net length, closed seasons, prohibition of explosives and poisons
11 Jun 1993	Minimum legal size 30 cm total length (*Fisheries and Oyster Farms Act 1935—Regulation no. 199, 1993*)
11 Jun 1993	Recreational bag limit 20 fish (*Fisheries and Oyster Farms Act 1935—-Regulation no. 199, 1993*)
1 Sep 2001	Commercial net fishing ban, except for incidental catch up to 100 kg per fisher per day taken using ocean hauling nets and 50 kg per fisher per day using any other nets, in the Ocean Hauling and Estuary General Fisheries
12 Sep 2014	Recreational bag limit (daily limit) reduced from 20 to 10; in-possession limit (home freezer limit) remains 20

The stock was previously assessed with data through to 2014 by Leigh et al. (2017) who assessed the stock at approximately 50% exploitable biomass ratio in 2012. This assessment contains updates to data and methodology. Key updates include: improvements to the stock assessment model outlined in Leigh et al. (2019), new methods of calculating harvest targets and forward projections of the biomass response to these harvest targets.

In 2020, the Queensland Department of Agriculture and Fisheries commissioned an update to the stock assessment for tailor. This assessment aims to determine the status of the Australian east coast biological stock. This report provides 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).

2 Methods

2.1 Data sources

Data sources included in this assessment (Table 2.1) were used to determine catch rates, create total annual harvests (combining commercial and recreational harvests) and length and age compositions. Data were used according to their quality, quantity and temporal-spatial resolution. 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 harvest	1988–2019	Logbook data collected by Fisheries Queensland
	1997–2019	Logbook data collected by New South Wales Department of Primary Industries, Fisheries
	1945–1981	Queensland Fishboard data (Halliday et al. 2007)
	1945–1997	New South Wales historical commercial harvest records
Recreational harvest	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; Webley et al. in prep)
	2013, 2017	New South Wales survey using similar methodology to the NRIFS (West et al. 2015; Murphy et al. 2020)
Queensland fishing club catch rate	1954–2001	(Leigh et al. 2017)
Biological data	1976, 1978–1980, 1986–1990, 1995–1997, 1999–2019	(Bade 1977; Pollock 1984a; Halliday 1990; Hoyle et al. 2000; Fisheries Queensland 2013a; Fisheries Queensland 2013b; Fisheries Queensland 2017; Fisheries Queensland 2018) and New South Wales Department of Primary Industries, Fisheries
Lunar data	1988–2019	Continuous daily luminous scale of 0 (new moon) to 1 (full moon) (O'Neill et al. 2014)
Wind data	1988–2019	Bureau of Meteorology

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 harvest of tailor in kilograms, the geographic location of each harvest available in 30 or 6 minute grids and the fishing method used.

Historical commercial data for Queensland (1945–1981) were sourced from estimated harvests in annual reports by the Queensland Fish Board state-owned marketing agency (Halliday et al. 2007). These data were annual weights in kilograms with some regional information.

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 harvest data were sourced from New South Wales historical records: 1945–1984 (provided in financial years) and 1984–1997 (provided monthly). Both sources were in kilograms of fish by region.

2.1.2 Recreational

All recreational surveys provided estimates of the number of tailor harvested and discarded per trip and combined this with demographic information to estimate annual totals at 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 only one year of data, Indigenous fishing data were not used as an input for this assessment.

2.1.4 Charter

The commercial logbook databases included data from the charter fisheries from both Queensland and New South Wales. These were not used in the assessment because the harvest size was already included in recreational harvest estimates.

2.1.5 Biological

Length-frequency data of tailor from the Australian east coast were available from 1976 onwards. Most of these data were fishery-dependent, i.e. samples were taken from recreational and commercial harvests and measured by scientific staff. The sampling procedures improved greatly from 1999 when Fisheries Queensland began routine annual monitoring. Information was chosen and compiled using the same methods as Leigh et al. (2017).

Age data supplied by Queensland's Fishery Monitoring Program are classified into age groups (see Appendix B) (Fisheries Queensland 2017; Fisheries Queensland 2018). Age group is expressed in whole years, and is the maximum age class fish would reach within a designated sampling season. Age group is the preferred age type used in routine analyses because it groups fish in the same cohort together, irrespective of when they were caught during a sampling season.

Age and length information were also collected as part of a series of scientific studies conducted in New South Wales (Schilling et al. 2017; Schilling et al. 2018; Schilling et al. 2019; Brodie et al. 2018; Lawson et al. 2018). Age data from New South Wales were aged using the same methods as Queensland Fishery monitoring (see Appendix B). These data were collected with a variety of fishing methods and hence could not be used in the model due to the difficulty in applying a representative selectivity curve.

2.2 Harvest estimates

2.2.1 Commercial

Commercial harvest estimates were calculated in two stages:

1. Convert historical annual commercial harvests from financial years (July to June) to calendar years (January to December). Assumptions were made to fit the annual patterns of when the majority of the commercial catch was taken for each state and followed the method used in Leigh et al. (2017).

   Queensland: It was assumed that the harvest was taken from July to December.

   New South Wales: It was assumed that the harvest was taken from January to June.

2. Interpolate Queensland commercial harvests between 1981 and 1988.

   Queensland: Commercial harvests in the years 1981–1987 were interpolated by fitting a straight line to the logs of the commercial harvests at two endpoints:

   - The average of the 1979 and 1980 harvests halfway between 1979 and 1980
   - The average of the 1988 and 1989 harvests halfway between 1988 and 1989.

   Working on the log scale allowed the interpolation to fit a constant percentage rate of increase or decrease of the harvest over the interpolated period, which was regarded as more realistic than a constant number of tonnes.

2.2.2 Recreational

Recreational harvest estimates were calculated in four stages:

1. Split data into groups. This method follows Leigh et al. (2017).

   Queensland: Data for the years 1997–2014 were grouped into 'Fraser' and 'non-Fraser' (any location that wasn't Fraser) regions.

2. 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 (1997, 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.

3. Convert numbers to weight. This method follows Leigh et al. (2017).

Queensland: Data provided were in numbers of fish retained. A weight multiplier of 0.558 kg per fish was used to convert these data.

New South Wales: Data for the years 2000 and 2013 were provided as numbers of fish in 'Estuarine' and 'Oceanic' groups. A weight multiplier of 0.499 kg for fish caught in estuaries and 0.593 kg for fish caught on ocean beaches was used. Once fish numbers had been converted to weight, these harvests were then added together for each year to create a single weight for each year. The 2017 data were provided as a weight so no changes were necessary.

4. Hindcast. This method differs slightly from Leigh et al. (2017) and was changed according to recommendations made by the project team focus group.

   Queensland: For each of the 'Fraser' and 'non-Fraser' regions, an average of the harvest weights for the years 1997–2002 was taken and applied to the 1996 year for hindcasting.

   For the Fraser region, hindcasting was performed by multiplying a vector of Fraser Island visitor number proportions by the derived 1996 harvest weight (Fraser Island Defenders Organisation 2015). This vector was created by taking the number of visitors for each year and dividing by the number of visitors in 1996. For the non-Fraser region, hindcasting was performed using a vector of Queensland human population proportions proportions which was created in a similar fashion (ABS 2014). The Fraser and non-Fraser harvests were then added together for each year to create a single weight for Queensland for each year.

   New South Wales: Hindcasting for New South Wales was performed in the same way using the New South Wales year 2000 harvest weight and a vector of the New South Wales human population proportions (ABS 2014).

5. 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 harvest estimates. The harvest 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 harvests 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, harvest in the 2017 year was assumed to be the same for each of the 2018 and 2019 years.

2.3 Abundance indices

Annual catch rates were standardised for tailor using data based on commercial daily fishing records. Three separate catch rate analyses were conducted: one for Queensland gillnet and one for each of New South Wales net and line. In addition, a fourth catch rate (Queensland fishing club) was sourced from Leigh et al. (2017). These catch rates were used to represent the model fleets Queensland commercial, New South Wales commercial, New South Wales recreational and Queensland recreational respectively.

Ocean beach catch rates were not calculated for this assessment due to the added complexity of search time and competition between tailor and sea mullet market prices. Although ocean beach fishing methods comprise a large proportion of the commercial harvest (see Figure A.1, Appendix A), it is more important to focus on a catch rate that can capture the abundance of the stock through consistency of fisher behaviour.

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

- Similar fishing methods were grouped together. In the early years of the Queensland database, fishing methods were not well distinguished. The process by which fishing methods were distinguished in the early logbook years is outlined in Appendix A. This method has been updated since the previous assessment (Leigh et al. 2017).
- 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.
- Fishers who fished in only one year during the period of analysis were omitted.
- Two sinusoidal variables were included to indicate lunar phases (lunar and lunar advanced by a quarter of a phase).
- Wind vectors were also added. These included linear vectors (north–south and east–west) and their quadratic components.

Leigh et al. (2017) considered species groups commonly associated with tailor on the basis of the average catch of tailor over records in which a particular other species was caught. However, for this assessment, no associated species were found to be significant. This could be due to the change in the way that fishing methods have been distinguished since the last assessment (see Appendix A).

The analysis used the quasi-negative-binomial generalised linear model (GLM) which is similar to the quasi-Poisson model used in the previous assessment (Leigh et al. 2017). The extension from quasi-Poisson to quasi-negative-binomial allows the variance of the residuals from the GLM to be more closely controlled so that data are weighted optimally and random “noise” in the resulting abundance estimates is minimised.

The quasi-Poisson variance formula is

$$V(y) = \sigma\mu, \tag{2.1}$$

where V denotes variance, y is the dependent variable (catch in a fisher–day), σ is the dispersion parameter and μ is the mean or expectation of y. The quasi-negative-binomial model extends this to

$$V(y) = \sigma\left(\mu + \mu^2/\phi\right), \tag{2.2}$$

where ϕ is the negative-binomial shape parameter. The limit $\phi \to \infty$ recovers the quasi-Poisson model.

Explanatory variables included in GLMs are shown in Table 2.2. All explanatory variables other than lunar phase and wind terms were defined as categorical variables or “factors”. The month:location term was the interaction between month and location. Mesh size and net length were converted from continuous variables to categorical ones because the relationships between these variables and catch rates were complex.

Table 2.2: Explanatory variables included in GLMs for each catch rate

Explanatory variable	QLD gillnet	NSW line	NSW net
fisher ID	yes	yes	yes
calendar year	yes	yes	yes
month	yes	yes	yes
location	yes	yes	yes
month:location	yes	yes	yes
lunar phases	yes	not significant	not significant
linear wind terms	yes	yes	not significant
quadratic wind terms	not significant	yes	not significant
mesh size	yes	not available	not available
net length	yes	not available	not available

2.4 Biological information

Extensive work was performed in Leigh et al. (2017) to source biological parameters for use in population modelling. Most of these parameters have been used again for this assessment and are presented below.

2.4.1 Length conversion

Minimum legal size (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 tailor, both measured in centimetres (Bade 1977; Leigh et al. 2004; Leigh et al. 2017):

$$FL = 0.896\ TL - 0.1178 \tag{2.3}$$

$$TL = 1.114\ FL + 0.1764. \tag{2.4}$$

2.4.2 Weight conversion

Fishery models are commonly structured by length (fork length) whereas commercial fishery catches are measured by weight. Bade (1977, p. 78) provides the following formula for converting fork length (FL, in cm) to weight (W, in kg) (Leigh et al. 2004; Leigh et al. 2017):

$$\text{W} = 1.203 \times 10^{-5}\ FL^{3.01} \tag{2.5}$$

2.4.3 Minimum legal size

The population model accounts for the minimum legal size (MLS) applicable to to each model fleet in each year of the model. Details of MLS restrictions over time are found in Table 1.1. MLS restrictions are imposed as a total length measurement and were converted to fork length through the use of Equation 2.3 for input to the population model.

2.4.4 Discard mortality

When line-caught fish are returned to the sea by fishers, not all of them survive. Discard mortality with an emphasis on Australia was reviewed by Smith (2004). A discard mortality rate of 0.3 (30% of fish released do not survive) was used in the previous stock assessment (Leigh et al. 2017) and this rate has been repeated for this assessment.

2.4.5 Ageing

Ages have been grouped for use in the population model following the method used by Leigh et al. (2017) (see Appendix B).

2.4.6 Fecundity and maturity

Fecundity and maturity schedules in the population model followed methods by Leigh et al. (2017). Fecundity was assumed to be proportional to weight and fish were considered to be fully mature in their second year of life. Maturity (m) was input to the model as a binary function of age where $m = [0, 1, 1, 1, 1, 1, 1]$.

2.5 Population model

An annual, age and length-structured population model was fitted to the data to determine the number of tailor in each year and each age group. The model used was the SAIGE (Stock Assessment with Individual Growth Equations) population model Leigh et al. (2019). A full technical description of SAIGE is given in Leigh et al. (2019). This model is similar to the model used in the previous assessment (Leigh et al. 2017) with some improvements to the numerical algorithms.

Structuring by length in addition to age for tailor allowed the model to take detailed account of the MLS for this species, and the changes in MLS over time. The model also included individual variability in growth, equivalent to growth-type groups (Punt et al. 2001) but modelled continuously so as not to require arbitrarily selected discrete values for the asymptotic length L_∞.

A feature of the SAIGE model is the decoupling of its reference lengths, used in the population dynamics, from the lengths used in length-frequency and age-at-length data. This allows growth to be modelled smoothly and the precision of the model to be chosen independently of the length data.

Much of the data preparation for model inputs used the same methodology as the previous tailor assessment (Leigh et al. 2017). The model had 4 fleets: Queensland recreational, New South Wales recreational, Queensland commercial and New South Wales commercial. These fleets had different selectivity functions and different MLS restrictions.

2.5.1 Model assumptions

The model is based on the following assumptions:

1. The fishery was in a fished equilibrium state prior to 1945 with prior fishing equal to 1945 harvests.
2. The size (or length) L_0 of a fish at age zero, is normally distributed with some mean μ and variance σ^2.
3. Each fish grows according to an individual von Bertalanffy growth function (von Bertalanffy 1938). The growth rate κ is constant and asymptotic size L_∞ is normally distributed, independently of L_0 , with some mean λ and variance ρ^2.
4. The weight and fecundity of a fish are parametric functions of size.
5. The proportion of fish mature, m_a, depends on age.
6. The instantaneous natural mortality rate M is constant for all ages and sizes.
7. Recreational (line-based) fishing follows a logistic selectivity function (see Equation 2.6).

8. Commercial (gill net) fishing follows a symmetric double logistic selectivity function (see Equation 2.7).
9. The proportion of fish vulnerable to fishing is the product of a parametric function of size, $V(L)$, with a function of time and age.
10. Once an individual fish becomes vulnerable to fishing, it remains vulnerable up to a threshold age which is either pre-set or the age at which it reach maximum vulnerability to fishing. More simply expressed, the fish exposed to fishing this year are those that were already exposed last year, with the addition of some more that have grown big enough to be newly exposed to fishing. Above the threshold age this assumption does not apply.
11. Above its threshold age, a fish grows deterministically to the corresponding quantile of length at the next age. The threshold age is conceived as an age at which the fish is already highly vulnerable to fishing, so for vulnerability calculations its exact growth trajectory beyond that age is irrelevant.
12. Fishing takes place in a pulse in the middle of each year, over a short enough period that natural mortality, although it happens all year round, can be neglected over the duration of the fishing season; i.e. the fishery is a Type 1 fishery in the terminology of Ricker (1975, p. 10).

The equation for logistic selectivity describing the vulnerability of fish to recreational line fishing is given by

$$V(L) = 1 / \left(1 + \exp\{-\ln(19)(L - L_{50}^{(\text{line})})/(L_{\text{diff}}^{(\text{line})} - L_{50}^{(\text{line})})\}\right), \tag{2.6}$$

where, L is the size of a fish, L_{50} is the size at 50% vulnerability and L_{diff} is the additional size required to reach 95% vulnerability from 50% vulnerability.

Similarly, the equation for symmetric double logistic selectivity describing the vulnerability of fish to commercial net fishing is given by

$$V(L) = \frac{4 \exp\{-\ln(19)(L - L_{50}^{(\text{net})})/(L_{\text{diff}}^{(\text{net})} - L_{50}^{(\text{net})})\}}{\left(1 + \exp\{-\ln(19)(L - L_{50}^{(\text{net})})/(L_{\text{diff}}^{(\text{net})} - L_{50}^{(\text{net})})\}\right)^2}. \tag{2.7}$$

2.5.2 Model parameters

Parameters used in the model are listed in Table 2.3. Attempts were made to estimate as many of the parameters as possible and not fix them outside the model.

Table 2.3: Parameters used in the model—the final column states whether the parameter is estimated in the model or fixed outside the model

Parameter	Description	Estimated?
μ	Mean size at age zero, L_0.	No
σ	Standard deviation of size at age zero, L_0.	Yes
λ	Mean asymptotic size, L_∞; actually parameterised as the mean size at the highest age in the model, for ease of guessing initial values.	No
ρ	Standard deviation of asymptotic size, L_∞.	Yes
κ	Growth rate parameter in von Bertalanffy growth function.	Yes
$\ln(R_0)$	Natural log of virgin recruitment.	Yes
r_{comp}	Recruitment compensation ratio (Goodyear 1977); actually parameterised as $\ln(r_{\text{comp}} - 1)$ to give it a distribution closer to normal.	No
d_t	Log-recruitment deviations.	Yes
M	Instantaneous natural mortality rate	Yes
$L_{50}^{(\text{line})}$	Length at 50% vulnerability to line fishing;	Yes
$L_{\text{diff}}^{(\text{line})}$	Difference between lengths at 95% and 50% vulnerability;	Yes
$L_{50}^{(\text{net})}$	Length at 50% vulnerability to gillnet fishing;	Yes
$L_{\text{diff}}^{(\text{net})}$	Difference between lengths at 95% and 50% vulnerability;	Yes

2.5.3 Model uncertainty

While attempting to fit the model, various scenarios for the parameter M were trialled. Varying lower bounds for M as low as 0.2 were trialed. In addition, attempts were made to fix M at a lower level; values between 0.4 and 1.2 in increments of 0.05 were tested. The model did not converge properly or fit well with any of these scenarios. The final model run had a lower bound of 0.7 and an upper bound of 1.8 for M. These bounds are lower than those used in the Leigh et al. (2017) assessment.

The parameters μ and λ were also tested at varying values. Again, the model did not converge properly or fit well with values much different to those used in the Leigh et al. (2017) assessment. Attempts were made to use the same values as Leigh et al. (2017), however the model did not converge properly with the values. These parameters were finally fixed at $\mu = 4$ cm and $\lambda = 55$ cm as these gave the best model convergence and fits.

As in Leigh et al. (2017), attempts were made to estimate the recruitment compensation ratio r_{comp}. These attempts were unsuccessful as r_{comp} tended to go to either 1 or infinity, neither of which is a sensible value. It was decided to fix r_{comp} to a value that produced sensible results, neither an extremely large population on which fishing had a negligible effect, nor a population that was being "mined" over the history of the fishery and was unable to replenish itself. A value of $r_{\text{comp}} = 6$ was chosen as a fixed value for the model This value was the mid-value considered in Leigh et al. (2017). Note that an r_{comp} value of 6 equates to a steepness (h) of 0.6 (Mace et al. 1988).

Two model scenarios of differing future recruitment were undertaken. Maximum sustainable yield (MSY) and 60% biomass harvest targets were calculated using an average (deterministic) recruitment and also a low recruitment scenario. This low recruitment scenario was devised using the log transformed averages of the last 10 recruitment deviations in the model. These two recruitment scenarios were also used for future years in projection modelling.

A further scenario using the harvest reconstruction method from Leigh et al. (2017) was planned, however due to time constraints this was not performed.

The model was coded in both ADMB (Fournier et al. 2012) and R (R Core Team 2020). The ADMB version of the population model found maximum likelihood estimates and then performed Markov chain Monte Carlo (MCMC) to provide random samples of possible parameter values. When MCMC analysis was performed, a total of 330 000 simulations were run for each model scenario and saved every 50th simulation for a total of 6600 simulations. The R version of the model provided extra detail, reference points and plots.

2.5.4 Forward projections

Model parameters determined were used to provide forward projections of spawning biomass and future harvest targets, following the harvest control rule (Department of Agriculture and Water Resources 2018).

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_{60}). Below 20% spawning biomas, fishing mortality remains set at zero, and above 60% spawning biomass fishing mortality remains set at F_{60} (Figure 2.1). 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.

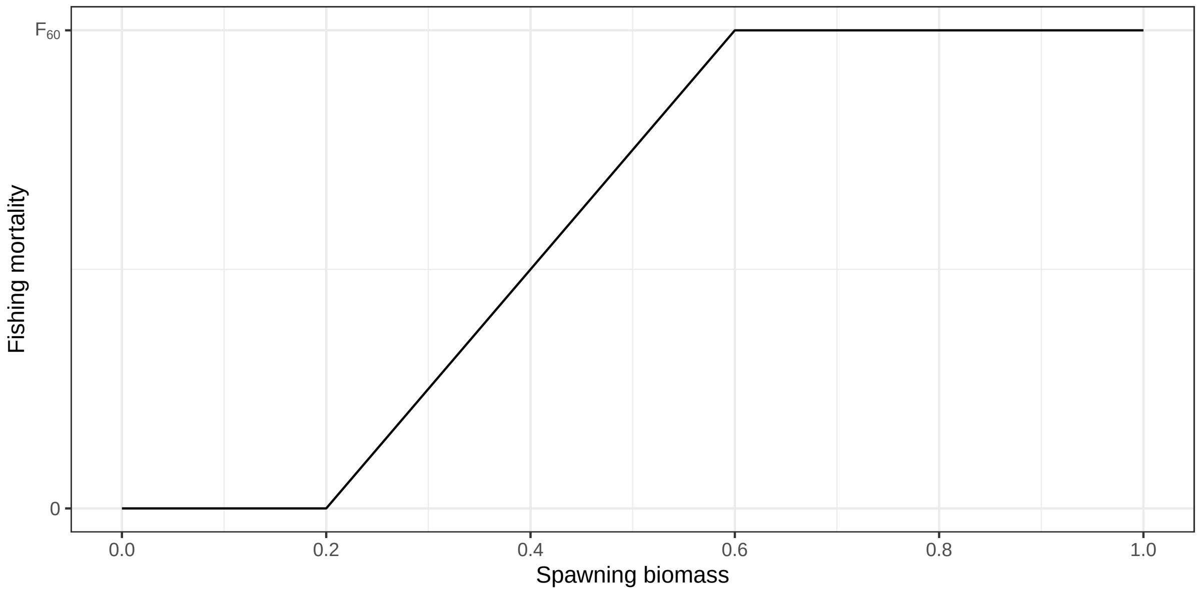

Figure 2.1: The harvest control rule

Forward projections were modeled using average (deterministic) and low recruitment scenarios into the future. The low recruitment scenario used the average recruitment deviations for the last 10 years of the model during which time recruitment has been low. Projected harvests were determined year by year in response to the biomass ratio of the previous year.

3 Results

3.1 Model inputs

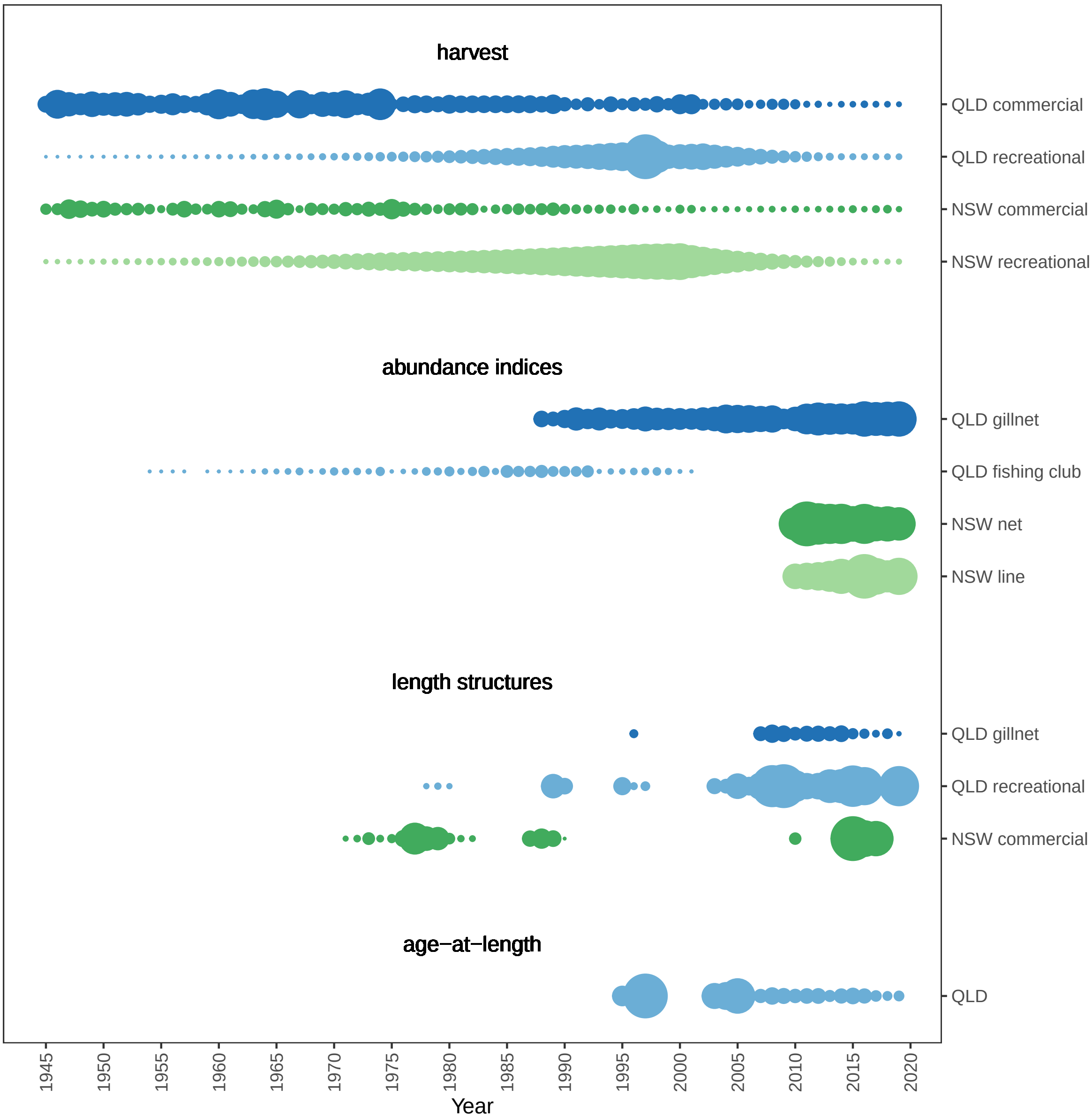

Figure 3.1: Compilation of data sources for input into the population model
Note: Circle sizes are proportional to total harvest for harvests; to precision for indices and to total numbers for length compositions and age-at-length data

3.1.1 Harvest estimates

The total harvest consisted of catch from four fleets: Queensland recreational, New South Wales recreational, Queensland commercial and New South Wales commercial (Figure 3.2). Harvests show an increase from around 380 t at the beginning of the time series to a peak of just over 1250 t in the late

1990s and then declining again to around 200 t in 2019. Current harvests are much lower now than at the beginning of the time series.

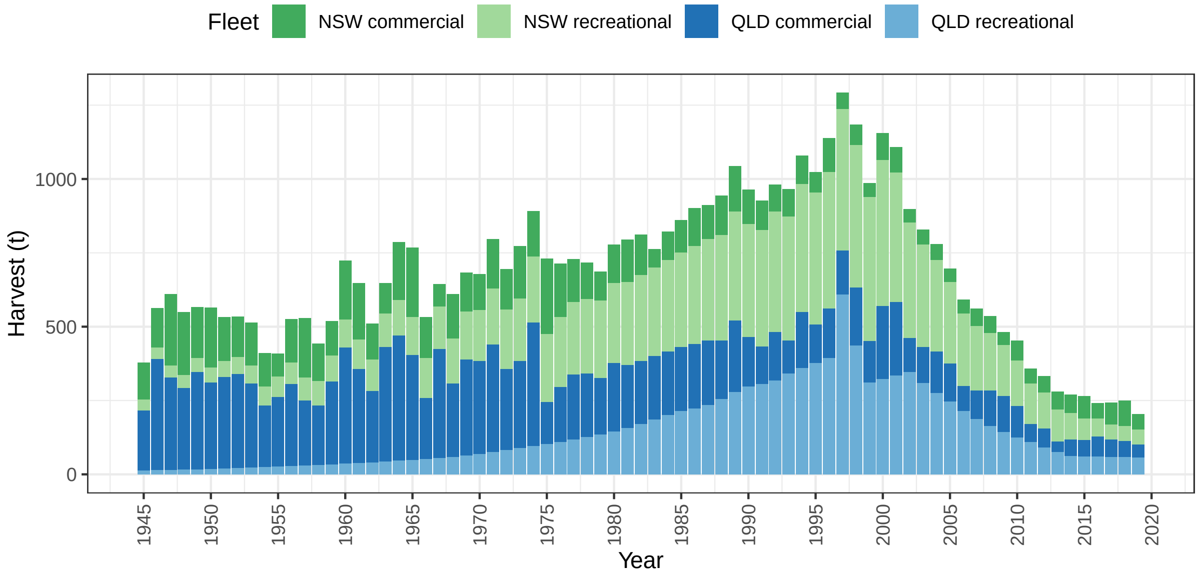

Figure 3.2: Tailor estimated harvest (retained catch) from commercial and recreational sectors for Queensland and New South Wales east coast from 1945 to 2019

Over the last 5 years (2015–2019) total harvest averaged 240 tonnes per year, including 59 t (24.5%) for Queensland recreational, 56 t (23.3%) for New South Wales recreational, 57 t (23.8%) for Queensland commercial and 68 t (28.4%) for New South Wales commercial (Figure 3.2).

The 2019 harvest at 204 t varied only slightly from the 5 year average with 45 t (22.3%) by the Queensland commercial sector, 52 t (25.5%) by the New South Wales commercial sector, 57 t (28%) by the Queensland recreational sector, and 49 t (24.1%) by the New South Wales recreational sector (Figure 1).

Figure 3.3 shows the reconstructed harvests for each fleet and which components are original data, adjusted data and estimated. Note that recreational data are driving the high peak in harvests in the late 1990s shown in Figures 3.2 and 3.3. Commercial harvest has slightly decreased during this time.

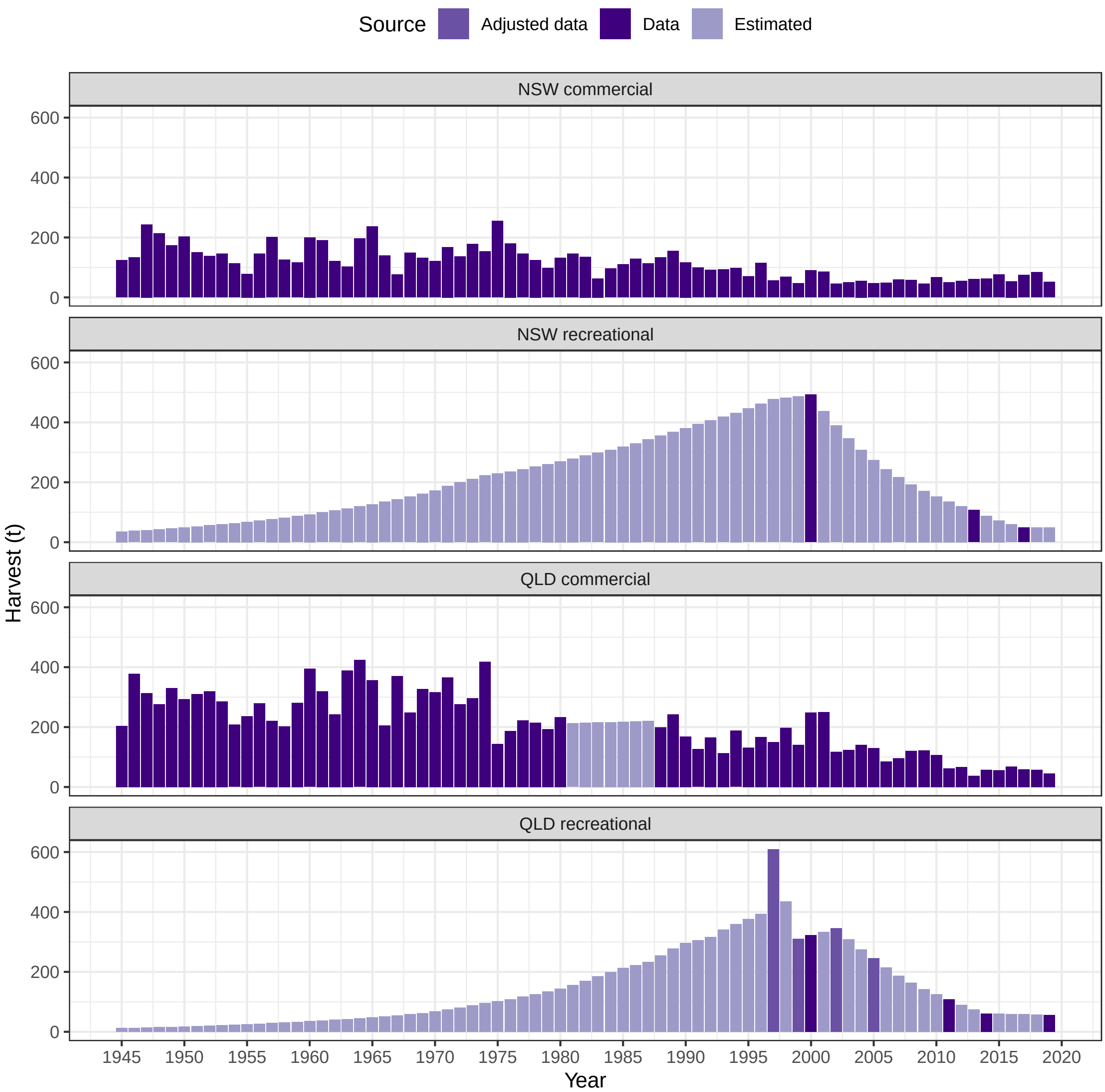

Figure 3.3: Tailor harvest reconstructions for commercial and recreational sectors in Queensland and New South Wales east coast from 1945 to 2019

3.1.2 Standardised catch rates

Standardised catch rates were calculated to represent trends in abundance for the Australian east coast tailor stock. Three separate catch rate analyses were conducted: one for Queensland gillnet and one for each of New South Wales net and line (Figure 3.4). In addition, a fourth catch rate (Queensland fishing club) was sourced from Leigh et al. (2017) (Figure 3.5). These catch rates were used to inform the model fleets Queensland commercial, New South Wales commercial, New South Wales recreational and Queensland recreational respectively and were assumed to be proportional to mid-season exploitable biomass. These catch rates were calculated using available data and may be subject to hyperstability.

Figure 3.4: Annual commercial standardised catch rates for Queensland and New South Wales tailor

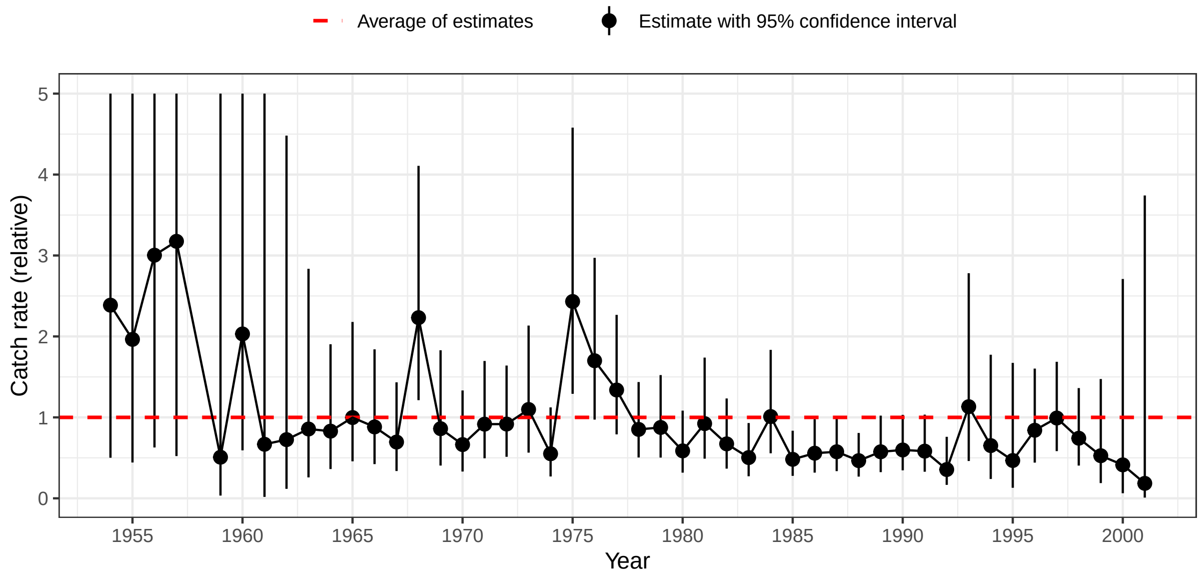

Figure 3.5: Annual recreational standardised catch rates for tailor caught by Queensland fishing club after corrections for fishing power (Leigh et al. 2017)

Catch rates for Queensland gillnet, fishing club and New South Wales line show a decrease in the later years while the New South Wales net fishery shows an increase since 2011. The Queensland fishing club catch rate (Leigh et al. 2017) covers an earlier time period (1954–2001) and has a higher level of uncertainty.

The Queensland gillnet catch rate was heavily impacted by the increase in MLS from 30 to 35 cm total length in 2010. The model was able to account for this change under the assumption that fisher behaviour stayed the same. It could not account for a behavioural change brought about by, for example, fishers' becoming unwilling to target tailor after the increase in MLS.

3.2 Model outputs

Results from the population model encompass trends shown from harvests, abundance indices and biological data. Results shown here are from median values of the MCMC model output.

3.2.1 Model parameters

Parameters estimated in the model are listed in Table 3.1. Where possible parameters were estimated within the model. Only the parameters μ, λ and r_{comp} were fixed. Recruitment deviations are listed separately in Appendix D.

Table 3.1: MCMC model parameters with upper and lower confidence intervals — parameters with no upper or lower confidence interval are fixed parameters

Parameter	Description	Median	2.5%	97.5%
μ	Mean size at age zero, L_0.	4	–	–
σ	Standard deviation of size at age zero, L_0.	10.22	10.19	10.32
λ	Mean asymptotic size, L_∞; actually parameterised as the mean size at the highest age in the model, for ease of guessing initial values.	55	–	–
ρ	Standard deviation of asymptotic size, L_∞.	11.12	10.84	11.5
κ	Growth rate parameter in von Bertalanffy growth function.	0.49	0.48	0.5
$\ln(R_0)$	Natural log of virgin recruitment.	16.85	16.71	17.01
r_{comp}	Recruitment compensation ratio; actually parameterised as $\ln(r_{\text{comp}}-1)$ to give it a distribution closer to normal.	6	–	–
M	Instantaneous natural mortality rate	1.31	1.25	1.37
$L_{50}^{(\text{line})}$	Length at 50% vulnerability to line fishing;	30.2	30.02	30.37
$L_{\text{diff}}^{(\text{line})}$	Difference between lengths at 95% and 50% vulnerability;	2.55	2.31	2.82
$L_{50}^{(\text{net})}$	Length at 50% vulnerability to gillnet fishing;	35.27	34.98	35.56
$L_{\text{diff}}^{(\text{net})}$	Difference between lengths at 95% and 50% vulnerability;	10.1	9.62	10.57

3.2.2 Model fits

Fits to the commercial catch rate, size and age compositions are shown in Appendix D. Fits to estimated assessment targets are also shown in Appendix D.

3.2.3 Biomass

The spawning biomass trajectory through time was determined as a proportion relative to an assumed unfished spawning biomass. Modelling included a warm-up phase with an assumed level of constant harvest prior to 1945, hence an initial biomass ratio was obtained. This assumed level of harvest was equal to the level of harvest in 1945.

The model has predicted that spawning biomass was initially around 80% of virgin spawning biomass (Figure 3.6). The stock then declined from the mid-1970s to the early 2000s where it fluctuates around the 50% mark.

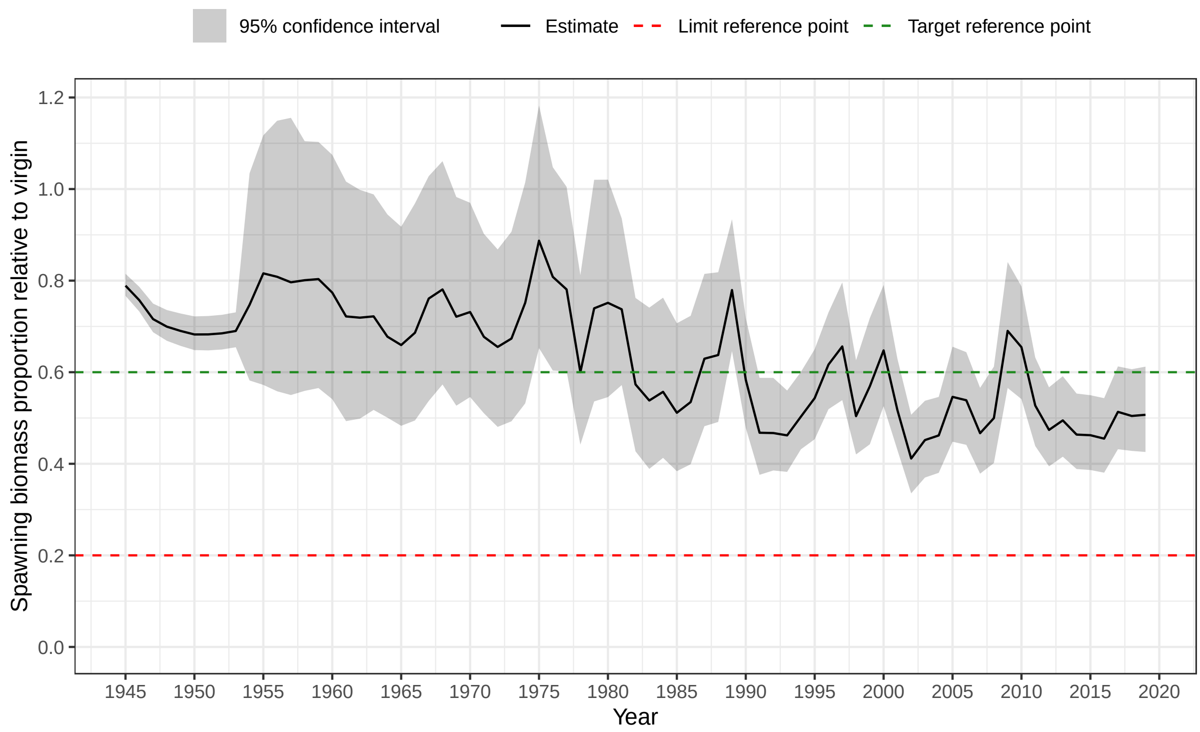

Figure 3.6: Annual spawning biomass relative to virgin spawning biomass for Queensland and New South Wales east coast tailor

Figure 3.7 shows periods of high and low recruitment from the mid-1970s to the late 1990s, declining to a period of low recruitment since 2010.

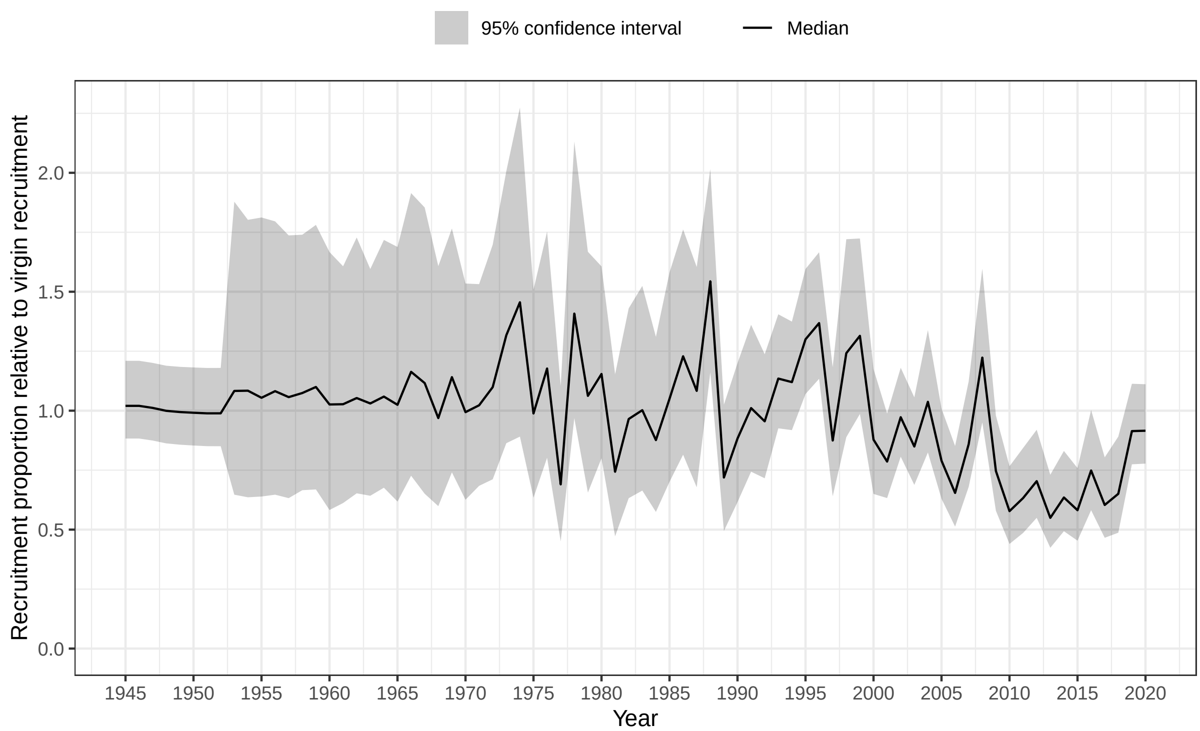

Figure 3.7: Annual recruitment relative to virgin recruitment for Queensland and New South Wales east coast tailor

3.2.4 Harvest targets

The model predicted the current and target indicators for average and low recruitment scenarios (Table 3.2, Figure 3.8). Note here that for the last 15 years harvests have been below the average-recruitment scenario targets although biomass has not increased above target levels (Figures 3.8 and 3.6). Low recruitment during this time (see Figure 3.7) has played a role in the limited biomass increase following extended reduced fishing. This highlights the importance of investigating a low recruitment scenario and displaying harvest targets relevant to low recruitment.

Table 3.2: Current and target indicators—estimate (average) refers to average recruitment and Estimate (low) refers to low recruitment where the average of the last 10 years recruitment was used

Indicator	Estimate	Estimate (average)	Estimate (low)
2019 spawning biomass ratio	51%		
MSY spawning biomass ratio		0.35%	0.24%
Average 5 year harvest (2015–2019)	240 t		
2019 harvest	204 t		
2019 harvest shares:			
QLD commercial	45 t (22.3%)		
NSW commercial	52 t (25.5%)		
QLD recreational	57 t (28.0%)		
NSW recreational	49 t (24.1%)		
Harvest at MSY		857 t	469 t
Harvest at 60% spawning biomass		685 t	76 t

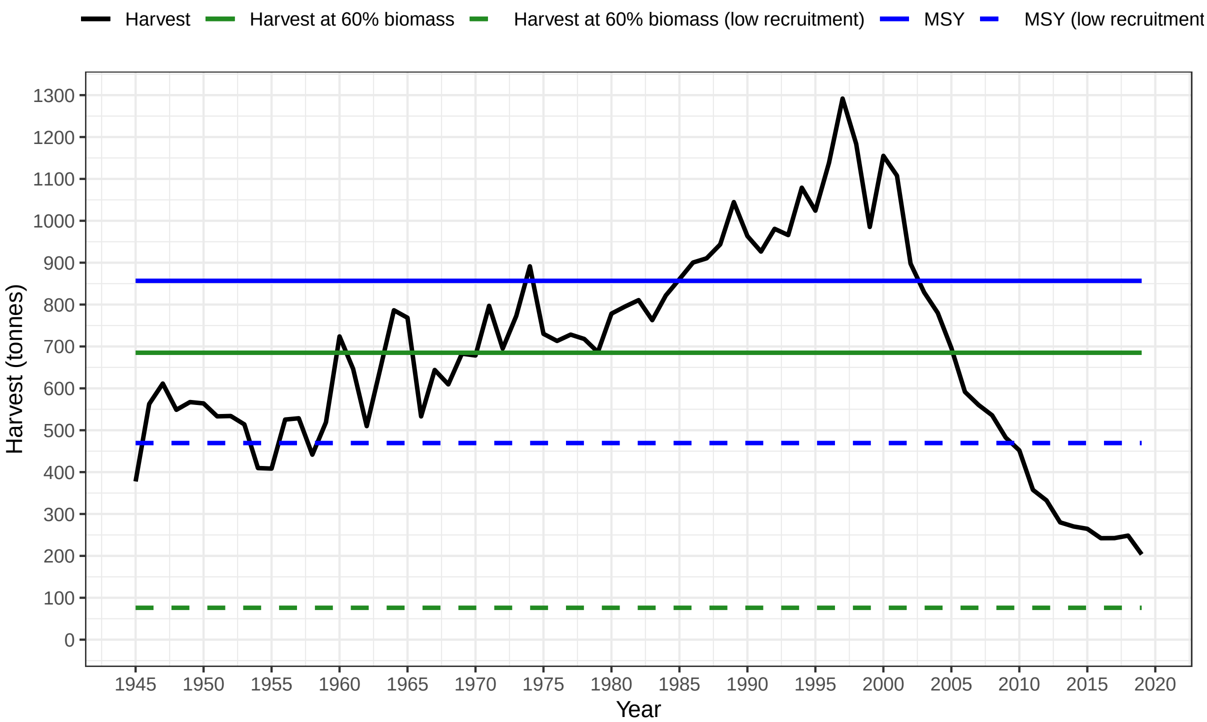

Figure 3.8: Annual harvest with predicted harvest targets for Queensland and New South Wales east coast tailor

Yield curves shown in Figures 3.9 and 3.10 depict equilibrium harvests and their resulting spawning biomass levels possible under each recruitment scenario. Note here that the maximum biomass possible under a low recruitment scenario as a ratio of past spawning biomass is around 64% (Figure 3.10). This leads to a very low harvest target when aiming for a biomass of 60% as not fishing at all results in a biomass of only 64%. A biomass of 50% under the low recruitment scenario corresponds to a harvest of around 240 t which coincides with the current biomass level and average harvest.

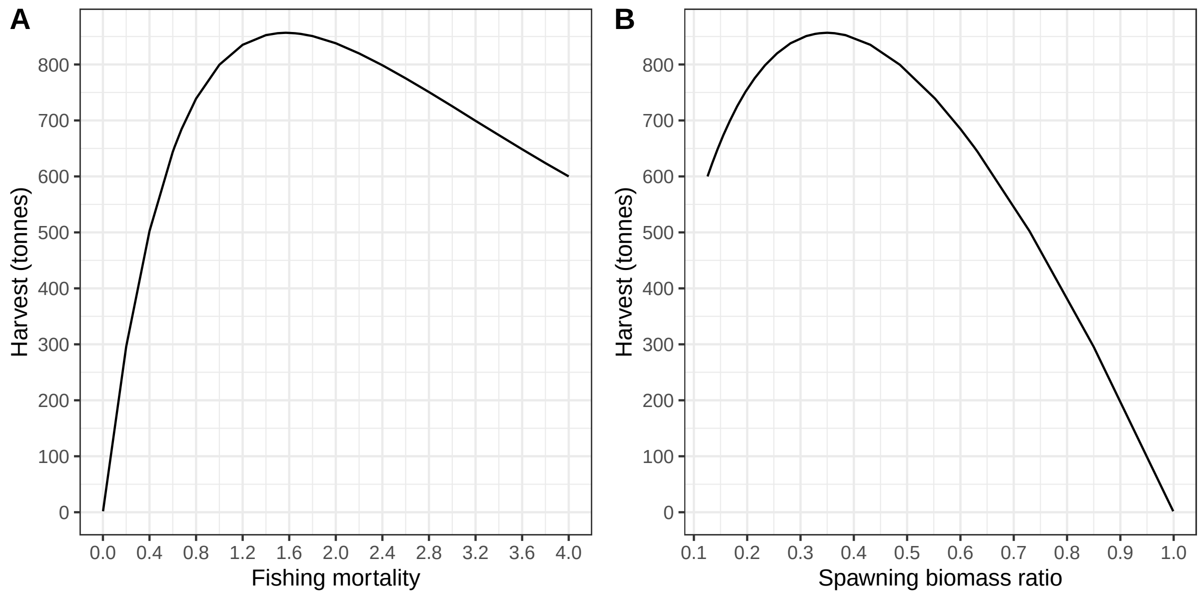

Figure 3.9: Yield curves under an average recruitment scenario showing (A) predicted harvest in response to fishing mortality F and (B) harvest corresponding to equilibrium spawning biomass levels for Queensland and New South Wales east coast tailor

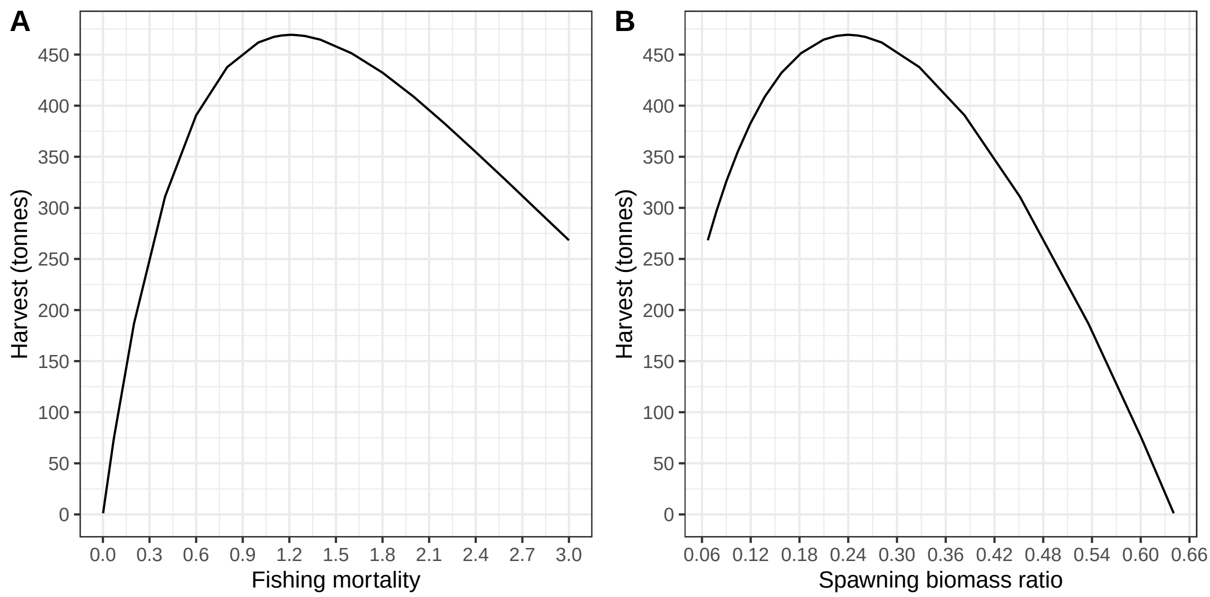

Figure 3.10: Yield curves under a low recruitment scenario showing (A) predicted harvest in response to fishing mortality F and (B) harvest corresponding to equilibrium spawning biomass levels for Queensland and New South Wales east coast tailor

3.2.5 Projections

Projected harvests to attain 60% spawning biomass under average recruitment (Figure 3.11) and low recruitment (Figure 3.12) are displayed in Table 3.3. These harvests were calculated using a harvest control rule as required by Queensland fishery management and are for Queensland recreational, New South Wales recreational, Queensland commercial and New South Wales commercial combined.

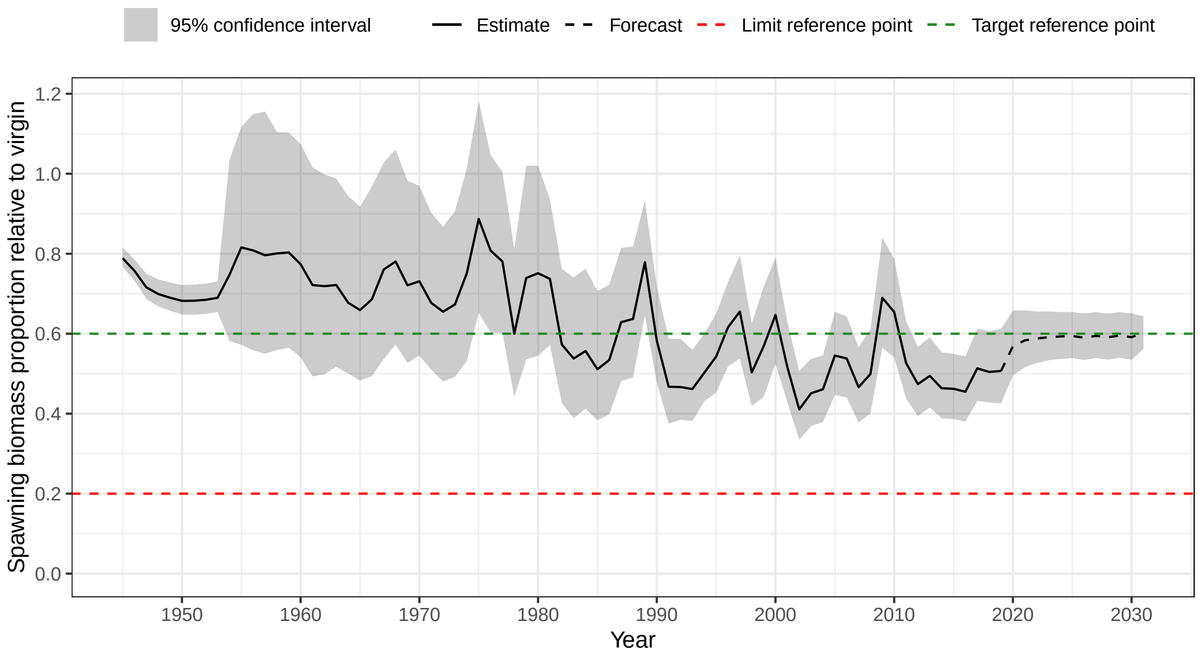

Figure 3.11: Annual spawning biomass relative to virgin spawning biomass with projected future biomass using the harvest control rule and average future recruitment

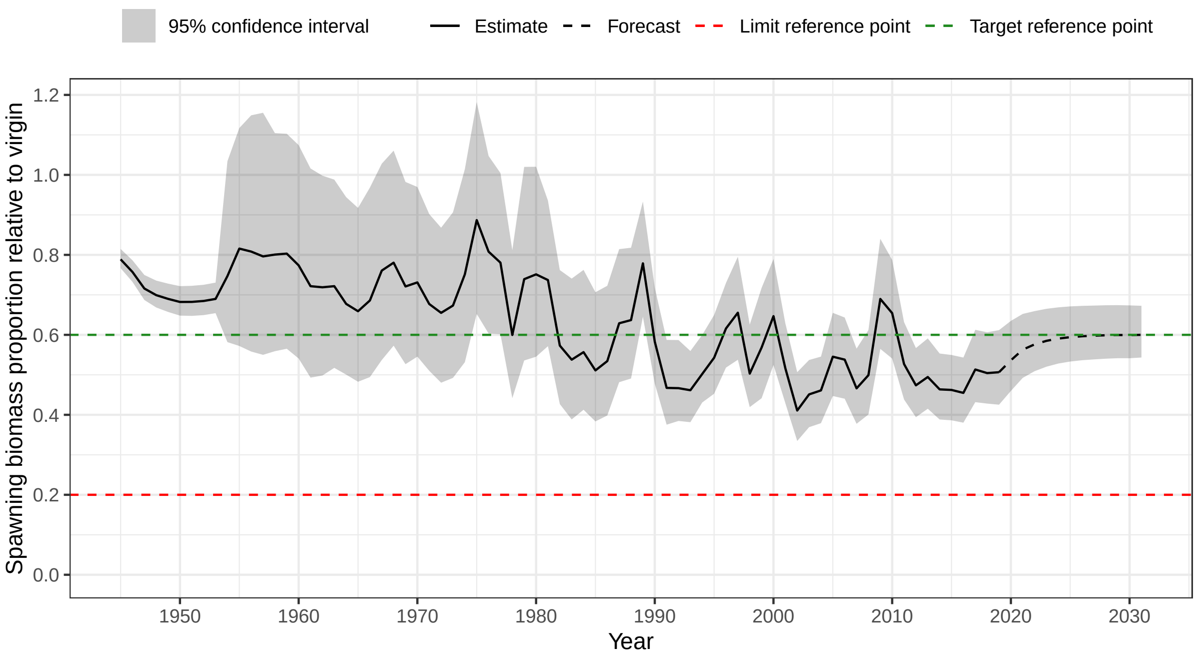

Figure 3.12: Annual spawning biomass relative to virgin spawning biomass with projected future biomass using the harvest control rule and low future recruitment applies to this scenario for Queensland and New South Wales east coast tailor

Note: Low recruitment is determined by the average recruitment for the past 10 years

Table 3.3: Projected harvests required under the harvest control rule for average and low recruitment scenarios

Year	Average recruitment		Low recruitment	
	Harvest	Biomass	Harvest	Biomass
2020	496 t	57%	53 t	54%
2021	620 t	58%	60 t	56%
2022	646 t	59%	66 t	58%
2023	655 t	59%	68 t	59%
2024	659 t	59%	70 t	59%

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% biomass (Department of Agriculture and Fisheries 2017). This assessment presents targets to rebuild the fishery to 60%.

Over the last 5 years (2015–2019) total harvest averaged 240 t per year, including 59 t (24.5%) for Queensland recreational, 56 t (23.3%) for New South Wales recreational, 57 t (23.8%) for Queensland commercial and 68 t (28.4%) for New South Wales commercial.

Total harvest estimates show a marked decline since 2000. Over the last 2 decades, decreased harvest has coincided with a gradual implementation of management restrictions (Table 1, Figure 3.2, Figure 3.3). It is speculative as to whether this is a cause of current low harvests or a response to declining fish abundance or both. Under current management restrictions it would not be possible to harvest tailor at the same level today as at the height of the fishery in the 1990s.

Catch rates presented in this report are produced using available data and may be subject to hyperstability. Hyperstability may lead to overestimates in fish abundance and hence overestimate fishery performance (O'Neill et al. 2018).

Results show that spawning biomass is currently at 51% of virgin levels and requires rebuilding to target levels under the Queensland Sustainable Fisheries Strategy (Department of Agriculture and Fisheries 2017). Model indications are that recruitment has been low for the last 10 years, which may explain why biomass levels have not increased even though harvests have been low during this time.

MSY was estimated at 857 t per year and the yield consistent with maintaining a biomass ratio of 60% was estimated at 685 t. However precautions should be taken as model analyses identified that recruitment has been low for the past 10 years leading to a difficulty in stock recovery, even though fishing levels have been low during this time. A second scenario with continued low recruitment was also performed. This second scenario estimated MSY at 469 t per year and the yield consistent with maintaining a biomass ratio of 60% at 76 t should this low recruitment continue into the future.

The harvest control rule under average (deterministic) recruitment suggests a target of 496 t initially to begin rebuilding exploitable biomass to 60%. Forward projections of the model suggest that rebuilding would occur in around 5 years. It should be noted, however, that harvest has been much lower than this for the past 10 years and rebuilding to 60% has not occurred. This is because there has been a sustained period of low recruitment during this time.

The low recruitment scenario of the model assumes that recruitment will continue to be low (averaging the same as it has for the past 10 years) into the future. The harvest control rule under low recruitment suggests a target of 53 t initially to begin rebuilding exploitable biomass to 60%. Forward projections of the model suggest that rebuilding would occur in around 6 years.

Under the low recruitment scenario, the maximum biomass possible is 64% of the initial virgin spawning biomass. This 64% biomass is only possible if no fishing takes place.

Harvesting at current levels would result in a 50% biomass under low recruitment but would rebuild the stock should recruitment improve. It is unknown what levels of recruitment may happen in the future.

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 four fleets. Data inputs included total harvest (Queensland recreational, New South Wales recreational, Queensland commercial and New South Wales recreational), standardised catch rates (Queensland fishing club, New South Wales commercial line, Queensland commercial gillnet and New South Wales commercial net), fishery-dependent length compositions and age-at-length data.

Overall, the model performed well, achieving good fits to the majority of data. The Queensland fishing club catch rates did not fit as well as other catch rates, however this was considered acceptable as this catch rate had higher levels of uncertainty.

4.2 Environmental influences

Model results showing that recruitment has been low for some time infers that environmental impacts to the stock are likely. Possible sources of environmental change are coastal development and climate change.

Changes to temperatures and ocean currents may influence the location and availability of food sources and affect schooling behaviours. Temperature changes may also influence the timing and location of spawning and natural mortality rates (Houde 1987; Frank et al. 1990; Drinkwater 2005; Rose 2005; Takasuka et al. 2007; Brodie et al. 2018; Schilling et al. 2020). These effects have the potential to impact the stock size of tailor.

4.3 Recommendations

4.3.1 Monitoring and research

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

Targeted research into the various impacts of environmental changes on tailor would increase understanding and benefit future assessments and management of the fishery.

4.3.2 Management

It is recommended that average and low recruitment scenarios be considered together when setting management targets. It is unknown what levels of recruitment may happen in the future, hence it is recommended to apply a cautious approach when setting management targets.

4.3.3 Assessment

Prior or during the next assessment, it is recommended that work is done to include an ocean beach fleet into the model so that fishery monitoring ocean beach length data may be used.

It is recommended that investigations into the possibility of using harvest as an abundance indicator or some other method be performed to produce an ocean beach catch rate and also address possible hyperstability issues in the data.

It is also recommended that the next assessment consider harvest reconstruction scenarios between the methods used in this assessment and Leigh et al. (2017). It will be important to discover the effect of these different scenarios on model outcomes.

Additionally, it is considered important for future assessments of tailor that MCMC be performed.

Finally, future assessments could be improved upon by including environmental aspects in the model. This assessment indicates that environmental aspects could play a role in the current biomass levels, hence it is important that it be investigated and understood.

4.4 Conclusions

This assessment has estimated the status of the eastern Australian (Queensland and New South Wales component) tailor stock. Analysis suggests that spawning biomass has declined from the mid-1970s to the early 2000s and is currently at around 51% (for 2019). The study presents biological harvest levels that would be required under the Queensland Sustainable Fisheries Strategy to begin rebuilding the stock to levels consistent with 60% of unfished biomass.

References

ABS (2014). *Australian Historical Population Statistics*. Catalogue no. 3105.0.65.001. Canberra: Australian Bureau of Statistics. URL: http://www.abs.gov.au/ausstats/abs@.nsf/cat/3105.0.65.001 (visited on 11/10/2016).

Ayvazian, Suzanne G., Brent S. Wise, and Glen C. Young (Nov. 2002). "Short-term hooking mortality of tailor (*Pomatomus saltatrix*) in Western Australia and the impact on yield per recruit". In: *Fisheries Research* 58.2, pp. 241–248. URL: http://dx.doi.org/10.1016/S0165-7836(01)00387-3.

Bade, T. M. (1977). "The Biology of Tailor (*Pomatomus saltatrix* Linn.) from the East Coast of Australia. MSc thesis, University of Queensland, Brisbane". MA thesis. Brisbane: University of Queensland.

Broadhurst, M. K., P. A. Butcher, and B. R. Cullis (Aug. 2012). "Catch-and-release angling mortality of south-eastern Australian *Pomatomus saltatrix*". In: *African Journal of Marine Science* 34.2, pp. 289–295. URL: http://dx.doi.org/10.2989/1814232X.2012.675127 (visited on 03/13/2017).

Brodie, Stephanie, Lenore Litherland, Hayden Schilling, Julian Pepperell, and Iain Suthers (2018). "Citizen science records describe the distribution and migratory behaviour of a piscivorous predator, *Pomatomus saltatrix*". In: *ICES Journal of Marine Science* 75.

Callihan, Jody L., Lynn T. Takata, Ryan J. Woodland, and David H. Secor (May 2008). "Cohort splitting in bluefish, Pomatomus saltatrix, in the US mid-Atlantic Bight". en. In: *Fisheries Oceanography* 17.3, pp. 191–205. URL: http://onlinelibrary.wiley.com.ezp3.library.uq.edu.au/doi/10.1111/j.1365-2419.2008.00468.x/abstract (visited on 11/04/2016).

Claydon, Wallace C. (1996). *Remembering Len Thompson, the Legend of Bait Spinning*. Brisbane: Queensland Department of Primary Industries.

Department of Agriculture and Fisheries (2017). *Queensland Sustainable Fisheries Strategy 2017-2027*.

Department of Agriculture and Water Resources (2018). *Guidelines for the Implementation of the Commonwealth Fisheries Harvest Strategy Policy*. Report.

Dichmont, Catherine M., Malcolm Haddon, Kate Yeomans, and Katherine Kelly (1999). *Proceedings of the South-east Queensland Stock Assessment Review Workshop*. Tech. rep. Conference and Workshop Series QC99003. Brisbane: Queensland Department of Primary Industries.

Drinkwater, K. F. (2005). "The response of Atlantic cod (\emphGadus morhua) to future climate change". In: *ICES Journal of Marine Science* 62. Type: Journal Article, pp. 1327–1337.

Fisheries Queensland (2013a). *Fisheries Long Term Monitoring Program Sampling Protocol – Tailor 2007 onwards Section 1*. Department of Agriculture and Fisheries, Brisbane, Australia.

— (2013b). *Fisheries Long Term Monitoring Program Sampling Protocol – Tailor 2007 onwards Section 2*. Department of Agriculture and Fisheries, Brisbane, Australia.

— (2017). *Fisheries Long Term Monitoring Program Sampling Protocol – Fish Ageing: Section 2: Tailor*. Department of Agriculture and Fisheries, Brisbane, Australia.

— (2018). *Fisheries Long Term Monitoring Program Sampling Protocol – Fish Ageing: March 2018.* Department of Agriculture and Fisheries, Brisbane, Australia.

Fournier, D.A., H.J. Skaug, J. Ancheta, J. Ianelli, A. Magnusson, M.N. Maunder, A. Nielsen, and J. Sibert (2012). "AD Model Builder: using automatic differentiation for statistical inference of highly parameterized complex nonlinear models". In: *Optimization Methods and Software* 27, pp. 233–249.

Frank, K. T., R. I. Perry, and K. F. Drinkwater (1990). "Predicted response of Northwest Atlantic invertebrate and fish stocks to CO2 induced climate change". In: *Transactions of the American Fisheries Society* 119. Type: Journal Article, pp. 353–365.

Fraser Island Defenders Organisation (2015). *Moonbi, the Newsletter of FIDO*. Fraser Island Defenders Organization. URL: http://www.fido.org.au/moonbi/ (visited on 11/10/2016).

Goodyear, C. Phillip (1977). "Assessing the Impact of Power Plant Mortality on the Compensatory Reserve of Fish Populations". In: *Proceedings of the Conference on Assessing the Effects of Power-Plant-Induced Mortality on Fish Populations*. Ed. by Webster Van Winkle. Pergamon, pp. 186 –195. URL: http://www.sciencedirect.com/science/article/pii/B9780080219509500211.

Haimovici, M. and L. C. Krug (1996). "Life history and fishery of the enchova, *Pomatomus saltatrix*, in southern Brazil". en. In: *Marine and Freshwater Research* 47.2, pp. 357–363. URL: http://www.publish.csiro.au/?paper=MF9960357 (visited on 11/04/2016).

Halliday, Ian (1990). *Tailor Tagging Project: Summary of 1988 and 1989 Results*. Tech. rep. Brisbane: Queensland Department of Primary Industries, p. 8.

Halliday, Ian and Julie Robins (2007). *Environmental Flows for Sub-tropical Estuaries: Understanding the Freshwater Needs of Estuaries for Sustainable Fisheries Production and Assessing the Impacts of Water Regulation*. Tech. rep. Brisbane: Department of Primary Industries and Fisheries. URL: http://frdc.com.au/research/Documents/Final_reports/2001-022-DLD.PDF (visited on 11/10/2016).

Henry, Gary W. and Jeremy M. Lyle (2003). *The National Recreational and Indigenous Fishing Survey*. Tech. rep. Canberra: Australian Government Department of Agriculture, Fisheries and Forestry. URL: http://eprints.utas.edu.au/2526/1/Henry_Lyle_Nationalsurvey.pdf (visited on 11/10/2016).

Higgs, Jim (1999). *RFISH Technical Report No. 2: Results from the 1997 Diary Round*. Tech. rep. Brisbane: Queensland Department of Primary Industries.

— (2001). *Recreational Catch Estimates for Queensland Residents. RFISH Technical Report No. 3*. Tech. rep. Brisbane: Queensland Department of Primary Industries.

Higgs, Jim, Len Olyott, and Kirrily McInnes (2007). *Experimental Results from the Third Statewide Recreational Fishing Information System Diary Program (2002)*. Tech. rep. Brisbane: Queensland Department of Primary Industries and Fisheries.

Houde, E. D. (1987). "Fish early life dynamics and recruitment variability". In: *American Fisheries Society Symposium*. Vol. 2. Type: Journal Article, pp. 17–29.

Hoyle, Simon D., Ian W. Brown, Catherine M. Dichmont, Michelle J. Sellin, M. Cosgrove, and Mark F. McLennan (June 2000). *Integrated Fish Stock Assessment and Monitoring Program*. Tech. rep. QO99011, FRDC Project 1994/161. Brisbane: Department of Primary Industries. URL: http://frdc.com.au/research/Documents/Final_reports/1994-161-DLD.pdf (visited on 08/03/2016).

Juanes, F., J. A. Hare, and A. G. Miskiewicz (Mar. 1996). "Comparing early life history strategies of *Pomatomus saltatrix*: A global approach". en. In: *Marine and Freshwater Research* 47.2, pp. 365–379. URL: http://www.publish.csiro.au/mf/MF9960365 (visited on 11/07/2016).

Kellet, B. (1998). "Temporal spawning patterns and management considerations for the southern Queensland Pilchard (*Sardinops sagax*) and Tailor (*Pomatomus saltatrix*) stocks." In: *Queensland Department of Primary Industries, Brisbane*.

Lawson, Ashley (2015). *An Investigative Analysis of Queensland's Statewide Recreational Fishing Surveys: Identifying Bias in Self-reported Catch and Effort Data*. Tech. rep. Brisbane: Department of Agriculture and Fisheries.

Lawson, Christopher, Iain Suthers, James Smith, Hayden Schilling, John Stewart, Julian Hughes, and Stephanie Brodie (2018). "The influence of ontogenetic diet variation on consumption rate estimates: A marine example". In: *Scientific Reports* 8.

Leigh, G. M., Wen-Hsi Yang, M. F. O'Neill, J. McGilvray, and J. Wortmann (2019). *Stock assessments of bream, whiting and flathead (*Acanthopagrus australis, Sillago ciliata and Platycephalus fuscus*) in South East Queensland*. Tech. rep. Brisbane: Department of Agriculture and Fisheries.

Leigh, George M. and Michael F. O'Neill (2004). *Stock Assessment of the Queensland–New South Wales Tailor Fishery (Pomatomus saltatrix)*. Tech. rep. QI04065. Brisbane: Department of Primary Industries and Fisheries. URL: https://www.daf.qld.gov.au/fisheries/monitoring-our-fisheries/data-reports/sustainability-reporting/stock-assessment-reports/tailor-fishery-assessment (visited on 11/09/2016).

Leigh, George M., Michael F. O'Neill, and John Stewart (2017). *Stock assessment of the Australian east coast tailor (Pomatomus saltatrix) fishery*. Tech. rep. Brisbane: Department of Agriculture and Fisheries. URL: era.daf.qld.gov.au/5689/ (visited on 05/28/2018).

Lund, William A. and George C. Maltezos (Oct. 1970). "Movements and migrations of the bluefish, *Pomatomus saltatrix*, tagged in waters of New York and southern New England". In: *Transactions of the American Fisheries Society* 99.4, pp. 719–725. URL: http://afs.tandfonline.com/doi/abs/10.1577/1548-8659(1970)99%3C719%3AMAMOTB%3E2.0.CO%3B2 (visited on 03/13/2017).

Lyman, Henry (1987). *Bluefishing*. New York: Nick Lyons Books.

Mace, P. M. and I. J. Doonan (1988). *A Generalized Bioeconomic Simulation Model for Fish Population Dynamics*. Wellington, NZ: Ministry of Fisheries. New Zealand Fishery Assessment, Research Document 88/4.

Mann, Rob (1992). *Tailor Project 1991: Aerial Survey of Tailor Stocks in South-east Queensland*. Tech. rep. Brisbane: Queensland Department of Primary Industries, p. 13.

McInnes, Kirrily (2008). *Experimental Results from the Fourth Queensland Recreational Fishing Diary Program (2005)*. Tech. rep. Brisbane: Department of Primary Industries and Fisheries.

Miskiewicz, A. G., B. D. Bruce, and P. Dixon (Mar. 1996). "Distribution of tailor (*Pomatomus saltatrix*) larvae along the coast of New South Wales, Australia". en. In: *Marine and Freshwater Research* 47.2, pp. 331–336. URL: http://www.publish.csiro.au/mf/MF9960331 (visited on 03/13/2017).

Morton, R. M., Ian A. Halliday, and Darren S. Cameron (Dec. 1993). "Movement of tagged juvenile tailor (*Pomatomus saltatrix*) in Moreton Bay, Queensland". en. In: *Marine and Freshwater Research* 44.6, pp. 811–816. URL: http://www.publish.csiro.au/mf/MF9930811 (visited on 12/13/2016).

Murphy, J.J., F.A. Ochwada-Doyle, L.D. West, K.E. Stark, and J.M. Hughes (2020). "The NSW Recreational Fisheries Monitoring Program - survey of recreational fishing, 2017/18". In: *NSW DPI - Fisheries Final Report Series No. 158*.

Nurthen, Roderick K., Ray Cameron, and David A. Briscoe (1992). "Population genetics of tailor, *Pomatomus saltatrix* (Linnaeus) (Pisces: Pomatomidae) in Australia". en. In: *Marine and Freshwater Research* 43.6, pp. 1481–1486. URL: http://www.publish.csiro.au/?paper=MF9921481 (visited on 12/13/2016).

O'Neill, Michael F., Joanne Langstreth, Sarah M. Buckley, and John Stewart (2018). *Stock assessment of Australian east coast Spanish mackerel : Predictions of stock status and reference points*. Monograph. URL: http://era.daf.qld.gov.au/id/eprint/6202/ (visited on 02/04/2019).

O'Neill, Michael F., George M. Leigh, You-Gan Wang, J. Matías Braccini, and Matthew C. Ives (Oct. 2014). "Linking spatial stock dynamics and economics: Evaluation of indicators and fishery management for the travelling eastern king prawn (*Melicertus plebejus*)". In: *ICES Journal of Marine Science* 71.7, pp. 1818–1834. URL: http://dx.doi.org/10.1093/icesjms/fst218.

Pepperell, Julian G. (June 2009). *The Good Old Days? Historical Insights into Coastal NSW Fish Populations and Their Fisheries*. Tech. rep. Sydney: New South Wales Department of Primary Industries, p. 103. URL: http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0010/264475/Historic-insights-into-NSW-Fisheries.pdf.

Pollock, Barry R. (1984a). "Effects of capture injury and tag-type on the recovery rate of tagged tailor, *Pomatomus saltatrix* (Linnaeus)". In: *Queensland Journal of Agricultural and Animal Science* 41.2, pp. 121–23.

Pollock, Barry R. (Aug. 1984b). “Relations between migration, reproduction and nutrition in yellowfin bream *Acanthopagrus australis*”. In: *Marine Ecology Progress Series* 19, pp. 17–23. URL: http://www.int-res.com/articles/meps/19/m019p017.pdf (visited on 04/19/2017).

— (1984c). “The tailor (*Pomatomus saltatrix*) fishery at Fraser Island and its relation to the life-history of the fish”. In: *Proceedings of the Royal Society of Queensland* 95, pp. 23–28.

Punt, André E., Robert A. Campbell, and Anthony D. M. Smith (Jan. 2001). “Evaluating empirical indicators and reference points for fisheries management: Application to the broadbill swordfish fishery off eastern Australia”. In: *Marine and Freshwater Research* 52.6, pp. 819–832. URL: http://www.publish.csiro.au/paper/MF00095 (visited on 08/31/2015).

Queensland Department of Employment, Economic Development and Innovation (2009). *Guidelines for commercial operators in the East Coast Inshore Finfish Fishery / [Queensland Primary Industries and Fisheries]*. Brisbane: Queensland Primary Industries and Fisheries.

R Core Team (2020). *R: A language and environment for statistical computing*. Vienna. URL: http://www.R-project.org/.

Ricker, W.E. (1975). *Computation and Interpretation of Biological Statistics of Fish Populations*. Vol. Bulletin of the Fisheries Research Board of Canada, Vol 191. Ottawa: Department of the Environment, Fisheries and Marine Service.

Robillard, Eric, Christian S. Reiss, and Cynthia M. Jones (Apr. 2008). “Reproductive biology of bluefish (*Pomatomus saltatrix*) along the East Coast of the United States”. In: *Fisheries Research* 90.1–3, pp. 198–208. URL: http://www.sciencedirect.com/science/article/pii/S0165783607002743 (visited on 11/04/2016).

Rose, G. A. (2005). “On distributional responses of North Atlantic fish to climate change”. In: *ICES Journal of Marine Science* 62. Type: Journal Article, pp. 1360–1374.

Schilling, H. T., J. A. Smith, J. Stewart, J. D. Everett, J. M. Hughes, and I. M. Suthers (2019). “Reduced exploitation is associated with an altered sex ratio and larger length at maturity in southwest Pacific (east Australian) Pomatomus saltatrix”. In: *Mar Environ Res* 147, pp. 72–79.

Schilling, Hayden T., Jason D. Everett, James A. Smith, John Stewart, Julian M. Hughes, Moninya Roughan, Colette Kerry, and Iain M. Suthers (2020). “Multiple spawning events promote increased larval dispersal of a predatory fish in a western boundary current”. In: *Fisheries Oceanography* 29.4, pp. 309–323.

Schilling, Hayden T., Julian M. Hughes, James A. Smith, Jason D. Everett, John Stewart, and Iain M. Suthers (2017). “Latitudinal and ontogenetic variation in the diet of a pelagic mesopredator (Pomatomus saltatrix), assessed with a classification tree analysis”. In: *Marine Biology* 164.4, p. 75.

Schilling, Ht, P Reis-Santos, Jm Hughes, Ja Smith, Jd Everett, J Stewart, Bm Gillanders, and Im Suthers (2018). “Evaluating estuarine nursery use and life history patterns of *Pomatomus saltatrix* in eastern Australia”. en. In: *Marine Ecology Progress Series*, DOI: 10.3354/meps12495. URL: http://www.int-res.com/prepress/m12495.html (visited on 02/22/2018).

Shepherd, Gary R., Joshua Moser, David Deuel, and Pam Carlsen (2006). “The migration patterns of bluefish (*Pomatomus saltatrix*) along the Atlantic coast determined from tag recoveries”. In: *Fishery Bulletin* 104.4, pp. 559–570. URL: http://fishbull.noaa.gov/1044/shepherd.pdf (visited on 03/13/2017).

Smith, K., P. Lewis, J. Brown, C. Dowling, A. Howard, Rod C. J. Lenanton, and B. Molony (2013). *Status of nearshore finfish stocks in south-western Western Australia Part 2: Tailor*. Tech. rep. Perth, WA: Department of Fisheries. URL: http://www.fish.wa.gov.au/Documents/research_reports/frr247.pdf.

Smith, Tara M. (2004). *Background and proposed design for an experiment to estimate discard mortality of line-caught Tailor (*Pomatomus saltatrix*) in Australia’s east coast recreational fishery*. Brisbane:

Department of Primary Industries and Fisheries. URL: https://www.daf.qld.gov.au/fisheries/monitoring-our-fisheries/data-reports/sustainability-reporting/stock-assessment-reports/mortality-of-line-caught-tailor (visited on 04/03/2017).

Stead, David George (1906). *Fishes of Australia: A Popular and Systematic Guide to the Study of the Wealth Within Our Waters*. Sydney: William Brooks.

Takasuka, A., Y. Oozeki, and I. Aoki (2007). “Optimal growth temperature hypothesis: why do anchovy flourish and sardine collapse or vice versa under the same ocean regime?” In: *anadian Journal of Fisheries and Aquatic Sciences* 64. Type: Journal Article, pp. 768–776.

Taylor, Stephen, James Webley, and Kirrily McInnes (2012). *2010 Statewide Recreational Fishing Survey*. Tech. rep. Brisbane: Department of Agriculture, Fisheries and Forestry. URL: http://era.daf.qld.gov.au/id/eprint/6926/2/2010%20SWRFS-Final%20V4.pdf (visited on 12/19/2019).

von Bertalanffy, Ludwig (May 1938). “A quantitative theory of organic growth (Inquiries on growth laws. II)”. In: *Human Biology* 10.2, pp. 181–213. URL: http://www.jstor.org/stable/41447359 (visited on 10/09/2015).

Ward, T. M., Jonathan Staunton-Smith, Simon D. Hoyle, and Ian A. Halliday (2003). “Spawning patterns of four species of predominantly temperate pelagic fishes in the sub-tropical waters of southern Queensland”. In: *Estuarine, Coastal and Shelf Science* 56.5–6, pp. 1125–1140. URL: http://dx.doi.org/10.1016/S0272-7714(02)00318-9.

Webley, James A. C., Kirrily McInnes, Daniella Teixeira, Ashley Lawson, and Ross Quinn (2015). *Statewide Recreational Fishing Survey 2013–14*. Tech. rep. Brisbane: Department of Agriculture and Fisheries. URL: http://era.daf.qld.gov.au/id/eprint/6513/1/2013-14SRFS%20Report.pdf (visited on 12/19/2019).

West, Laurie D., Kate E. Stark, Jeff J. Murphy, Jeremy M. Lyle, and Faith A. Ochwada-Doyle (Dec. 2015). *Survey of Recreational Fishing in New South Wales and the ACT, 2013/14*. Tech. rep. Fisheries Final Report Series, No. 149. Wollongong, Australia: NSW Department of Primary Industries. URL: http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0010/600130/West-et-al-Survey-of-rec-fishing-in-NSW-ACT-2013-14-2016_04_05.pdf (visited on 05/23/2016).

Wilk, Stuart J. (Aug. 1977). *Biological and fisheries data on bluefish, Pomatomus saltatrix (Linnaeus)*. Tech. rep. Technical Series Report No. 11. Highlands, NJ: National Marine Fisheries Service. URL: National%20Marine%20Fisheries%20Service (visited on 03/13/2017).

Williams, Fred (1982). *A History of Fraser Island: Written in Sand*. Brisbane: Jacaranda Press.

Williams, Lew (2002). *Queensland's Fisheries Resources: Current Condition and Recent Trends 1988–2000*. Tech. rep. Information Series QI02012. Brisbane: Queensland Department of Primary Industries.

Zeller, Brad M., Barry R. Pollock, and L. E. Williams (1996). “Aspects of the life history and management of tailor (*Pomatomus saltatrix*) in Queensland”. In: *Marine and Freshwater Research* 47, pp. 323–329.

Appendix A Protocol for specifying fishing methods in Queensland logbooks

In the early years of Fisheries Queensland logbook reporting, fishing methods were not always recorded as accurately as they are today. Many entries were recorded as a default of unspecified gillnetting (i.e. 04). The method shown below was developed by Fishery Monitoring to tease out obvious tunnel netting, haul netting and ocean beach netting from gillnetting for catches with the unspecified netting category. It uses a combination of net length, catch weight, location, and fishing method. A single data field on its own was not considered adequate.

First, non-valid regions were corrected:

- Some logbook data are recorded against landlocked grids of U33, U34 or U35. It was acknowledged that these catch records had been erroneously recorded with a U grid and should be a V grid.
- Update U34 to V34, update U33 to V33, update U35 to V35

Next, records with a default unspecified fishing method (04) were allocated to an assumed fishing method. Note that the order in which these steps are completed is important.

1. If net length ≥ 1000 m, assume fishing method code (FMC) 04 = 44 - tunnel netting
    - most catches with a FMC of 44 - tunnel netting use a net length of 1000 m or longer
    - most catches with FMC of either 14, 24, 54 using a net length between 400 m and 800 m
    - most haul net (64) catches use a net length between 400 m and 800 m
    - most ocean beach (34) catches use a net length between 200 m and 400 m
2. For remaining 04 catch, if catch weight ≥ 200 kg and grid is not U or V, assume FMC 04 = 34 - ocean beach netting
3. For remaining 04 catch, if catch weight ≥ 200 kg and grid is U or V, assume FMC 04 = 64 - haul netting
4. For remaining 04 catch, if catch weight < 200 kg and if net length < 500 m and mesh between 0.05 and 0.075 assume FMC 04 = 34 - ocean beach netting
    - Regulations state an ocean beach net must be less than 500 m (with a mesh size between 12 and 70 mm). For catches < 200 kg where net length < 500 m was combined with a net mesh size between 0.05 and 0.075, over 60% of net harvest weight (with a fishing method) was by ocean beach netting (34).
5. For remaining 04 catch, if catch is from the grids W35 or W36 FMC 04 = 34 - ocean beach netting
    - In these two grids the majority of the net harvest weight (with a fishing method) was by ocean beach netting. Mesh size is always between 0.05 and 0.075 but net lengths up to 800 m are recorded. This step pulls out catches made along ocean beaches that probably use a general purpose net (as opposed to an ocean beach net).
6. For remaining 04 catch, if catch is in grids W32, W33, W37, W38 (grid locations where catch from both ocean beach and estuarine locations can occur) then those with a net length between 600 and 800 m and mesh size is between 0.07 and 0.089 assume FMC 04= 142454 - mixed gillnetting.
    - A notation of '142454 - mixed gillnetting' is used as a notation where the fishing method is a form of gillnetting but it was undetermined which one - 14 -drifting gillnetting, 24 - anchored

gillnetting, 54 - ring netting. It was not necessary to differentiate further as for the purpose of this assessment we only wished to know methods that fell under the umbrella of 'gillnetting'
   - Within these grids, approximately 95% of net harvest weight $<$ 200 kg was by a gill net of these dimensions.
7. For the remaining catch, if catch is from an estuarine location where fishery knowledge indicates that ocean beach netting is not plausible or historically has not occurred (Fraser inshore, Moreton Bay valid LTMP sampling locations) FMC 04 = 142454 - mixed gillnetting.
   - This step may have accidentally included some small estuarine haul catches (64) but this was considered acceptable.
8. Any further remaining catch is left with a FMC of 04 - unspecified gillnetting as no reliable fields were found to assign an assumed FMC to the remaining records.

The method further adjusts FMC for 64 - haul netting and 34 - ocean beach netting depending on catch location (i.e. estuarine or ocean beach). However, for the purposes of this assessment this procedure was not continued as we were only interested in which fishing methods were gillnet and which were not (Figure A.1, Table A.1).

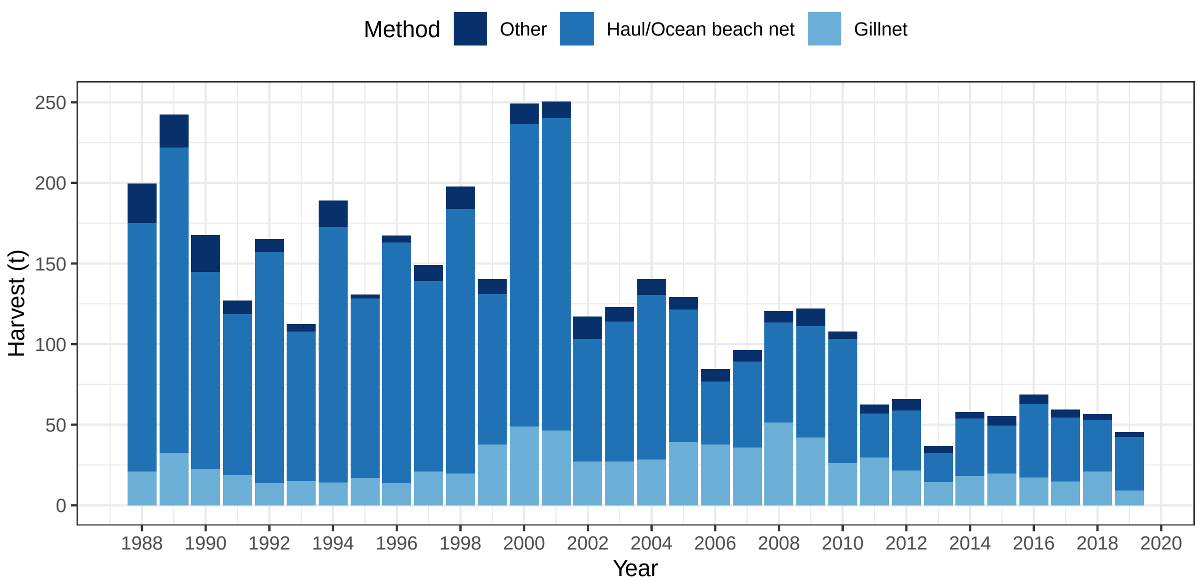

Figure A.1: Plot showing harvest allocated to Gillnet and Haul/Ocean beach net fishing methods for the Queensland commercial tailor fishery

Table A.1: Fishing method codes (FMC) with descriptions allocated to Gillnet and Haul/Ocean beach net fishing methods for the Queensland commercial tailor fishery

Fishing method	FMC	Description
Gillnet	24	Anchored gillnetting
	14	Drifting gillnetting
	04	Gillnetting
	54	Ring Netting
Haul/Ocean beach net	64	Haul Netting
	34	Ocean Beach Netting
	34	Ocean Beach Netting Duplicate Operation
Other	104	Back Netting
	94	Cast Netting
	61	Demersal longline
	31	Dropline (Demersal longline)
	05	Fish trapping
	11	Handline
	01	Line fishing
	06	Potting (Crab)
	52	Scoop/Dab Netting
	84	Stripe Netting/Set Pocket Net
	07	Trawling
	41	Trolling
	51	Trotline (Demersal longline)
	44	Tunnel Netting

Appendix B Specifying age groups

Age data supplied by Queensland's Fishery Monitoring Program are classified into age groups (Table B.1) (Fisheries Queensland 2017; Fisheries Queensland 2018). Age group is expressed in whole years, and is the maximum age class fish would reach within a designated sampling season. Age group is the preferred age type used in routine analyses because it groups fish in the same cohort together, irrespective of when they were caught during a sampling season.

Fish birth is assumed to occur on 1 September each year. For use in the population model, age groups have been reclassified to 0+ for age groups 0 and 1, (0–15 months old), 1+ for age group 2 (16–27 months old) and so on up to age group 6+ for fish in age group 7 and above (Table B.1). This follows the method used in Leigh et al. (2017).

Table B.1: Differences between Age class and Age groups determined by Queensland Fishery Monitoring and age groups used in the population model

Calendar year 1:

Nominal birth date 1st												
Opaque zone formation												
Spawning												
Month	J	F	M	A	M	J	J	A	S	O	N	D
Age class									0	0	0	0
Age group									0	0	0	0
Biological age (months)									0	1	2	3
Model age group									0+	0+	0+	0+

Calendar year 2:

Nominal birth date 1st												
Opaque zone formation												
Spawning												
Month	J	F	M	A	M	J	J	A	S	O	N	D
Age class	0	0	0	0	0	0	0	0	1	1	1	1
Age group	1	1	1	1	1	1	1	1	1	1	1	1
Biological age (months)	4	5	6	7	8	9	10	11	12	13	14	15
Model age group	0+	0+	0+	0+	0+	0+	0+	0+	0+	0+	0+	0+

Calendar year 3:

Nominal birth date 1st												
Opaque zone formation												

Continued on next page

Table B.1 – *Continued from previous page*

Spawning												
Month	J	F	M	A	M	J	J	A	S	O	N	D
Age class	1	1	1	1	1	1	1	1	2	2	2	2
Age group	2	2	2	2	2	2	2	2	2	2	2	2
Biological age (months)	16	17	18	19	20	21	22	23	24	25	26	27
Model age group	1+	1+	1+	1+	1+	1+	1+	1+	1+	1+	1+	1+

Appendix C Phase plots

Figures C.1 and C.2 shows the trajectory of fishing pressure vs spawning biomass over time. Harvest targets for the average recruitment (Figure C.1) and low recruitment (Figure C.2) scenarios are overlaid on each phase plot.

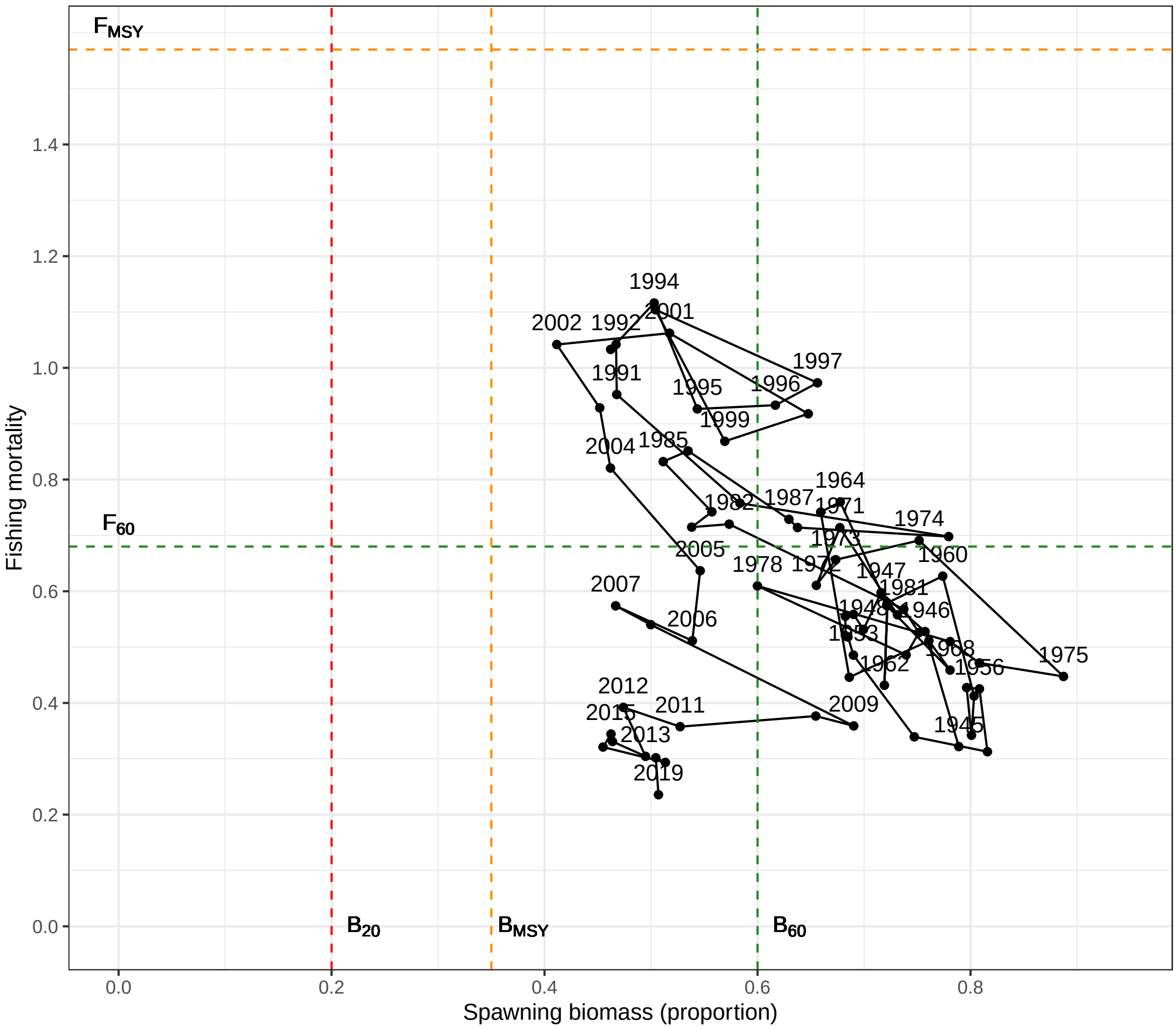

Figure C.1: Phase plot of fishing pressure over time relative to the predicted spawning biomass proportion for Queensland and New South Wales east coast tailor with average recruitment scenario targets

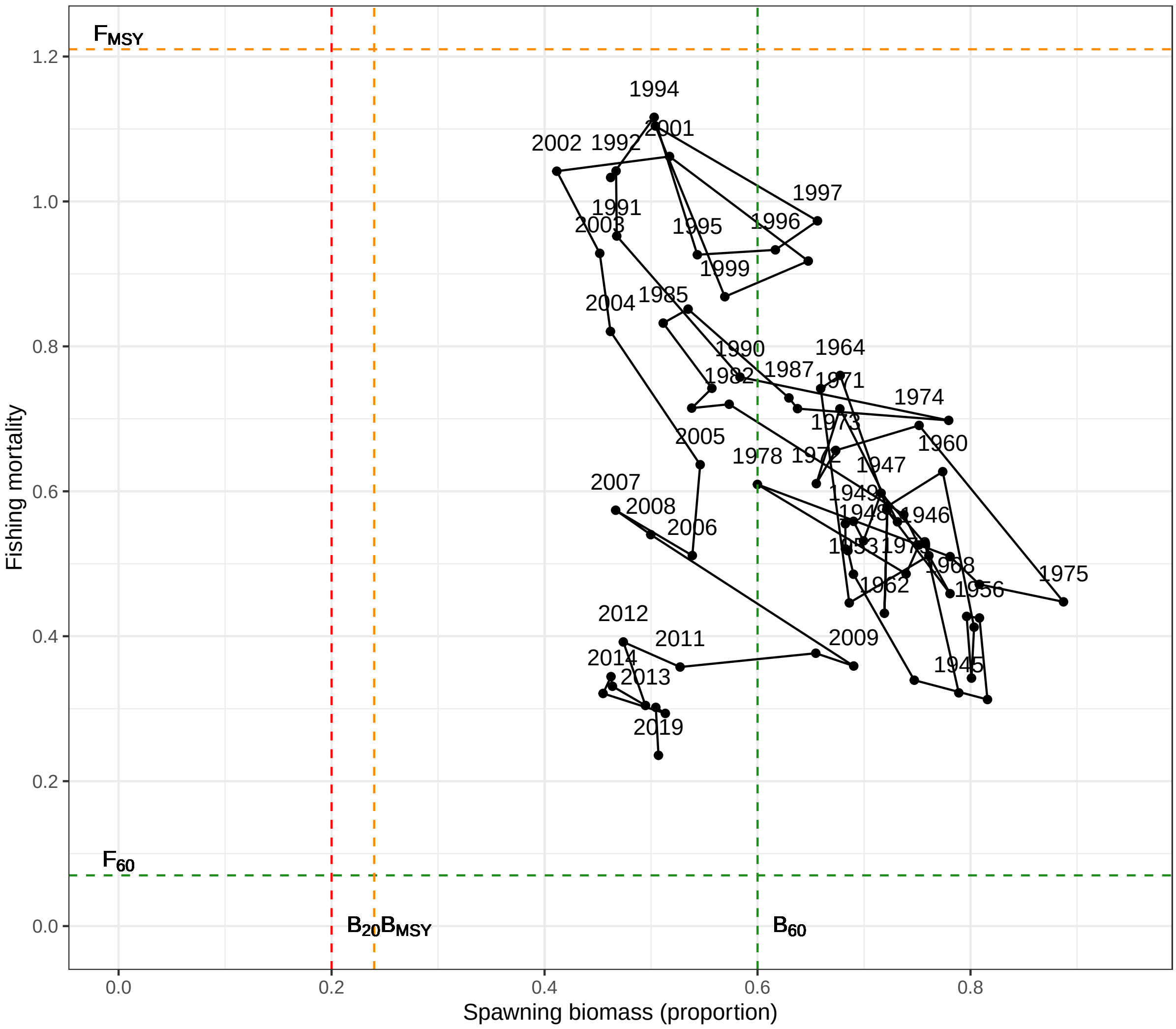

Figure C.2: Phase plot of fishing pressure over time relative to the predicted spawning biomass proportion for Queensland and New South Wales east coast tailor with low recruitment scenario targets

Appendix D Model paramenters and fits

D.1 Recruitment deviation estimates

Table D.1: MCMC recruitment deviation parameters with upper and lower confidence intervals

Year	Median	2.5%	97.5%
1954	-0.0111	-0.5498	0.5084
1955	-0.0302	-0.5155	0.4488
1956	-0.0199	-0.5287	0.4906
1957	-0.033	-0.529	0.436
1958	-0.0018	-0.5041	0.4757
1959	0.012	-0.4486	0.4872
1960	-0.0557	-0.5818	0.3985
1961	-0.0408	-0.5071	0.3595
1962	0.0059	-0.4966	0.5159
1963	-0.0129	-0.504	0.4143
1964	0.0167	-0.4302	0.467
1965	-0.0021	-0.4913	0.4409
1966	0.1182	-0.3252	0.5791
1967	0.0551	-0.4331	0.5473
1968	-0.0977	-0.5369	0.3706
1969	0.064	-0.3644	0.4768
1970	-0.0515	-0.4904	0.3217
1971	-0.031	-0.4212	0.3254
1972	0.0567	-0.3472	0.4388
1973	0.2387	-0.1622	0.6235
1974	0.3233	-0.1262	0.7174
1975	-0.0998	-0.4844	0.2764
1976	0.0461	-0.3186	0.3924
1977	-0.4602	-0.858	-0.0535
1978	0.2637	-0.0815	0.608
1979	0.0354	-0.4129	0.4452
1980	0.0649	-0.299	0.3745
1981	-0.3661	-0.8015	0.0274
1982	-0.0994	-0.4981	0.2636
1983	0.0006	-0.4062	0.4108
1984	-0.1132	-0.5356	0.2616
1985	0.0561	-0.3418	0.4267
1986	0.2341	-0.1781	0.5848

Continued on next page

Table D.1 – *Continued from previous page*

Year	Median	2.5%	97.5%
1987	0.0884	-0.3329	0.4303
1988	0.3995	0.1144	0.63
1989	-0.3706	-0.7018	-0.0586
1990	-0.2037	-0.5559	0.0853
1991	0.0028	-0.3032	0.2694
1992	0.0106	-0.2765	0.2342
1993	0.1775	-0.01	0.3477
1994	0.1645	-0.0043	0.3258
1995	0.2794	0.1329	0.4288
1996	0.3051	0.1413	0.462
1997	-0.1757	-0.4787	0.1088
1998	0.1643	-0.1395	0.4203
1999	0.2827	0.0044	0.5087
2000	-0.1571	-0.4325	0.0838
2001	-0.2942	-0.46	-0.1385
2002	-0.025	-0.149	0.0997
2003	-0.0866	-0.2331	0.0524
2004	0.0859	-0.0428	0.2249
2005	-0.1938	-0.3253	-0.0621
2006	-0.425	-0.5607	-0.2839
2007	-0.1418	-0.2797	0.0032
2008	0.2504	0.1167	0.3921
2009	-0.2626	-0.4331	-0.1007
2010	-0.5952	-0.7879	-0.4026
2011	-0.4804	-0.6518	-0.3085
2012	-0.3134	-0.4547	-0.1686
2013	-0.5235	-0.6815	-0.3719
2014	-0.3872	-0.538	-0.2328
2015	-0.446	-0.6002	-0.2956
2016	-0.186	-0.3435	-0.0114
2017	-0.3919	-0.5725	-0.2184
2018	-0.349	-0.5745	-0.1193

D.2 Catch rate fits

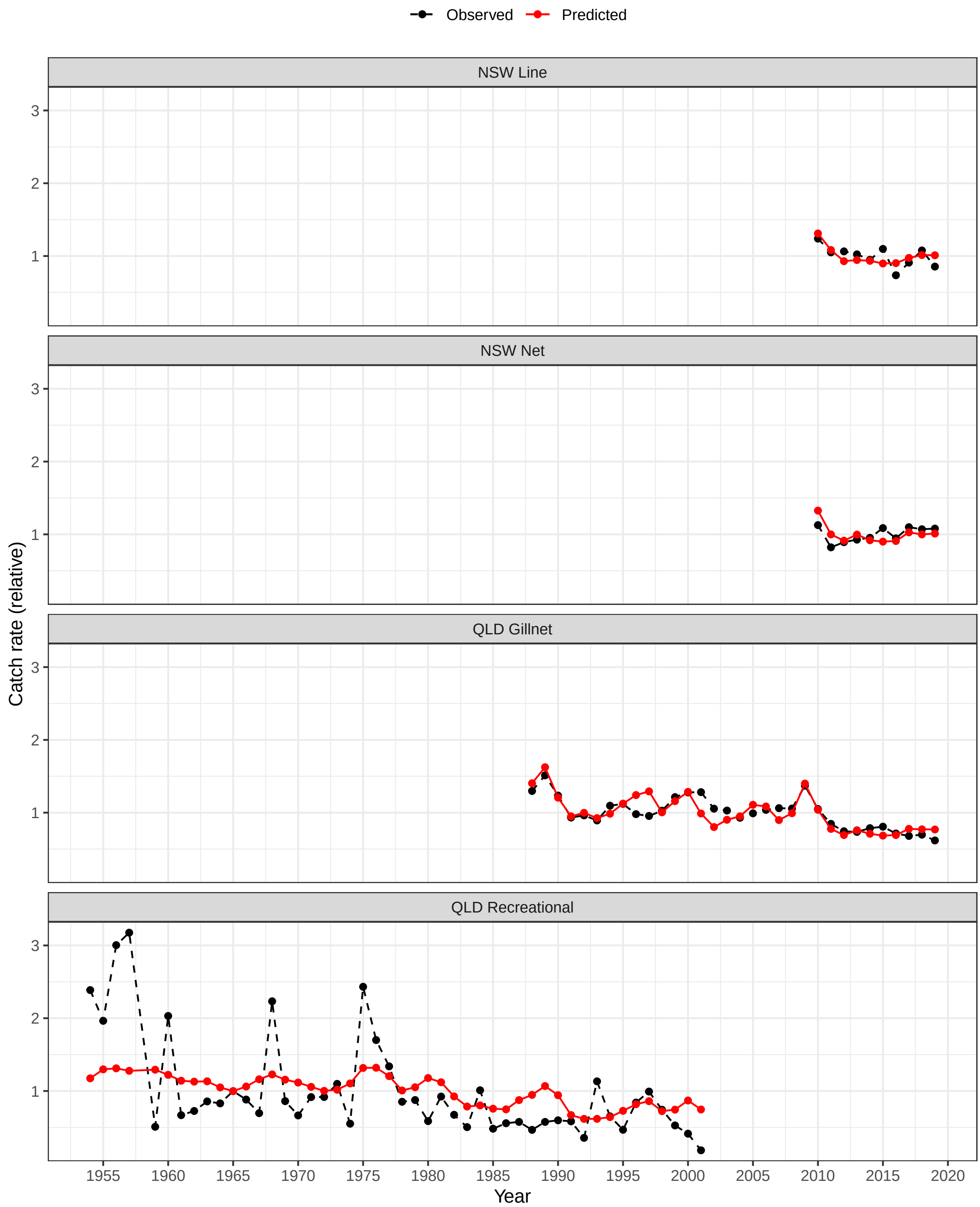

Figure D.1: MCMC model fit to catch rates

D.3 Length fits

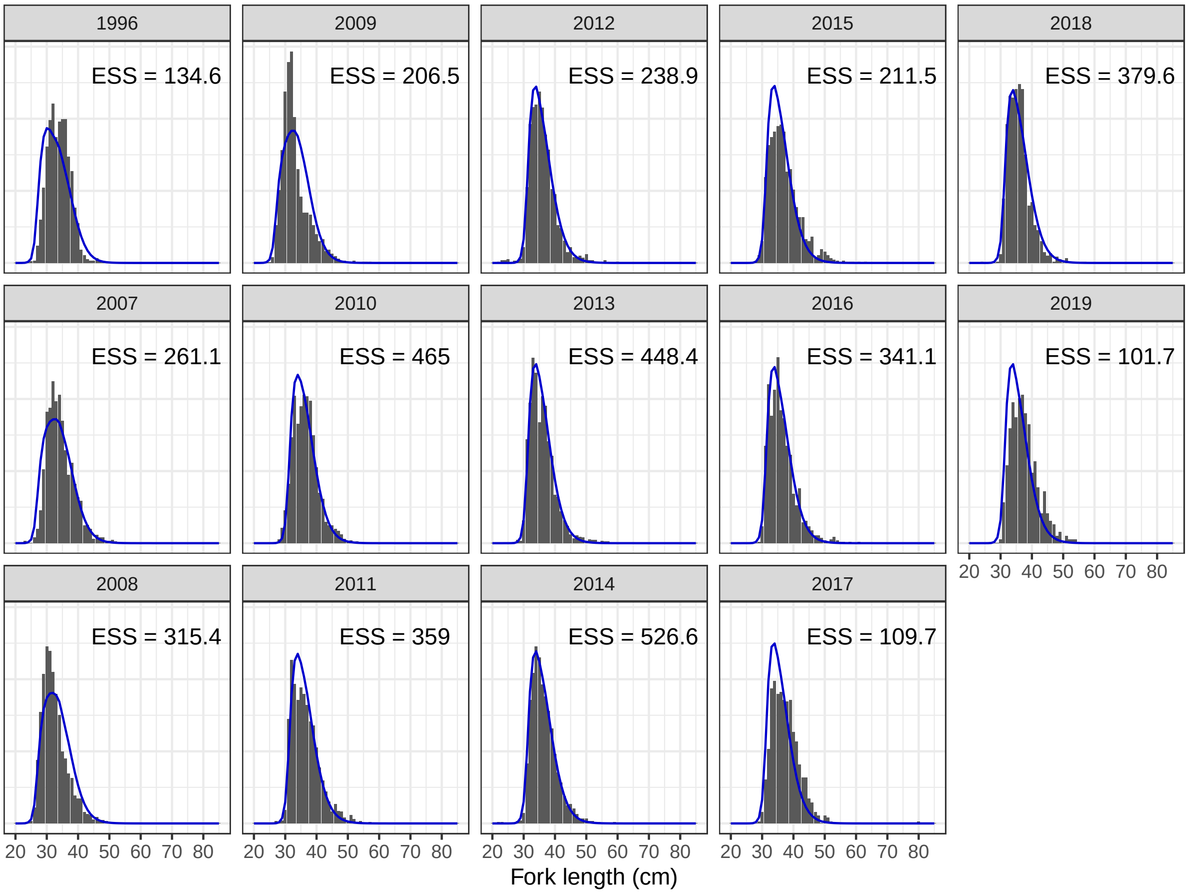

Figure D.2: MCMC model fit to Queensland gillnet length structures
The effective sample size (ESS) is shown for each year

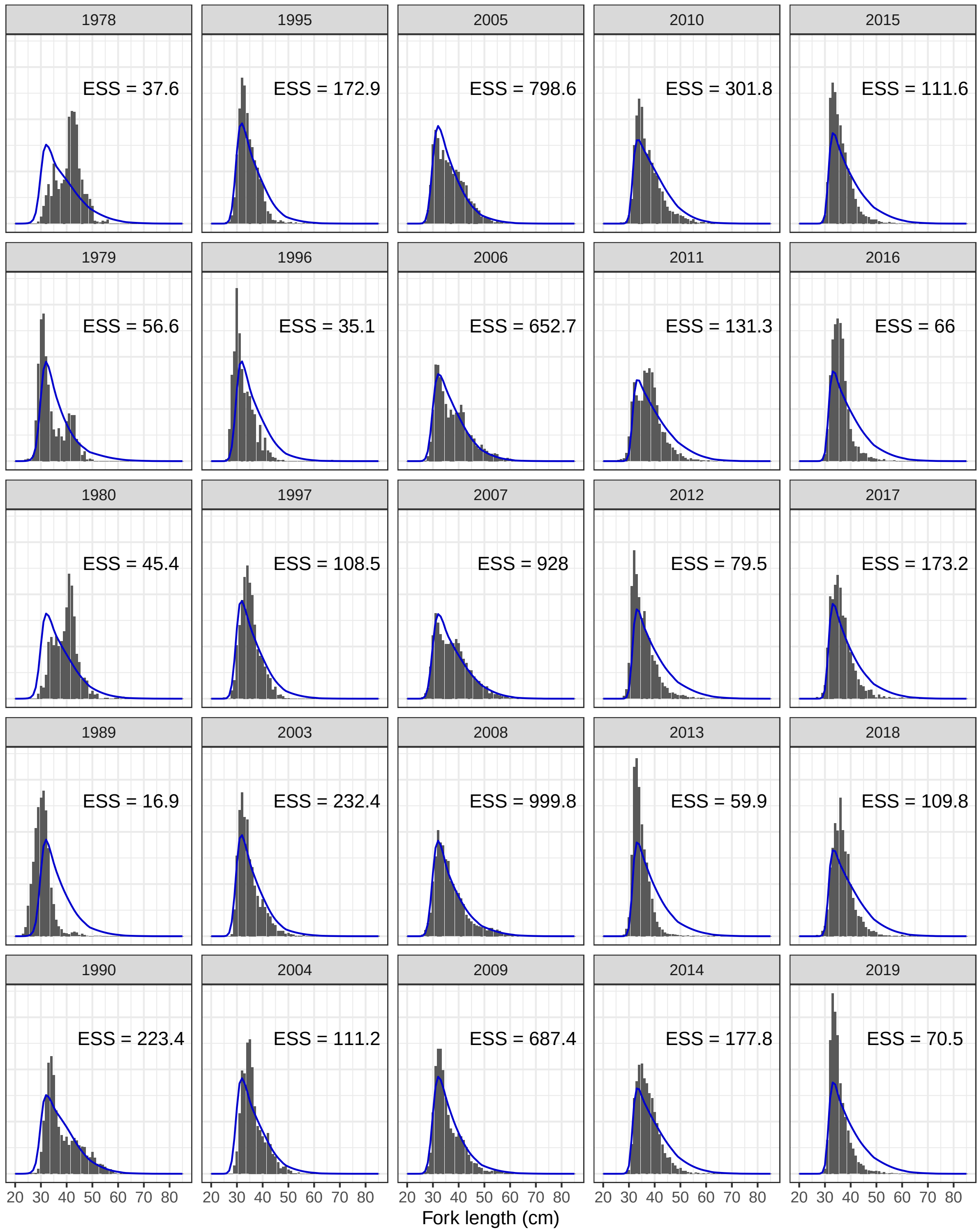

Figure D.3: MCMC model fit to Queensland recreational length structures
The effective sample size (ESS) is shown for each year

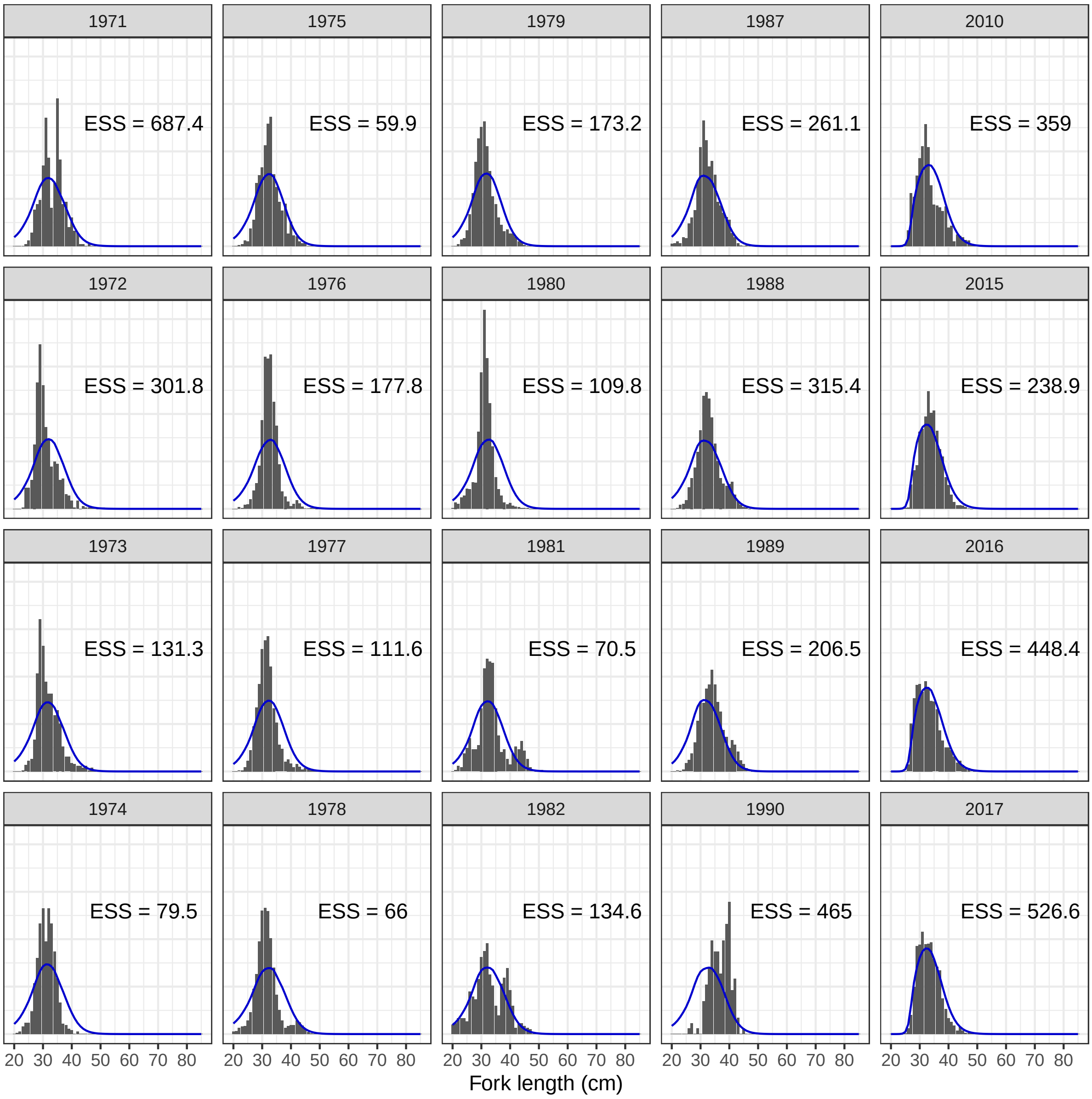

Figure D.4: MCMC model fit to New South Wales commercial length structures
The effective sample size (ESS) is shown for each year

D.4 Age fits

Input and model predicted age-at-length data were applied to the Queensland input and predicted length structures to create Queensland recreational age structures.

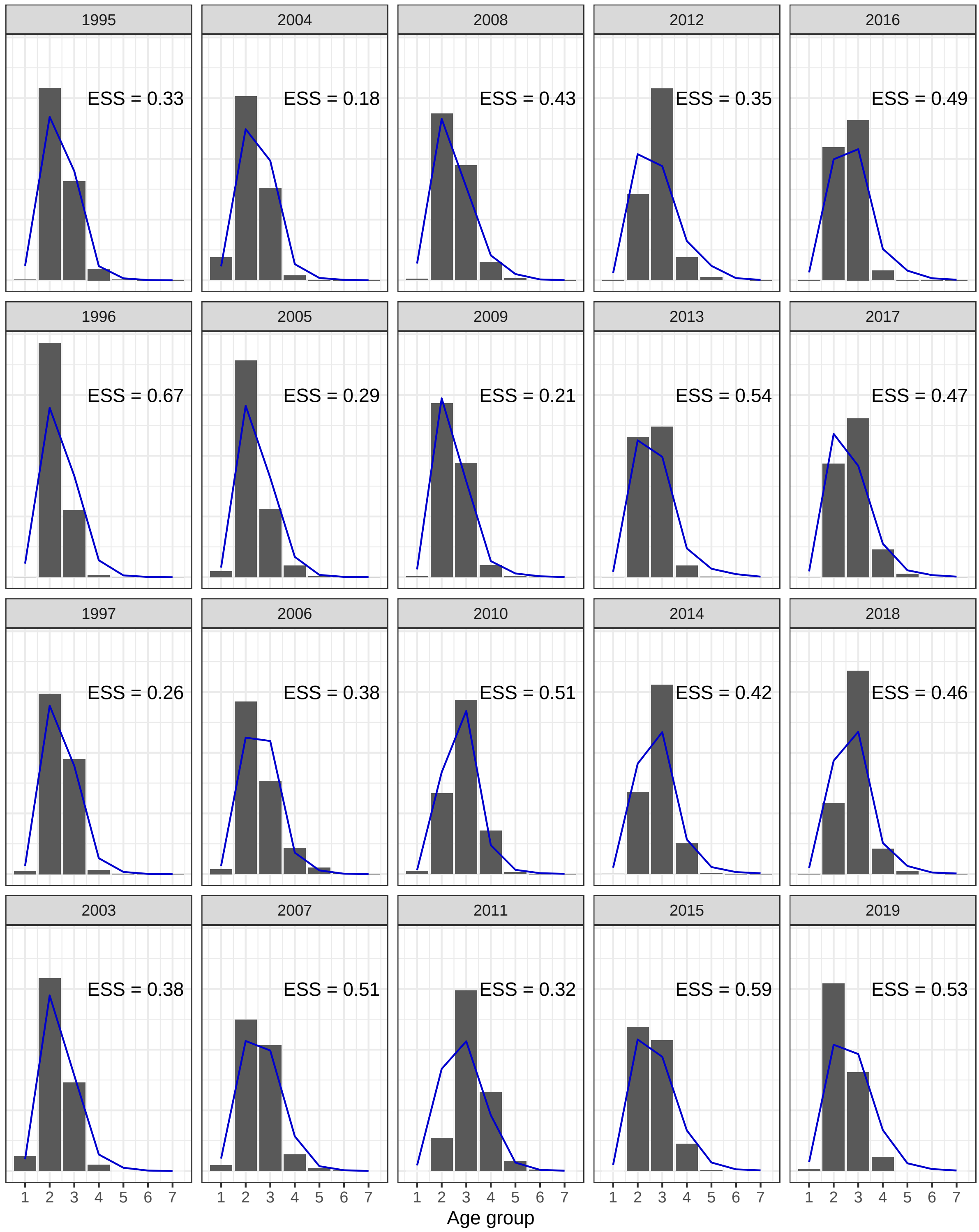

Figure D.5: MCMC model fit to Queensland recreational age structures
The effective sample size (ESS) is shown for each year

D.5 Parameter and target fits

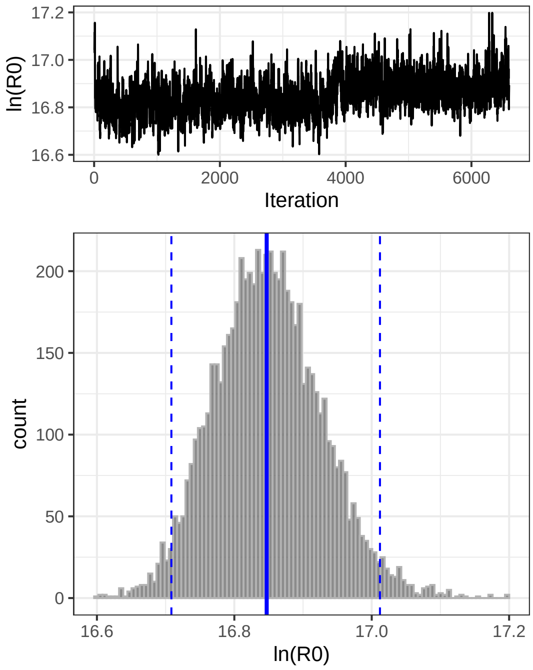

Figure D.6: Trace plot and histogram of $ln(R_0)$ (log of virgin recruitment)
Note: The blue line shows the median of the MCMC run, the blue dashed lines show the 95% confidence interval of the MCMC run

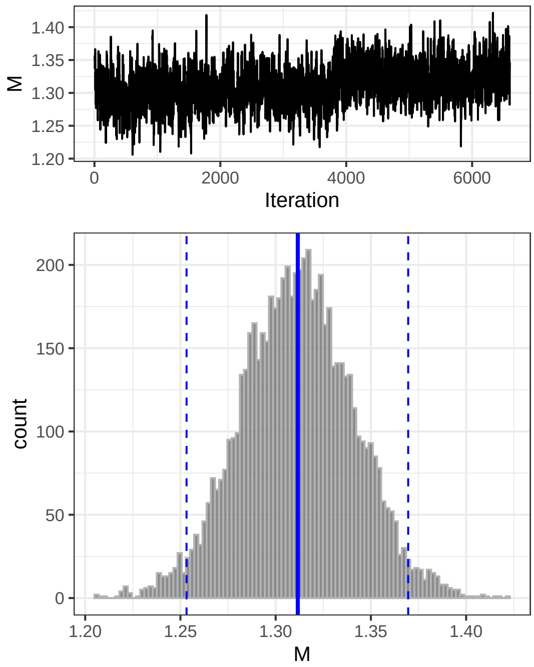

Figure D.7: Trace plot and histogram of M (natural mortality)
Note: The blue line shows the median of the MCMC run, the blue dashed lines show the 95% confidence interval of the MCMC run

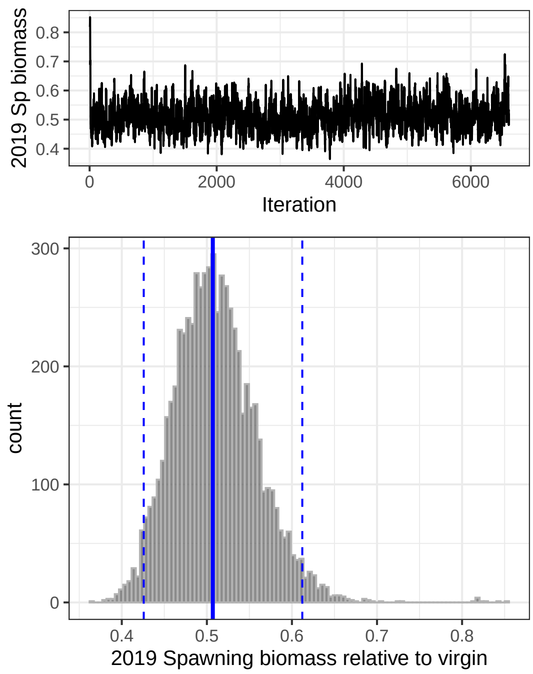

Figure D.8: Trace plot and histogram of the 2019 spawning biomass
Note: The blue line shows the median of the MCMC run, the blue dashed lines show the 95% confidence interval of the MCMC run

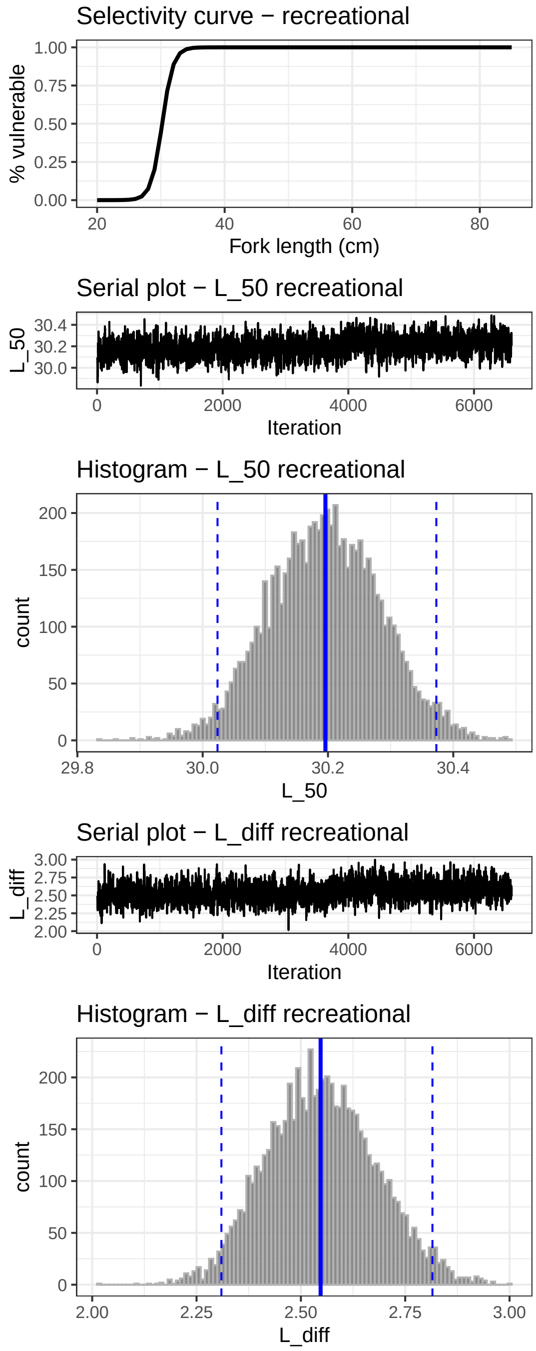

Figure D.9: Selectivity curve and trace plot and histograms of L_{50} and L_{diff} for the Queensland and New South Wales recreational model fleets

Note: The blue line shows the median of the MCMC run, the blue dashed lines show the 95% confidence interval of the MCMC run

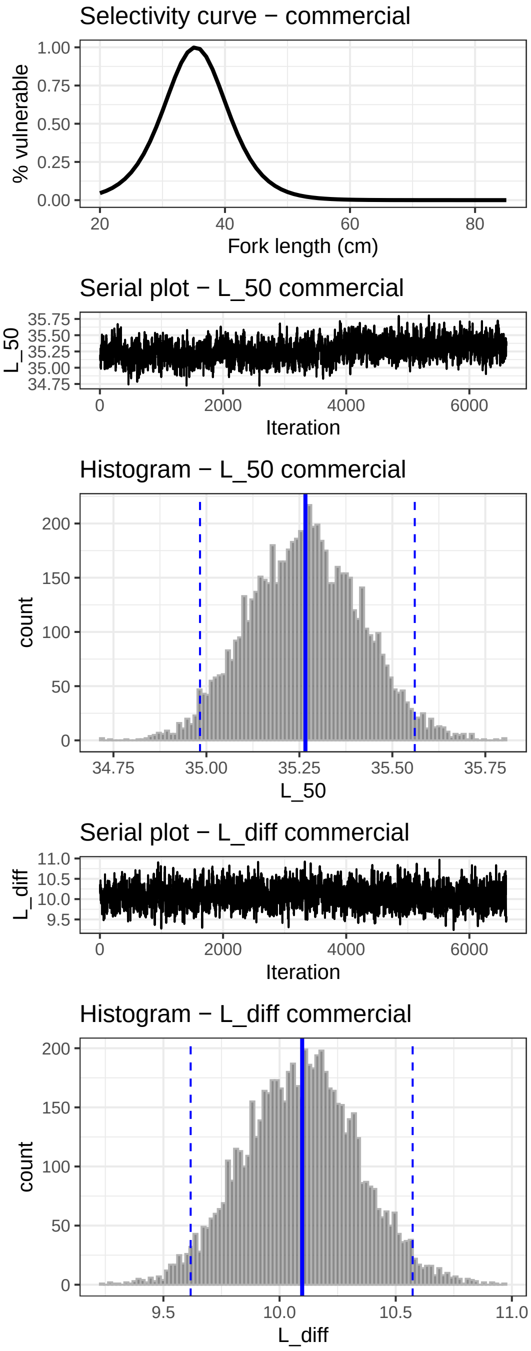

Figure D.10: Selectivity curve and trace plot and histograms of L_{50} and L_{diff} for the Queensland and New South Wales commercial model fleets

Note: The blue line shows the median of the MCMC run, the blue dashed lines show the 95% confidence interval of the MCMC run

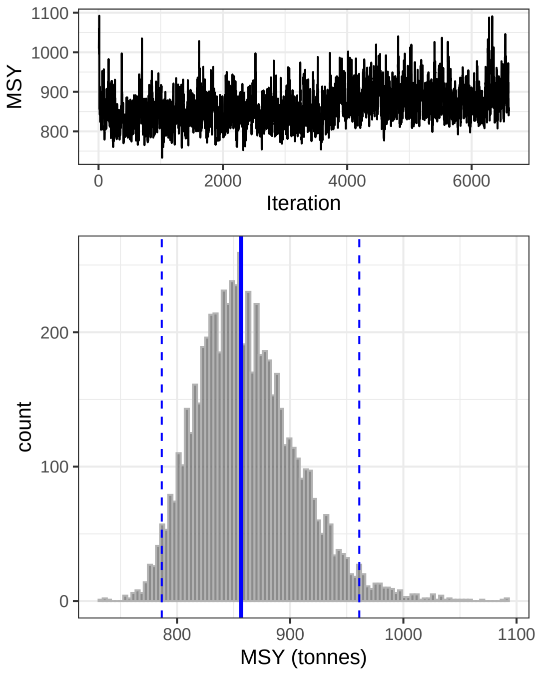

Figure D.11: Trace plot and histogram of MSY with average recruitment
Note: The blue line shows the median of the MCMC run, the blue dashed lines show the 95% confidence interval of the MCMC run

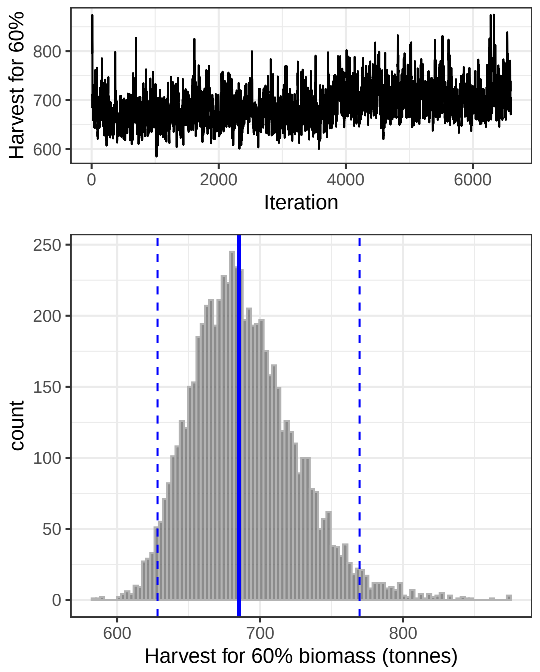

Figure D.12: Trace plot and histogram of harvest at equilibrium 60% spawning biomass with average recruitment
Note: The blue line shows the median of the MCMC run, the blue dashed lines show the 95% confidence interval of the MCMC run

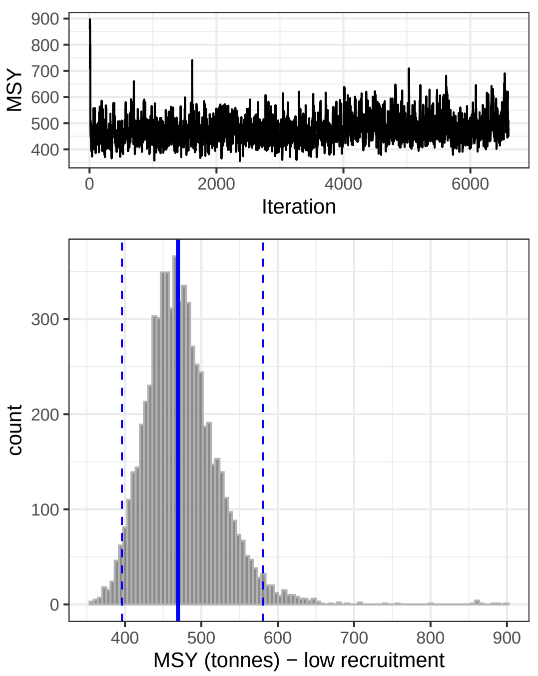

Figure D.13: Trace plot and histogram of MSY for the low recruitment scenario
Note: The blue line shows the median of the MCMC run, the blue dashed lines show the 95% confidence interval of the MCMC run

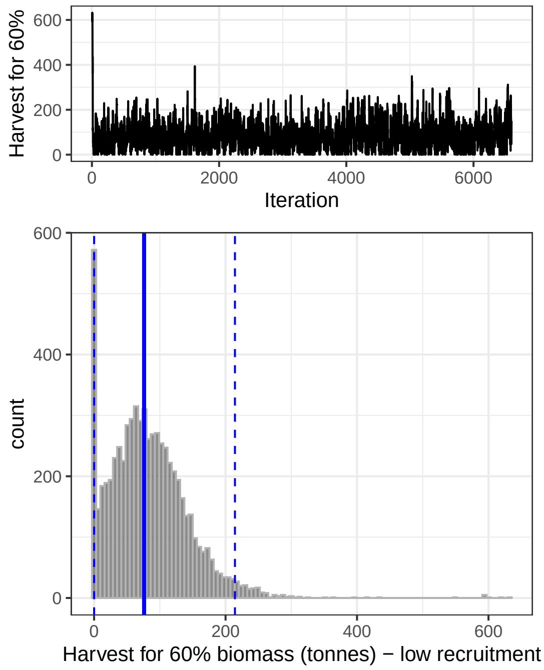

Figure D.14: Trace plot and histogram of harvest at equilibrium 60% spawning biomass for the low recruitment scenario
Note: The blue line shows the median of the MCMC run, the blue dashed lines show the 95% confidence interval of the MCMC run