



Stock assessment of Australian east coast sea mullet (*Mugil cephalus*), with data to December 2024



This publication has been compiled by R. A. Lovett ¹, M. F. O'Neill ¹, A. Prosser ¹ and J. Stewart ².

¹ Fisheries Queensland, Department of Primary Industries, Queensland Government.

² Fisheries and Forestry, Department of Primary Industries and Regional Development, New South Wales Government.

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Executive summary

Introduction

Sea mullet (*Mugil cephalus*) occur in tropical and subtropical waters worldwide. Along the east coast of Australia, they form a single continuous stock spanning New South Wales to central Queensland. The species inhabits coastal, estuarine and freshwater environments, with notable spawning aggregations forming along the coast during late autumn and winter. For this assessment, data were collated between Baffle Creek (24.5° S) in Queensland and Eden (37.5° S) in New South Wales.

The species live around 16 years with a maximum recorded size of 64 cm fork length (about 4 kg). Sexual maturity is reached at 3–4 years of age (Smith and Deguara 2002). Preliminary research indicates that sea mullet may exhibit partial migration, with most mature individuals participating in the spawning run, although the proportion migrating remains uncertain (Virgona et al. 1998; Fowler et al. 2016).

Sea mullet are commercially caught in large numbers with nets. In order of 3,000–5,000 tonnes (t) are taken per year, with just over two-thirds caught from New South Wales waters. The species comprise the largest catch by weight of all finfish taken in commercial fisheries in New South Wales and Queensland. Non-commercial catches are minimal.

Indicative beach prices are typically \$1–\$5 per kg depending on the sex and spawning condition of sea mullet (Queensland Government, unpublished data; BDO EconSearch (2024) and Curtotti et al. (2025)). Roed females are more valuable than males and often exported, either as whole roe-bearing females or more commonly as processed (dried/salted) roe. In recent years of reduced catch 2022–2024, the combined New South Wales and Queensland landings value was calculated to be approximately AUD\$11–\$13 million per year.

In 2025, a stock assessment was commissioned to establish the status of the Australian east coast sea mullet stock. Status assessed the level of spawning biomass which refers to the weight of egg production by mature females. Estimates were presented as a ratio or percentage, comparing annual spawning biomass to the estimated unfished level. The stock was assumed to be near unfished levels prior to 1899.

This is the fourth stock assessment of Australian east coast sea mullet. The stock has previously been assessed 3 times with data through to the end of 2003, 2016 and 2020 (Bell et al. 2005; Lovett et al. 2019; Lovett et al. 2022) (Figure C.1). The previous assessment estimated the spawning biomass in 2021 to be 37% relative to unfished levels with a credible interval of 30–45% (Lovett et al. 2022).

Methods

The assessment used an age-structured model with an annual time step by calendar year, using catch, standardised catch rates, age and length composition data. The population dynamics were structured for 2 sexes and 4 fleets. The fleets identified estuarine and ocean beach netting in New South Wales and Queensland. The stock assessment used Stock Synthesis (a computer program used for assessing stock status), with results based on Markov chain Monte Carlo (MCMC) simulations.

This assessment analysed combinations of data to form an ensemble of 24 scenarios. Unlike the previous assessment, this appraisal combined the outcomes from a greater suite of models. The previous stock assessment used outputs from a single 'base case' model based on expert consensus of the project team.

The ensemble approach, used here, allocated weightings to each of the scenarios. The scenarios considered the following key influences:

- Four catch rates from New South Wales and Queensland estuarine and ocean beach sectors.
- Two vulnerability assumptions.
- Three annual rates of natural mortality, ($M = 0.33$ —allowing for a longevity of around 16 years, with lower and upper alternatives of $M = 0.28$ and $M = 0.37$).

The work was overseen by an advisory group that consisted of scientists and managers from the New South Wales Department of Primary Industries and Regional Development, and the Queensland Department of Primary Industries.

Results

Spawning biomass

The results of this assessment (Table 1 and Figure 1) indicate that at the start of 2025, the spawning biomass was between 25% and 76% of unfished levels (95% credible interval). The midpoint (median) estimate of spawning biomass was 39%, meaning half the estimates were higher and half were lower. The median was preferred as a central tendency measure as it is less prone to the influence of outliers and skewness.

The results also summarised the probability of the 2025 spawning biomass falling into 4 categories—below 20%, between 20% and 40%, between 40% and 60%, and above 60% (Table 1, Figure 1). There was about 54% likelihood for spawning biomass being less than 40% and about 46% likelihood for being greater. Over the last 5 years (2020–2024), the harvest rate ranged 10–21% per year, meaning around 15% of the exploited biomass was removed by fishing each year. Sustainable harvest rates (fishing pressure) are typically less than natural mortality (Froese et al. 2016; Hilborn and Walters 2021).

Table 1: Stock status indicators for Australian east coast sea mullet at the beginning of 2025

Indicator	Value
Spawning biomass ratio at the beginning of 2025 (relative to unfished)	
Median	39%
Range (95% credible interval)	25–76%
Probability below 20%	0.1%
Probability between 20% and 40%	53.9%
Probability between 40% and 60%	35.1%
Probability above 60%	10.9%
Harvest rate per year (2020–2024)	
Median	15%
Range (95% credible interval)	10–21%

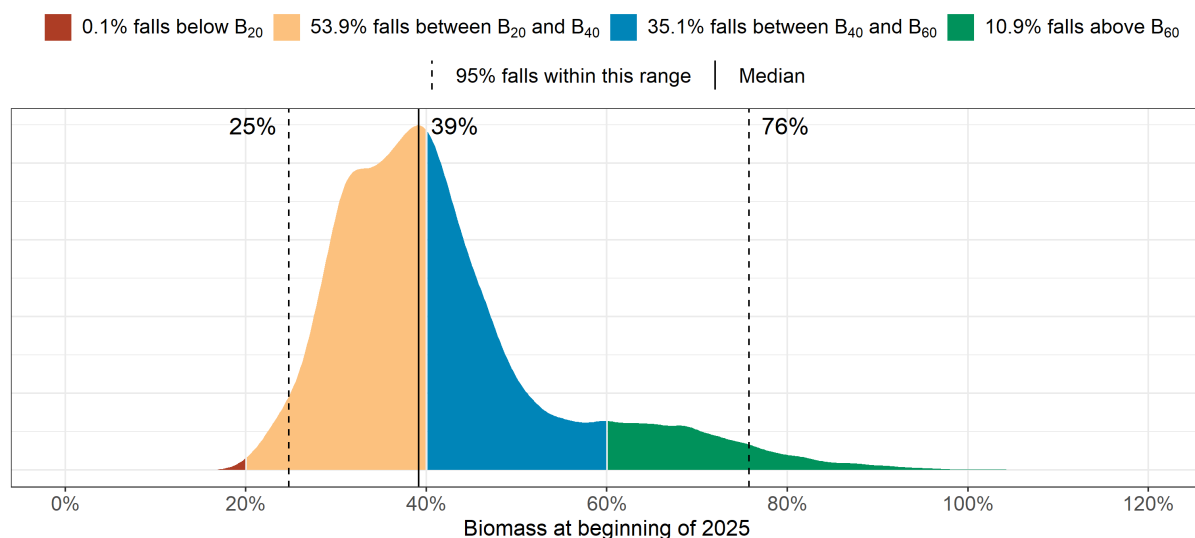


Figure 1: Probability distribution of the spawning biomass ratio of Australian east coast sea mullet at the beginning of 2025 across the MCMC ensemble with the credible interval and probability of spawning biomass falling into the 4 categories indicated

The spawning biomass trajectory (Figure 2) showed a general decline from 1980 until around 2016 after which the spawning stock level exhibited a steady increase into 2025. This increase was associated with reduced catches of around 3,000–4,000 t per year.

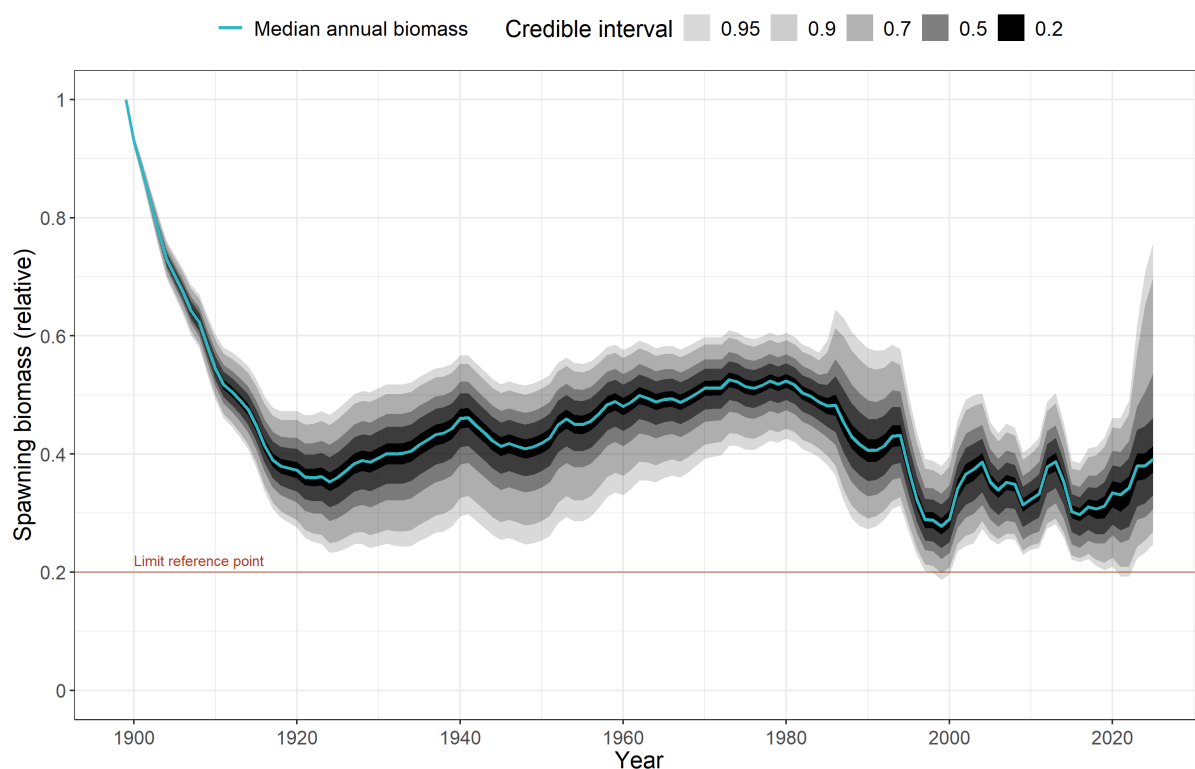


Figure 2: Spawning biomass trajectory relative to unfished levels for Australian east coast sea mullet from the MCMC ensemble

Catch

Total retained catches per year of sea mullet varied through time, with clear multi-decadal phases (Figure 3). Catch rose from relatively low levels in the early 1900s to a sustained period of higher catches of 4,000–5,000 tonnes per year between 1910 and 1985 before increasing again to a broad peak of 5,000–7,000 tonnes per year in the 1990s to early 2000s.

In the most recent period (roughly the mid-2010s onward), total catch declined, reaching comparatively lower levels by the early 2020s. Over the last 5 years (2020 to 2024), total catch (all sectors combined) averaged 3,531 tonnes per year from Australian east coast waters (Figure 3).

Across the full time series, New South Wales contributed the largest share of total catch. The average 2020–2024 catch share was 70% taken from New South Wales waters and 30% from Queensland waters. Queensland's contribution became more prominent from the 1980s and into the 1990s–2000s, coinciding with the period of highest total catches, but it remained secondary to New South Wales throughout.

Overall variation in annual catch was largely driven by catch levels in New South Wales, which account for the largest increases and decreases through time. In contrast, catches from Queensland have declined since 2022.

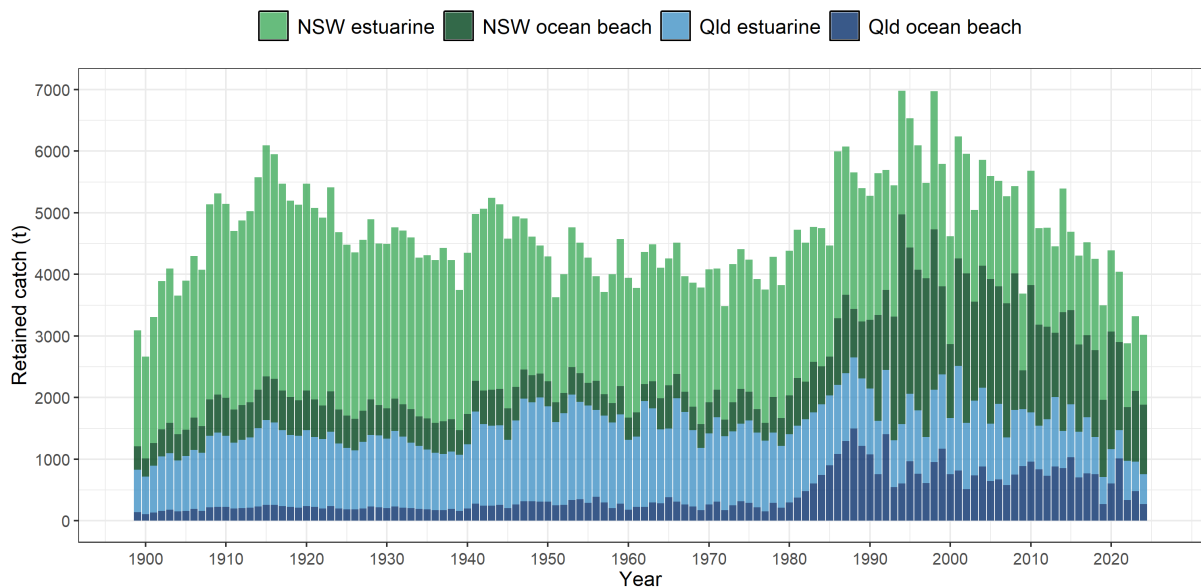


Figure 3: Estimated catch between 1899 and 2024 for Australian east coast sea mullet

Catch rates

Commercial catch rates from New South Wales and Queensland were standardised to derive indices of legal-size sea mullet abundance over time, separately for the estuarine gill net and ocean beach net sectors (Figure 4).

Catch rates were standardised by year, month, latitude, fishing operator, east–west wind strength and fishing effort, where data permitted. Daily commercial logbook reports commenced in 2010 in New South Wales and 1988 in Queensland.

Standardised catch rates showed differing temporal patterns among states and fishing methods. Confidence intervals were wider for ocean beach fishing than for gill netting, reflecting lower data availability and fewer operators.

In New South Wales, estuarine gill net catch rates exhibited moderate year-to-year variability, while ocean beach net catch rates were more variable with high variance.

In Queensland, estuarine gill net catch rates showed long-term variation and a gradual decline, whereas ocean beach net catch rates displayed pronounced variability, particularly in more recent years.

Catch rate trends should be interpreted cautiously, given potential changes in fisher reporting behaviour over time and the likelihood of bias arising from targeted fishing on spatial aggregations of sea mullet.

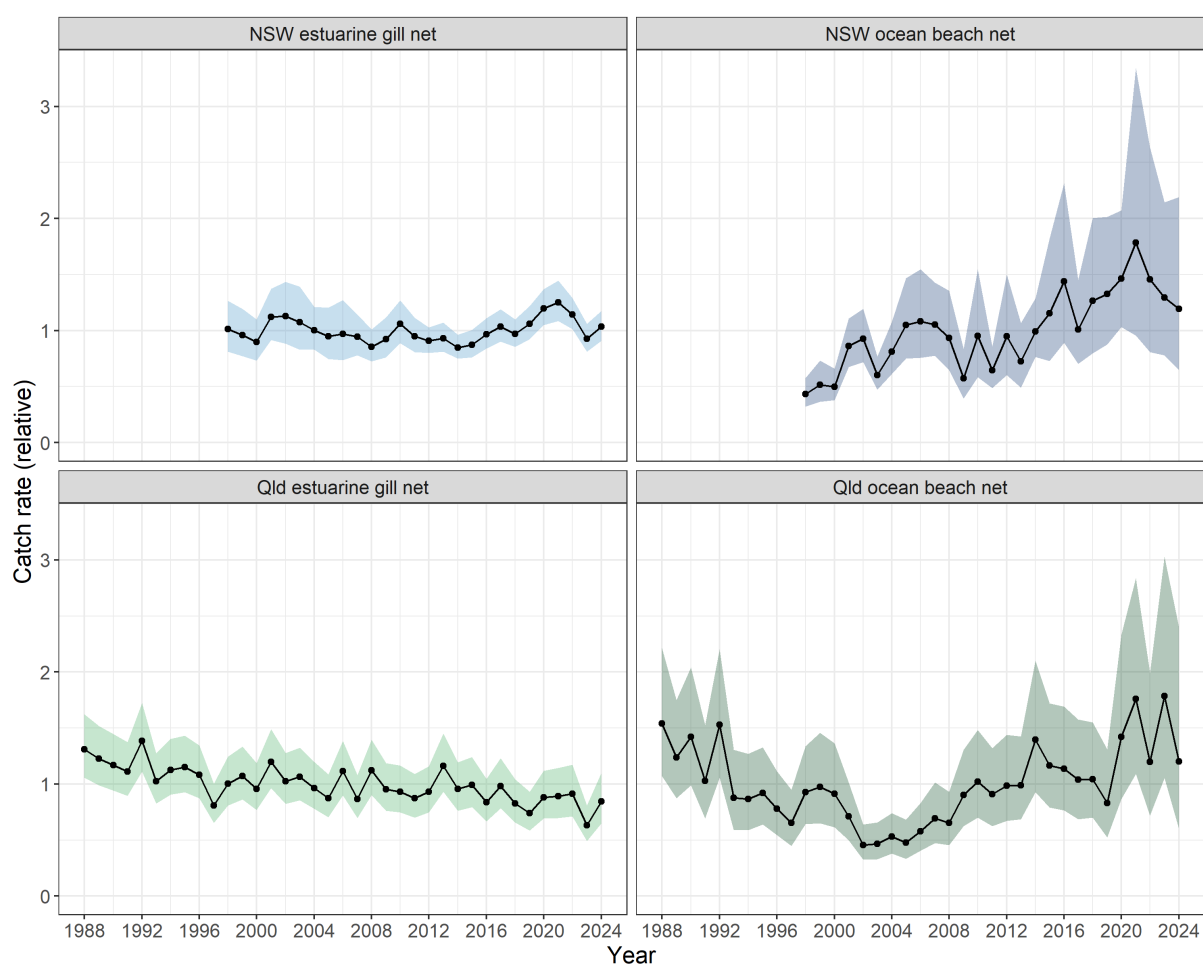


Figure 4: Annual standardised commercial catch rates for Australian east coast sea mullet—shaded regions represent 95% confidence intervals with extra standard deviation input to the population model

Age compositions

Fish sampled from ocean beaches during the spawning run were, on average, older and larger than estuarine fish (Figure 5). Mean age showed periodic fluctuations, consistent with year-to-year variation in recruitment of new young fish entering the population and mortality. Most sampled fish were aged 3–6 years, with relatively few older individuals, suggesting sustained higher fishing mortality of the stock over time.

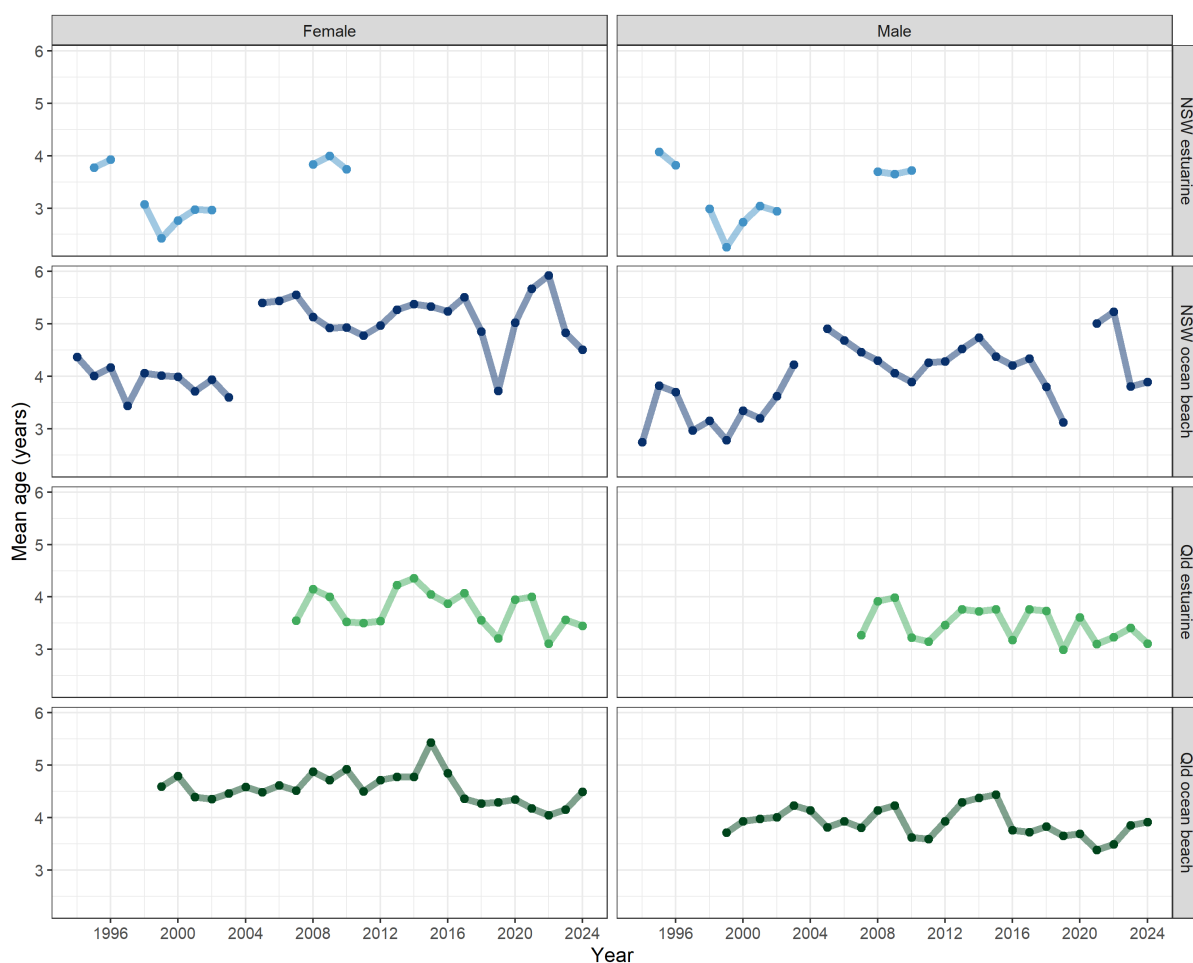


Figure 5: Mean age over time by sex and fishing sector for Australian east coast sea mullet

Key influences

Spawning biomass estimates were influenced by historical fishing pressure and catch, recruitment, and variation in catch rate indices. Elevated catches from the 1980s to early 2000s contributed to the long-term decline in spawning biomass. Since around 2010, recruitment has shown no clear improvement. This has likely limited recent catch tonnages. Higher ocean beach catch rates also influenced model results. However, these signals might be inflated due to fish schooling behaviour, potential targeting bias, changes in operators and lack of fishing effort data accounting for search time. Differences among datasets and model assumptions contributed to the range of spawning biomass results.

Conclusion

The assessment indicated the sea mullet spawning stock at the start of 2025 remained above the limit reference point of 20% spawning biomass. However, it is likely below the range of 40–60%. A joint New South Wales and Queensland target reference point for this shared stock is yet to be defined through harvest strategies.

Spawning biomass has declined over recent decades. There was a moderate increase towards 2025, linked to reduced catch. However, there has been no clear improvement in recruitment since 2010.

Recruitment, spawning migration and regional catches remain variable. Catch and catch rates have also declined in some northern areas, including waters north of Noosa.

The assessment indicates that reduced fishing pressure since 2020 is associated with an increase in modelled sea mullet abundance. This result is conditioned on accurate signals of improved catch rates and age structure. Future management of annual catch and effort levels is best considered alongside harvest strategy policies, their target reference points, fishery working group advice, and regional social factors influencing fishing behaviour.

Stakeholder feedback generally indicated that the assessment results were broadly consistent with recent fishing experience and supported the use of multiple data sources. Participants highlighted environmental change, regional variation and changes in fishing participation and practices as important factors influencing fishery indicators, and supported ongoing data improvements and stakeholder engagement to strengthen future assessments.

Acknowledgements

The authors proudly acknowledge Aboriginal peoples and Torres Strait Islanders and the Traditional Owners of the land on which we live and work. We recognise their ongoing connection to Country, and their role in caring for and maintaining the land and sea for thousands of years.

The work was guided by an advisory group that consisted of the authors and scientists and managers from the New South Wales Department of Primary Industries and Regional Development and the Queensland Department of Primary Industries. The role of the group was collaborative to share interpretation and decision making on information and results. Advisory group members in alphabetical order, were:

- Jennifer Larkin—Fisheries Resource Officer (Data) (Fisheries Queensland, DPI)
- Geoffrey Liggins—Stock Assessment (New South Wales, DPIRD)
- Robyn Lovett—Stock Assessment (Fisheries Queensland, DPI)
- Daniel McInnes—Fishery Manager (Fisheries Queensland, DPI)
- Michael O'Neill—Stock Assessment (Fisheries Queensland, DPI)
- Andrew Prosser—Biological monitoring representative (Fisheries Queensland, DPI)
- John Stewart—Biological monitoring/Stock Assessment (New South Wales, DPIRD)
- Michelle Winning—Chair/Fisheries Assessment Manager (Fisheries Queensland, DPI)
- Joanne Wortmann—Stock Assessment (Fisheries Queensland, DPI)

The group is thanked for contributing their time, knowledge and engaging constructively over the course of the project ensuring a transparent and evidence-based approach.

Special thanks go to John Stewart, Andrew Prosser, Jennifer Larkin and Carlie Heaven who provided the catch and biological data.

We also wish to acknowledge and thank the many fishers, seafood processors and scientists who have contributed to past and ongoing research on the Australian east coast sea mullet stock.

An online stakeholder consultation was held to obtain feedback on the assessment outcomes, data inputs, assumptions and broader fishery issues. Industry representatives in attendance included Greg Savage (MBSIA President), fish processors Matt Vujica, Robin Passmore and Matt Poile, and commercial fishers Mark Alexander and Ben Gilliland. Our special thanks go to these stakeholders whose valuable insight has meant that this assessment could be considered not only in a scientific context, but also in the context of their extensive on-water experience. Staff attendees at this meeting included Alex Campbell, Ari Gillham, Shirin Hyatt, Jeff Ikin, Robyn Lovett, Michael O'Neill, Andrew Prosser, Michelle Wenner, Joanne Wortmann and Georgia Young from Fisheries Queensland DPI and John Stewart from New South Wales DPIRD.

We extend our sincere thanks to Shirin Hyatt, Michelle Wenner, Ari Gillham and Renae Kerry for the considerable time, effort and commitment they contributed to planning and delivering this stakeholder consultation meeting. Their drive to develop this meeting, together with their thoughtful design, creativity and attention to detail, was central to its success. We also gratefully acknowledge their efforts in arranging participants, communicating with fishers, carefully recording stakeholder feedback and clearly

reporting the meeting outcomes to executives. Their dedication and collaborative approach were greatly appreciated.

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This report is an update of Lovett et al. (2022) and hence much of the text is reproduced here.

Glossary

ACN	Authority chain number. Anonymous logbook identifier for Qld operators.
Authorised FisherID	Like ACN, for anonymously identifying operators in NSW logbooks.
age	Age refers to the age group (cohort) in years.
B	Spawning biomass ratio. This assessment refers to spawning biomass (measured by egg production), relative to an unfished spawning biomass.
B_{limit}, B_{20}	Spawning biomass limit reference point, the point below which the risk to the spawning population is regarded as unacceptable under the NSW and Qld harvest strategy policies.
B_0	Mean equilibrium virgin unfished spawning biomass, average spawning biomass level if fishing had not occurred. Virgin state corresponds to the first year assessed.
BOM	Bureau of Meteorology, Australian Government.
Catch	For this assessment, 'catch' refers to retained catch (also called harvest).
Catch rate	Index of fish abundance, referred to as the average catch rate standardised (adjusted) to a constant vessel, fishing power, seasonal and spatial pattern through time. All references to catch rates were standardised.
Catchability, q	The ability to catch fish. More formally, it is defined as the proportion of fish caught with a single unit of standardised fishing effort. Catchability is the interaction of the fishing gear and a fish's behaviour, whereas fishing power is a property of the fishing effort, gear and practices.
CFISH	Commercial fisheries information system, which is the compulsory commercial logbook database managed by Fisheries Queensland.
CI	Confidence interval or credible interval if from Markov chain Monte Carlo.
CPUE	Catch per unit effort. Common abbreviation for catch rate.
CV	Coefficient of variation, a statistical measure of variability that indicates the size of standard deviation relative to the estimate.
DPI	Department of Primary Industries, Queensland Government.
DPIRD	Department of Primary Industries and Regional Development, New South Wales Government.
EC	East coast.
EPBC	Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act). The EPBC Act and regulations are Australia's main national environmental legislation.
Ensemble	A group of analyses or scenarios interpreted together as a whole, rather than individually.
ESS	Effective Sample Size, a statistical term that relates to the sample size needed to achieve a specific level of precision, relevant to population model tuning for age and length composition data.
F	Fishing mortality is the rate or fraction of fish removed from the exploitable population because of fishing.
Fishery	This stock assessment evaluated Australian east coast sea mullet. The assessment was conducted on the whole (genetic) stock. The fishery covers all fishing sectors: commercial, charter, recreational and Traditional Owners.
FL	Fork length, measured from the tip of fish's nose to the fork in its tail (caudal fork)
Fleet	A term used to identify a fishing activity or sector, that can have different types or areas of fishing. Typically, a fleet will have its own vulnerability schedule, which describes the ages or sizes of fish caught.
FM	Fisheries Monitoring program by DPI.
FP	Fishing power. Refers to a deviation in actual fishing effort from a standard unit.

FRDC	Fisheries Research and Development Corporation.
GAM	Generalised additive model.
GLM	General or Generalised linear model.
h	Beverton-Holt steepness parameter. Defines how larvae and juveniles increase their survival rates when the spawning stock size decreases (Hilborn and Walters 1992).
Harvest rate u	Fraction of vulnerable sized fish caught each year. This signifies the annual fishing mortality F , where $u = 1 - \exp(-F)$ and $F = -\log(1-u)$.
ITQ	Individual transferable quota.
Log	Used to denote the natural logarithm base e . Also labelled as "ln" in other contexts.
M	Natural mortality is the annual rate at which fish in the population die due to natural causes, excluding human-related factors like fishing.
MCMC	Markov chain Monte Carlo—a statistical simulation for approximating the final ('posterior') distribution of a quantity.
MEY	Maximum economic yield. The catch and effort level that allows maximum commercial profit for fishers.
MLE	Maximum Likelihood Estimation—a statistical method of estimating the parameters that best explain the data.
MLS	Minimum legal size. Currently 30 cm TL.
MSY	Maximum sustainable yield. The maximum level at which the species can be exploited without long-term depletion. MSY takes fish at the same rate the population can replace itself.
NSW	New South Wales
Overfished	A fish population with a spawning biomass below the spawning biomass limit reference point (B_{limit})
Overfishing	When a fish population is experiencing too much effort, and the removal rate exceeds the target level.
QFB	Queensland Fish Board, marketing authority until 1981.
Qld	Queensland.
R	Free programming language for statistical computing and graphics.
RBC	Recommended biological catch (t). The total allowable annual catch by all fishing sectors, minus discards.
Recruitment	The number of new young fish (the 0+ age group) born into the population in a year.
R_0	Virgin recruitment.
Reference point	Fishery health indicators on the level of fishing, catch or spawning biomass. It is a benchmark for interpreting results and gauging the status of a fishery.
RROCK	R Repository of Collective Knowledge. R package with functions by Fisheries Queensland that collates all useful stock assessment techniques.
RSE	Relative standard error, like a CV.
Sector	A term used to distinguish types of fishing activities or fleets.
SS	Stock Synthesis software for stock assessment modelling.
SSAND	Standardised Stock Assessment Numerical Displays. R package with functions by Fisheries Queensland that collates useful stock assessment techniques, particularly for Stock Synthesis outputs.
Stock	A distinct population that breeds mostly within itself. It also describes characteristics of a species group with definable attributes which are of interest to fishery managers.
Survival rate	Fraction of fish surviving each year after fishing (F) and natural mortality (M).
t	Tonnes.
TACC	Total allowable commercial catch.
TACE	Total allowable commercial effort.
TL	Total length, measured from the tip of fish's nose to the end of its tail lying freely in its normal position.

Unfished spawning biomass (100%)	The expected average spawning biomass of a stock in the absence of fishing, around which natural variation occurs due to processes such as recruitment and natural mortality. Without fishing, unfished spawning biomass moves up and down around 100% due to recruitment variability.
Vulnerability	Probability of catching a fish by size and age. This is a result of fish being present in the fishing area (fishery) and their susceptibility to the fishing gear. Vulnerability defines the exploitable component of fish biomass. Sometimes also described as selectivity.
Year	A fishing year from 1 January to 31 December.

1 Introduction

Sea mullet (*Mugil cephalus*) along Australia's east coast form a single stock that extends from Baffle Creek in central Queensland to Eden near the New South Wales–Victoria border (Krück et al. 2013). This stock supports an important commercial fishery, where the New South Wales (NSW) and Queensland (Qld) governments manage and monitor harvests that occur in their marine waters. The fishery operates in both estuarine and coastal waters and provides affordable food, bait, and income for many coastal communities.

Sea mullet are valued because almost the entire fish can be sold. The flesh, roe, gut and skeletons are sold into domestic and overseas markets for food and bait. Prices typically range from \$1–\$5 per kilogram, depending on the sex and spawning condition of the fish. Females carrying roe are more valuable than males and are often selected out for processing and exported. Between 2022 and 2024, the combined commercial value of sea mullet landings from New South Wales and Queensland was around \$11–\$13 million per year. Previous years of higher catch had landing values in excess of \$12–\$17 million per year (Stewart et al. 2018; BDO EconSearch 2020; Curtotti et al. 2025).

The life cycle of sea mullet is seasonal and closely linked to spawning migrations. Each year during autumn and winter, many mature fish move from estuaries and rivers to coastal waters to spawn. Large spawning aggregations form at river mouths before fish move along the coast during what is commonly called the 'ocean beach spawning run' (Smith and Deguara 2002; Williams 2002).

Tagging studies show that spawning fish tend to move northward during this period (Kesteven 1953; Virgona et al. 1998). Not all mature fish participate every year; some remain in estuarine or coastal waters and may skip spawning in certain years (Virgona et al. 1998; Fowler et al. 2016). This partial migration means that not all of the adult population is exposed to fishing during the spawning run (Fowler et al. 2016). However, this behaviour remains poorly understood, and additional data are needed to support annual inference. The possible loss of connectivity between freshwater/upper estuarine waters due to physical barriers (such as weirs and dams) and rainfall/flow regimen may also prevent the migration of adults in freshwater environments or juveniles from entering higher reaches of freshwater (Loneragan 1999).

After spawning, sea mullet larvae and juveniles settle into sheltered estuaries, rivers and freshwater habitats (Williams 2002). As they grow and mature, they gradually move into coastal waters. Most sea mullet reach maturity by 3–4 years of age, which coincides with the ages most commonly caught during the spawning season (Smith and Deguara 2002).

There are clear differences in how females and males use the spawning migration. Males generally migrate at younger ages and in higher numbers than females, while females tend to join the spawning run at older ages and larger sizes (Stewart et al. 2018). As a result, ocean beach catches often contain more males, whereas estuarine catches usually show a more even mix of sexes (Stewart et al. 2018).

Sea mullet also have strong cultural importance for many Aboriginal communities along the east coast. Historically, the annual mullet run was central to seasonal fishing, food sharing and cultural practices. Indigenous fishing continues as an important component of cultural connection to sea country and is

recognised alongside commercial and recreational fishing in fisheries management (*Compass: Reviving the Mullet Run* 2026).

Recreational fishing pressure on adult sea mullet is relatively low (Prosser 2016). The species is difficult to catch with hook and line because of its feeding habits, which focus on small organisms and detritus (Smith and Deguara 2002; Prosser 2016). In Queensland, some recreational fishers use cast or drag nets to catch various mullet species, while in New South Wales recreational netting is prohibited and a mix of species are only taken by small traps or rod and line (Prosser 2016).

The commercial fishery is divided into 2 main sectors in both states: estuarine netting and ocean beach netting. Estuarine fishing mainly uses gill nets and targets fish within rivers, estuaries and nearshore areas throughout the year. Ocean beach fishing targets spawning aggregations during autumn and winter using large beach haul nets deployed along surf beaches and near estuary mouths. Although fishing methods and regulations differ between Queensland and New South Wales, both sectors contribute substantially to total catches.

Historical changes in fishery management and assessment results are detailed in Appendix C and Table C. Sea mullet on Australia's east coast have been assessed 3 times previously, most recently using data to 2020 (Lovett et al. 2022) which estimated spawning biomass to be around 37% of unfished levels, with 30–45% credible interval.

Given ongoing fishing, requirements for quota management, and declining catches in some regions, an updated assessment was needed. This assessment contains updates to data and methodology that included using Stock Synthesis software to form an ensemble of analyses or scenarios interpreted together as a whole, rather than individually.

The results are intended to support sustainable management of this shared stock and to inform harvest strategies and regulatory decisions in both New South Wales and Queensland. This report also supports environmental assessments related to the sea mullet fishery and co-management of shared stocks: ([EPBC 2024](#)).

2 Methods

2.1 Regions

Data were stratified into latitudinal regions across New South Wales and Queensland waters (Figure 2.1 and Table F.2). Regions comprised one-degree latitude bands in New South Wales and half-degree bands in Queensland, reflecting the spatial resolution of logbook data. Regions were labelled using latitudes in decimal degrees. The latitudes for region 27.75 near the Gold Coast and region 36 near Eden were extended to be inclusive of these areas.

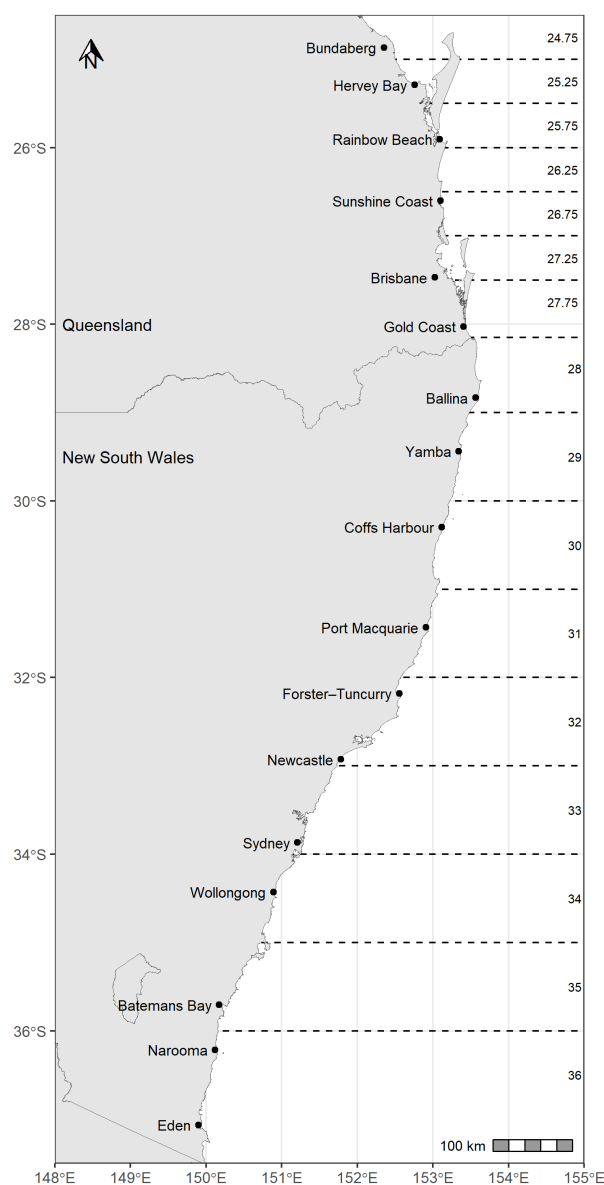


Figure 2.1: Spatial extent of the sea mullet fishery in New South Wales and Queensland—latitude bands show how the fishery was divided into spatial strata for analysis

2.2 Data sources

The data in this assessment were used to determine annual catch rates, total catch and length and age compositions. Data were compiled in calendar years to align with abundance and reproduction peaks (Table 2.1)

Table 2.1: Data sources compiled for the sea mullet stock assessment

Data	Years	Source
New South Wales catch	1899–1941	Kesteven (1942)
	1940–1983	Historic data collected by the DPIRD, Fisheries
	1984–1997	Monthly logbook data collected by the DPIRD, Fisheries
	1997–2024	Monthly logbook data (with more detail on fishing methods) collected by the DPIRD, Fisheries
	2009–2024	Daily logbook data collected by the DPIRD, Fisheries
Queensland catch	1925–1940	Kesteven (1942)
	1941–1950	Thomson (1953)
	1951–1980	Queensland Fish Board (QFB) (Halliday and Robins 2007)
	1988–2024	Daily logbook data collected by the DPI
New South Wales biological data	1990–2000	DPIRD, Fisheries
	2003–2024	
Queensland biological data	1999–2024	DPI: Department of Primary Industries and Fisheries (2007), Fisheries Queensland (2009), and Fisheries Queensland (2014)
Wind data	1988–2024	Bureau of Meteorology (BOM)

New South Wales commercial logbook data were available from July 1984. These data were recorded in 3 separate datasets comprised of monthly regional catch information for the period July 1984–June 1997, monthly regional catch information (including catch method and effort) from July 1997 onwards and detailed daily regional information from July 2009 onwards.

Historical commercial catch data were sourced from New South Wales historical records: July 1940 to June 1942 and July 1944 to June 1984 (provided in annual financial years) in kilograms of fish by class of water, Thomson (1953) and Kesteven (1942) which were reported in units of boxes with an average weight in pounds per box.

Queensland commercial data were sourced from the Fisheries Queensland compulsory logbook records, which began in 1988. These data contained daily entries where fishers recorded retained catch of sea mullet in kilograms and the geographic grid (30 or 6 minute scale) where the majority of the catch was taken.

Historical commercial data for Queensland (1924–1981) were sourced from published catches in Kesteven (1942), Thomson (1953) and annual reports by the Queensland Fish Board (QFB) state-owned marketing agency (Halliday and Robins 2007). The QFB data were annual weights in kilograms with some regional information. Data from Thomson (1953) were annual catches in pounds and data from Kesteven (1942) were reported in units of boxes with an average weight in pounds per box.

Fishery dependent age and length compositions of sea mullet were monitored in New South Wales since 1994 and in Queensland since 1999. Biological information from samples were summarised for commercial catches of sea mullet. These data were provided in age group (years) and fork length (mm).

In Queensland, long-established access to monitor commercial catch is suitable for direct sampling of age and length information. Negligible amounts of catch from the recreational and Indigenous sectors allows length and age information to be scaled to total catch, providing age and length structures representative of the fishery. In New South Wales, fisheries monitoring apply a similar spatially (one degree of latitude) and temporally (monthly) stratified sampling regime to produce data that are representative of fishery landings.

Queensland Fisheries monitoring apply a scaling factor to the raw age and length data. When 100% of a fisher's catch cannot be sampled (i.e., when time constraints or circumstance do not permit each sea mullet in a catch to be individually measured), a representative sub-sample of the catch is measured and the percentage of the total catch that is sampled is recorded (Department of Primary Industries and Fisheries 2007; Fisheries Queensland 2009; Fisheries Queensland 2014). The raw length and age data are then scaled by the percentage of the catch sampled. The scaled length frequencies are then weighted according to the proportion of the total annual catch reported for each sampling region thereby ensuring that the derived age and length distributions are representative of the entire Queensland catch. The resulting total sample size from the scaling and weighting process are upweighted to total catch.

2.3 Catch

Commercial logbooks and historical records were compiled to reconstruct the history of retained catch from 1899 to 2024 (Figure 3). A graphical representation of data used in the reconstruction is shown in Figure 2.2.

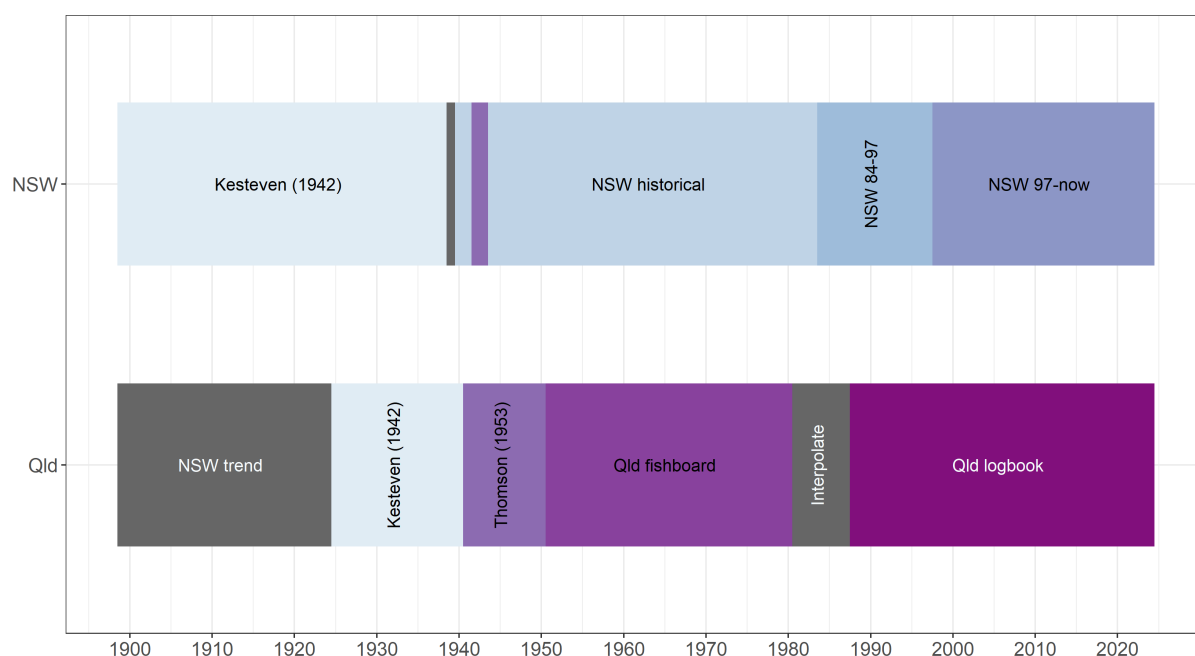


Figure 2.2: Data sources used for retained catch reconstruction of sea mullet for New South Wales and Queensland and from 1899 to 2024

The data components in the reconstructions by state were:

New South Wales

1. Data on Figure 2.2:

1997–2024: *NSW 97–now*. These logbook data began in July 1997 and were split into ocean beach and estuarine fishing methods. Data were collated on a monthly basis and ended at December 2024.

1984–1997: *NSW 84–97*. These logbook data began in July 1984 and concluded in June 1997. Data were collated on a monthly basis and were split into ocean beach and estuarine fishing methods.

1940–1942 & 1944–1984: *NSW historical*. These data were in financial years and were split into ocean beach and estuarine fishing methods. Further research into the validity of the reported fishing methods for these data were performed and the advisory group decided to use this information as reported.

1941–1950: *Thomson (1953)*. These data were reported in financial years in pounds and then converted to metric tonnes.

1899–1939: *Kesteven (1942)*. These data were reported in financial years in units of boxes with a weight in pounds per box. These were converted to metric tonnes.

2. Estimate missing 1942–43 and 1943–44 financial years from *NSW historical: Thomson (1953)* data were similar to *NSW historical* records by financial year. The trend from the Thomson data were used to predict the missing 1942–43 and 1943–44 financial years from *NSW historical*.

3. Interpolate missing 1939–40 financial year.

4. Apply fishing method proportions: The fishing method proportions from 1941–42 and 1944–45 were interpolated to split the 1942–43 and 1943–44 data into estuarine and ocean beach. Then mean annual fishing method proportions from 1940–1950 were applied to all years prior to 1940–41.

5. Consolidate to calendar year: The mean monthly proportions for each fishing method from 1984–1994 were applied to the data. These data were then consolidated to annual catch for each estuarine or ocean beach fishing method.

Queensland

1. Data on Figure 2.2:

1988–2024: *QLD logbook*. These logbook data were split into ocean beach and estuarine fishing methods.

1951–1980: *QLD fishboard*. Financial year data in kilograms converted to metric tonnes.

1941–1950: *Thomson (1953)*. These data were reported in financial years in pounds and then converted to metric tonnes.

1925–1940: *Kesteven (1942)*. Data were reported in financial years in units of boxes with a weight in pounds per box. These were converted to metric tonnes.

2. Hindcast prior to 1925: The New South Wales financial year catch trend was used to hindcast.
3. Apply fishing method proportions: The New South Wales financial year fishing method proportions were applied to all years up to the 1980–81 financial year.
4. Apply monthly proportions: The mean monthly proportions for each fishing method from the 1988–1997 data were applied to the data.
5. Interpolate 1981–1987: This interpolation was performed on a monthly-fishing method scale.
6. Consolidate to calendar year: Data were consolidated to annual catch for each estuarine or ocean beach fishing method.

2.4 Catch rates

Commercial catches of sea mullet were mostly taken by estuarine gill and ocean beach nets. Catch rates from these fleets were used as an abundance index for exploitable-sized sea mullet. Estuarine haul net catch records were considered for analysis but not chosen due to low and infrequent occurrence.

Zero catches were not included, because of the lack of reporting and they could not be identified from associated species catches.

Data were collated into a single catch observation for each operator-day or operator-month. Log-book catch rates were recorded in daily and monthly datasets in New South Wales and daily data for Queensland.

The analyses were performed on log-transformed catches, using general linear models (LM) based on a normal distribution with identity link. The LM models were computed in the software R (R Core Team 2025, version 4.5.1).

In summary across analyses, the LM type and variables were:

- *Log weight*: natural log-transformed catch per fishing operation day or month (log kg).
- *Operator*: anonymous ACN or AuthorisedFisherID codes for different fishing operations (factor).
- *Latitude band*: spatial half or one degree latitude bands fished by the relevant fleet (factor).
- *Year*: calendar years (factor).
- *Month*: month of the calendar year (factor).
- *Good wind*: east-west wind component less than the 75th quantile (binary variate 1 = TRUE and 0 = FALSE, only significant in Qld).
- *Log shots*: log number of ocean beach shots per operator-day (offset variate, NSW daily data only).
- *Log days*: log number of normalised days fished per operator-month (offset variate, NSW monthly data only).
- *Model family and link function*: normal and identity link.

For an easier alternative to modelling wind components, a binary variable 'good wind' was calculated from the east-west wind component. In general, offshore winds related to calmer near-shore/surf conditions and better catchability of sea mullet. The binary variable reduced correlation with seasonality (the model month-term).

The variables used in each analysis are shown in Table 2.2.

Table 2.2: Explanatory variables included as model terms in each catch rate analysis for Australian east coast sea mullet

Explanatory variables	NSW daily data		NSW monthly data		Qld daily data	
	Estuarine	Ocean beach	Estuarine	Ocean beach	Estuarine	Ocean beach
Operator	Y	Y	Y	Y	Y	Y
Year x Latitude-band	Y	Y	Y	Y	Y	Y
Month	Y					
Year x Month		Y	Y	Y	Y	Y
Good wind	N.S.	N.S.	-	-	Y	Y
Log number of shots	Offset	-	-	-	-	-
Log normalised days	-	-	Offset	Offset	-	-
Y	yes in model					
-	data not applicable					
blank	term not used					
N.S	non-significant and excluded					

From each LM, standardised mean catch rates and standard errors were calculated using the 'emmeans' package (Lenth and Piaskowski 2026). These predictions were on a reference grid of predictor settings, with factor weightings applied for averaging. For more details read Appendix F.1.

For Stock Synthesis, extra standard deviation (SD) parameters were calculated for catch rates. The SD parameters represented the mean difference between the residual standard error from a Loess (spline) model and LM standard errors. The Loess models were simple splines by year on log standardised catch rates. The method followed Sporcic (2022) and O'Neill et al. (2024), and a recommendation by Punt (2023). The extra standard deviations were log scale $\approx$ CV.

Catch rates from New South Wales data series (daily and monthly logbooks) were combined into a continuous time series ("spliced") by standardising each series and aligning them over common periods. This approach assumed that relative year-to-year trends were comparable, while allowing for differences in scale between datasets. The spliced series was used in Stock Synthesis and produced similar outcomes to analyses using separate daily or monthly indices. Daily catch rate indices were initially preferred, but earlier monthly data were retained to provide a longer time series, consistent with recommendations to maximise information across datasets and to not split catch rate series by time (Hoyle et al. 2024).

Further methods are detailed in the report Appendix F.1 for catch rates.

2.5 Biological relationships

Biological relationships are plotted in Appendix G.1, Figure G.1. This plot includes the length–weight relationship, maturity at age, and individual spawning output (maturity multiplied by fecundity) by age. All length measurements were analysed as fork length (FL cm).

2.5.1 Weight

The following formulas derived from New South Wales and Queensland data were used for converting individual fish fork length FL , in cm to weight W , in kg:

$$W^{\text{female}} = 1.1584 \times 10^{-5} FL^{3.0707} \quad (2.1)$$

$$W^{\text{male}} = 1.799 \times 10^{-5} FL^{2.9380} \quad (2.2)$$

The adjusted R-squared for the relationships was 0.97, as estimated from a log-transformed linear model ($\ln(W) \sim -1 + \text{sex} + \text{sex} : \ln(FL)$). The linear model estimated parameters for the log intercepts and power coefficients by sex. The linear model residual standard error was 0.09571 (F-statistic: 1.377e+05 on 4 and 16939 DF, p-value: < 2.2e-16).

2.5.2 Growth

Von Bertalanffy growth curve parameters were sourced from Stewart et al. (2018). These parameters were based on the relationship:

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

where $L_{\infty} = 43.7$ cm, $\kappa = 0.42$ year⁻¹ and $t_0 = -0.68$ years for females and $L_{\infty} = 36.97$ cm, $\kappa = 0.60$ year⁻¹ and $t_0 = -0.36$ years for males. The L_{∞} parameters were given in fork length (FL).

For Stock Synthesis, the growth curve used the following variances in fish length at age:

- standard deviation (sd) of young female fish of 4 cm, equating to a coefficient of variation (CV) of 0.1
- sd in old female fish of 6 cm and CV of 0.14
- sd in young male fish of 3 cm and CV of 0.08
- sd in old male fish of 6 cm and CV of 0.14.

The standard deviations and CVs were calculated from growth curve residuals, by comparing mean lengths against observed lengths.

2.5.3 Maturity

The proportion mature m at age a (for 0+ to 17+ age groups) was derived from composite female age distributions from the ocean beach fishery (see Appendices A and G.1)

$$m_a = [0, 0, 0.1064, 0.5637, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1]. \quad (2.4)$$

2.5.4 Fecundity

Fecundity parameters were derived from Virgona et al. (1998) data and defined by the following gonad weight (kg)–fork length (cm) relationship:

$$W^{\text{gonad}} = 2.747 \times 10^{-7} FL^{3.5603} \quad (2.5)$$

The adjusted R-squared for the relationship was 0.32, as estimated from a log-transformed linear model ($\ln(W^{\text{gonad}}) \sim \ln(FL)$). The linear model estimated parameters for the log intercept and power coefficient. The linear model residual standard error was 0.4992 (F-statistic: 562.7 on 1 and 1183 DF, p-value: < 2.2e-16). The gonad weight data were mature spawning female sea mullet with maturation stages ≥ 4 (Virgona et al. 1998).

2.5.5 Natural mortality

Natural mortality (M per year) described the instantaneous rate at which sea mullet die from natural causes, such as predation, disease, or old age, rather than from fishing. In this assessment, the same natural mortality rate was used for both female and male fish, and it was assumed to stay constant through time and across all ages.

Natural mortality was informed by how long sea mullet are known to live. In fish populations, lifespan is closely linked to natural mortality: species that live longer tend to have lower natural mortality rates (Hamel and Cope 2022; Punt et al. 2026).

Australian east coast sea mullet have been recorded to live up to 17 years. Across more than 50,000 aged fish collected from monitoring and research programs, older fish were observed between 14–17 years. Based on these data, and on the upper tails of the observed age distribution, a maximum mid-year age of 16.5 years was chosen as a reasonable estimate for the stock (Punt et al. 2026).

This maximum age (A_{max}) was then used in an internationally recognised Hamel method $M = 5.4/A_{max}$ that estimates natural mortality from lifespan (Hamel and Cope 2022). Using this approach, natural mortality was estimated at $M = 0.33$ per year, meaning that roughly 28% of fish ($1 - e^{-0.33} = 0.28$) would be expected to die naturally each year in the absence of fishing.

Stock assessments often estimate A_{max} by looking at the number of old fish found in otolith samples. A_{max} is the maximum age a fish typically lives to in an unfished or lightly fished population (Hamel and Cope 2022; Hoyle and Dunn 2024).

The Hamel and Cope (2022) empirical method for M was calculated using the online resource [The Natural Mortality Tool: Empirical Estimators of Natural Mortality \(M\)](#).

To reflect uncertainty, the assessment did not rely on a single value. Instead, a range of plausible natural mortality values was considered in the model, with lower and higher values around the central estimate included in the ensemble of scenarios. This allowed the results to account for variation in natural mortality, rather than assuming it was known precisely.

Alternate values of 0.28 and 0.37 per year were used in the ensemble, based on 25th and 75th percentiles of a log normal distribution with a natural mortality mean (μ) of 0.33 and CV of 0.2, where

$$sdlog = \sqrt{\ln(1 + CV^2)} \quad (2.6)$$

$$meanlog = \ln(\mu) - 0.5 * sdlog^2 \quad (2.7)$$

The CV of 0.2 was based on Cope and Hamel (2022), and used for within-species variation to map a range of mean natural mortality for a longevity of 16.5 years $\pm$ 2 years. The percentile values of 0.28 and 0.37 were comparable to changing the input values of A_{max} for approximately 14 and 19 years. Using broader percentiles or CV produced more extreme M values that were too dissimilar to the range of older ages sampled.

Previous stock assessments of sea mullet have used similar values for natural mortality, and estimates for the species in Australia have generally fallen within this range. Higher values of natural mortality were not considered because they would imply a shorter lifespan of less than 14 years, which is not supported by the age data.

In the previous stock assessment, Lovett et al. (2022) estimated M per year in Stock Synthesis at 0.31 for females and 0.28 for males, with a standard error of 0.024.

Historically, natural mortality rates estimated for sea mullet in Australia have ranged 0.22–0.57 per year (Bell et al. 2005; Lovett et al. 2019; Lovett et al. 2022; Kienzle 2015).

2.5.6 Steepness

Steepness (h) describes how well the sea mullet population can replace itself when the number of spawning fish is reduced. In simple terms, it reflects how survival of eggs and young fish improves when there are fewer adult fish competing for resources (Hilborn and Walters 1992; Goodyear 1977; Myers et al. 1999). Steepness therefore provides a measure of the stock's resilience to fishing.

In the population model, steepness controls the relationship between the size of the spawning stock and the number of new young fish produced each year. A higher steepness means the population can maintain relatively high recruitment even when spawning biomass is low, while a lower steepness means recruitment drops more as the stock declines.

The assessment used a higher steepness value of $h = 0.75$, which aligned to the FRDC project 2002/094 recommendation by Punt et al. (2005). The last assessment considered a steepness of $h = 0.66$ and the effect of this change is displayed in the bridging analysis performed (see Appendix I).

The $h = 0.75$ setting was informed by several lines of evidence, including values used for sea mullet and closely related fisheries in Australia and overseas, the results of model testing, and known features of sea mullet biology. In particular, it is hypothesised that not all mature sea mullet join the spawning migration each year, meaning that some adults are not exposed to fishing (Fowler et al. 2016; Stewart et al. 2018). This behaviour provides a degree of buffering that supports fish recruitment when the spawning stock is fished.

For striped mullet (*Mugil cephalus*) in North Carolina Waters, in the USA, the Stock Synthesis steepness prior was set at 0.77 (NCDMF North Carolina Division of Marine Fisheries 2022). Meta-analyses show that the steepness values used in stock assessments can vary between species and stocks, possibly according to the productivity of habitats (Punt et al. 2005; Myers et al. 1999; Thorson 2020).

The stock–recruitment relationship was modelled using a Beverton–Holt function, which is commonly used in fisheries stock assessments (Haddon 2001). This function describes how recruitment varies with spawning biomass and allows for density-dependent survival, where survival of eggs and young fish is lower when the population is large and higher when the population is small (Hilborn and Walters 1992). Recruitment variability was included in the model for recent decades to capture year-to-year changes in the number of young fish entering the population.

2.6 Population model

The assessment period spanned from 1899 through to 2024, based on available information.

An annual sex and age-structured population model was fitted to the data to determine the number of sea mullet in each year, age group and sex using the software package Stock Synthesis (SS; version 3.30.24.2). A full technical description of Stock Synthesis is given in Methot et al. (2019).

The software was used to analyse trends in catch, catch rate, fish age, length and biological data, to estimate a time series of spawning biomass. Uncertainty was quantified through parameter differentiation and MCMC simulations.

2.6.1 Assumptions

Assumptions for formulating inputs to the model included:

- Sea mullet comprised a single stock along Australia's east coast between Baffle Creek (24.5° S) in Qld and Eden (37.5° S) in NSW.
- The fishery began from a near unfished state in 1899.
- Fish moved and mixed over time.
- The fraction of fish that are female at birth was 50%.
- Growth occurs according to the von Bertalanffy growth curve.
- The weight and fecundity of sea mullet were parametric functions of their size.
- The instantaneous natural mortality rate was constant and did not depend on age or sex.
- Catch rates were proportional to abundance.
- Annual recruitment was a Beverton-Holt function of stock size. It was assumed deterministic before 1982 and stochastic between 1982 and 2024.

2.6.2 Parameters

Parameters were estimated within the model where possible, to enable the best possible fit to available data. Uninformative priors were used.

The natural logarithm of unfished recruitment ($\ln(R_0)$) was estimated within the model. This parameter was the natural logarithm of the number of recruits in 1899.

Random walk age-based vulnerability parameters were estimated with separate vulnerability curves for ocean beach and estuarine fleets. The random walk vulnerability function used a newer format available in Stock Synthesis (SS; version 3.30.24.2) which differs slightly from the function used in Lovett et al. (2022). Additionally, some scenarios in the ensemble model used a length-based dome shaped vulnerability function for estuarine fleets and length-based logistic vulnerability for ocean beach fleets.

Recruitment deviations improved fits to composition data and abundance indices as variability in recruitment annually allowed for changes in the population on shorter time-scales than fishing mortality alone. Due to Stock Synthesis bias adjustment for recruitment deviations and the availability of increased diagnostic outputs, it was considered appropriate to start recruitment deviations from the year 1982 as set out in the previous assessment (Lovett et al. 2022; Methot and Taylor 2011).

2.6.3 Ensemble

This assessment used an ensemble approach, combining a set of 24 model scenarios. Using an ensemble helps account for uncertainty in the data and in key scientific assumptions, and avoids placing too much weight on any one set of assumptions. The ensemble approach provides advice that can better reflect lower and upper bounds of the stock assessment results (Millar et al. 2015).

Each scenario in the ensemble was fitted independently to its data. The scenarios differed in how key aspects of the stock and fishery were represented, such as natural mortality, catch-rate trends, and the proportion of fish available to the fishery. Together, these scenarios captured the main uncertain-

ties and alternative hypotheses considered important by the advisory group. Care was taken to avoid over-representing any single assumption or viewpoint.

The key requirement for inclusion in the ensemble was that each scenario represented a likely view of how the sea mullet stock and fishery may be operating. The ensemble therefore provided a balanced and transparent basis for assessing stock status.

The ensemble explored 3 main factors between models:

- **Catch rate** trends, using 4 indices from New South Wales and Queensland estuarine and ocean beach catch rates.
- **Vulnerability**, representing fish availability to the fishery. Scenarios assumed either that a modest proportion of mature fish were not exposed (combined age and length vulnerability) or that most mature fish were vulnerable to fishing (age only vulnerability).
- **Natural mortality**, using 3 values of 0.33, 0.37 and 0.28 per year (representing an estimated most likely value with its upper and lower quartiles as described in Section 2.5.5).

In total, these factors produced 24 model scenarios as shown in Table 2.3.

Table 2.3: Ensemble scenarios for Australian east coast sea mullet

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Catch rates																								
Qld estuarine gill net																								
Qld ocean beach net																								
NSW estuarine gill net																								
NSW ocean beach net																								
Vulnerability																								
Age and length																								
Age only																								
Natural mortality																								
M = 0.33																								
M = 0.37																								
M = 0.28																								

Models were combined in the ensemble using weighted averaging (Millar et al. 2015), so scenarios supported by more reliable information gave a higher contribution to the final results. The ensemble weightings were applied as follows:

- **Catch rates** weightings were derived from a combination of:
 - Area weighting (70% New South Wales and 30% Queensland) which was consistent with recent catch shares and spatial coverage of the coastal line for sea mullet (calculated using latitude bands in Table F.2).
 - [Inverse-variance weighting](#) was applied to catch rates within each state providing a statistical way to deal with unequal levels of variability (Fay et al. 2011; Cope and Hamel 2022; Higgins et al. 2024). This also reduced the influence of ocean-beach catch rates which may be more affected by hyperstability as sea mullet form dense schools during the spawning run (Lovett et al. 2022; Leigh et al. 2017). This approach assumed that variances were reliable and reflected the relative accuracy of catch-rate signals, resulting in appropriate credible intervals for the combined ensemble result.
- **Vulnerability** assumptions about fish availability to the fishery were given equal weight.

- **Natural mortality** values were weighted by their represented quartiles of the described log normal distribution (half weight for the lower and upper M values of 0.28 and 0.37 and full weight for the more likely estimate of 0.33 per year). This assumed the Hamel and Cope (2022) maximum age methodology (see natural mortality methods in section 2.5.5).

Table 2.4: Weightings for the catch rates component of the ensemble by their variance and area for Australian east coast sea mullet

Catch rate fleet	Area weight	Variance weight	Area-variance weight
NSW estuarine gill net	0.70	0.83	0.58
NSW ocean beach net	0.70	0.17	0.12
Qld estuarine gill net	0.30	0.76	0.23
Qld ocean beach net	0.30	0.24	0.07

Further details on ensemble construction and weightings can be found in Section 2.6.3 and Table H.1. The final composition of the ensemble reflected 2 variance components:

1. within each model due to variability in the data (from MCMC simulations)
2. between models due to different scientific assumptions.

2.6.4 Sensitivity

Further models incorporating additional aspects were run, however many of these scenarios did not affect results, and were therefore excluded from the final ensemble. We report on the influence of these factors nonetheless, and results of these model runs are displayed in Section 3.2.4. These additional scenarios explore the stock assessment model's sensitivities to the following factors:

- historical catch rate and length frequencies
- the effect of multiple catch rates included in a model
 - all catch rates
 - NSW & Qld estuarine (gill net) catch rates
 - NSW & Qld ocean beach catch rates
- the effect of no catch rates
- using NSW daily catch rates instead of spliced catch rates
- using NSW monthly catch rates instead of spliced catch rates.

2.6.5 MCMC

A Markov chain Monte Carlo (MCMC) simulation was performed on all scenarios. A total of 500,000 iterations were run per scenario, with every 100th draw after the first 2,000 saved to investigate the posterior defined by Stock Synthesis. This resulted in a total of 4,980 saved iterations per scenario.

Convergence of the MCMC was monitored using a factor ($\hat{R}$) (Gelman et al. 2004). Effective sample sizes for each estimated parameter was also calculated, indicating the number of independent draws. Success was determined for values $0.99 < \hat{R} < 1.01$ and independent draws > 400 (Vehtari et al. 2020; Monnahan 2024). Effective sample size and $\hat{R}$ outcomes are displayed in Appendix H.1.3. MCMC results were used to report spawning biomass estimates.

The ensemble was constructed by sub-sampling the iterations from each scenario according to scenario weightings, resulting in a total of 34,356 iterations (Section 2.6.3 and Table H.1).

2.6.6 Bridging

A bridging analysis was conducted to track how model results changed from the previous assessment to the current assessment. This approach isolates the effect of each methodological or data update by introducing changes step-by-step.

Each change was added sequentially to the previous assessment model, allowing the influence of individual updates on the maximum likelihood spawning biomass estimates to be identified.

Bridging analysis results can be found in Appendix I.

3 Results

3.1 Model inputs

3.1.1 Data availability

Model inputs illustrated in Figure 3.1 relate to the ensemble model (as defined in Table 2.3).

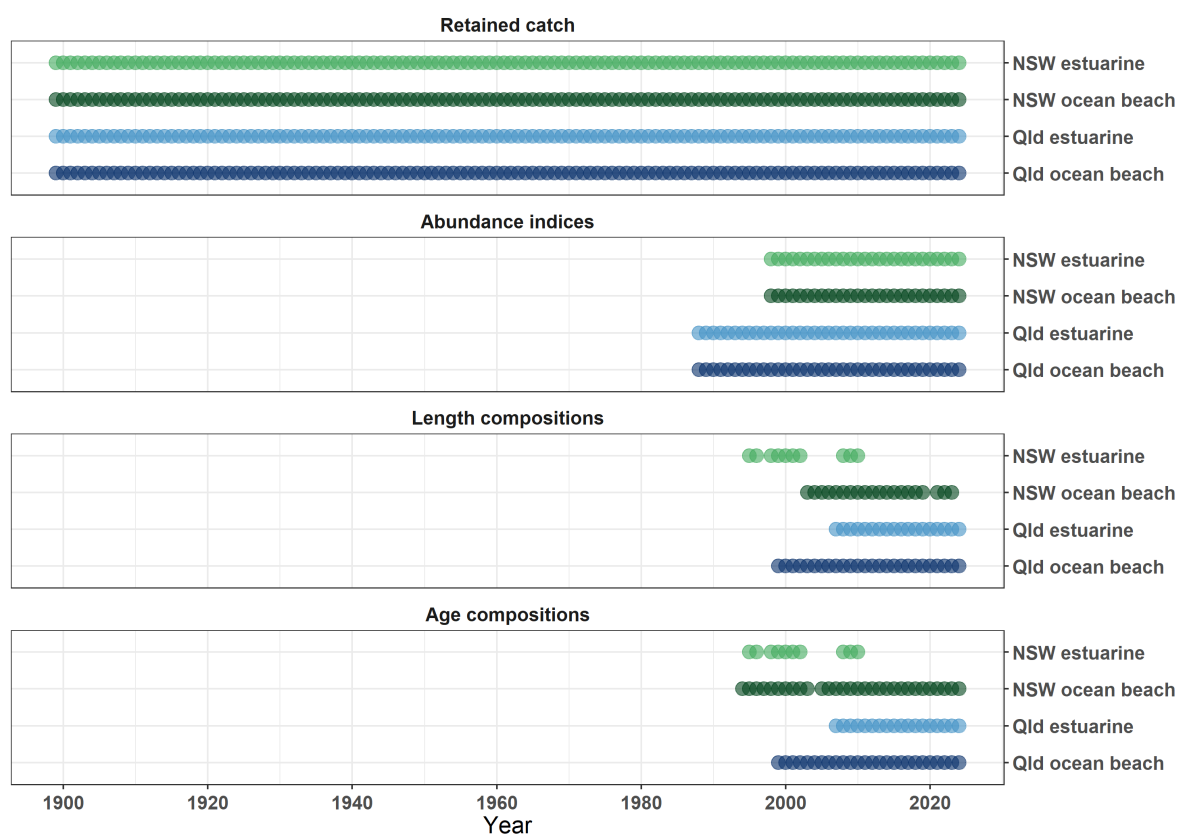


Figure 3.1: Data presence by year for each data type and fleet for the Australian east coast sea mullet ensemble

3.1.2 Catch

Overall catch consisted of catch from 4 fleets: New South Wales estuarine, New South Wales ocean beach, Queensland estuarine and Queensland ocean beach (Figure 3.2). Catches for the period 1910–1985 were around 4,000–5,000 t per year. Following this period, catches increased to a peak of around 7,000 t in 1994 and 1998, and have since declined to 3,021 t in 2024. Plots of regional and monthly catch are displayed in Appendix E.

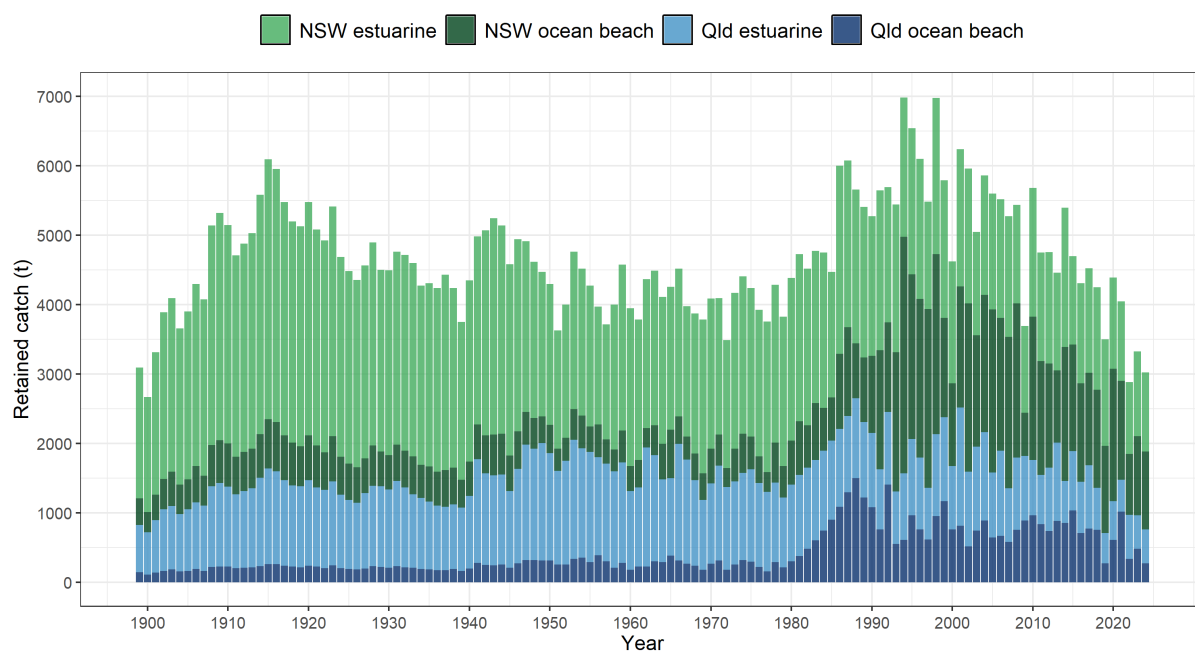


Figure 3.2: Estimated catch between 1899 and 2024 for Australian east coast sea mullet

Over the last 5 years (2020–2024) the retained catch per year averaged 3,531 t per year, including 2,466 t for New South Wales and 1,065 t for Queensland. The recent decline in total east-coast catch coincides with a marked reduction in Queensland catches from 2022 onwards. Catch shares for 2024 are shown in Figure 3.3.

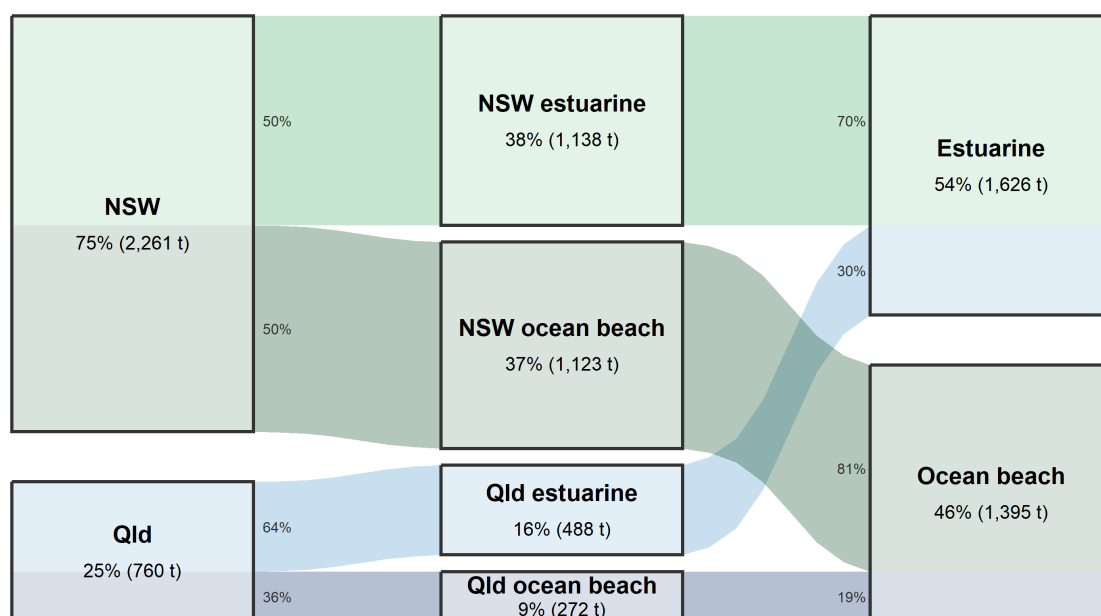


Figure 3.3: Catch shares in 2024 for Australian east coast sea mullet

3.1.3 Catch rates

Standardised catch rates exhibited differing temporal patterns among states and fishing methods (Figure 3.4).

In New South Wales, estuarine gill net catch rates were relatively steady, whereas ocean beach net catch rates were more variable and associated with wider confidence intervals. As described in Section 2.4, NSW catch rates input to the population model were spliced together using catch rates produced from monthly or daily records. Further details on these individual catch rates series can be found in Appendix F.

In Queensland, estuarine gill net catch rates showed gradual long-term variation, while ocean beach net catch rates displayed greater inter-annual variability, including increased variance in more recent years.

Across both States, ocean beach net fisheries showed higher variability than estuarine gill net fisheries. Regional catch rates are presented in Appendix F.2.

Residuals plots and diagnostics across catch rate analyses were satisfactory (Appendix F.3).

Model fits to catch rates are shown in Appendix H.1.1.1.

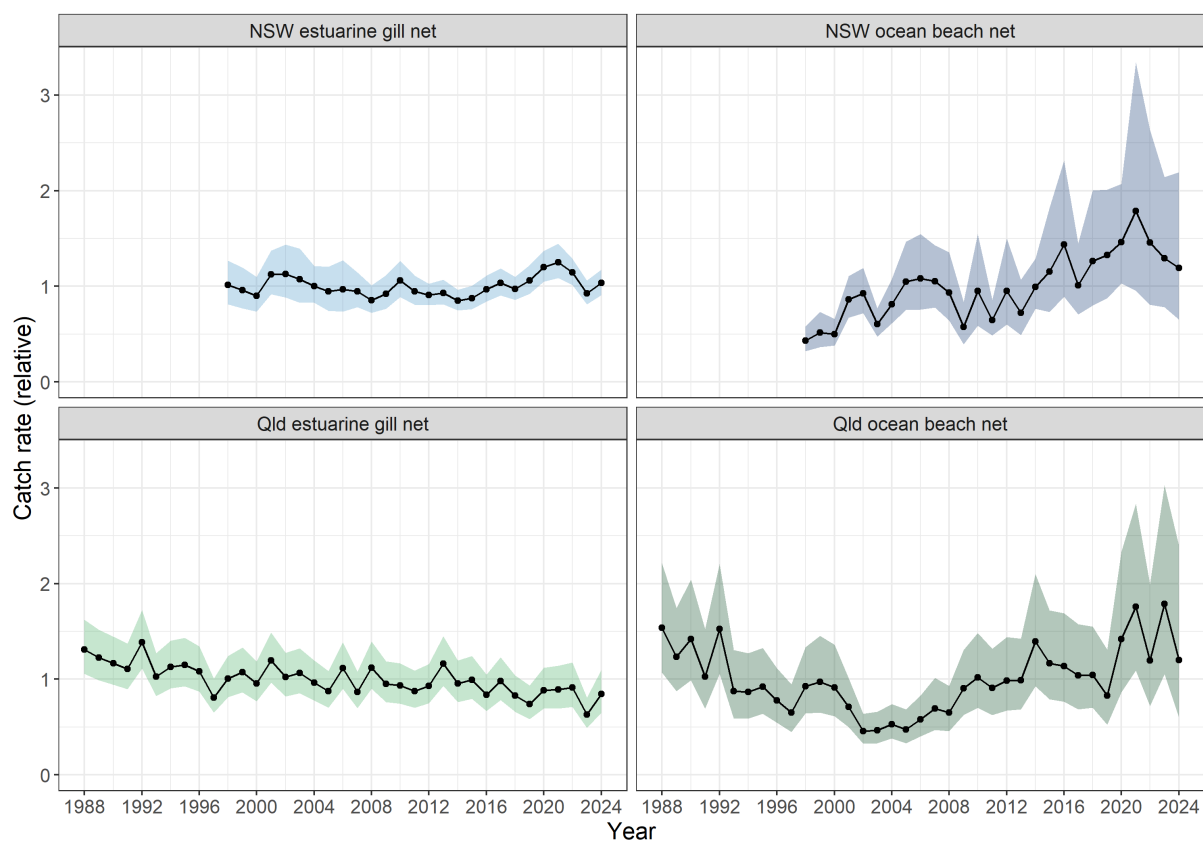


Figure 3.4: Annual standardised commercial catch rates for Australian east coast sea mullet—shaded regions represent 95% confidence intervals with extra standard deviation input to the population model

3.1.4 Age compositions

Figure 3.5 shows age compositions for each fleet and year in descending order. For illustration and detail, the figure x-axis was truncated to 9 years, with relatively few older individuals suggesting sustained higher fishing mortality over time. For NSW, female and male sampling were stratified and actual sex ratios were unknown. Age compositions were input to the model for each sex separately.

Age composition data show that most sampled fish were between 3 and 5 years of age across fleets, with relatively few younger (age 1–2) or older individuals (age 6–9). This pattern was consistent between estuarine and ocean beach fisheries, although ocean beach samples tended to include a broader range of ages.

In New South Wales estuarine fishing, age structure was relatively stable through time, with moderate year-to-year variation and consistent representation of middle age classes. No monitoring was conducted in later years.

In contrast, New South Wales ocean beach showed a broader spread of ages, including slightly higher proportions of older fish in some years, reflecting the aggregation of mature spawning individuals. In 2023 and 2024, ages 5–9 were less represented in the New South Wales ocean beach fishery. This was consistent with relatively weaker 3–4 year old cohorts in 2021 and 2022 and limited progression into older age groups.

In Queensland estuaries, age composition displayed limited variation in the last 5 years, with earlier years showing occasional shifts in the relative strength of cohorts, suggesting variability in recruitment and survival.

Queensland ocean beach exhibited more variable age structure among years, with fluctuations in the presence of older age classes and a stronger influence of more dominant 4 and 5 year old cohorts in 2024 (regionally different to NSW ocean beach).

Across all fleets, temporal changes in age composition primarily reflect variation in cohort strength and mortality, rather than consistent directional shifts.

Model fits to age compositions are shown in Appendix H.1.1.3.

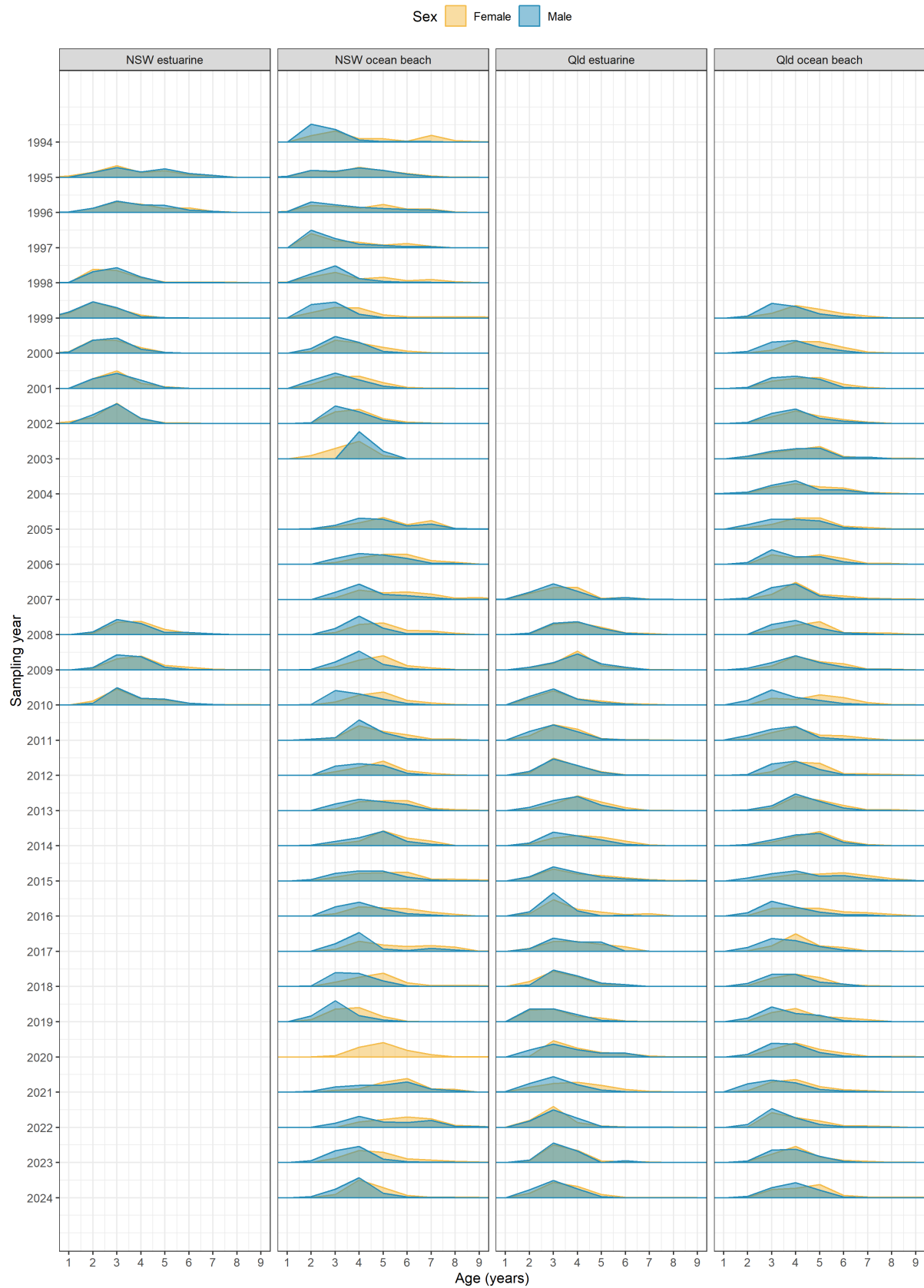


Figure 3.5: Age composition data (relative proportions within each year and fleet) for ages 1–9 of Australian east coast sea mullet—female and male distributions were derived independently within sex and year and therefore do not convey information on sex ratio

Note: females only were aged for NSW ocean beach in 2020

3.1.5 Length compositions

Figure 3.6 shows length compositions input to the population model for each fleet. For NSW, female and male sampling were stratified and actual sex ratios were unknown. Length compositions for each sex (where available), were input to the population model separately.

Length composition data show that most fish captured across all fleets were within a relatively narrow size range of approximately 30–45 cm fork length, with a modal peak typically between 32 and 38 cm. Smaller fish (<30 cm) and larger fish (>45 cm) were less common throughout the time series.

In New South Wales estuarine fisheries, length distributions were relatively stable among years, with consistent modal sizes and moderate year-to-year variation in the spread of lengths. In contrast, New South Wales ocean beach fisheries generally displayed a broader size distribution, with periodic increases in larger female fish.

In Queensland estuaries, length compositions showed greater variability among years, with shifts in modal length and relative frequencies of size classes, suggesting variation in cohort strength and growth. Queensland ocean beach fisheries also exhibited more variable length distributions, with some years characterised by stronger representation of larger fish and others dominated by mid-sized individuals.

Across all fleets, annual variation in length composition appeared to be driven by differences in cohort strength, growth, and availability to the fishery, rather than consistent directional changes in size structure over time. Length composition data are best interpreted alongside age composition data, as similar size ranges can reflect different age structures depending on growth, mortality and recruitment patterns.

Model fits to length compositions are shown in Appendix H.1.1.2.

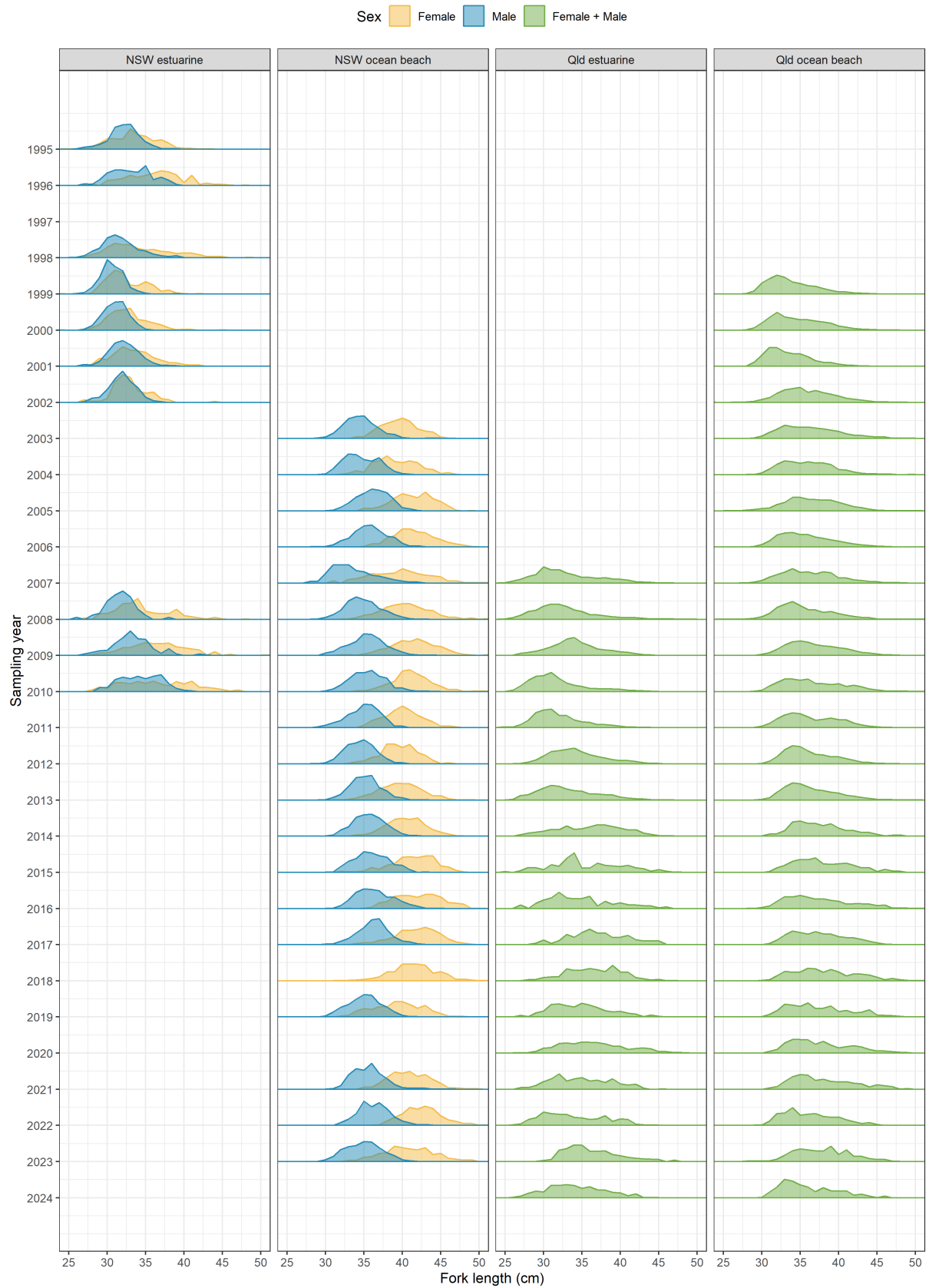


Figure 3.6: Length composition data (relative proportions within each year and fleet) for lengths 25–50 cm of Australian east coast sea mullet—female and male distributions (where shown), were derived independently within sex and year and therefore do not convey information on sex ratio

3.2 Model outputs

3.2.1 Parameters

Parameter estimates across the ensemble are listed in Table 3.1. Comparisons between each scenario in the ensemble are detailed in Appendix H.2.1, Figures H.17 and H.18.

The parameter $\ln(R_0)$ behaved similarly for the 2 different vulnerability assumptions within the ensemble, however for the 3 different values of M , $\ln(R_0)$ estimated at higher values for a higher M and lower values for a lower value of M (Figures H.17 and H.18).

Model setup and estimated parameters differed from Lovett et al. (2022) (see Appendix I) with the exception of the parameter $\ln(R_0)$. Lovett et al. (2022) estimated $\ln(R_0)$ at a value of 10.53 (credible interval 10.25–10.67), which is a similar value and credible interval to this assessment indicating stability between assessments.

Likelihood profiles over the parameter $\ln(R_0)$ are presented in Appendix H.1.2.

Table 3.1: Summary of parameter estimates for Australian east coast sea mullet from the weighted ensemble—MCMC Median is median parameter value, MCMC 2.5% and 97.5% indicates 95% credible interval

Parameter	MCMC median	MCMC 2.5%	MCMC 97.5%
$\ln(R_0)$	10.58	10.28	10.87
Age and length vulnerability			
Estuarine; $\ln(\text{Age}_1^{\text{female}})$	3.03	1.68	5.79
Estuarine; $\ln(\text{Age}_2^{\text{female}})$	1.63	1.38	1.87
Estuarine; $\text{DbIN}^{\text{peak}}$	31.75	30.65	33.00
Estuarine; $\text{DbIN}^{\text{ascend}}$	3.05	2.20	4.29
Ocean beach; $\ln(\text{Age}_1^{\text{female}})$	1.19	0.86	1.55
Ocean beach; $\ln(\text{Age}_2^{\text{female}})$	0.70	0.53	0.87
Ocean beach; L_{50}	32.01	31.45	32.54
Ocean beach; $L_{50}^{\text{female offset}}$	6.24	5.61	6.93
Ocean beach; L_{95}	3.74	3.07	4.59
Age only vulnerability			
Estuarine; $\ln(\text{Age}_1^{\text{female}})$	3.94	2.66	5.76
Estuarine; $\ln(\text{Age}_2^{\text{female}})$	1.51	1.21	1.83
Estuarine; $\ln(\text{Age}_3^{\text{female}})$	0.30	0.09	0.51
Estuarine; $\ln(\text{Age}_1^{\text{male}})$	4.41	2.99	5.87
Estuarine; $\ln(\text{Age}_2^{\text{male}})$	1.49	1.21	1.78
Estuarine; $\ln(\text{Age}_3^{\text{male}})$	0.21	0.03	0.42
Ocean beach; $\ln(\text{Age}_1^{\text{female}})$	2.49	1.95	3.12
Ocean beach; $\ln(\text{Age}_2^{\text{female}})$	1.25	1.01	1.50
Ocean beach; $\ln(\text{Age}_3^{\text{female}})$	0.57	0.33	0.80
Ocean beach; $\ln(\text{Age}_4^{\text{female}})$	0.27	0.05	0.51
Ocean beach; $\ln(\text{Age}_1^{\text{male}})$	1.99	1.66	2.33
Ocean beach; $\ln(\text{Age}_2^{\text{male}})$	0.87	0.66	1.06
Ocean beach; $\ln(\text{Age}_3^{\text{male}})$	0.13	0.01	0.34

3.2.2 Vulnerability

Vulnerability patterns varied among fleets and scenarios, with broadly consistent shapes but differences in the magnitude of vulnerability across ages and lengths. Across scenarios, vulnerability generally increased with age and length, reaching a plateau for older age classes (approximately ages 4–6) and mid-to-larger size classes (around 32–40 cm fork length).

In estuarine fisheries, vulnerability was more concentrated over a narrower range of ages and lengths, with peak vulnerability occurring for mid-aged individuals and moderate-sized fish. This pattern was relatively consistent across scenarios. In contrast, ocean beach fisheries displayed broader vulnerability across both age and length, with greater representation of older and larger fish, consistent with the aggregation of fish during the spawning period.

Differences among scenarios were generally modest, with similar overall vulnerability shapes but some variation in the rate at which vulnerability increased with age and length, and in the extent of decline at older ages or larger sizes. These differences reflect alternative assumptions about fleet behaviour and data weighting rather than strong changes in estimated vulnerability patterns.

Overall, vulnerability patterns indicate that the fishery primarily targets mid-aged and mature individuals, with sector-specific differences in the range of ages and sizes vulnerable to capture.

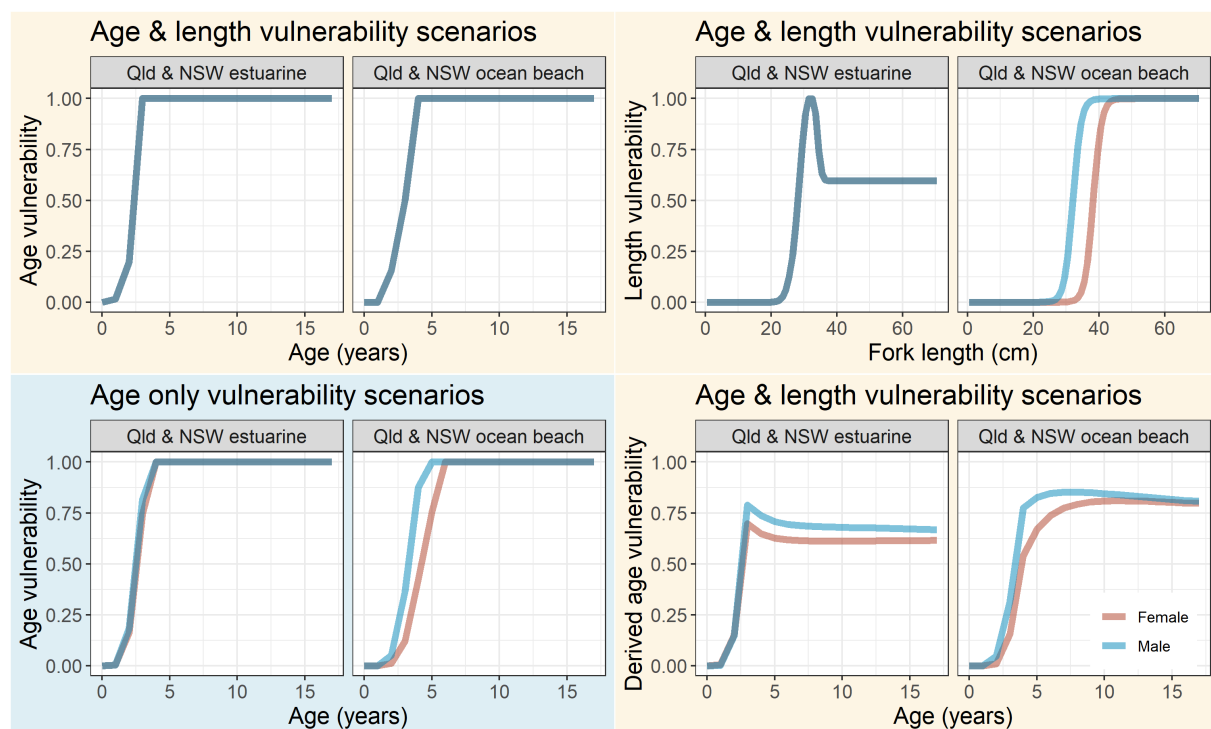


Figure 3.7: Model estimated vulnerability in 2024 for the Australian east coast sea mullet ensemble model

3.2.3 Spawning biomass

The spawning biomass trajectory through time was determined as a proportion relative to an assumed unfished spawning biomass in 1899 (Figure 3.8). The spawning biomass trajectory shows that there was an initial decline in the early 1900s during the start of the fishery to just below 40% in the 1920s. From 1922, spawning biomass gently increased, reaching a peak in the 1970s which coincided with

a low point in catches. From 1980, spawning biomass declined concurrent with an increase in fishing pressure. Recent years (2018–2025) has shown an increase in spawning biomass coinciding with low catches. The addition of recruitment deviations to the model since 1982 has revealed a cyclic fluctuation in spawning biomass ranging 30% to 43%.

The model has predicted that spawning biomass at the start of 2025 is around 39% of virgin spawning biomass (with a credible interval ranging 25% to 76%).

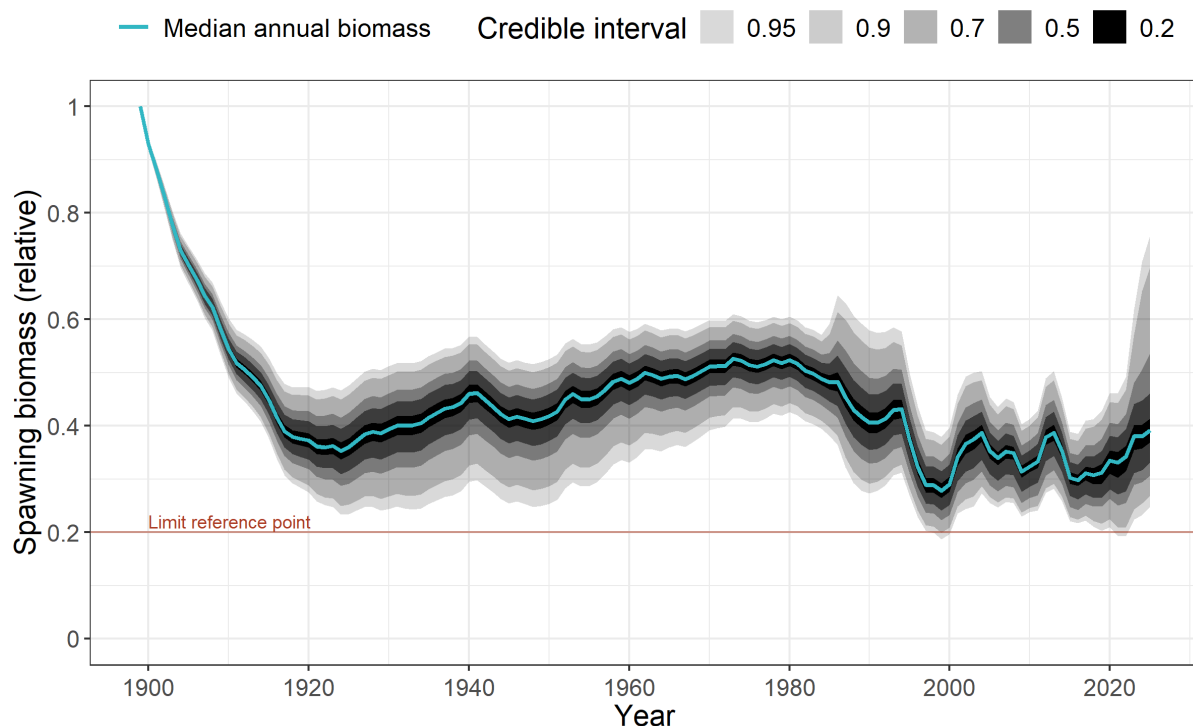


Figure 3.8: Predicted spawning biomass trajectory relative to unfished, from 1899 to 2025 for the Australian east coast sea mullet ensemble model

The ensemble model is compiled from different scenarios that encompass 3 key model differences (catch rates, vulnerability and natural mortality M). Figures 3.9–3.11 display subset groups within the ensemble compared to the ensemble for each of these key differences.

Figure 3.9 shows the comparative difference of each catch rate group to the ensemble. These model groupings large variation in final spawning biomass depending on fishing method in particular. As described in Section 2.6.3, catch rate scenarios were weighted using analysis of variance and also by state (see Table 2.4). As a result, ocean beach fishing scenarios had a much lower contribution to the final spawning biomass in the ensemble although the effects can be seen in the wider credible interval evident in Figure 3.8.

In Figure 3.10, the comparative difference of each vulnerability group to the ensemble is shown. Little difference is shown here between these 2 model groups.

Figure 3.11 displays the effect of the different values of natural mortality (M) considered in the ensemble, indicating a higher spawning biomass for a higher M and a lower spawning biomass for a lower value of M .

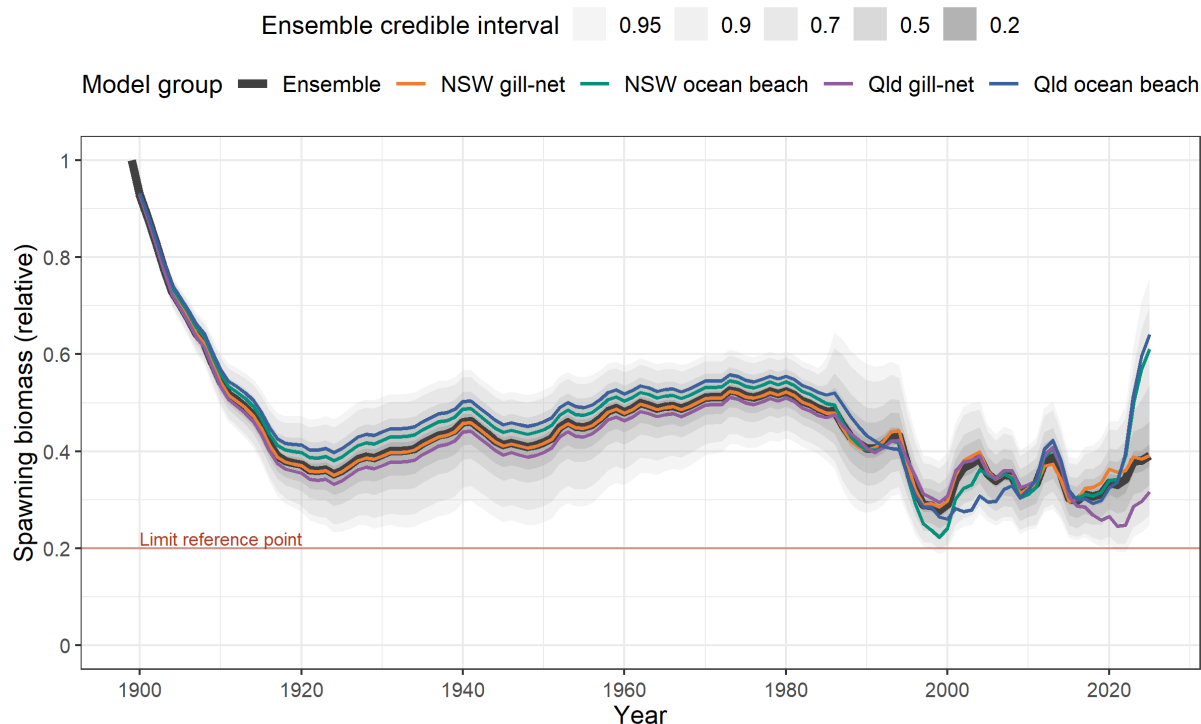


Figure 3.9: Predicted spawning biomass trajectory relative to unfished for Australian east coast sea mullet from 1899 to 2025 for each catch rate subset of the ensemble compared to the ensemble model

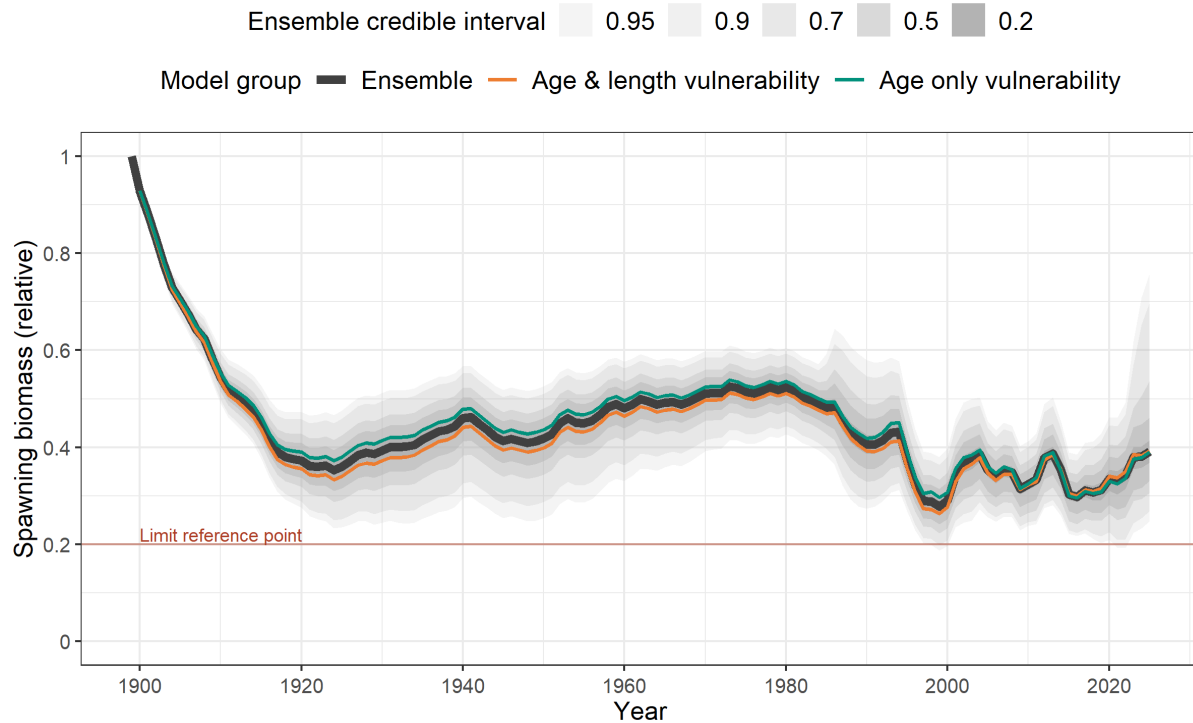


Figure 3.10: Predicted spawning biomass trajectory relative to unfished for Australian east coast sea mullet from 1899 to 2025 for each vulnerability subset of the ensemble compared to the ensemble model

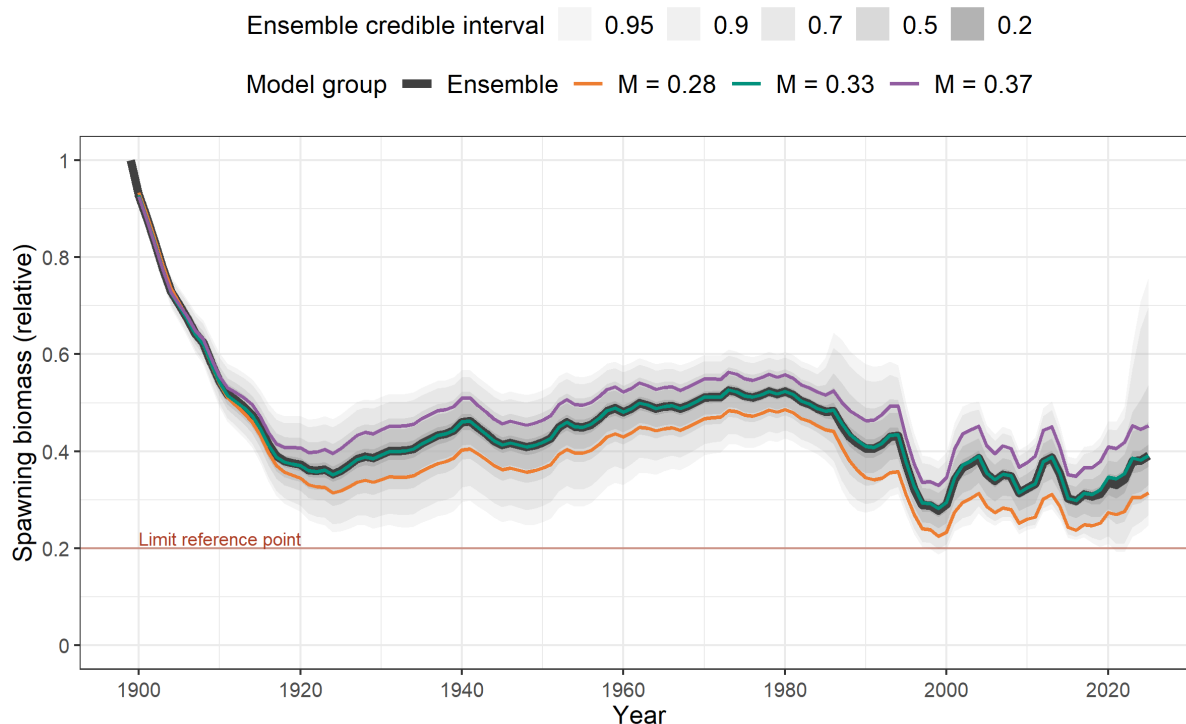


Figure 3.11: Predicted spawning biomass trajectory relative to unfished for Australian east coast sea mullet from 1899 to 2025 for each natural mortality subset of the ensemble compared to the ensemble model

3.2.4 Sensitivity

Figure 3.12 details the additional sensitivity scenarios conducted as described in 3.2.4. These scenarios did not form part of the ensemble.

For the scenario detailing the inclusion of early historical (1940s) catch-rate and length data (trajectory 2), results show that although spawning biomass suffered a higher initial depletion, the inclusion had minimal influence on the estimated spawning biomass ratio for 2025. Additionally, these scenarios suffered poor convergence, with $\hat{R}$ ranging 1.07–1.23 for the $\ln(R_0)$ parameter (see Section 2.6.5). The inclusion of historical catch rates without historical length data (trajectory 3) showed a similar trajectory to the ensemble with good convergence statistics.

The exploration of including multiple catch rates at once instead of giving each a scenario (trajectories 4, 6 and 7) showed similar outcomes to the ensemble groupings detailed in Figure 3.9.

The exclusion of catch rates from the model (trajectory 5) produces an outcome that is fit only to biological monitoring data. This model is similar to the ensemble with the exception of a trough spanning 2015–2025 with its lowest point in 2021. The final spawning biomass of this model however, concludes at a similar place to the ensemble.

The investigation of NSW daily catch rates (trajectory 8) shows little difference to the ensemble.

Trajectory 9 shows the effect of using NSW monthly catch rates. Results show a higher final spawning biomass.

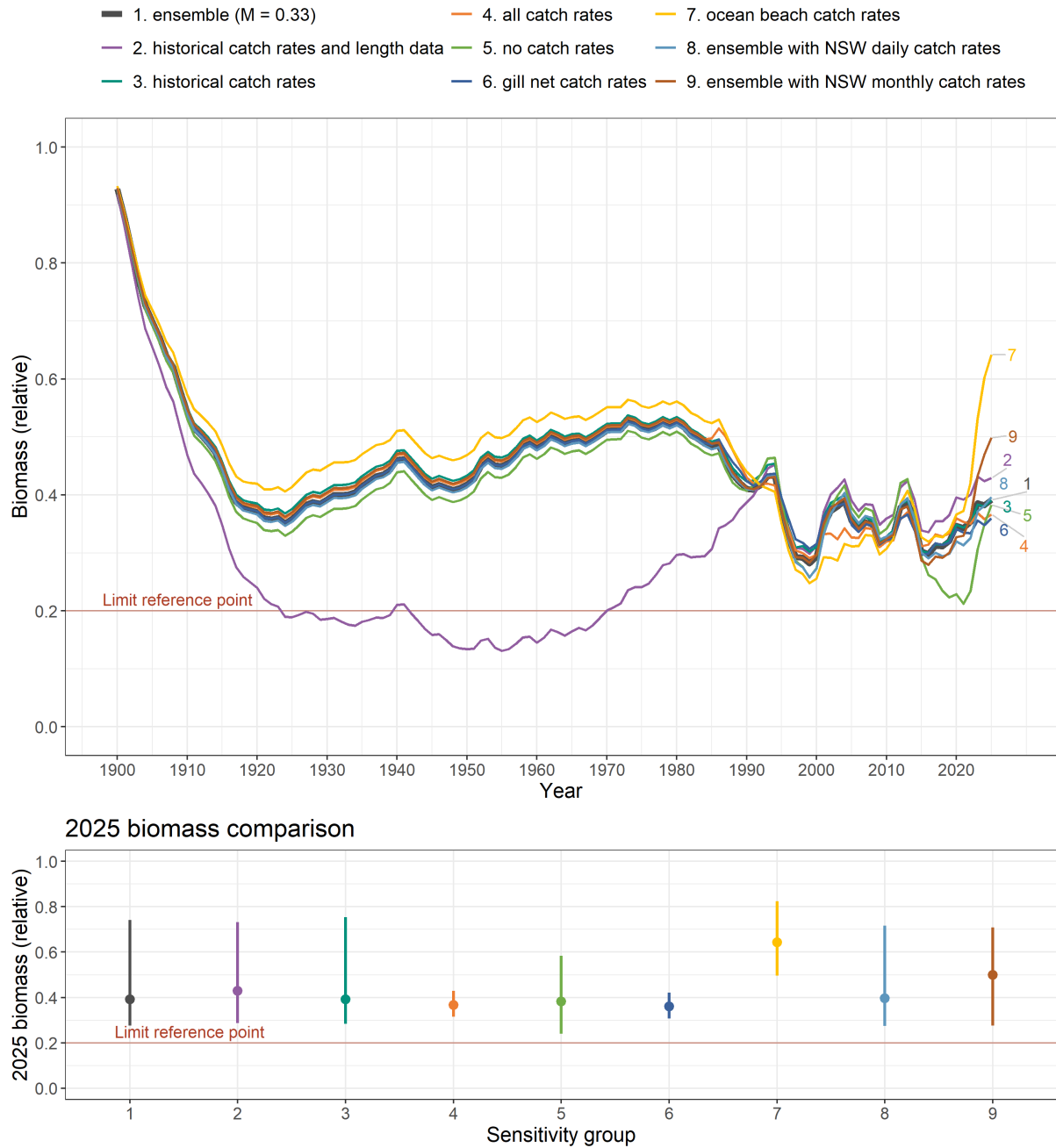


Figure 3.12: Predicted spawning biomass trajectory relative to unfished for Australian east coast sea mullet from 1899 to 2025 for each sensitivity group compared to the $M = 0.33$ subset of the ensemble model

4 Discussion

4.1 Model influences

Catch rates were input as only one catch rate per scenario. Within the ensemble, these scenario groupings showed the greatest variation. It was therefore considered important to find a suitable method of calculating weightings for these scenarios within the ensemble. Weightings were applied based on the variance between catch rates for each fishing method and habitat proportions between states. Due to the variation between catch rate groupings within the ensemble, these weightings were influential on the final spawning biomass result.

Sensitivity scenarios where all catch rates were input to the model simultaneously (comparable with Lovett et al. (2022)) were performed and produced spawning biomass trajectories broadly consistent with the ensemble, providing confidence that the weighting scheme did not materially bias outcomes.

The ensemble considered 2 different vulnerability options representing fish availability to the fishery. Scenarios assumed either that a modest proportion of mature fish were not exposed or that most mature fish were vulnerable to fishing. Results showed little difference between these 2 scenario groupings. The bridging analysis showed only a minor difference in outcomes when compared with the vulnerability setup for the previous assessment. The similarity between vulnerability scenarios suggests that monitoring data contain sufficient information to constrain estimates of vulnerability and fish availability despite unknown participation in spawning migrations.

Natural mortality (M) parameters chosen for this assessment included a range of feasible values. Scenario groupings for M within the ensemble indicated that the model was sensitive to this parameter, giving a higher spawning biomass to high values of M and a lower spawning biomass to low values of M .

4.2 Performance of the population model

Parameter estimation occurred using 2 methodologies across 24 scenarios: maximum likelihood estimation (MLE) and Markov chain Monte Carlo (MCMC) estimation. For MCMC estimation, each scenario was run with 500,000 iterations, using the standard Stock Synthesis algorithm. Final gradient diagnostics for all 24 MLE scenarios were satisfactory, indicating suitable convergence. Since final ensemble results were derived from MCMC outputs, model performance was also evaluated in the context of MCMC diagnostics. The trace plots, posterior density plots and $\hat{R}$ plots in Appendix H.1.3 indicate convergence was reasonable.

Model diagnostics indicated that the ensemble scenarios performed satisfactorily and provided a stable basis for inference. Maximum likelihood estimation converged successfully across all ensemble scenarios, and MCMC diagnostics supported reliable estimation of posterior distributions. Agreement between maximum likelihood and MCMC estimates further supports the robustness of model outputs.

Good fits to catch rates were assisted by the technique of performing separate scenarios for each catch rate index, which was a notable improvement in fits compared with the previous assessment (Lovett et al. 2022). Sensitivity scenarios where all catch rates were input to the model at once (comparable

with Lovett et al. (2022)) were performed and achieved similar results to the ensemble. Fits to age and length data inputs were also good.

The addition of historical catch rates and length data were explored and ultimately left as sensitivity scenarios. For those scenarios with historic length data input; while the MLE models did converge, MCMC convergence statistics showed they were less robust than other models. Additionally, the final results of these models were similar to the ensemble. Where historical catch rates only were input, outcomes from these scenarios were the similar to the ensemble and hence were used to inform sensitivity which reduced the number of models in the ensemble.

Many attempts were made to include age-at-length (age-length key) data in the model. These attempts resulted in poor convergence. The broad overlap between lengths and ages observed in sea mullet likely limits the utility of these data to estimate growth curves within the Stock Synthesis modelling framework.

The bridging analysis demonstrated that differences between this assessment and the previous assessment were driven primarily by revisions to biological assumptions, particularly female maturity schedules. Despite changes, both assessments support a similar overall narrative of long-term stock depletion followed by partial rebuilding in recent years.

4.3 Stakeholder feedback

Stakeholder feedback was generally supportive of the assessment and considered the results to be broadly consistent with recent fishing experience, including observations of older fish remaining in the stock and evidence of ongoing recruitment (Appendix B).

Participants supported the use of multiple data sources and emphasised that declining catches and catch rates should be interpreted cautiously because they may also reflect changes in fishing participation, workforce availability, market conditions, regulations, weather and fishing practices. Environmental change, including altered river connectivity, habitat degradation and declining water quality, was identified as an important source of uncertainty that may influence recruitment and stock productivity.

Stakeholders also highlighted regional differences in fishery performance and identified opportunities to strengthen future assessments through improved effort information, documentation of technological changes and continued industry engagement.

4.4 Recommendations

4.4.1 Stock assessment

Specific recommendations for a future sea mullet assessment include:

- Investigate fishing methods to improve the standardisation of ocean beach catch rates, including surveys of operators' drone adoption and seasonal and annual use. Stakeholders reported high drone use, but its effects on fishing power—through greater efficiency and improved detection and selection of fish schools and fish size—remain unclear. These effects may partly explain the recent increase in ocean beach catch rates.
- Continued evaluation of natural mortality and assumptions as new biological information becomes available.
- Investigation of spatially explicit modelling approaches to examine regional differences in stock dynamics.

- Consideration of environmental covariates influencing recruitment, cohort strengths and fish availability.

4.4.2 Monitoring

Monitoring data in the form of fishery-dependent length and age data were advantageous to this assessment. In particular, data collected in recent years by the New South Wales and Queensland Governments were of high quality. Continued monitoring of sea mullet age and length information that are representative of the fishery is important for the ongoing assessment and management of sea mullet.

Refinements of gill net and ocean beach net logbooks and data collection are needed in order to resolve conflicts of different patterns within regions and provide better effort information (such as search time and zero catches) to enable the improvement of catch rate indices of fish abundance.

4.4.3 Research

Fowler et al. (2016) found old fish up to 9 years of age that had never participated in the spawning run until the year they were captured (Stewart et al. 2018). Further research on otolith microchemistry is needed to quantify the proportion of the mature population that participates in the spawning run each year (Stewart et al. 2018; O'Neill 2006). Even though the vulnerability scenario results were not dissimilar, this is a research priority to confirm assessment assumptions and population scale through the model $\ln(R_0)$ parameter. In addition, such data will help explain assessment results associated with flow-driven movements of fish.

Queensland rivers tend to support longer freshwater residency up to 3 or 4 years, with flow-driven movements. New South Wales sea mullet show the same life-history pattern, but with less prolonged freshwater use. Understanding the intricacies of this life cycle is critical for identifying vulnerable ages to fishing, assessing recruitment patterns and success, and implementing management procedures that safeguard population resilience (spawning biomass).

Unpublished research by Banaghen et al. (2026), requires further examination showing localised stock issues and their possible causes in the northern section of the Qld fishery. The analysis of abiotic factors vs catch rates hypothesised an observed loss of catch around the Great Sandy Straits following 3 major flood events. The report proposed key factors impacting habitat quality/use that can be described by a changing climate and forms a warning for adjacent latitudes about stock resilience.

4.5 Conclusions

This stock assessment was commissioned to establish the status of the eastern Australian sea mullet stock and inform the management of the fishery in New South Wales and south-east Queensland. Spawning biomass was estimated to be between 25% and 76% at the beginning of 2025 relative to an assumed unfished state in 1899. This interval was generated over an ensemble of 24 scenarios. Some recommendations for future assessment and monitoring have been made.

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A Advisory group

The advisory group provided an important role in the stock assessment by bringing together expert knowledge from a range of relevant disciplines. This ensured the assessment was scientifically sound and transparent.

The following sections of this appendix briefly describe decisions and recommendations made by the advisory group for this assessment.

A.1 Catch reconstruction

A.1.1 Historical catch

A revisit of historical catch from Kesteven (1942), Thomson (1953), NSW 'HCatch' records and reviews of historical reports by the advisory group resulted in an update to the catch reconstruction used in Lovett et al. (2022).

Following a review of Kesteven (1942), tables and text within the report indicated that early data was not initially recorded for all regions and proportional adjustment were considered to be appropriate by the advisory group.

NSW 'HCatch' records indicated that the ocean beach fishery was a much smaller component of the catch than had been considered in Lovett et al. (2022). Further exploration of NSW paper records and historical reports supported these records as likely to be accurate. The advisory group therefore recommended the historical catch reconstruction reflect the proportion of historical ocean beach fishing as indicated by NSW 'HCatch' records.

A description of catch reconstruction can be found in Section 2.3

A.2 Catch rates

The estuarine fleets for each state were represented by gill net catch rates as determined in Lovett et al. (2022).

A.2.1 Qld logbook fishing methods

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 gill netting. An analysis was performed to update the algorithm which re-specified fishing methods in early years of logbook reporting. The update made minor changes to catch reconstruction but greatly improved ocean beach logbook data for catch rate analysis (see Appendix D). This change was supported by the advisory group.

A.2.2 NSW logbook time series

Two datasets were available for NSW catch rate analysis: monthly logbooks (1998–2024) and daily logbooks (2010–2024). Catch rates were derived for each of these datasets. Splicing data was initially discouraged in favour of allowing Stock Synthesis (SS) model dynamics to relate the 2 series using time-blocking, but further technical discussion was required against the Hoyle et al (2024) recommendation

for one time series and the preferred float Q catchability option in Stock Synthesis. Log transformation of catch rates was accepted.

A.3 Parameters

A.3.1 Biological parameters

Weight-length parameters were reviewed and the advisory group supported the use of separate male and female parameters.

Investigation of maturity data (Virgona et al. 1998), concluded with the decision by the advisory group to use ocean beach female age proportions (for ages 2–4) as a proxy for maturity at age.

A.3.2 Vulnerability

The modellers explored vulnerability, and age, length, age-at-length data input scenarios for this assessment. After reporting findings back to the group, the advisory group supported age or age and length data options with corresponding vulnerability in the ensemble of models.

A.3.3 Natural mortality and steepness

The advisory group endorsed the choice of fixed natural mortality and steepness parameters. Steepness was set at a value of 0.75. For natural mortality, the Hamel equation (Hamel and Cope 2022) provided a value of 0.33 with upper and lower quartiles of 0.28 and 0.37 based on observed sea mullet ages, and was accepted as a biologically realistic range by the advisory group.

A.4 Model specification

The advisory group recommended a bridging analysis be performed to compare past and new assessment methods (see Appendix I).

A.4.1 Ensemble model

The advisory group agreed on an ensemble of 24 model scenarios for the sea mullet stock assessment, combining alternative catch rate indices, vulnerability assumptions and natural mortality values. Each scenario within the ensemble was weighted as described in Section 2.6.3 with the support of the advisory group.

B Stakeholder presentation

An online sea mullet stock assessment meeting was held on 27 August 2026. The meeting ran from 12:30 pm to 2:41 pm. The purpose of the meeting was to present the results of the 2026 sea mullet stock assessment and obtain stakeholder feedback on the assessment outcomes, data inputs, assumptions and broader fishery issues.

Stakeholders were asked to share their views on fishery trends and performance. Their feedback is documented here.

Stakeholder attendees included Greg Savige (MBSIA President), fish processors Matt Vujica, Robin Passmore and Matt Poile, and commercial fishers Mark Alexander and Ben Gilliland. Staff included Robyn Lovett, Michael O'Neill, Andrew Prosser, Alex Campbell, Ari Gillham, Shirin Hyatt, Jeff Ikin, Michelle Wenner, Joanne Wortmann and Georgia Young from Queensland DPI and John Stewart from New South Wales DPIRD. Apologies were: commercial fishers Malcolm Campbell, Reid Dick, Paul Gregory, Peter Hancock, Tod Rew, Col Taplin and Jason Thomson, Fishing Industry NSW Inc. representative David Hogan, New South Wales DPIRD staff Geoff Liggins and Nicholas Giles, and Queensland DPI staff Daniel McInnes.

Summary

- Stakeholders generally considered the assessment results to be broadly consistent with recent fishing experience, particularly observations of older fish remaining in the stock and evidence of continued recruitment.
- Participants acknowledged that the assessment reported a spawning biomass within a plausible range supported by the use of multiple data sources and models.
- Considerable discussion focused on interpreting declining catch and catch rates in the context of reduced participation, ageing workforces, weather constraints and changing fishing practices.
- Stakeholders identified environmental change as a major source of change in the fishery, including altered river connectivity, water quality degradation, habitat loss and changing coastal conditions.
- Recruitment and stock productivity were considered likely to be influenced by environmental drivers, although the relative importance of individual factors remained uncertain.
- Regional differences were highlighted, with stronger catch declines reported in the northern end of the stock in Queensland than in southern areas and New South Wales.
- Fishers noted that operational factors, including labour shortages, market conditions and regulatory restrictions, can reduce catches independently of stock abundance.
- Participants emphasised the importance of distinguishing changes in fishing opportunity from changes in stock size when interpreting fishery indicators.
- Stakeholders identified opportunities to improve future assessments through additional effort information, better documentation of technological changes and continued stakeholder engagement.

Assessment results and interpretation

Stakeholders discussed the stock assessment findings and their consistency with fishing experience. Participants generally considered the presence of older age classes and increasing fish sizes observed in recent years to be consistent with signs of a stable or rebuilding stock. Several stakeholders viewed

the reported spawning biomass estimates and age structure as broadly reasonable in the context of their observations from the fishery.

Participants acknowledged that assessment results represented model-based estimates derived from multiple data sources and alternate plausible scenarios. Stakeholders recognised that the assessment incorporated commercial catch, standardised catch rates, age data, length composition data and biological information rather than relying solely on landed catch statistics.

Some participants questioned the interpretation of spawning biomass relative to historical unfished levels, particularly given long-term environmental changes. Stakeholders suggested that historical environmental conditions may differ substantially from contemporary conditions, potentially influencing the stock's productive capacity. These issues were raised as broader considerations rather than criticisms of the assessment itself.

Catch rates and effort interpretation

A major theme was the interpretation of catch rates and fishing effort.

It was noted that declining catches do not necessarily indicate declining abundance. Participants highlighted reductions in licence numbers, an ageing workforce, declining crew sizes and reduced recruitment of new fishers into the industry. Fishers reported that smaller crews may be unable to effectively manage large schools of fish, potentially resulting in reduced harvest despite fish being present.

Stakeholders also noted that fishing behaviour has changed over time. Participants reported targeting larger and more valuable fish, modifying mesh sizes and, in some cases, avoiding harvest when market demand is insufficient. These changes were considered capable of influencing catch rates independently of stock abundance.

Weather, flooding and access constraints were identified as additional factors affecting fishing opportunity. Several stakeholders reported that poor weather and beach access limitations had substantially restricted fishing activity in some years despite the continued presence of fish.

Fishers also described situations where large schools were observed but could not be effectively harvested because fish moved offshore, escaped during net operations or could not be fully encircled. Stakeholders considered such events difficult to capture in fishery-dependent datasets.

Recruitment and environmental drivers

Stakeholders identified environmental factors as a potentially important influence on recruitment and stock productivity.

Participants suggested that water temperature, water quality, river flows and broader climatic conditions may influence recruitment success and fish distribution. Stakeholders considered it likely that environmental conditions contribute to observed variability in stock indicators, although the underlying mechanisms remain uncertain.

Discussion also highlighted the extent to which contemporary environmental conditions differ from those that existed historically. Some representatives suggested that changes in environmental quality may influence the stock's potential productivity and carrying capacity.

Stakeholders generally considered environmental influences to be an important source of variation to recognise when interpreting stock assessment results.

Regional observations

Marked regional differences within the fishery were highlighted.

It was noted that catch declines appeared most pronounced in the northern end of the stock for Queensland estuarine fisheries, whereas southern Queensland and New South Wales fisheries were perceived to be comparatively more stable. Fishers operating in different regions reported varying experiences regarding fish abundance and access to fishing grounds.

Stakeholders cautioned that regional trends may reflect changes in fishing participation, regulations and access as well as changes in fish abundance. In particular, participants noted that some regions now have little or no effective fishing effort due to licence reductions, regulatory changes or economic constraints.

Several stakeholders considered that additional regional analyses may assist interpretation of assessment results, particularly where changes in fishing practices differ among regions.

Habitat and environmental change

Stakeholders reported a range of observations relating to habitat condition and environmental change.

Fishers reported concerns regarding tidal barrages and their potential effects on fish movement and connectivity between freshwater and estuarine habitats. Participants suggested that these structures may influence access to important habitat and potentially affect aspects of the species' life cycle.

Representatives also reported observations of declining water quality, increased turbidity, nutrient enrichment, algal blooms, sedimentation and reductions in seagrass abundance. Some participants linked these changes to agricultural runoff, coastal development, disturbance of acid sulfate soils and increased boat activity.

Declines in prawn abundance were also identified by some stakeholders as a broader indicator of reduced coastal productivity. These observations were presented as stakeholder experiences and perceptions rather than verified causal relationships.

Stakeholders generally considered habitat degradation and environmental change to be important contextual factors when interpreting long-term fishery trends.

Fishery economics and market influences

Participants emphasised that economic factors can influence fishing activity and catch records.

Stakeholders reported that market demand is increasingly concentrated on larger fish and that fishers may adjust targeting strategies accordingly. Participants also noted that some fish may be released or not retained when market conditions are unfavourable.

Economic viability, workforce availability and industry participation were identified as important drivers of effort. Stakeholders suggested that these factors may influence trends in catch and effort independently of stock abundance and should therefore be considered when evaluating fishery performance indicators.

Data limitations

Participants questioned how targeted fishing effort is defined within catch-rate analyses and sought clarification regarding thresholds used to classify fishing activity as directed mullet effort. Stakeholders considered this information important for interpreting standardised catch-rate trends.

Stakeholders also suggested that additional information on school size, unsuccessful fishing attempts and uncaught schools may improve understanding of fish availability and fishing efficiency. Participants considered that some important operational information is currently difficult to capture through existing monitoring programs.

Technological change was also discussed. Stakeholders noted increased use of drones and other technologies to locate fish schools more efficiently. Most participants considered that such technologies primarily improve search efficiency rather than directly increasing harvest capacity, although they acknowledged that technological development may influence future interpretations of fishing power.

Overall, stakeholders supported ongoing improvements to data collection and continued engagement between industry, managers and scientists.

Management considerations

Stakeholders acknowledged that the meeting was intended to communicate stock assessment results and gather feedback rather than discuss management decisions.

Participants discussed the shared nature of the Queensland-New South Wales stock and recognised the need for coordinated management arrangements across jurisdictions. Stakeholders supported continued consultation following publication of the assessment and identified fisheries working groups as an appropriate forum for future discussions regarding any management implications.

Several participants expressed interest in ongoing engagement and further communication after publication of the assessment.

C Fishery management

The commercial fishery is divided into 2 main sectors in both states: estuarine netting and ocean beach netting.

Estuarine fishing mainly uses gill nets and targets fish within rivers, estuaries and near shore areas throughout the year. Gill nets measure up to 800 m long. In addition, tunnel nets measuring up to 1.6 km and smaller haul nets measuring a few hundred metres were also used. New South Wales do not permit tunnel nets.

Ocean beach fishing targets spawning aggregations during autumn and winter using large beach haul nets deployed along surf beaches and near estuary mouths. Although regulations differ between New South Wales and Queensland, the ocean beach sectors can take substantial catches of sea mullet per day because fish can school in large numbers.

Haul nets measure up to 400–500 metres (m) long during ocean beach season and 800 m long outside of ocean beach season in Queensland. This activity yields roughly half of the total landings each year. Historically, a summertime 'hardgut' non-spawning mullet run used to form an important component of the catch (Smith and Deguara 2002; Virgona et al. 1998).

In 1995, New South Wales licensed the ocean beach sector of the fishery. Similar new licensing was implemented for the estuarine sector in 1997 (Smith and Deguara 2002). The estuarine and ocean beach net sectors in New South Wales were partitioned into 7 regions, each with a specific set of licence holders. In 2007 New South Wales introduced share-management for the ocean beach and estuarine fisheries. Effort limits were set in 2017–2018 through individual transferable commercial effort allowances (effort holdings). In 2026 there were 292 businesses with a general estuarine net holding and 153 with a ocean beach holding. There was no specific sea mullet total allowable commercial catch (TACC) in New South Wales.

In Queensland, a limited entry ocean beach (K) licence regulates the targeting of the spawning run of sea mullet. K licences allowed their holders to deploy ocean beach haul (seine) nets from April to August each year (Williams 2002). Out of season, any commercial fisher with a general net licence can net ocean beaches. In 2026, there were 228 small mesh and 47 large mesh gill net licences active in the Queensland area of the sea mullet fishery, plus 36 ocean beach K licences. The region 5 south east Queensland sea mullet competitive TACC is 1,614 t per year.

Changes to spatial and temporal management restrictions in the fishery are listed in Table C. In both states, the current minimum legal size for sea mullet is 30 cm total length (TL).

In the past 2 decades an exiting of ageing fishers from the fishery has contributed to losses of knowledge and expertise impacting activity and catches which may contribute to the variation in catch rates in the Qld ocean beach sector (A. Prosser, personal communication, 7 July 2026).

Table C.1: Management measures applied to sea mullet in New South Wales and Queensland waters.

Date	Measure
New South Wales	
1902–1935	Initial measures relating to fishing gear and practices; e.g., mesh size, net length, prohibition of explosives and poisons.
17 Dec 1935	Introduced minimum legal size 12 inches ($\approx$ 30.5 cm) TL <i>Fisheries and Oyster Farms Act 1935</i>
11 May 1951	Minimum length size increased to 14 inches ($\approx$ 35.5 cm) TL. The mesh of permissible nets was raised from 3 inches to 3 1/4 inches (Thomson 1953)
2 Nov 1951	Minimum length of 13 inches ($\approx$ 33 cm) TL (Thomson 1953)
20 Mar 1952	Minimum length of 14 inches TL from 1 March to 30 June and 13 inches TL from 1 July to 28 February (Thomson 1953)
1 Jul 1990	Minimum legal size 30 cm TL <i>Fisheries and Oyster Farms Act 1935-Regulation no. 357, 1990</i>
11 Jun 1993	Confirm minimum legal size 30 cm TL <i>Fisheries and Oyster Farms Act 1935-Regulation no. 199, 1993</i>
13 Jan 1995	Confirm minimum legal size 30 cm <i>Fisheries Management (General) Regulation, 1995-No. 11</i>
May 2002	Thirty Recreational Fishing Havens established. Resulted in 24% of all NSW estuarine waters being closed to commercial fishing, including several major systems
5 Feb 2007	Share management introduced for Ocean Beach Hauling. <i>Fisheries Management (Ocean Hauling Share Management Plan) Regulation 2006</i> . Minimum shareholdings required to fish
5 Feb 2007	Share management introduced for the Estuary General Fishery. <i>Fisheries Management (Estuary General Share Management Plan) Regulation 2006</i> . Minimum shareholdings required to fish
1 Dec 2017	Business Adjustment Program for ocean beach hauling. Ocean hauling managed by increased regional minimum share holdings. Crewing arrangements modified
1 Dec 2017	Business Adjustment Program for Estuary General Fishery. Mesh netting and hauling managed by regional minimum share holdings and effort quota
1 July 2018	From 2018 onward, the Total Allowable Fishing Committee (TAFC) began making annual determinations for fishing effort
1 July 2025	In 2025–2026 the TAFC formally recommended introducing catch quotas for sea mullet subject to Ministerial approval
Queensland	
1877–1914	Initial measures relating to fishing gear and practices; e.g., mesh size, net length, allowed species, powers of inspectors.
3 Dec 1914	Introduced minimum legal size 8 inches ($\approx$ 20 cm) total length (TL) <i>The Fish and Oyster Act of 1914</i>

Table C.1 —Continued on next page

Table C.1 —Continued from previous page

Date	Measure
1926–1933	Minimum legal size increased to 11 inches ($\approx$ 28 cm) TL February to July, 10 inches ($\approx$ 25.5 cm) TL August to January (Amendments 1926, 1929 and 1933 by Order in Council to <i>The Fish and Oyster Act of 1914</i>)
2 Nov 1952	Minimum legal size increased to 12 inch ($\approx$ 30.5 cm) TL for the months February to June, 11 inches minimum TL during other months. Prior to this, the 12 inch minimum covered only the months March to May (Thomson 1953)
18 Apr 1957	Minimum legal size 12 inches TL year round <i>Fisheries Act 1957</i>
16 Dec 1976	Minimum legal size changed to 30 cm TL all year round <i>Fisheries Act 1976</i>
1 Dec 1995	Closure to commercial ocean beach nets on some beaches around populated areas and in Moreton Bay on weekends; Great Sandy Strait on weekends; and the eastern (ocean beach) shore of K'gari from 1 September to 1 April <i>Fisheries Regulation, 1995 No. 325</i>
1 Sep 2003	Commercial ocean beach net fishing restricted on eastern beach of K'gari.
1 Mar 2009	<i>Introduction of the Marine Parks (Moreton Bay) Zoning Plan 2008</i>
1 Sep 2019	The Zoning Plan was remade and the Marine Parks (Moreton Bay) Zoning Plan 2019 commenced on 1 September 2019. The remake included minor administrative amendments only and no changes were made to zones, designated areas or entry and use requirements.
1 Jan 2019	Introduction of Vessel Monitoring System (VMS).
1 Sept 2021	Queensland east coast inshore fishery harvest strategy 2021–2026. Sea mullet competitive total allowable commercial catch (TACC) quota introduced for region 5 at 1,614 t.
1 Jan 2024	Throughout 2024 (January to October) a number of primary commercial N symbol fishing licences were surrendered as part of a structural adjustment scheme that was announced on the 16/11/2023. No ocean beach K symbols were retired. WTO conditions recommended for DPI to work with the New South Wales Government to ensure shared stocks of sea mullet (<i>Mugil cephalus</i>) remain sustainable.

Initial stock assessments of sea mullet used 3 population models fitted to data through 2003 (Bell et al. 2005). The results suggested heavy exploitation, with fishing responsible for around two-thirds of mortality in recruited fish. Exploitable biomass ratios in 2003 were estimated to lie between 22% and 59% (Figure C.1).

The sea mullet stock was previously assessed with data through to 2016 by Lovett et al. (2019) and predicted an exploitable biomass at around 50% (with a credible interval range of 42% to 60%) of virgin levels in 2016 (Figure C.1).

The 2021 age-structured assessment was intended to extend and complement the already available scientific documentation on the resource (Kesteven 1953; Virgona et al. 1998; Dichmont 1999; Smith and Deguara 2002; Bell et al. 2005; Lovett et al. 2019) and support the development of management procedures.

In 2021 the age-structured stock assessment was transferred from the 2016 custom model to the packaged software called Stock Synthesis. Eight scenarios were run, covering a range of modelling assumptions. Results suggested that spawning biomass in 2021 was estimated to be 37% (30–45% credible interval) of unfished spawning biomass (Figure C.1) (Lovett et al. 2022).

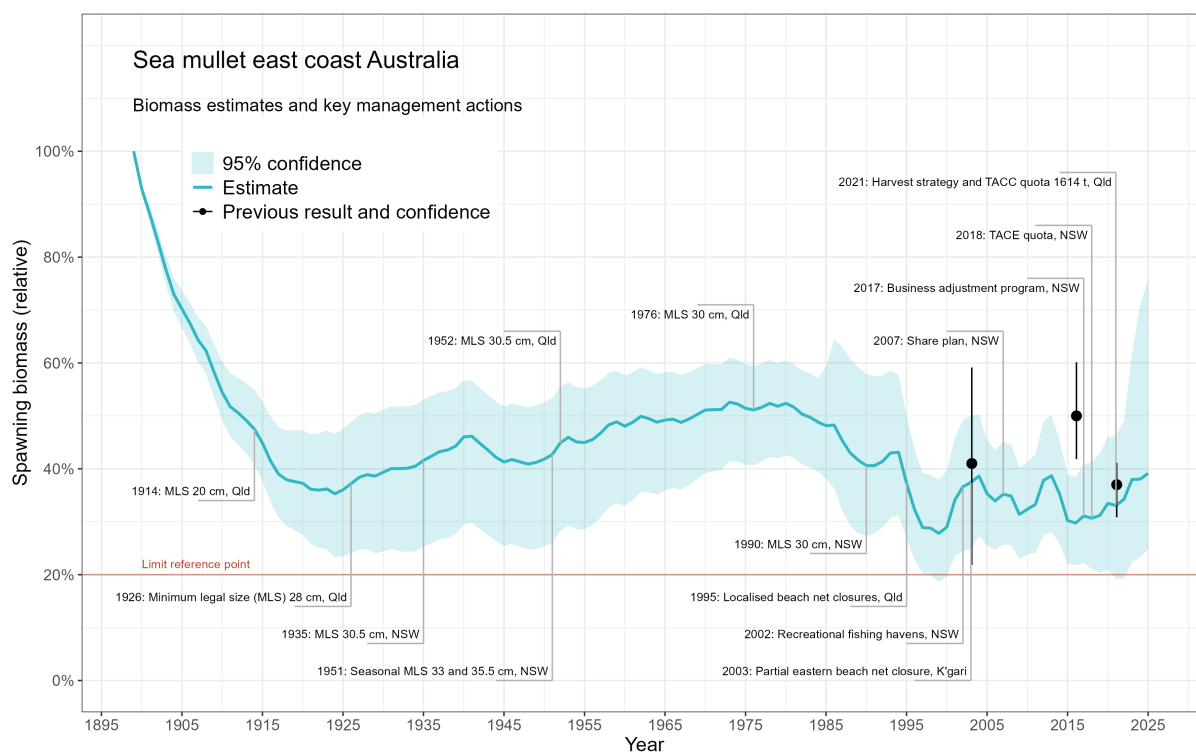


Figure C.1: Annual sea mullet spawning biomass estimates from the current stock assessment compared with key fishery dates and past assessment results in 2003, 2016 and 2021

Note: assessment results in 2003 and 2016 refer to exploitable biomass

D Identifying fishing methods in Queensland

D.1 Summary

- Catch thresholds have been used to identify netting methods for sea mullet in early years of the Queensland logbook.
- Many logbook entries were recorded as unspecified gill netting, when they were likely ocean beach.
- Results suggested a 300–700 kg threshold might be better than 1,000 kg, to identify ocean beach netting.
- 350 kg is used as the new data rule, based on the 90th percentile catch for gill netting.

D.2 Problem

Quantities of ocean beach sea mullet were reported without detailing the netting method or net size. This was prevalent pre-2000 in Queensland.

These catches were recorded in the logbook database as fishing method code 4. This code, intended for gill netting, mixed catches taken by gill and ocean-beach netting between 1 April and 31 August (the in-season ocean beach fishing months). As well, some quantities of haul netting (code 64) included ocean beach catches (code 34).

The 3 methods of netting differ in purpose, location, and regulations. In general:

- Gill netting was more frequent and used all year round. The nets capture fish by entanglement. Typically, gill netting is used in estuaries, rivers, nearshore waters, or along the coastline. A mix of species can be captured. Net lengths range 400–800 metres.
- Haul netting is typically used in estuaries, rivers, beaches, or nearshore areas to catch fish by encircling them with a net and then hauling it to shore or a boat. This is like ocean beach netting, but the length of net can vary 200–600 metres, is without a cod-end and used all year round taking a mixed of species.
- Ocean beach netting is only between April and August. It is conducted typically in the surf zone or on designated beaches of Hervey and Moreton Bay. The net is often deployed by boat to encircle fish and then retrieved onshore using cars or tractors. The net has a cod-end to retain large schools of fish and concentrate the catch as the net is retrieved from the beach. Net length is up to 500 metres. When targeted, sea mullet are generally taken with few other species.

Previously, in-season ocean beach net catches were separated using a catch per operation-day threshold developed by Fishery Monitoring. This subset approach aimed to select catches where the fishing method was likely ocean beach net. In past assessments 2 thresholds were applied to reallocate fishing methods to ocean beach:

1. If the fishing method code was 4 & in an ocean beach spatial grid & the sea mullet catch weight was $\geq 1,000$ kg & in-season, then allocate to ocean beach net.
2. If the fishing method code was 64 & in an ocean beach spatial grid & the sea mullet catch weight was $\geq 1,000$ kg & in-season, then allocate to ocean beach net.

Use of the 1,000 kg catch threshold can identify large ocean beach net catches. However, the high threshold potentially influences the time series of catches and catch rates. Allocating fishing methods based on the response patterns in catch weight (kg), can introduce different bias from year to year with changes in fish abundance. Hoyle et al. (2024) warns that bias can likely increase if thresholds are set high.

Three different versions of the threshold were compared: 350 kg, 500 kg and 1,000 kg, where 350 kg was roughly the 90th percentile catch for gill netting and 500 kg was roughly the median ocean beach.

Spatially, logbook catches were reported by 30×30-minute grids or 6×6-minute sites. In season ocean beach fishing methods were identified for select sites (called ob-only) and catches from larger ocean beach grids (called ob-grid) required the threshold discrimination of fishing methods. Ob-only sites were nested within ob-grid. Non ob-grid locations were assumed not to be ocean beach. See notes^{1 2}.

For catch rate analysis, only the gill net and ocean beach fishing methods were used. For catch estimates, all fishing methods that are not ocean beach were grouped as 'estuarine'.

D.3 Other approaches

Alternate statistical methods were tested to identify in-season sea mullet catches from ocean beach netting. Ideas considered (e.g. see multi-species targeting, in Hoyle et al. (2024)):

- a) Sub-setting rules based on sea mullet proportions in the daily catch.
- b) Multi-species Principal Coordinate Analysis (PCA) and Gaussian Mixture Model (GMM).
- c) Indicative vessels and their mean catches using GMM.
- d) Multi-variate statistics using covariates (Multidimensional Scaling - MDS).

Method a) – sea mullet proportions

The use of proportional thresholds identified a range of catches to add to ocean beach. Results, for sea mullet proportions ≥ 0.8 or 0.9 , tallied total catches near the 350 kg rule. The number of records and number of smaller catches increased for ocean beach, dropping the mean nominal catch per boat-day.

Method b) multispecies GMM

The multivariate data considered associated boat-day catches of sea mullet, bream, dart, flathead, tailor, trevally, drummers and sweeps, gar fish, and sharks. These species were more common and catch weights (kg) were cube-root transformed. The data were selected for ocean beach grids, months 4–8, non zero sea mullet weight, and fishing method codes (4, 34, 64), where codes 34 and 234 were both ocean beach = 34.

Principal coordinate analysis (PCA, using the 'prcomp' function from the R library 'mclust') was first performed on the species dataset. This reduced the number of dimensions of the data to 2 components.

¹Ocean beach only grids refer to grids and sites: 10W33, 10W37, 10W39, 12W34, 12W35, 12W36, 13W33, 13W34, 13W35, 13W36, 14W32, 14W33, 15W37, 16X37, 16X38, 17W33, 17W34, 17W35, 17W36, 17X37, 18W33, 18W34, 18W36, 19W32, 19W33, 19W36, 1W34, 1X37, 1X38, 1X39, 21X36, 21X37, 21X38, 22W33, 22W34, 22W35, 22W36, 22X37, 23W31, 23W33, 23W34, 23W35, 23W36, 24W31, 24W32, 24W36, 25W32, 25W36, 2W34, 2W35, 2W36, 2X38, 3W32, 3W34, 3W35, 3W36, 4W32, 4W33, 5W33, 5W37, 6W34, 6X37, 6X38, 6X39, 7W34, 7W35, 7X39, 8W32, 8W33, 8W34, 8W35, 8W36, 9W32, 9W33, W31, X36, X37, X38, X39.

²Ocean beach grids refer to those grids and sites in ocean beach only plus: 10W38, 11W34, 11W35, 13W32, 15W38, 16W34, 16W35, 18W32, 1W36, 20W37, 20W38, 21W35, 23W32, 25W37, 25W38, 3W37, 4W37, 5W38, 5W39, 6W35, 6W36, 7W36, W32, W33, W34, W35, W36, W37, W38, W39.

The R mclust package was used next to identify clusters using a Gaussian Mixture Model (GMM) in the first 2 PCA coordinates.

No clear result was discriminated to align clusters to a fishing method.

Method c) – indicative vessels

This analysis tested the generalisation that in-season fishing operations (vessels) were only net-type ocean beach or non-ocean beach.

The data included ocean beach grids, in-season months 4–8, non zero sea mullet weight and all fishing method codes.

For analysis, mean sea mullet catches were calculated per operator and method. Mean catch sizes were natural logarithm transformed. The R mclust package identified 3 rough clusters using a Gaussian Mixture Model with common standard deviation.

The assumption was that higher catching vessels were ocean beach netters. Allocation results were in between the 350 kg and 1,000 kg rule.

Method d) – MDS

Multidimensional Scaling (MDS) is a statistical technique used to visualise high-dimensional data by representing it in a lower-dimensional space, typically 2 dimensions.

The goal of MDS was to preserve the dissimilarities between the species data points, using a Bray Curtis distance matrix on cube-root transformed data. Data were selected for in-season months 4–8, ocean-beach only sites and non zero sea mullet catches.

MDS is commonly used in exploratory data analysis to uncover patterns, relationships, or clusters in the data. The exploratory analysis was to identify distinctive species among fishing methods reported from ocean beach sites.

- Results were hard to discriminate between fishing methods.
- Key species per method were:
 - flathead for gill netting
 - sea mullet for ocean beach
 - trevallies for haul netting.

E Catch

Figure E.1 displays the mean monthly catch over the past 10 years for each state and fishing method. The seasonality of sea mullet is evident here with the peak of the season occurring around early May in New South Wales and in mid-late June in Queensland. Estuarine fishing occurs year round with an increase around the peak of the season, whereas ocean beach fishing occurs only during the spawning season.

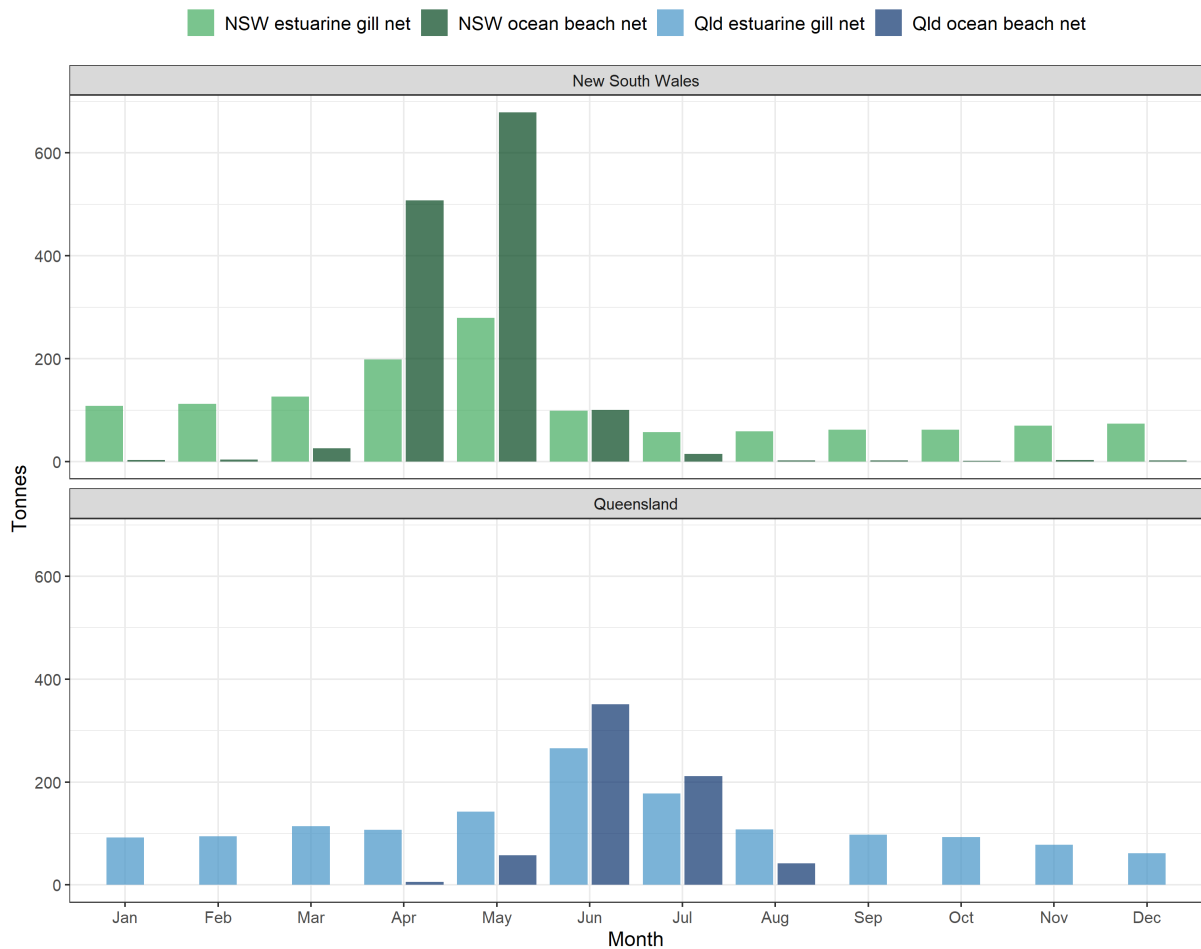


Figure E.1: Mean monthly catch of Australian east coast sea mullet for the period 2015–2024

Figure E.2 displays annual catch for each latitude grouping (as displayed in Figure 2.1).

Estuarine fishing dominates in northern and central regions, especially around 27–30° S, where catches were historically highest. Ocean beach fishing dominates further south, particularly in 30–33° S, where the largest beach-net catches occur. Most estuarine regions show a long-term decline since around 2010, whereas ocean beach fisheries exhibit greater variability, with some central NSW regions maintaining high catches for much longer.

Overall, the centre of estuarine production appears to lie in central Queensland–northern NSW, while the centre of ocean beach production lies further south in central NSW.

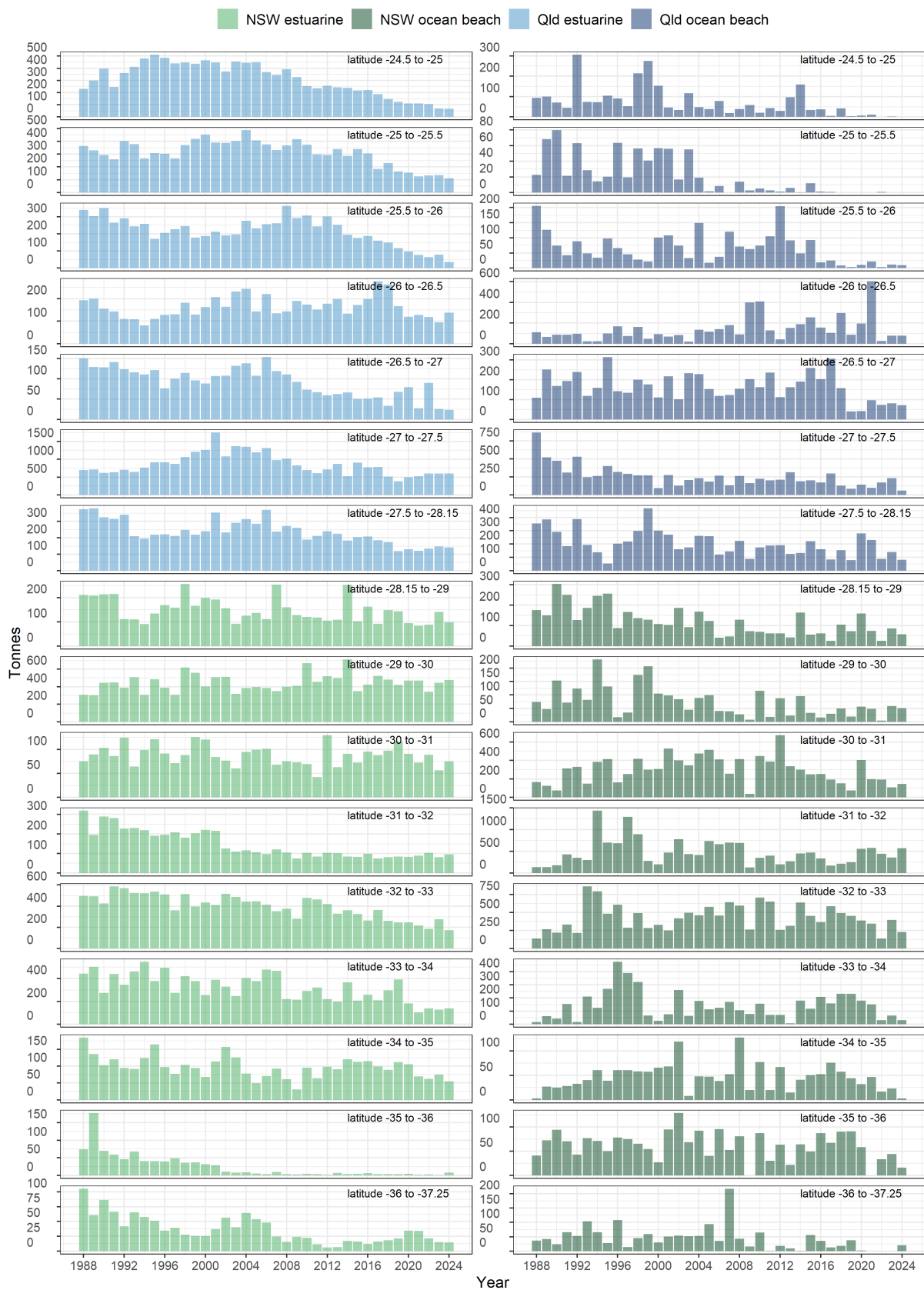


Figure E.2: Regional catch of Australian east coast sea mullet for the period 1988–2024—estuarine catches are shown on the left and ocean beach catches on the right (note that y-axes are different on each sub-plot)

F Catch rates

F.1 Methods

Data processing for catch rates included the following aspects:

- Similar fishing methods were grouped together. In the early years of the Queensland data fishing methods were not well distinguished. The process by which fishing methods were identified is outlined in Appendix D. Qld catch and catch rates used data rule '350 kg'.
- When an operation fished in multiple locations on the same day, all catch for that day was assigned to the location with the greatest individual catch.
- Operations who fished in only one year, over the years analysed, were omitted.
- Only used gill net operators who contributed at least 30 days history of sea mullet catch.
- Only used ocean beach operators who contributed at least 10 days history of sea mullet catch.
- Spatial areas were stratified for one degree latitude bands in NSW and half degree bands in Qld. Some northern and southern latitude bands were grouped to complete area-stratum data in each year (Table F.2).
- Wind data from BOM were appended to daily data. Vectors were calculated for north–south and east–west components (O'Neill et al. 2024).
- For NSW monthly data, effort was calculated as normalised days. Days were normalised by their means pre and post logbook changes in 2009. Pre-2009, monthly logbooks recorded all days fished for all species. Post, daily logbooks were associated with a species.
- Data was truncated to full calendar years available (i.e., NSW monthly logbook data began in 1999 rather than July 1998 and NSW daily logbook data began in 2010 rather than July 2009).

The general linear models (LM) for catch rate standardisations were:

$$\begin{aligned}\log(\text{weight}) &\sim \text{Operator} + \text{Year} \times \text{Latitude} + \text{Latitude} \times \text{Month} \\ &\sim \text{Operator} + \text{Year} \times \text{Latitude} + \text{Month} + \text{offset}(\log\text{numberofshots}) \\ &\sim \text{Operator} + \text{Year} \times \text{Latitude} + \text{Latitude} \times \text{Month} + \text{offset}(\log\text{normaliseddays}) \\ &\sim \text{Operator} + \text{Year} \times \text{Latitude} + \text{Latitude} \times \text{Month} + \text{offset}(\log\text{normaliseddays}) \\ &\sim \text{Operator} + \text{Year} \times \text{Latitude} + \text{Latitude} \times \text{Month} + \text{Goodwind} \\ &\sim \text{Operator} + \text{Year} \times \text{Latitude} + \text{Latitude} \times \text{Month} + \text{Goodwind}\end{aligned}\tag{F.1}$$

The 6 equations above were in order of the analyses 1) NSW gill net daily, 2) NSW ocean beach daily, 3) NSW gill net monthly, 4) NSW ocean beach monthly, 5) Qld gill net daily, and 6) Qld ocean beach daily. The variable name Latitude represented latitude-band. Gill netting was estuarine waters.

For each LM, the emmeans predictions were created from a factor interaction table for mean kg of sea mullet. The values on the log scale were back transformed to kg and bias corrected using the emmeans ref-grid function. In ref-grid, fishing operators were treated as nuisance factors with proportional marginal weights to simplify the size of the reference grid.

Emmeans then averaged the reference grid by year or year x latitude-band (Table F.1). For this, the mean seasonal pattern assumed proportional marginal weights for months and equal weights for each latitude band (Table F.2). Spatial weights were scaled to proportions and used to approximate habitat

weighting (Hoyle et al. 2024). Co-variate settings used the mean good-wind (proportion), and per-shot or per-day units as appropriate for each dataset/fleet.

The settings used to standardise catch rates for each fleet averaged across operators, locations, and months to represent typical conditions. Where relevant, mean values were used for wind, and effort was standardised using representative values to ensure results were comparable across datasets.

Table F.1: Prediction settings for annual standardised catch rates of sea mullet by fleet

Explanatory variables	NSW daily		NSW monthly		Qld daily	
Settings	Gill net	Ocean beach	Gill net	Ocean beach	Gill net	Ocean beach
Operator marginal weights	Y	Y	Y	Y	Y	Y
Latitude-band equal weights	Y	Y	Y	Y	Y	Y
Month marginal weights	Y	Y	Y	Y	Y	Y
Good wind mean	-	-	-	-	0.75	0.75
Log number of shots offset	-	0	-	-	-	-
Log normalised days offset	-	-	0	0	-	-

Y yes indicates the prediction weightings for each explanatory factor by dataset/fleet

- not applicable

Covariate and offset values are specified

Table F.2: Spatial weightings for sea mullet catch rates by dataset

Latitude range	Daily records		Monthly records	
	Gill net	Ocean beach	Gill net	Ocean beach
Qld				
-24.5 to -25	1		-	-
-25 to -25.5	1		-	-
-25.5 to -26	1	3	-	-
-26 to -26.5	1	1	-	-
-26.5 to -27	1	1	-	-
-27 to -27.5	1	1	-	-
-27.5 to -28.15	1.4	1.4	-	-
NSW				
-28.15 to -29	1		1	
-29 to -30	1		1	2
-30 to -31	1	3	1	1
-31 to -32	1	1	1	1
-32 to -33	1	1	1	1
-33 to -34	1	3	1	3
-34 to -35	1		1	
-35 to -36	1		1	
-36 to -37.25	1	-	1	-

- no spatial weight with little or no catch-effort

blank limited data summed into northern or southern extents

Weights listed as counts and were transformed into proportions in predictions

The main changes in standardisation from the previous stock assessment by Lovett et al. (2022) were:

1. removal of the negative offset on number of ocean beach operators—data supported a positive association (Appendix F.5)

2. net and mesh size data were not used—too many net records were incomplete and potential data filtering changed nominal means
3. switched from using a quasi-Poisson GLM to use a log-transformed linear model—to improve model diagnostics and better handle the strong right-skewness and dispersion
4. include year and latitude interactions—to allow spatial differences in fish abundance between years
5. Qld data rule '350 kg' rather than '1,000 kg'—allocated more data to ocean beach (Appendix D).

For sea mullet, a log transformation was used instead of a log-link. To compare predictions from a log-link model, a gamma GLM was applied to NSW and Qld daily ocean beach catch rates. A gamma GLM was used instead of quasi-Poisson GLM based on diagnostics, such as the mean–variance Taylor power law test > 2 (Hoyle et al. 2024). Prediction results were similar between log-link and log-transformed (Figure F.1), but the gamma GLM had lesser DHARMA residuals and failed dispersion test ($p < 0.05$).

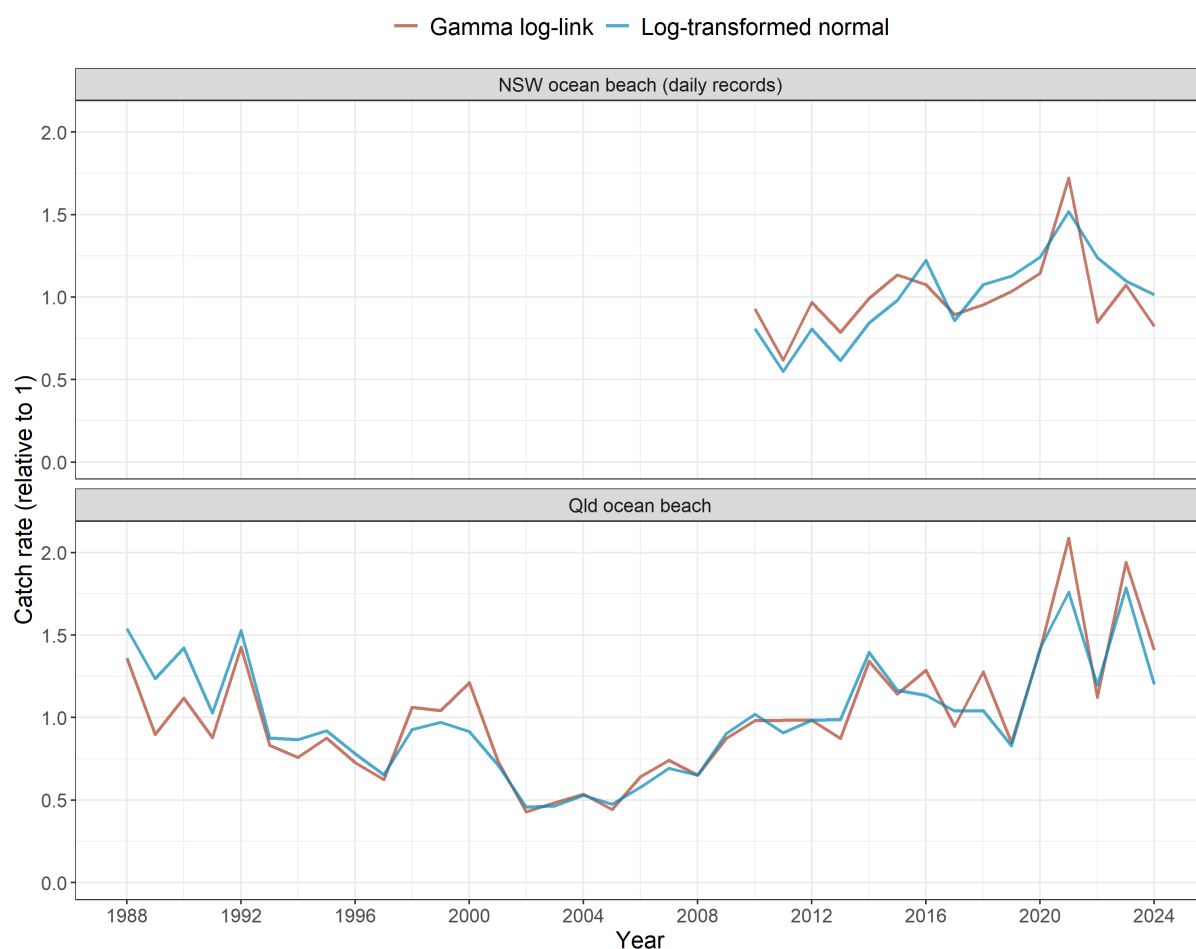


Figure F.1: Standardised catch rate comparison of sea mullet between the normal and gamma models for NSW ocean beach daily and Qld ocean beach data—normalised to a mean of 1

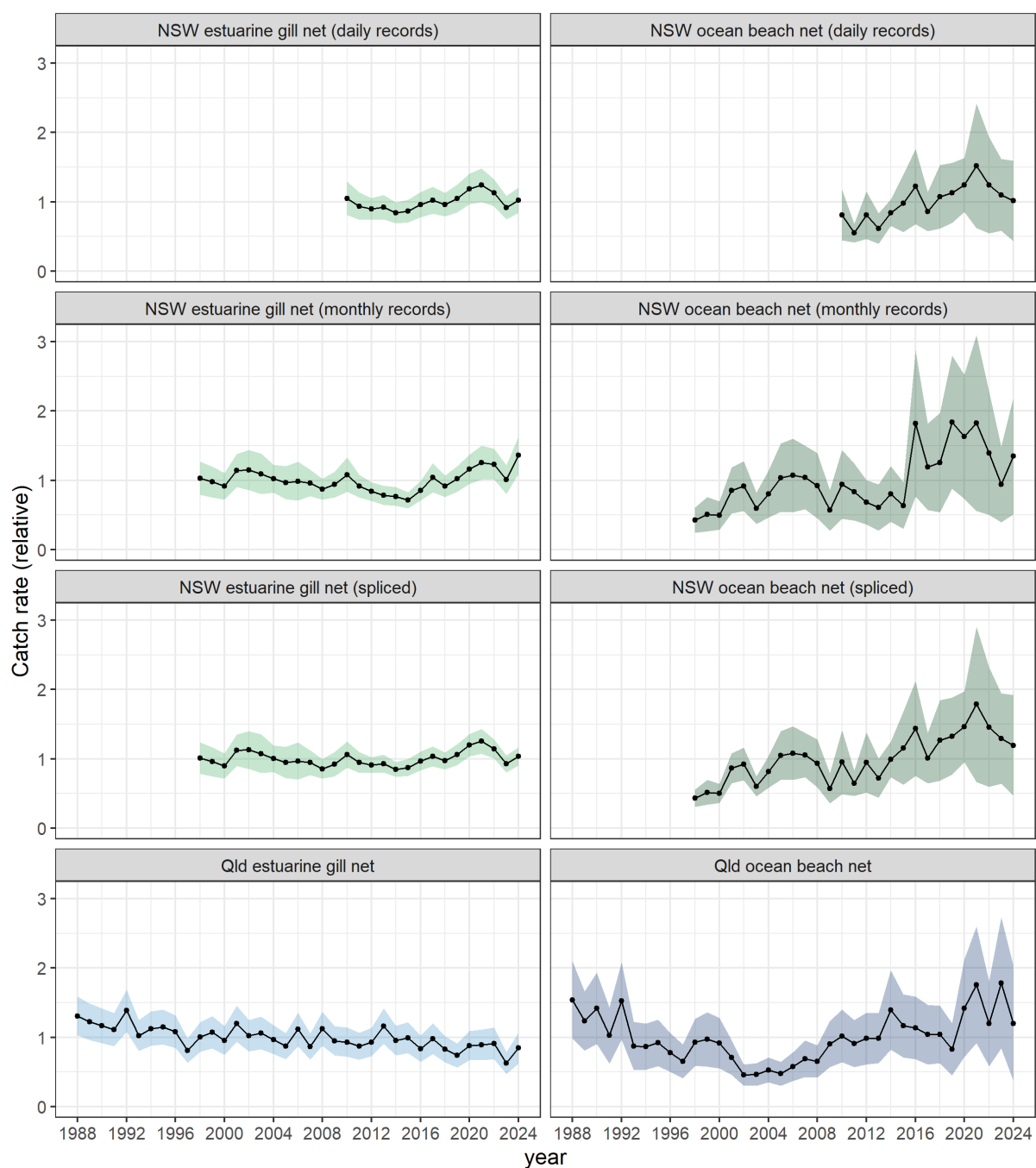


Figure F.2: Annual standardised commercial catch rates for Australian east coast sea mullet—shaded regions represent 95% confidence intervals with extra standard deviation input to the population model

F.2 Regions

Standardised sea mullet catch rates by year and region are shown in Figures F.3–F.6. Confidence intervals were wider for ocean beach fishing than for gill netting, reflecting lower data availability. Region definitions and groups are in Figure 2.1 and Table F.2.

Annual catch rates varied across New South Wales. Gill net catch rates increased in the north (latitudes 28–29, north of Coffs Harbour), were stable in central regions (latitudes 30–33, Coffs Harbour

to Sydney), and reduced south of Sydney (latitudes 34–36). Ocean beach netting of sea mullet was predominantly undertaken north of Sydney, with generally sustained catch rates.

Catch rates showed greater annual variability in Queensland waters. Gill net catch rates declined in northern regions (24.74–26.75, Bundaberg–Sunshine Coast), but remained reliable in recent years between Brisbane and the Gold Coast (regions 27.25–27.75). Ocean beach catch rates were generally lower between Bundaberg and Noosa (24.75–26.25), although increases were observed in regions 26.75–27.75 between the Sunshine and Gold Coasts.

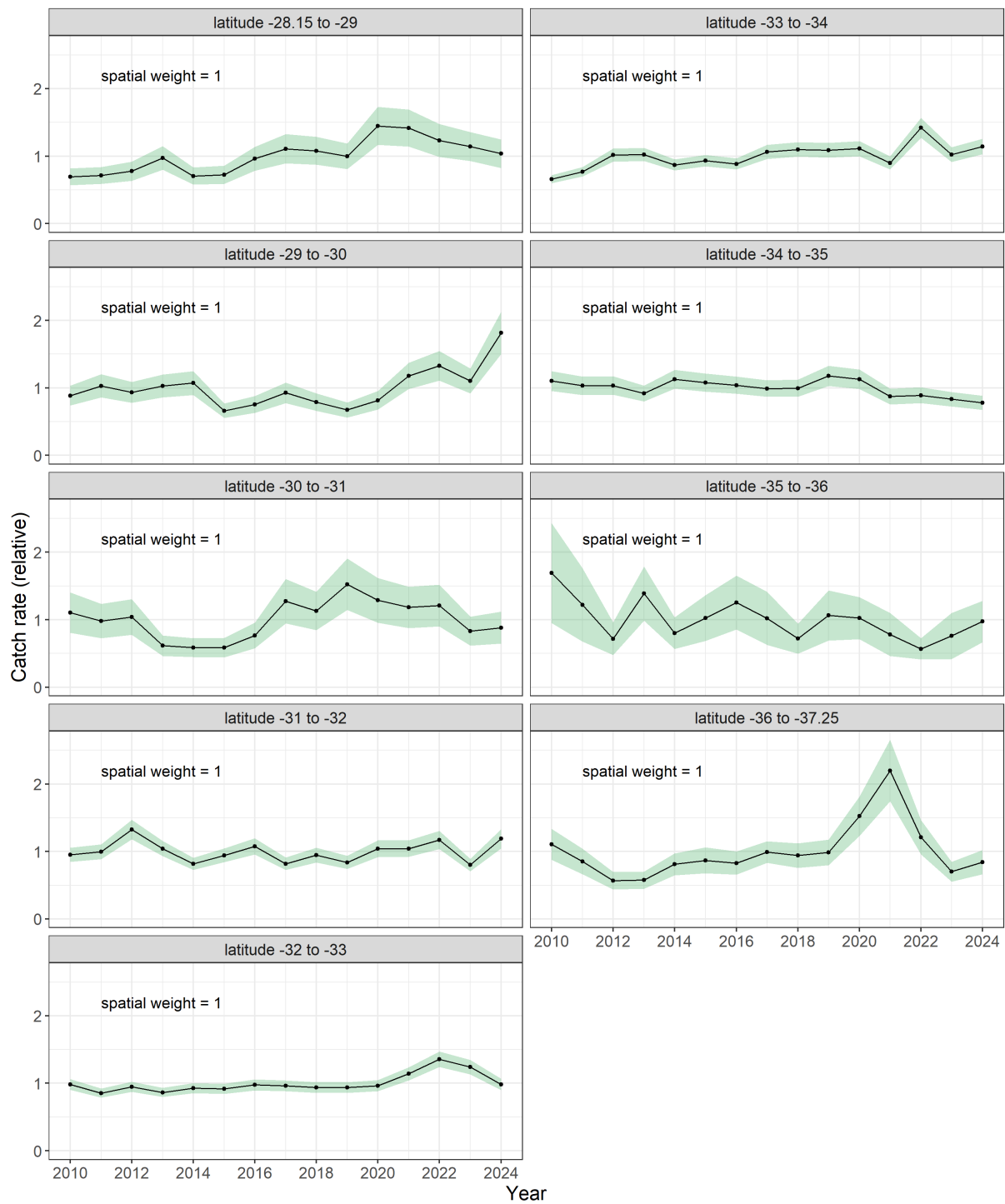


Figure F.3: Standardised mean catch rate of NSW estuarine-gill net sea mullet by latitude band. Error bars represent 95% confidence intervals. Results were proportional—scaled relative to the mean catch rate per operator day = 1.

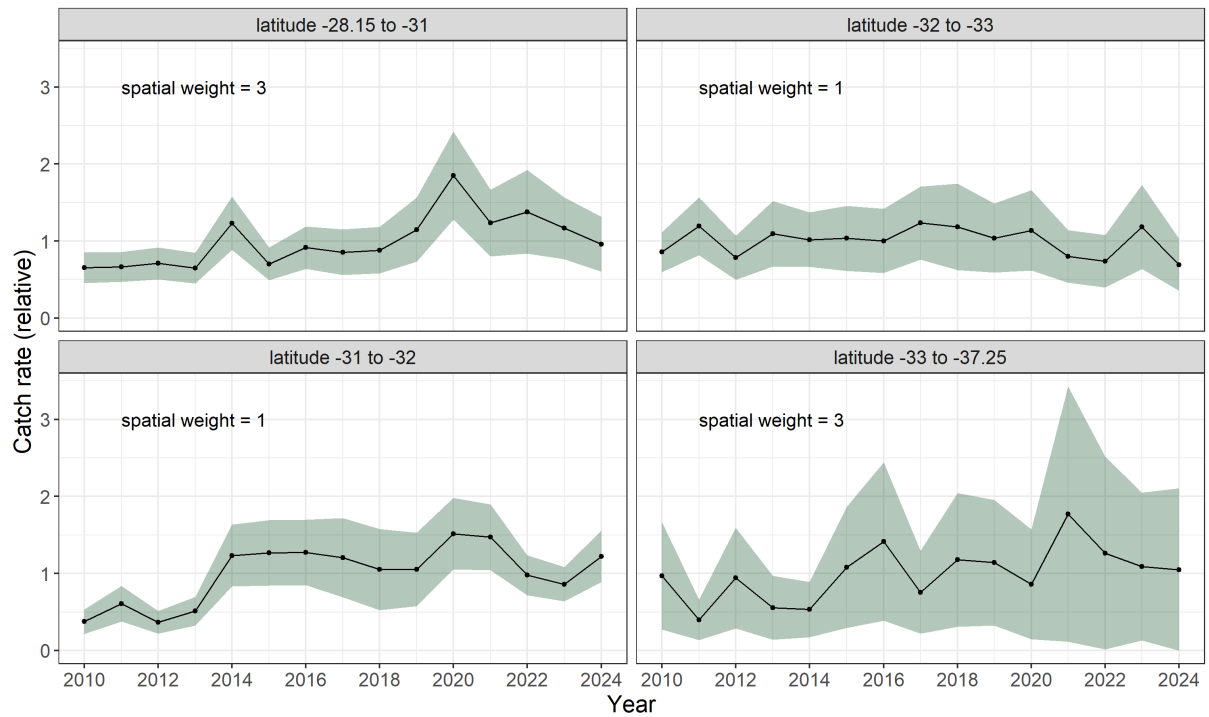


Figure F.4: Standardised mean catch rate of NSW ocean beach sea mullet by latitude band. Error bars represent 95% confidence intervals. Results were proportional—scaled relative to the mean catch rate per operator day = 1.



Figure F.5: Standardised mean catch rate of Qld estuarine-gill net sea mullet by latitude band. Error bars represent 95% confidence intervals. Results were proportional—scaled relative to the mean catch rate per operator day = 1.

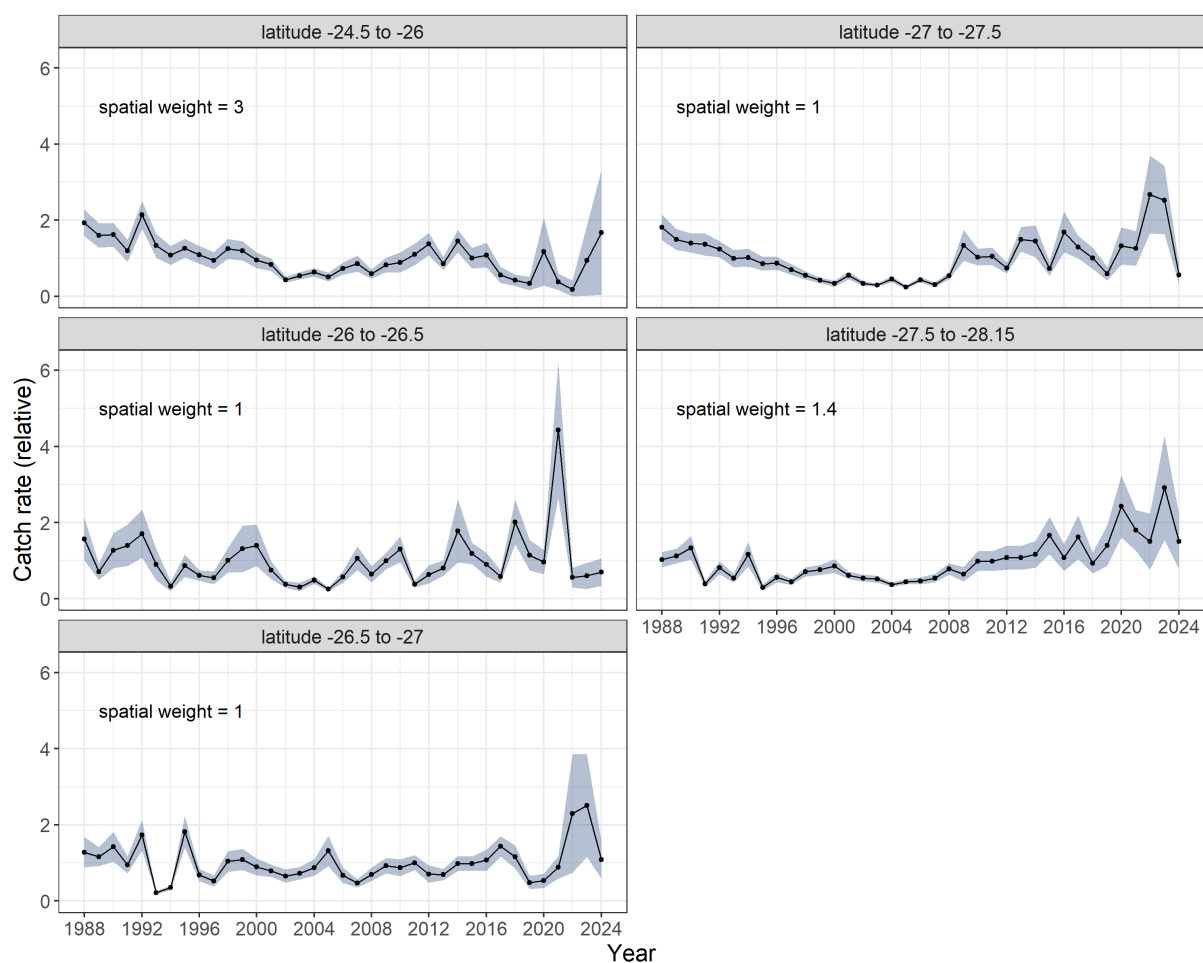


Figure F.6: Standardised mean catch rate of Qld ocean beach sea mullet by latitude band. Error bars represent 95% confidence intervals. Results were proportional—scaled relative to the mean catch rate per operator day = 1.

F.3 Diagnostics

F.3.1 NSW gill net daily

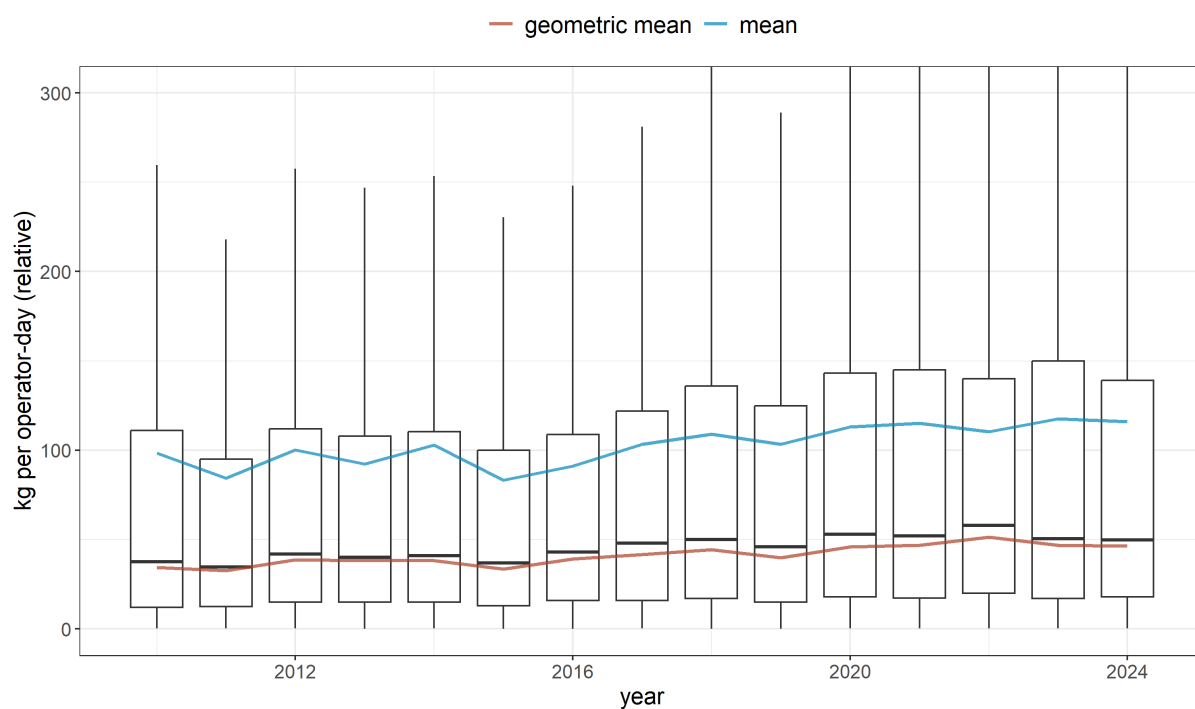


Figure F.7: Boxplot of the annual distribution of nominal daily catches per operator for the NSW gill net fleet

Table F.3: Analysis of variance table for the NSW gill net daily catch rate analysis—F statistics were derived from the R drop1 procedure, Adjusted R-squared = 0.365

Term	Df	RSS	F value	Pr(>F)
Residual	149748	212007.6		
Operator	369	269506.0	110.062	0.000
Year : Latitude band	112	215468.1	21.823	0.000
Latitude band : Month	88	217710.3	45.773	0.000

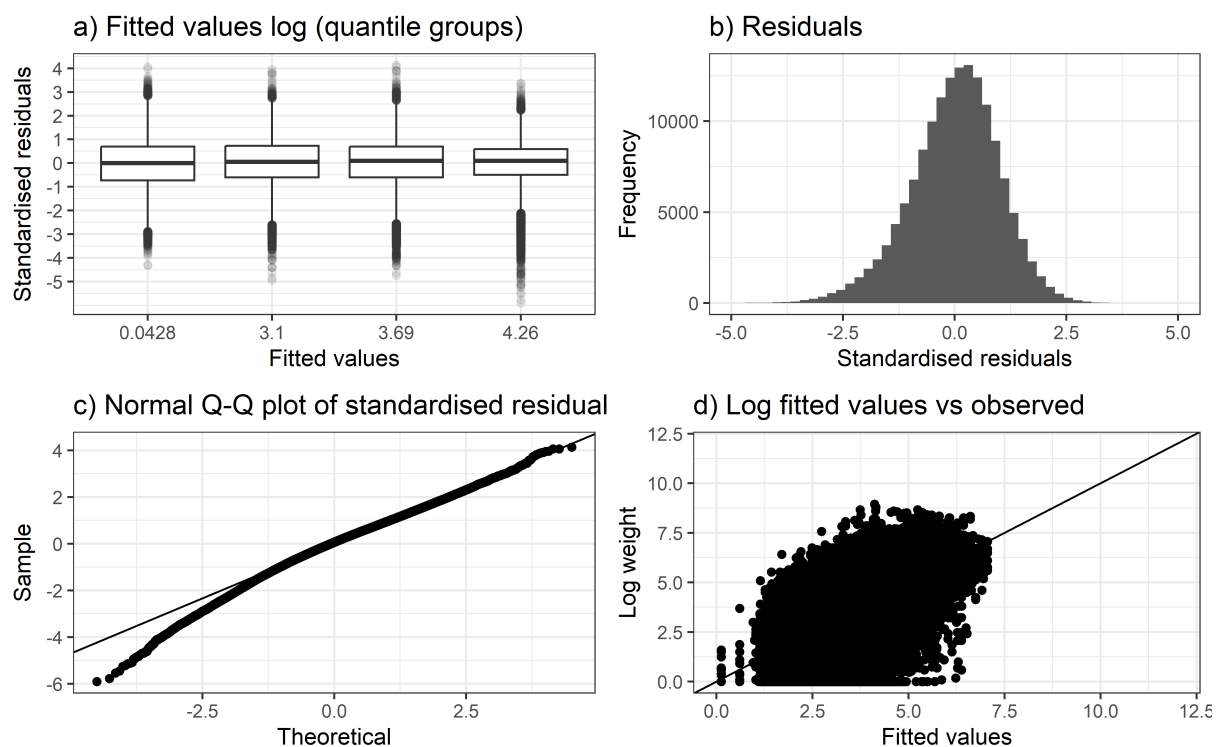


Figure F.8: Standardised residual plots from the NSW gill net daily catch rate analysis, for a) box plot of fitted values and residuals, b) histogram of residuals, c) normal quantile plot, and d) scatter plot of fitted values against log observed

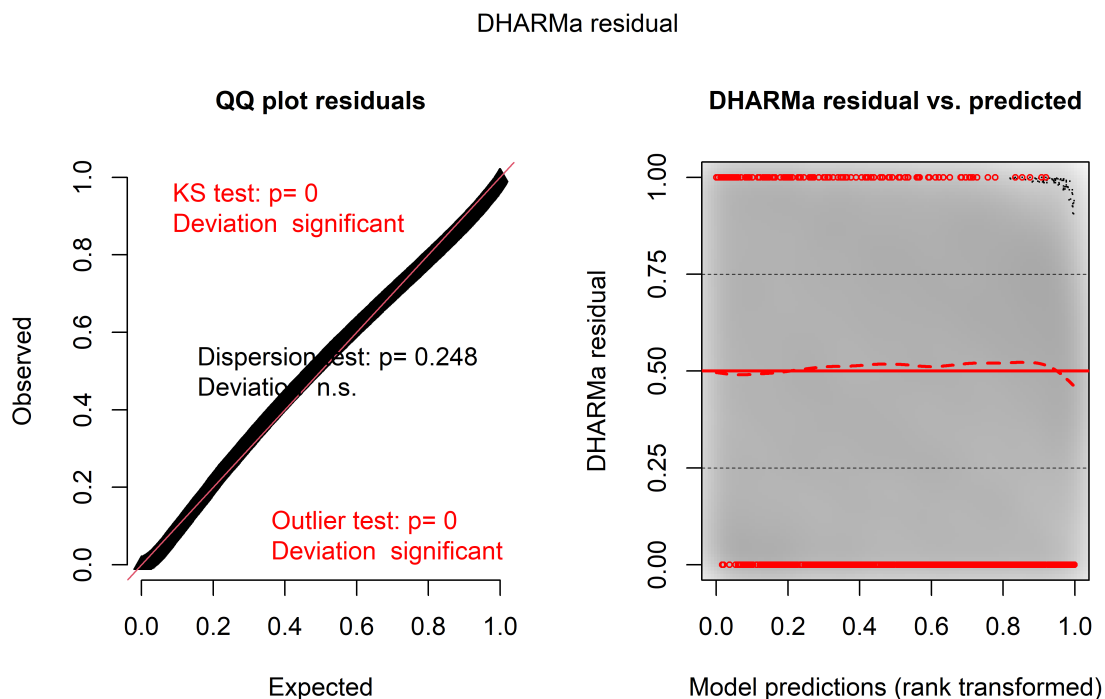


Figure F.9: Plot of DHARMA pit residuals from the NSW gill net daily catch rate analysis

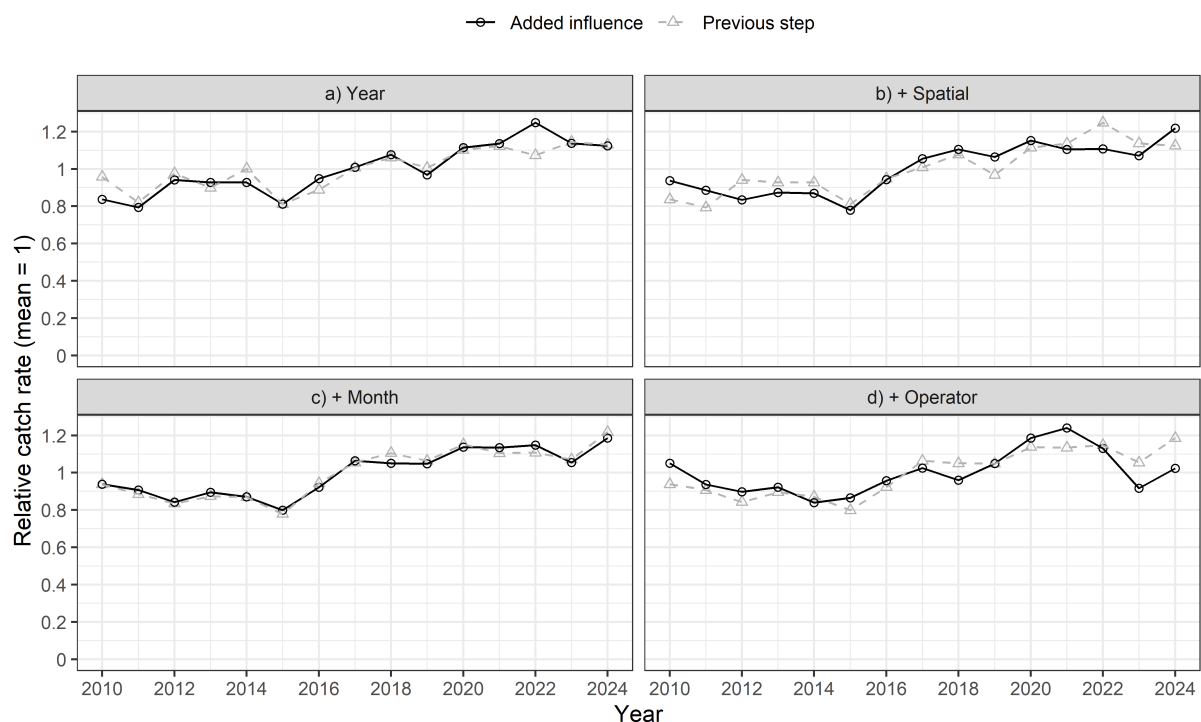


Figure F.10: Influence plot comparing the LM effects on standardised catch rates for the NSW gill net daily analysis—subplot: a) compared a year log-transformed response model to nominal catch rate, b) compared a year by latitude band model to model a, c) compared adding the latitude band by month interaction to model b, d) added operator to form the full model to compare to model c

F.3.2 NSW ocean beach daily

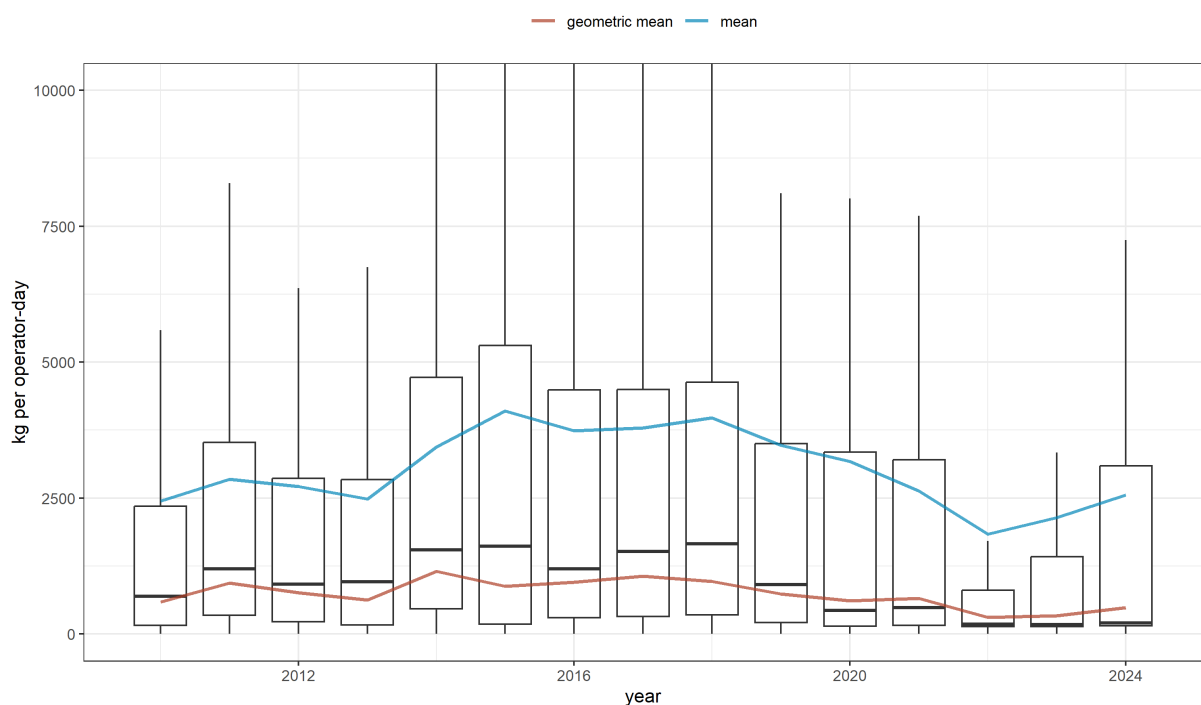


Figure F.11: Boxplot of the annual distribution of nominal daily catches per operator for the NSW ocean beach fleet

Table F.4: Analysis of variance table for the NSW ocean beach daily catch rate analysis—F statistics were derived from the R drop1 procedure, Adjusted R-squared = 0.482

Term	Df	RSS	F value	Pr(>F)
Residual	5823	12421.0		
Operator	83	15624.0	18.092	0.000
Month	11	15958.3	150.757	0.000
Year : Latitude band	42	12679.7	2.888	0.000

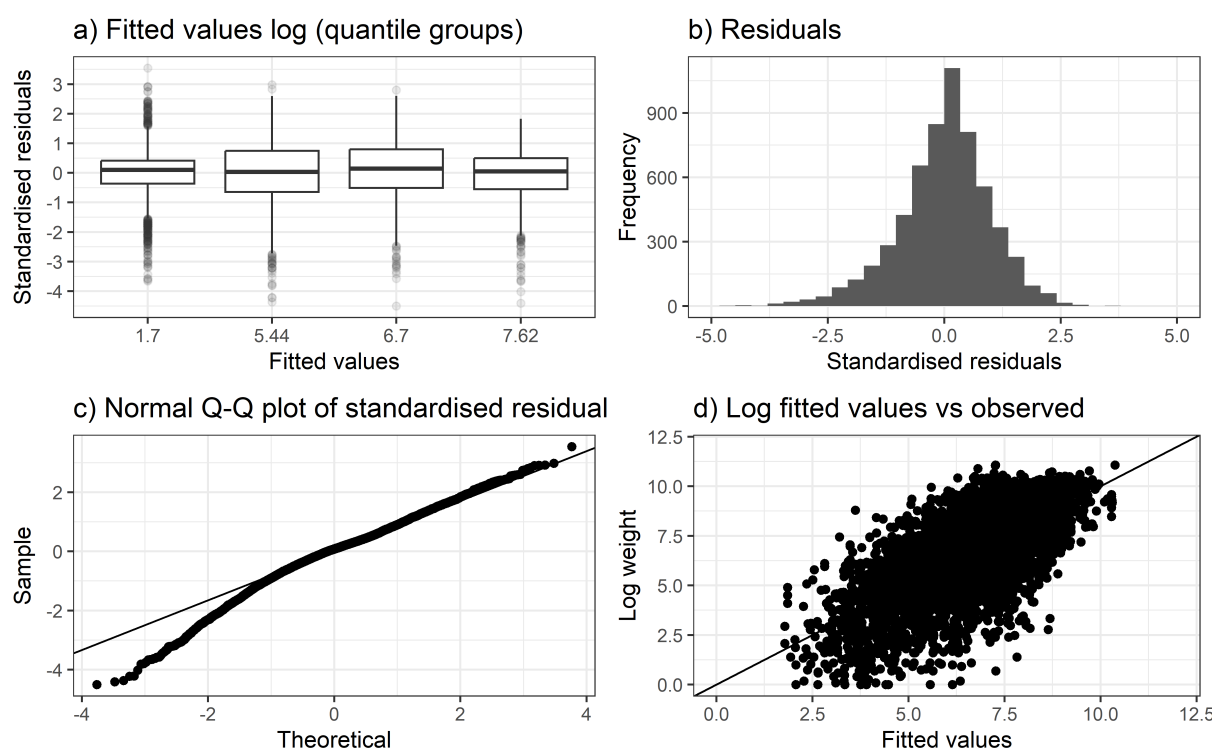


Figure F.12: Standardised residual plots from the NSW ocean beach daily catch rate analysis, for a) box plot of fitted values and residuals, b) histogram of residuals, c) normal quantile plot, and d) scatter plot of fitted values against log observed

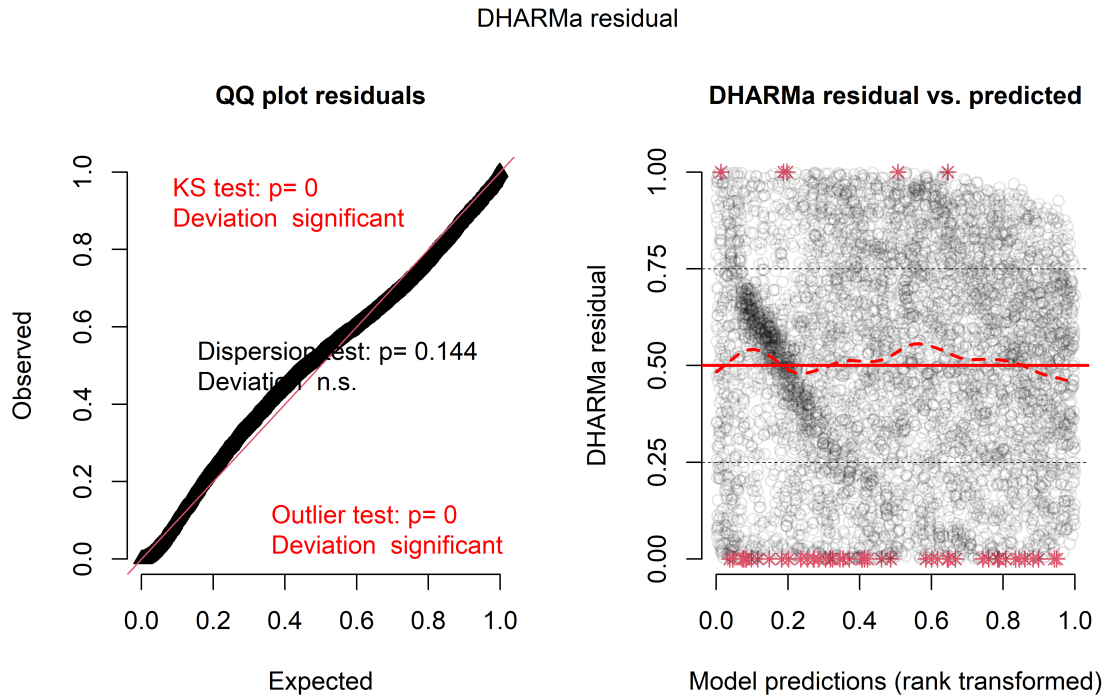


Figure F.13: Plot of DHARMA pit residuals from the NSW ocean beach daily catch rate analysis

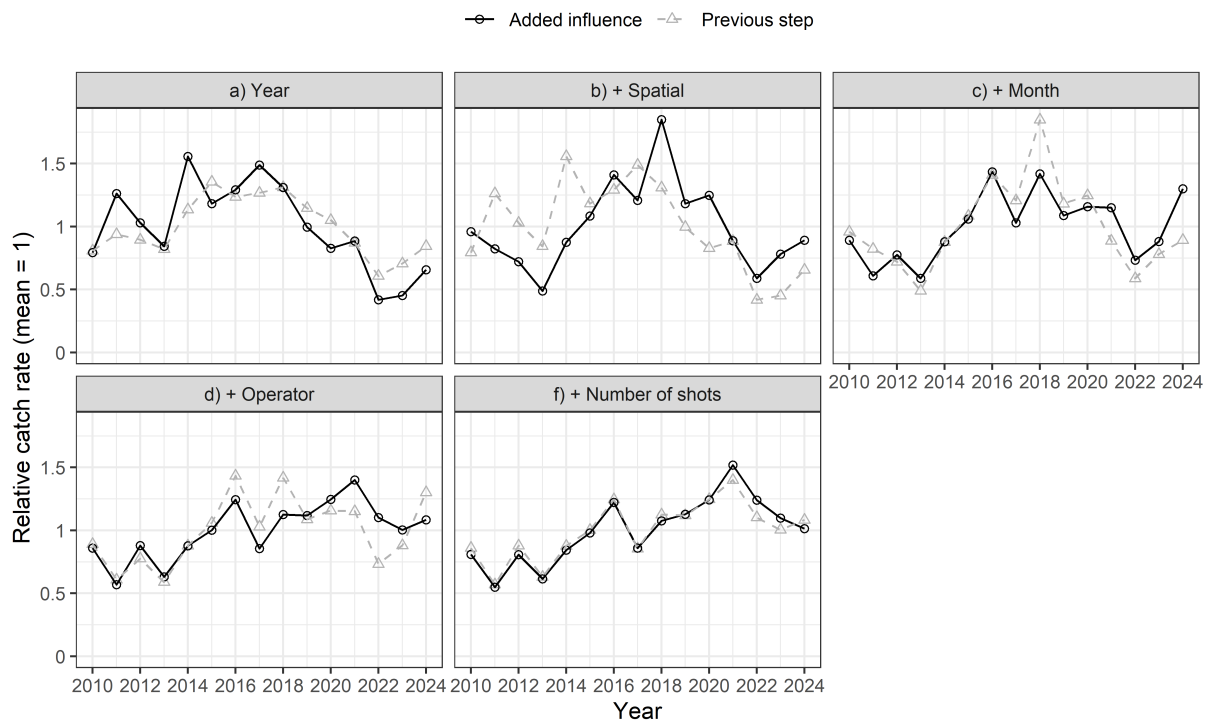


Figure F.14: Influence plot comparing the LM effects on standardised catch rates for the NSW ocean beach daily analysis—subplot: a) compared a year log-transformed response model to nominal catch rate, b) compared a year by latitude band model to model a, c) compared adding a common month effect to model b, d) added operator to compare to model c, e) compared the full model to model d, including the offset of log number of shots

F.3.3 NSW gill net monthly

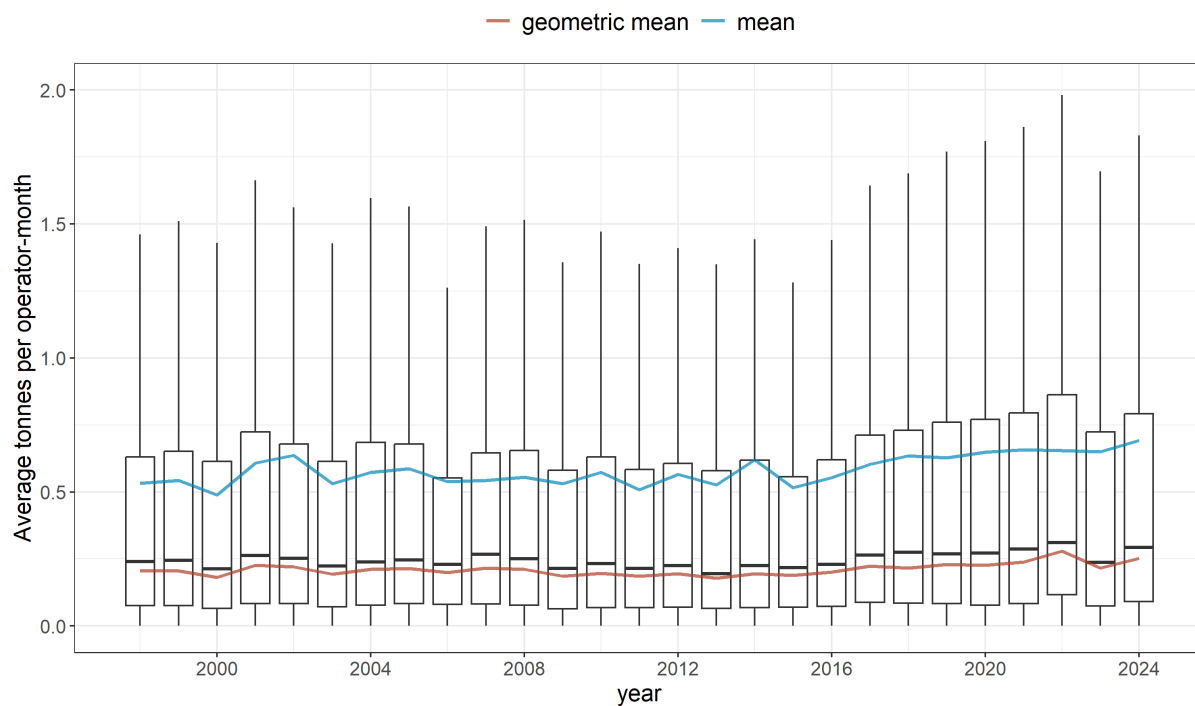


Figure F.15: Boxplot of the annual distribution of nominal monthly catches per operator for the NSW gill net fleet

Table F.5: Analysis of variance table for the NSW gill net monthly catch rate analysis—F statistics were derived from the R drop1 procedure. Adjusted R-squared = 0.371.

Term	Df	RSS	F value	Pr(>F)
Residual	51768	72456.3		
Operator	736	97739.8	24.544	0.000
Year : Latitude band	208	74926.2	8.484	0.000
Latitude band : Month	88	74591.3	17.334	0.000

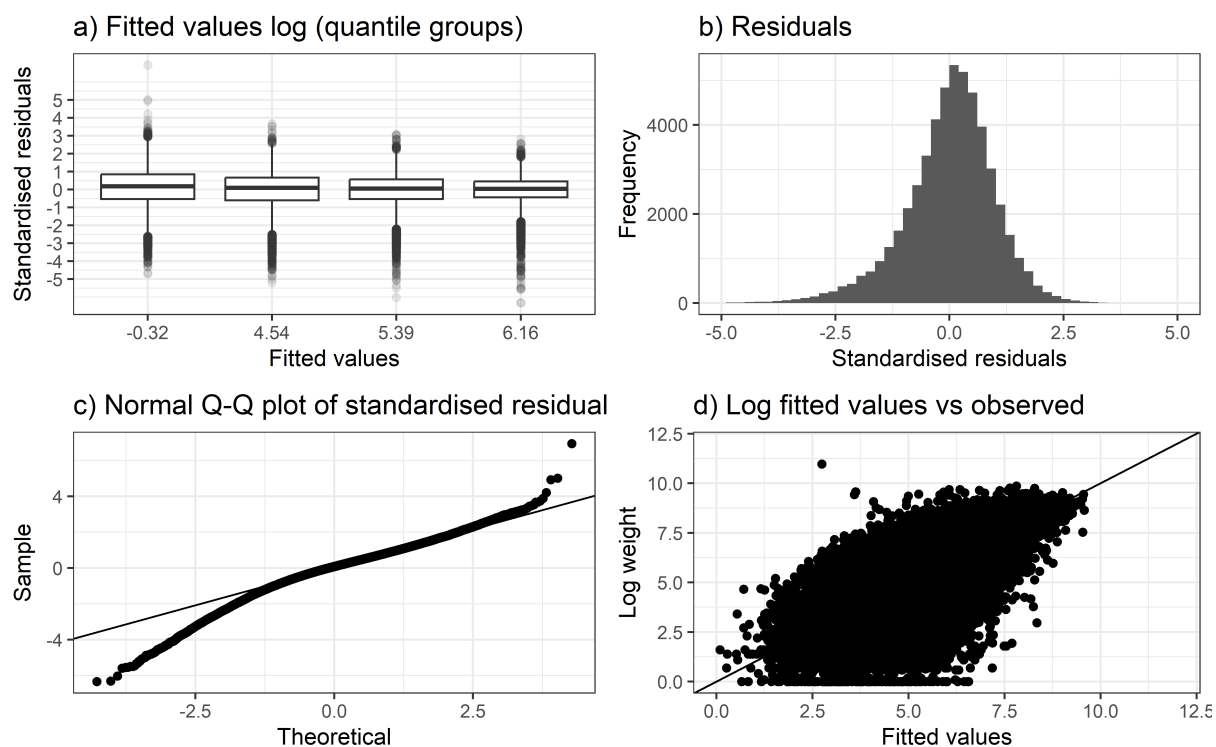


Figure F.16: Standardised residual plots from the NSW gill net monthly catch rate analysis, for a) box plot of fitted values and residuals, b) histogram of residuals, c) normal quantile plot, and d) scatter plot of fitted values against log observed

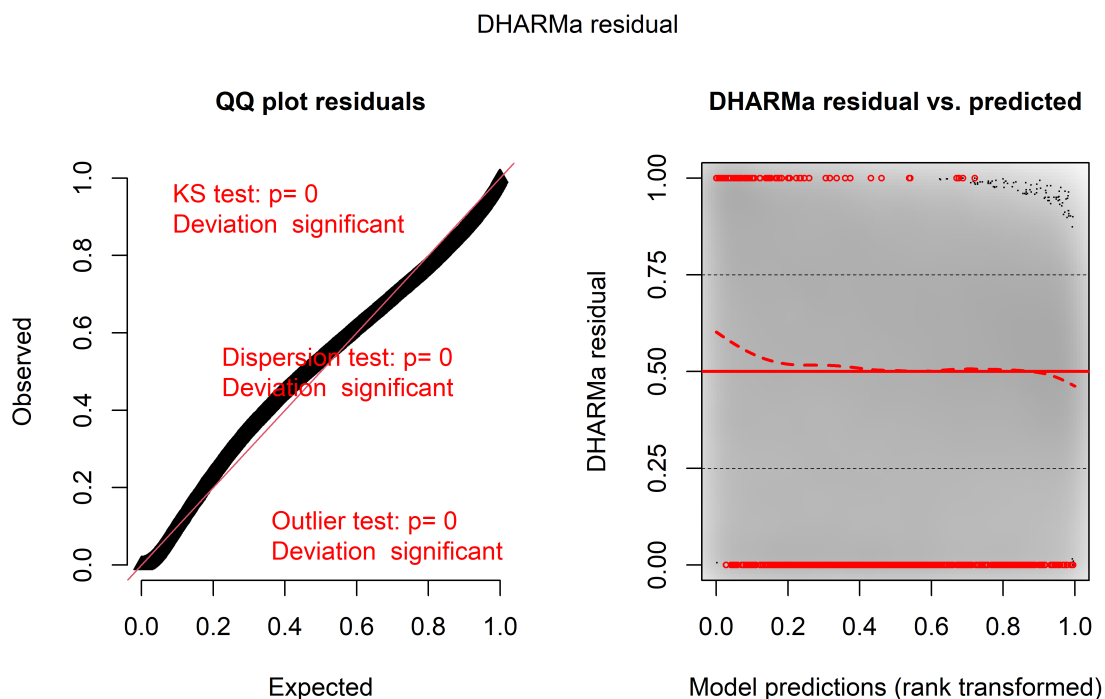


Figure F.17: Plot of DHARMA pit residuals from the NSW gill net monthly catch rate analysis

F.3.4 NSW ocean beach monthly

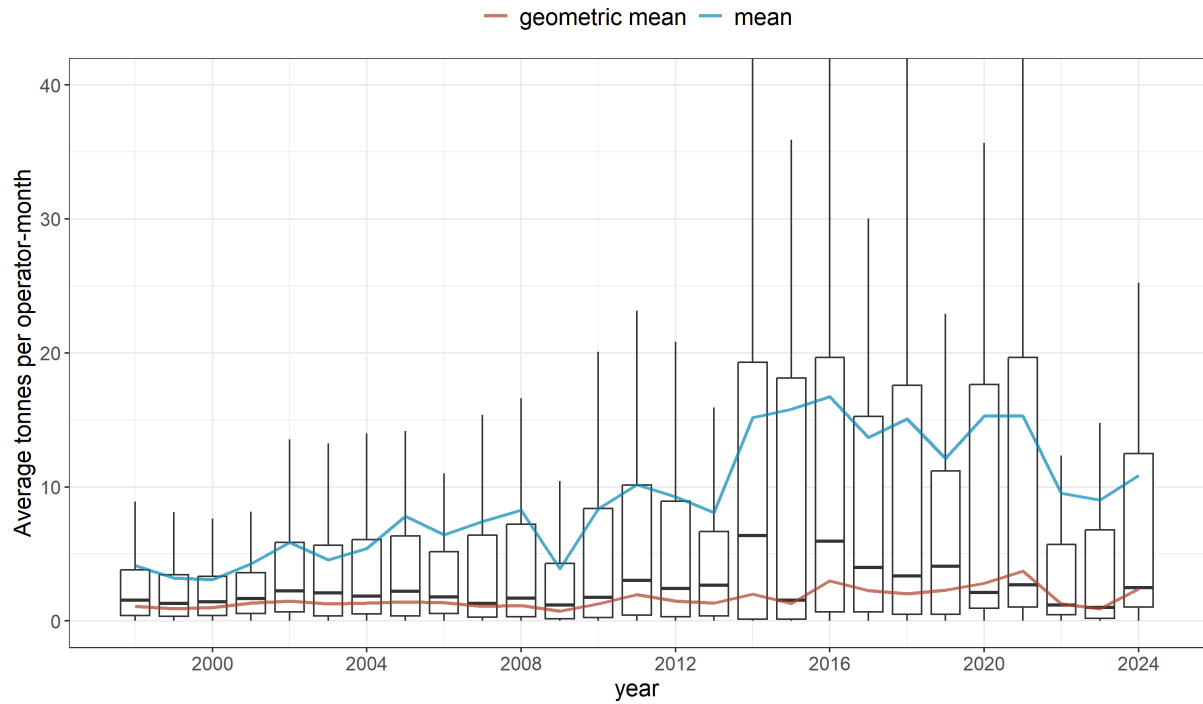


Figure F.18: Boxplot of the annual distribution of nominal monthly catches per operator for the NSW ocean beach fleet

Table F.6: Analysis of variance table for the NSW ocean beach monthly catch rate analysis—F statistics were derived from the R drop1 procedure, Adjusted R-squared = 0.534

Term	Df	RSS	F value	Pr(>F)
Residual	5345	10612.6		
Operator	294	14384.0	6.461	0.000
Year : Latitude band	104	11137.5	2.542	0.000
Latitude band : Month	44	11787.4	13.447	0.000

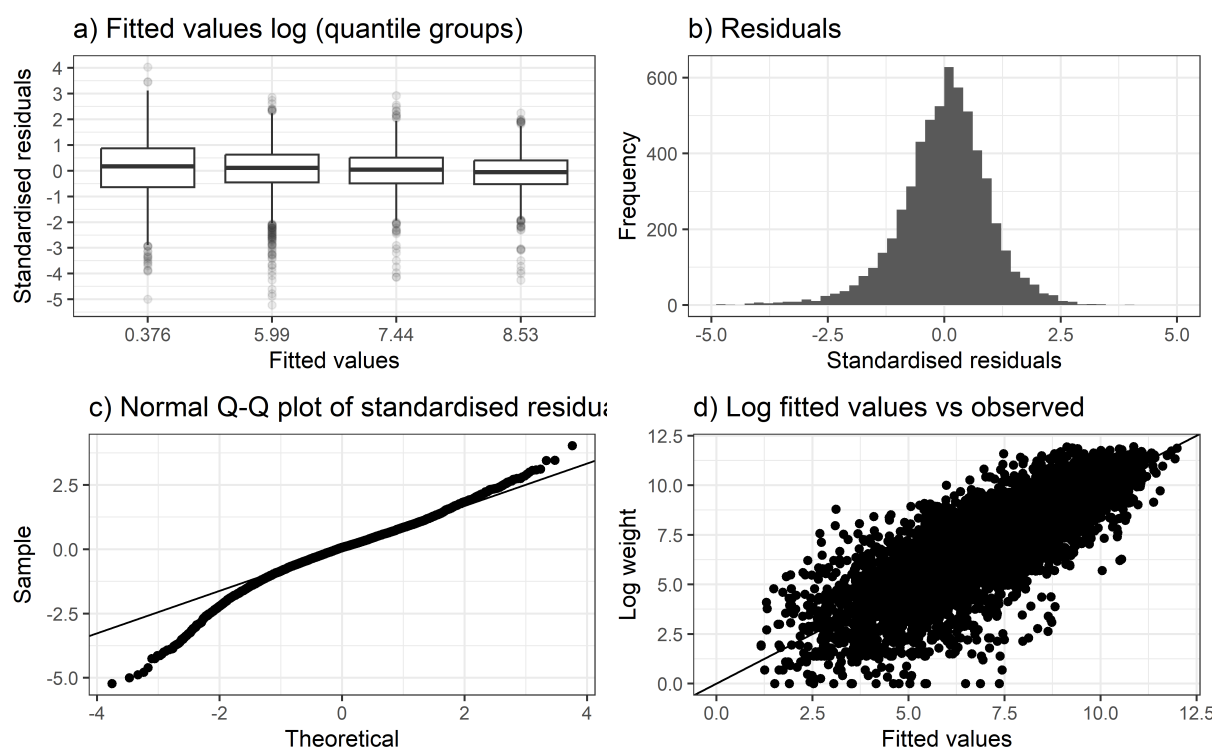


Figure F.19: Standardised residual plots from the NSW ocean beach monthly catch rate analysis, for a) box plot of fitted values and residuals, b) histogram of residuals, c) normal quantile plot, and d) scatter plot of fitted values against log observed

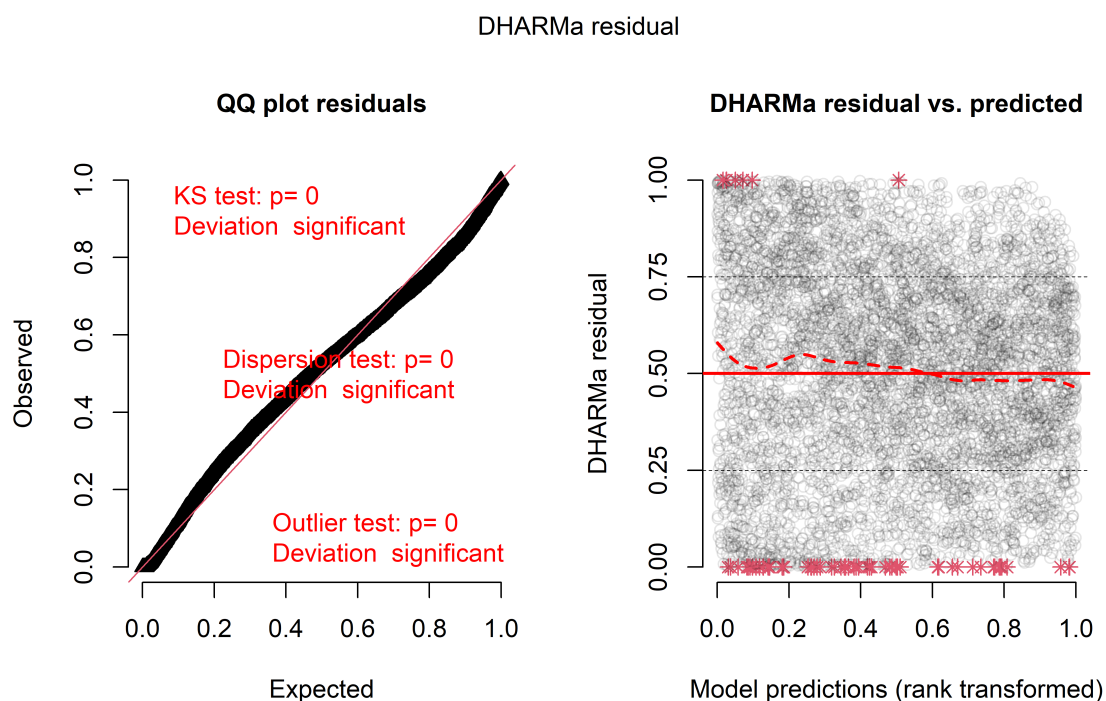


Figure F.20: Plot of DHARMA pit residuals from the NSW ocean beach monthly catch rate analysis

F.3.5 Qld gill net daily

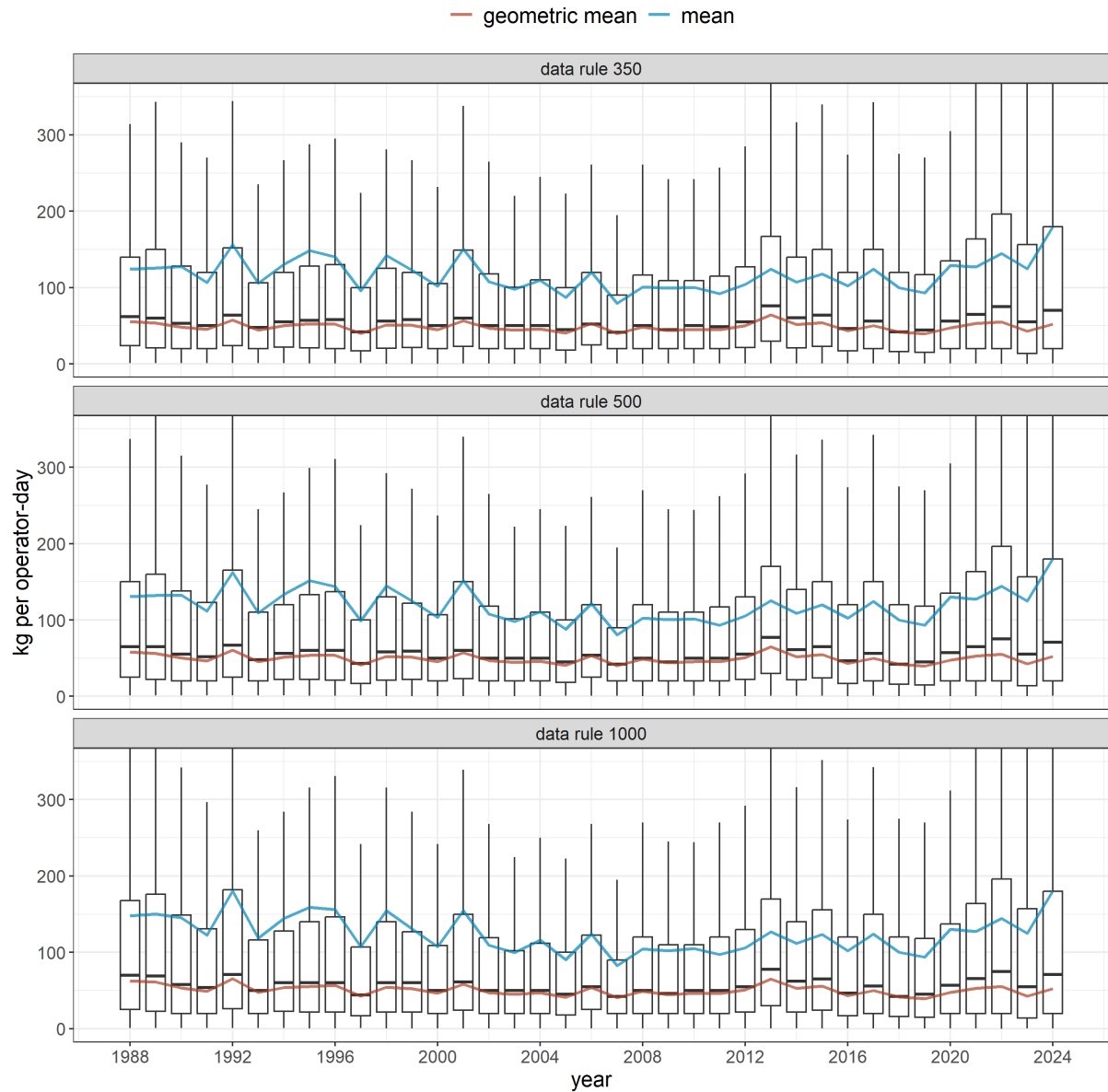


Figure F.21: Boxplot of the annual distribution of nominal daily catch rates by data rule for the Qld gill net fleet

Table F.7: Analysis of variance table for the Qld gill net daily catch rate analysis—F statistics were derived from the R drop1 procedure, Adjusted R-squared = 0.275 for the 350 kg data rule

Term	Df	RSS	F value	Pr(>F)
Residual	197248	267371.2		
Operator	445	326271.4	97.646	0.000
Good wind	1	267377.7	4.799	0.028
Year : Latitude band	216	272702.1	18.207	0.000
Latitude band : Month	66	271739.7	48.830	0.000

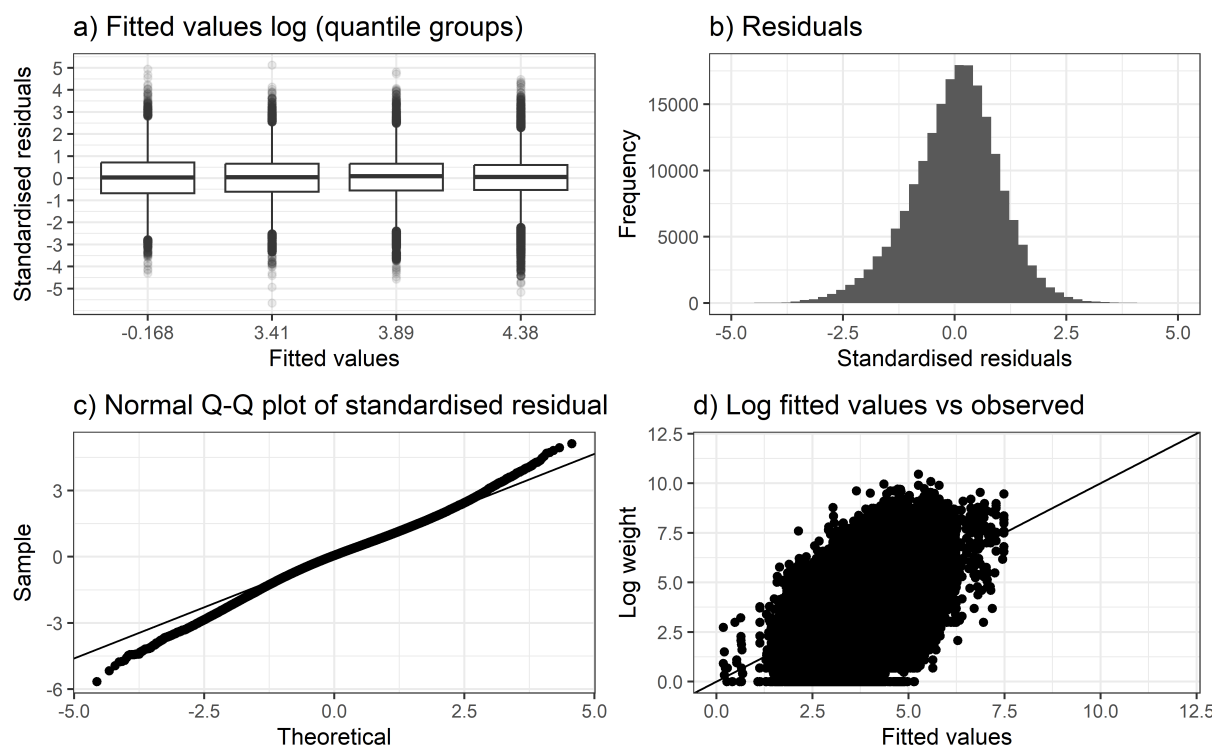


Figure F.22: Standardised residual plots from the Qld gill net daily catch rate analysis using the 350 kg data rule, for a) box plot of fitted values and residuals, b) histogram of residuals, c) normal quantile plot, and d) scatter plot of fitted values against log observed—residual plots were similar for the 500 and 1,000 kg data rules

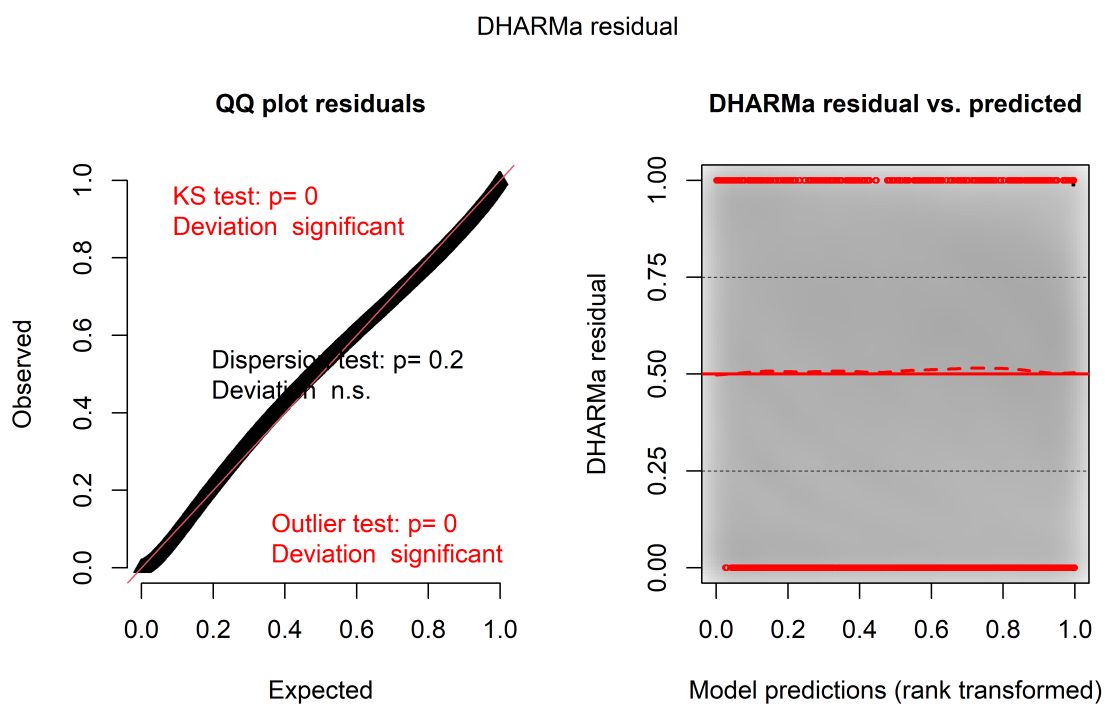


Figure F.23: Plot of DHARMA pit residuals from the Qld gill net daily catch rate analysis for the 350 kg data rule—the DHARMA results were similar for the 500 and 1,000 kg data rules

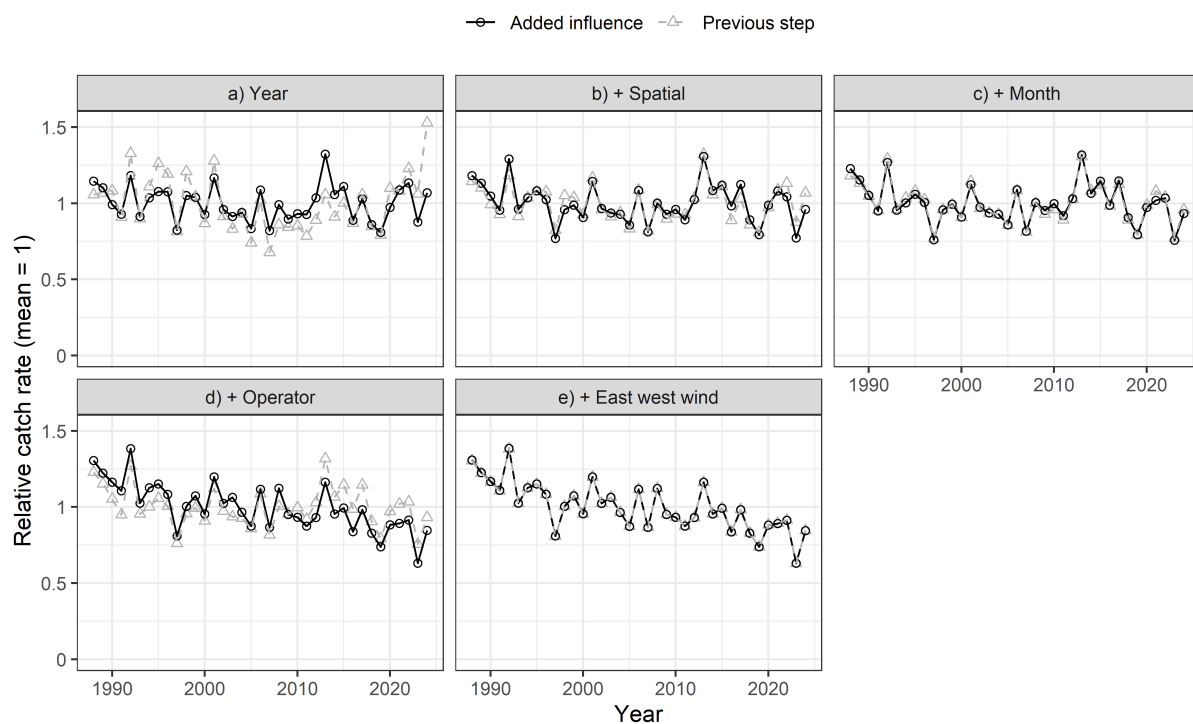


Figure F.24: Influence plot comparing the LM effects on standardised catch rates for the Qld gill net daily analysis, for the 350 kg data rule—subplot: a) compared a year log-transformed response model to nominal catch rate; b) compared a year by latitude band model to model a, c) compared adding the latitude band by month interaction to model b, d) added operator to compare to model c, e) added good wind to form the full model to compare to model d

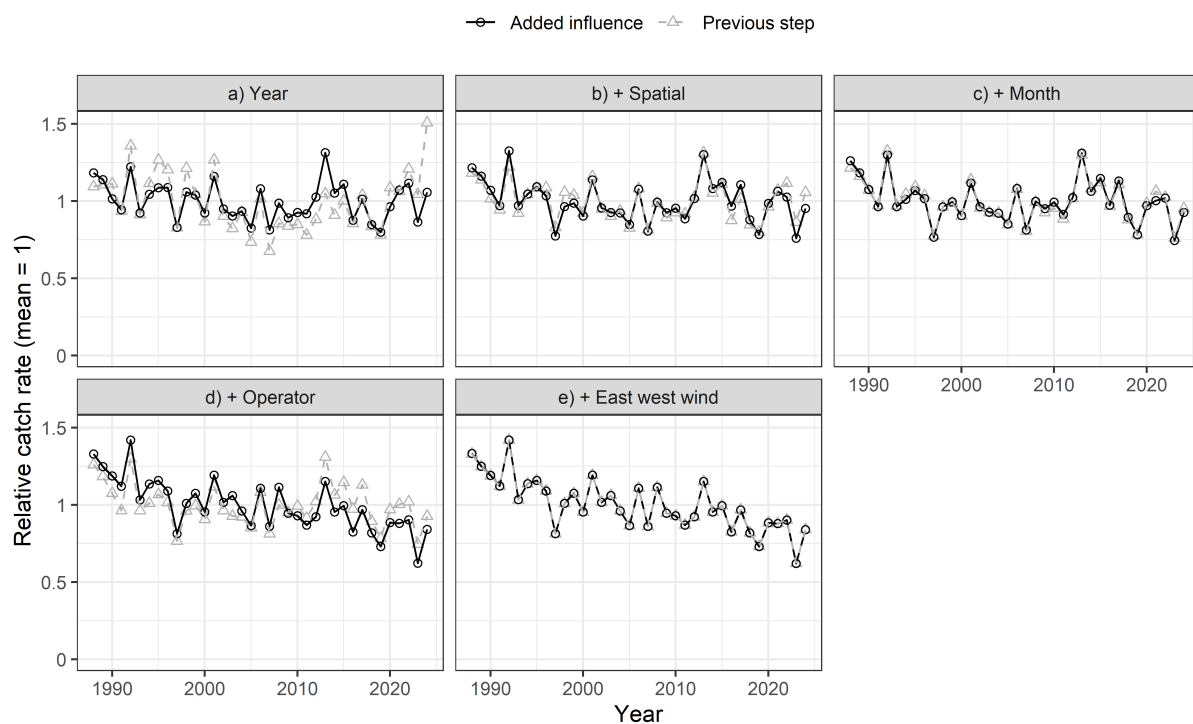


Figure F.25: Influence plot comparing the LM effects on standardised catch rates for the Qld gill net daily analysis, for the 500 kg data rule—subplot: a) compared a year log-transformed response model to nominal catch rate, b) compared a year by latitude band model to model a, c) compared adding the latitude band by month interaction to model b, d) added operator to compare to model c, e) added good wind to form the full model to compare to model d

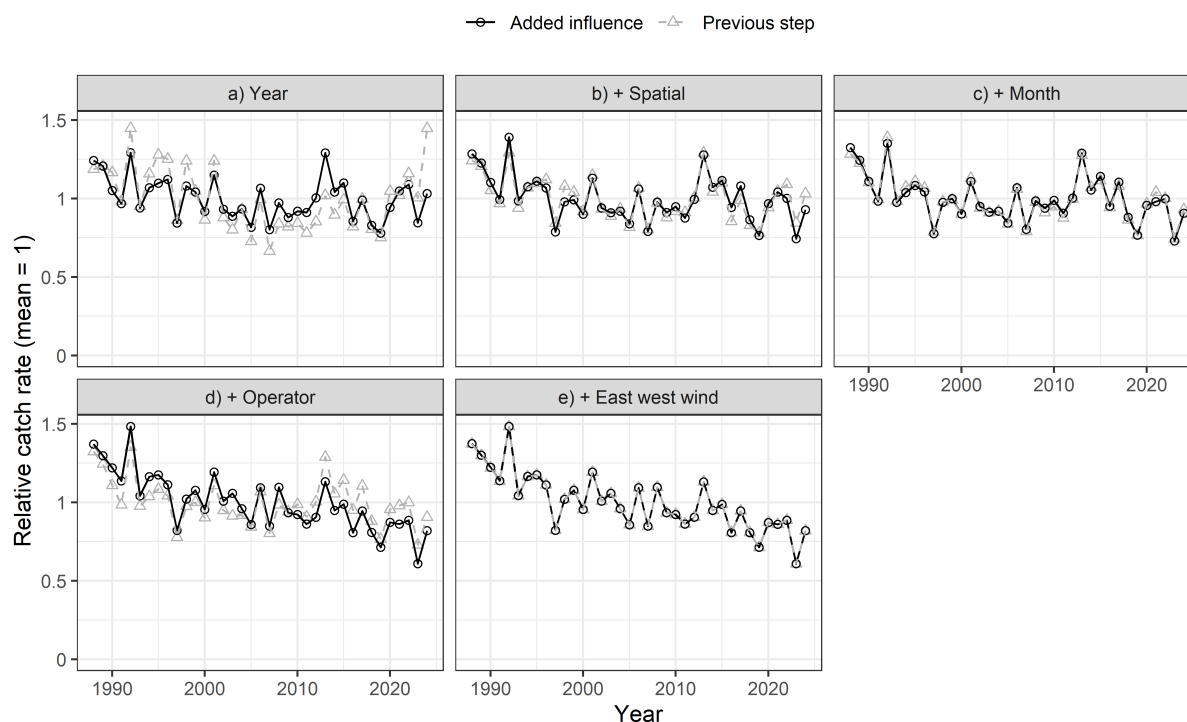


Figure F.26: Influence plot comparing the LM effects on standardised catch rates for the Qld gill net daily analysis, for the 1,000 kg data rule—subplot: a) compared a year log-transformed response model to nominal catch rate, b) compared a year by latitude band model to model a, c) compared adding the latitude band by month interaction to model b, d) added operator to compare to model c, e) added good wind to form the full model to compare to model d

F.3.6 Qld ocean beach daily

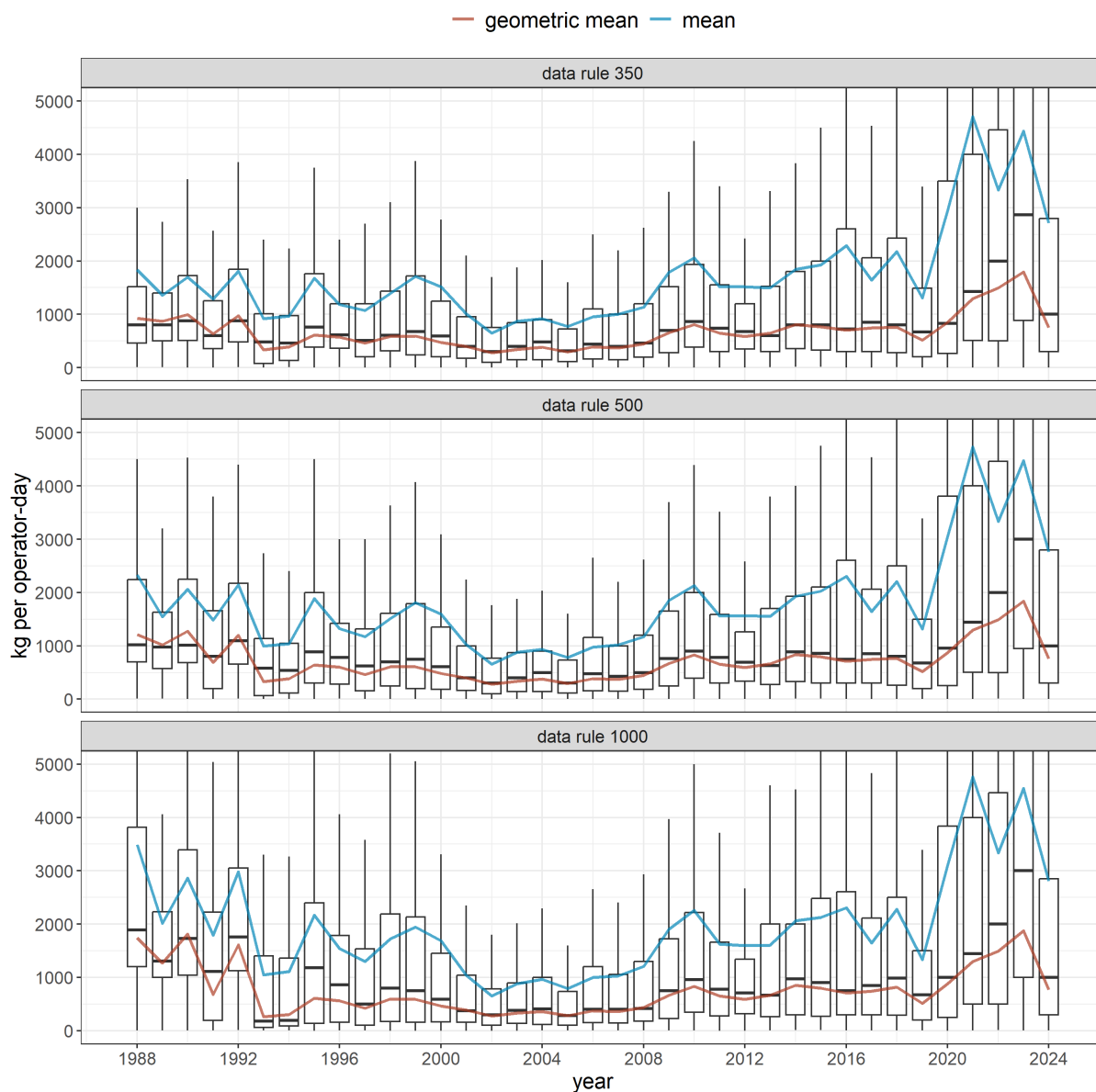


Figure F.27: Boxplot of the annual distribution of nominal daily catch rates by data rule for the Qld ocean beach fleet

Table F.8: Analysis of variance table for the Qld ocean beach daily catch rate analysis—F statistics were derived from the R drop1 procedure, Adjusted R-squared = 0.356 for the 350 kg data rule

Term	Df	RSS	F value	Pr(>F)
Residual	19801	27387.9		
Operator	153	32299.7	23.210	0.000
Good wind	1	27403.1	10.963	0.001
Year : Latitude band	144	29431.6	10.261	0.000
Latitude band : Month	16	27746.1	16.187	0.000

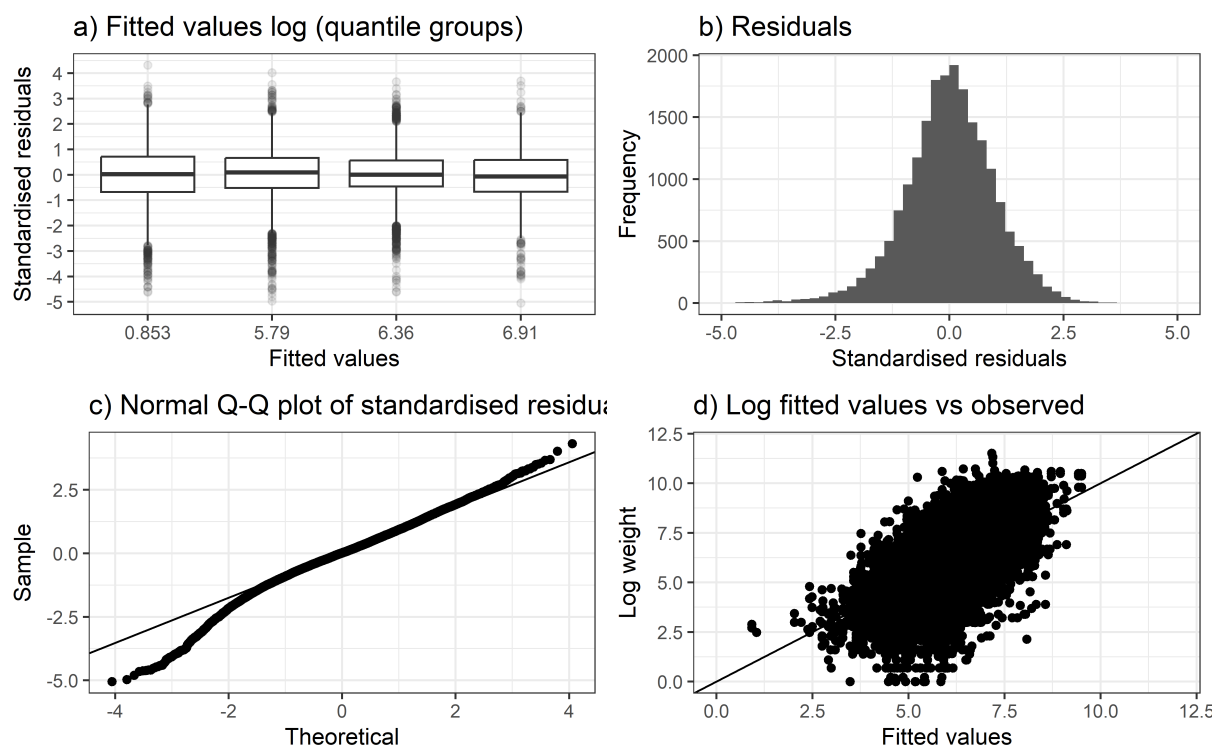


Figure F.28: Standardised residual plots from the Qld ocean beach daily catch rate analysis using the 350 kg data rule, for a) box plot of fitted values and residuals, b) histogram of residuals, c) normal quantile plot, and d) scatter plot of fitted values against log observed—residual plots were similar for the 500 and 1,000 kg data rules

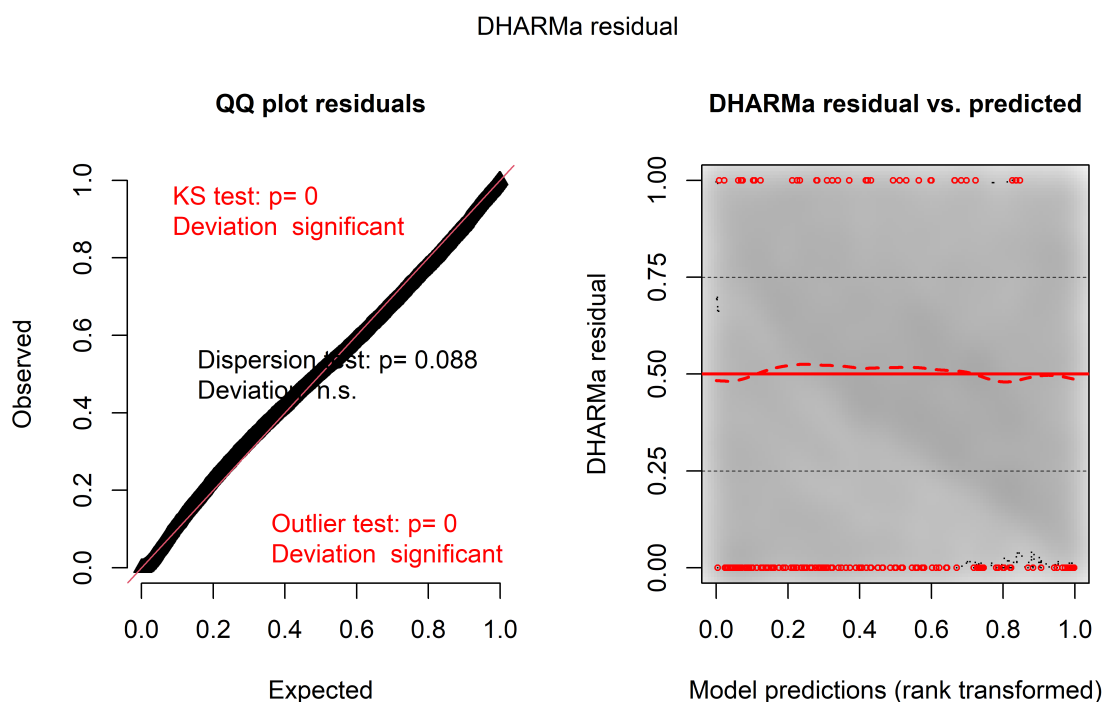


Figure F.29: Plot of DHARMA pit residuals from the Qld ocean beach daily catch rate analysis for the 350 kg data rule—the DHARMA results were similar for the 500 and 1,000 kg data rules

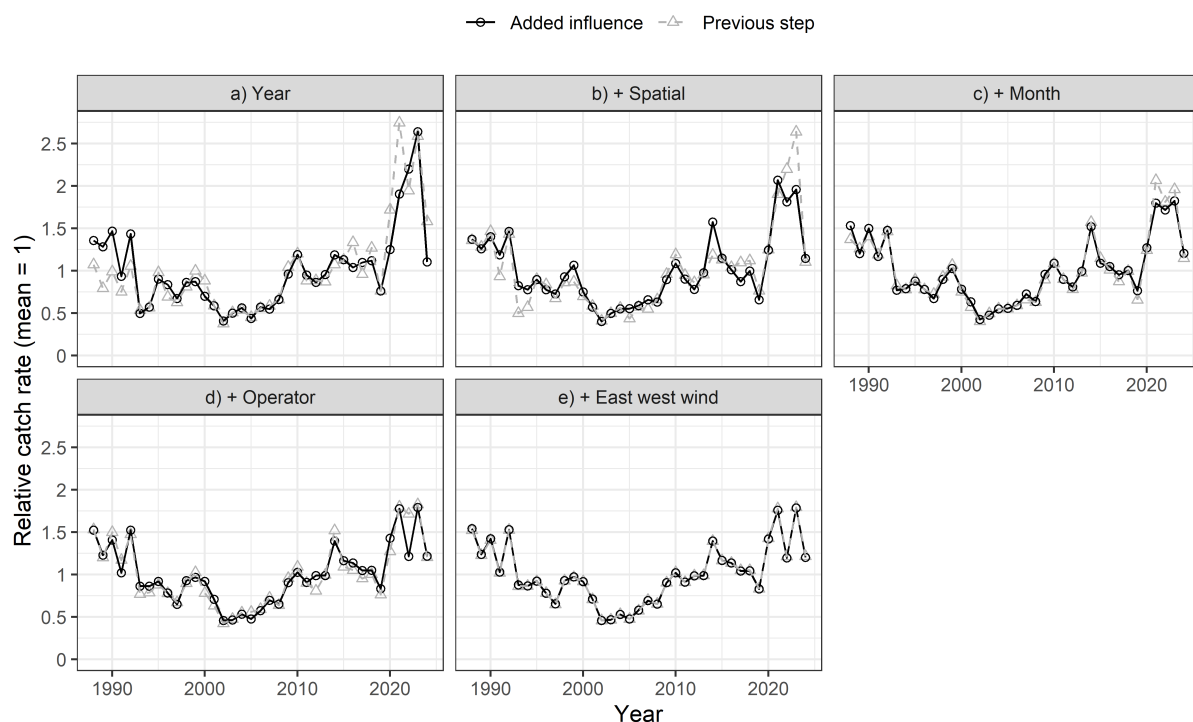


Figure F.30: Influence plot comparing the LM effects on standardised catch rates for the Qld ocean beach daily analysis, for the 350 kg data rule—subplot: a) compared a year log-transformed response model to nominal catch rate, b) compared a year by latitude band model to model a; c) compared adding the latitude band by month interaction to model b, d) added operator to compare to model c, e) added good wind to form the full model to compare to model d

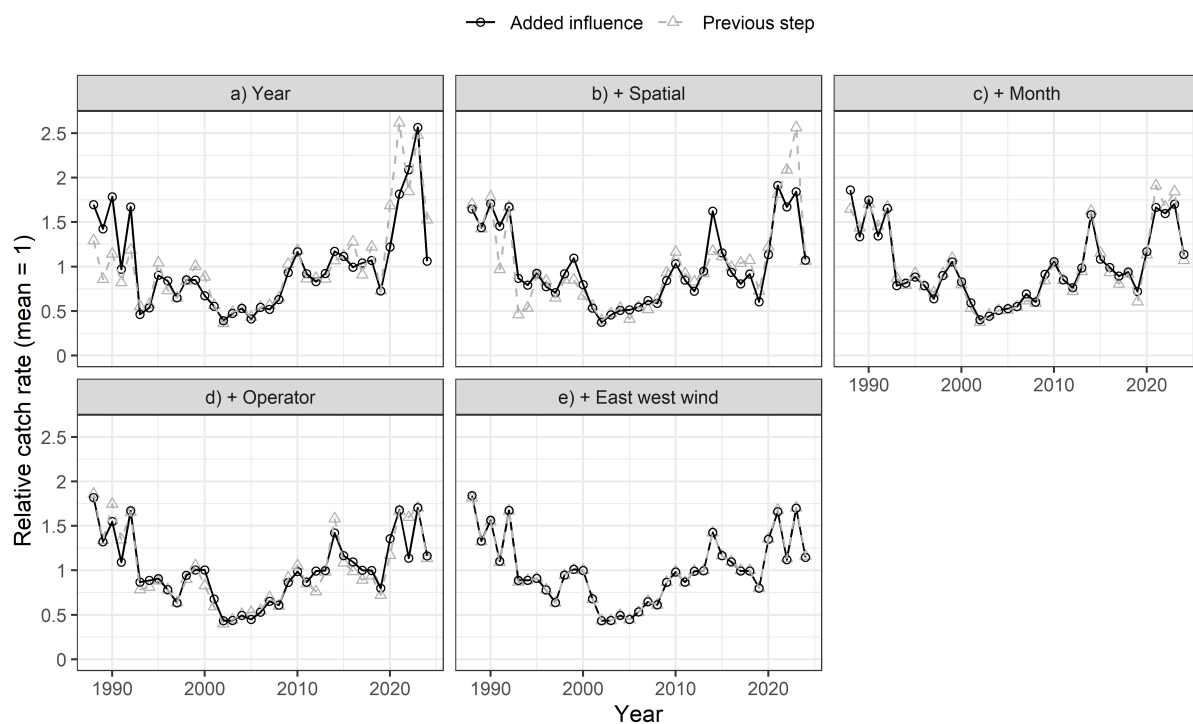


Figure F.31: Influence plot comparing the LM effects on standardised catch rates for the Qld ocean beach daily analysis, for the 500 kg data rule—subplot: a) compared a year log-transformed response model to nominal catch rate, b) compared a year by latitude band model to model a, c) compared adding the latitude band by month interaction to model b, d) added operator to compare to model c, e) added good wind to form the full model to compare to model d

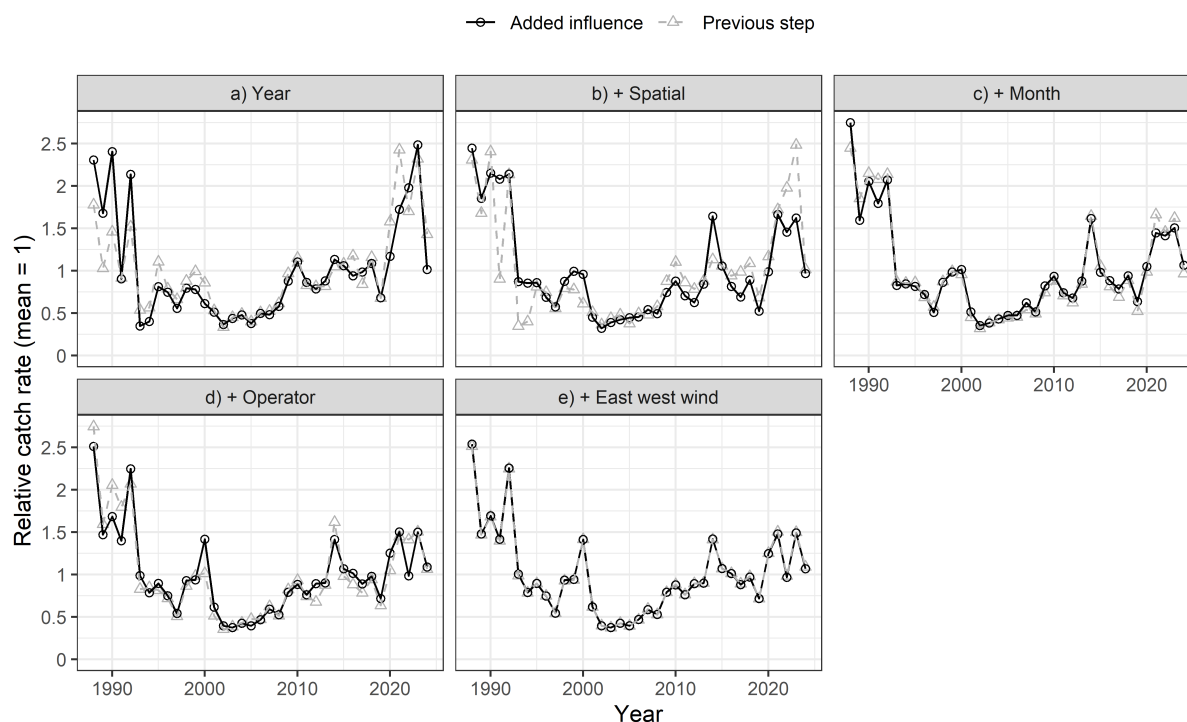


Figure F.32: Influence plot comparing the LM effects on standardised catch rates for the Qld ocean beach daily analysis, for the 1,000 kg data rule—subplot: a) compared a year log-transformed response model to nominal catch rate, b) compared a year by latitude band model to model a, c) compared adding the latitude band by month interaction to model b, d) added operator to compare to model c, e) added good wind to form the full model to compare to model d

F.4 Fishing power

Fishing-power results by fleet are displayed for NSW in Figure F.33 and Qld in Figure F.34. Results were relative to each dataset mean, as estimated from operator days of fishing effort and their parameter estimates from the linear models.

In NSW, the results showed an improved gill net fleet profile/power for estuarine sea mullet (for daily data and for monthly data). The fleet profile varied year-to-year for ocean beach netting. The ocean beach daily results had a fluctuating pattern, whereas the monthly results signaled a decline since 2018.

For Qld, increases in fleet profile/fishing power were evident for estuarine gill netting. The Qld ocean beach fleet results, like in NSW, were more variable from year-to-year compared to estuarine gill netting.

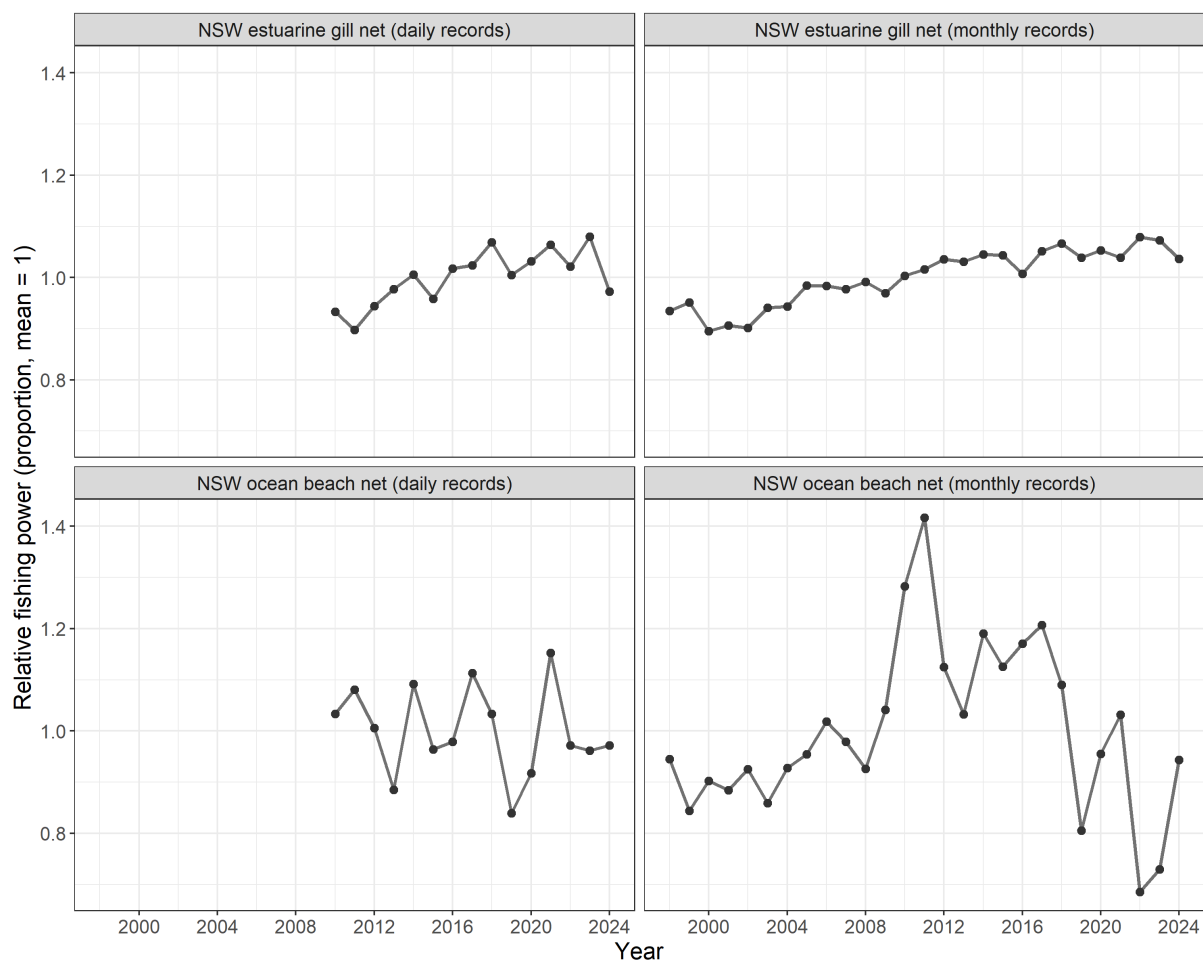


Figure F.33: Proportional annual change in fleet fishing power, as estimated from 4 different NSW datasets—each result was scaled relative to the mean = 1

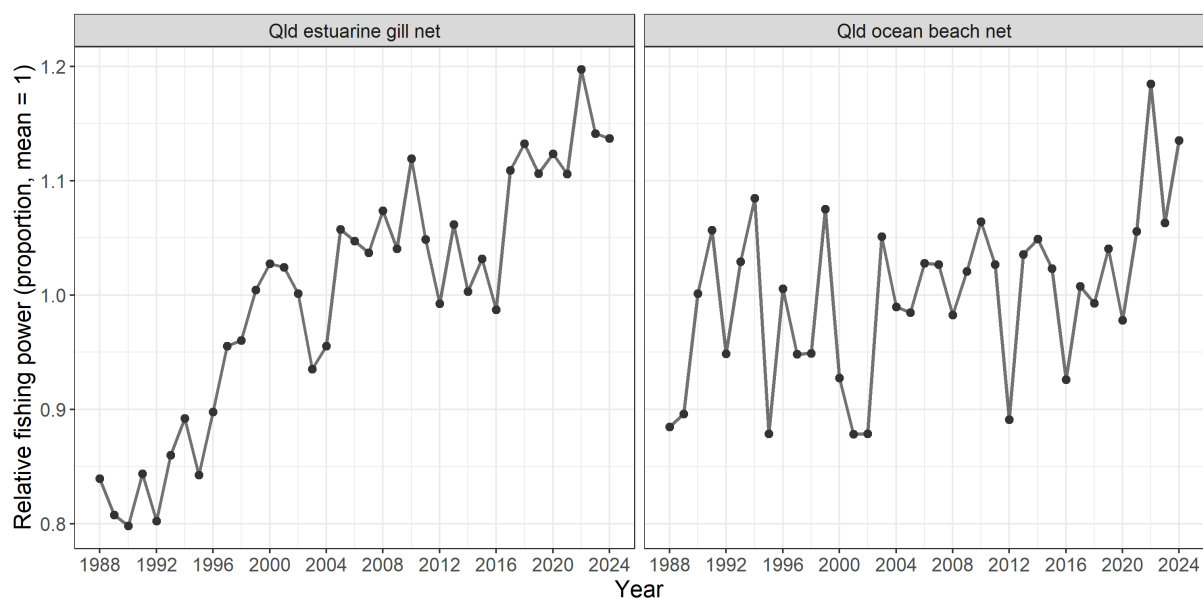


Figure F.34: Proportional annual change in fleet fishing power, as estimated from 2 different Qld datasets—each result was scaled relative to the mean = 1

F.5 Alternate Qld ocean beach catch rate

Brief

This exploratory analysis investigated catch rates in the Qld ocean beach fishery by year and latitude band. As sea mullet catches were the product of ocean beach fishing effort (operator days and weather) and abundance (number of schools and size of schools), trends in total catches might reflect changes in fish abundance (Quinn and Deriso 1999).

In the analysis, trends in total catches were assumed to index fish abundance after standardising for the number of operators fishing and winds. The reason for this approach was less hyperstability, with zero catch days considered. Also, the analysis tested if the number of operators should be negatively offset (as done in the previous 2020 assessment).

Data and GLM

Sea mullet catch, the number of operators and offshore winds were tallied by year, month and latitude band (half degree). Offshore winds were the number of good wind days, defined by the east-west wind components less than the 50th quantile (binary variate 1 = TRUE and 0 = FALSE).

The GLM equation for the analysis in R was:

$$\text{tonnes} \sim \exp(\text{year} \times \text{latitudeband} + \text{month} + \text{offset}(\log(\text{days}))) \quad (\text{F.2})$$

where the GLM type and variables were:

- *tonnes*: tonnage of sea mullet per year, month and latitude band (number)
- *year*: calendar years of complete data 1998 to 2024 (factor)
- *latitudeband*: 5 bands 25.75–27.75 (factor)
- *month*: ocean beach months 4–8 (factor)
- *days*: number of operators x (number of good east-west days + 1) (variate)
- *GLM family and link function*: Quasi-Poisson and log-link.

The emmeans R package predicted mean catch rates, using a mean log offset and proportional marginal weights for factors.

Results

The model had a high adjusted R-square, explaining 71% deviance. Model dispersion was 6.2 t. Modelling days as a covariate was equivalent to the offset, with a parameter estimate of 1.04 and standard error of 0.09. This signalled and included the positive effect of more operators (i.e. more fish and higher catches attracting more fishers). An offset model was used in predictions (Figure F.35 and Figure F.36).

Predicted catch rates highlight a fall in the northern latitude band 25.75, for the southern K'gari to Double Island Point area. There were large spikes in catches in 2016 and 2021, from the Noosa–Sunshine Coast (26.25) and Stradbroke Island south (27.75) areas. Catches appeared stable 2022–2024, with a decline in the Moreton Island area in 2024.

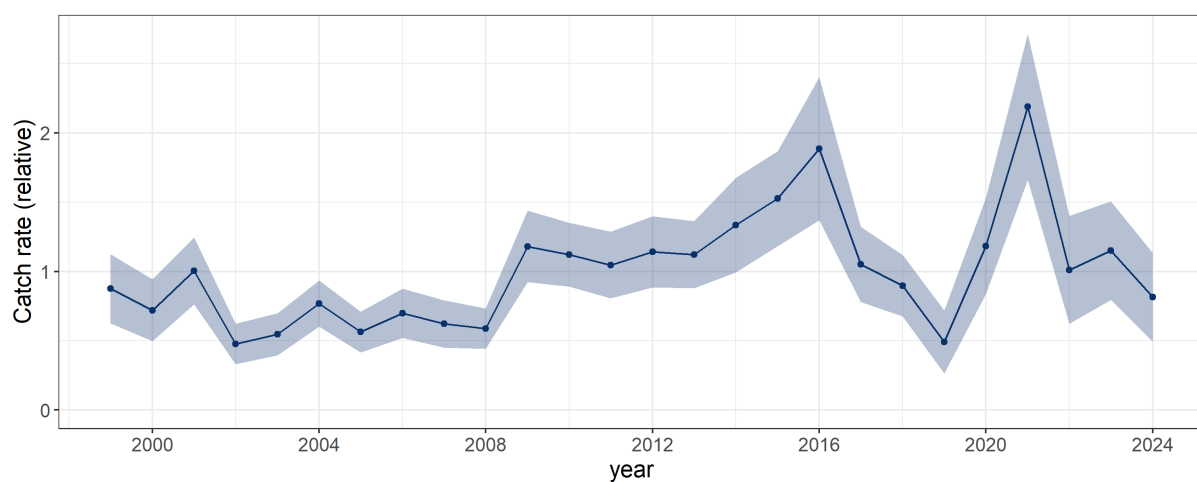


Figure F.35: Alternate standardised catch rate of Qld ocean beach sea mullet—shaded ribbon represents 95% confidence intervals

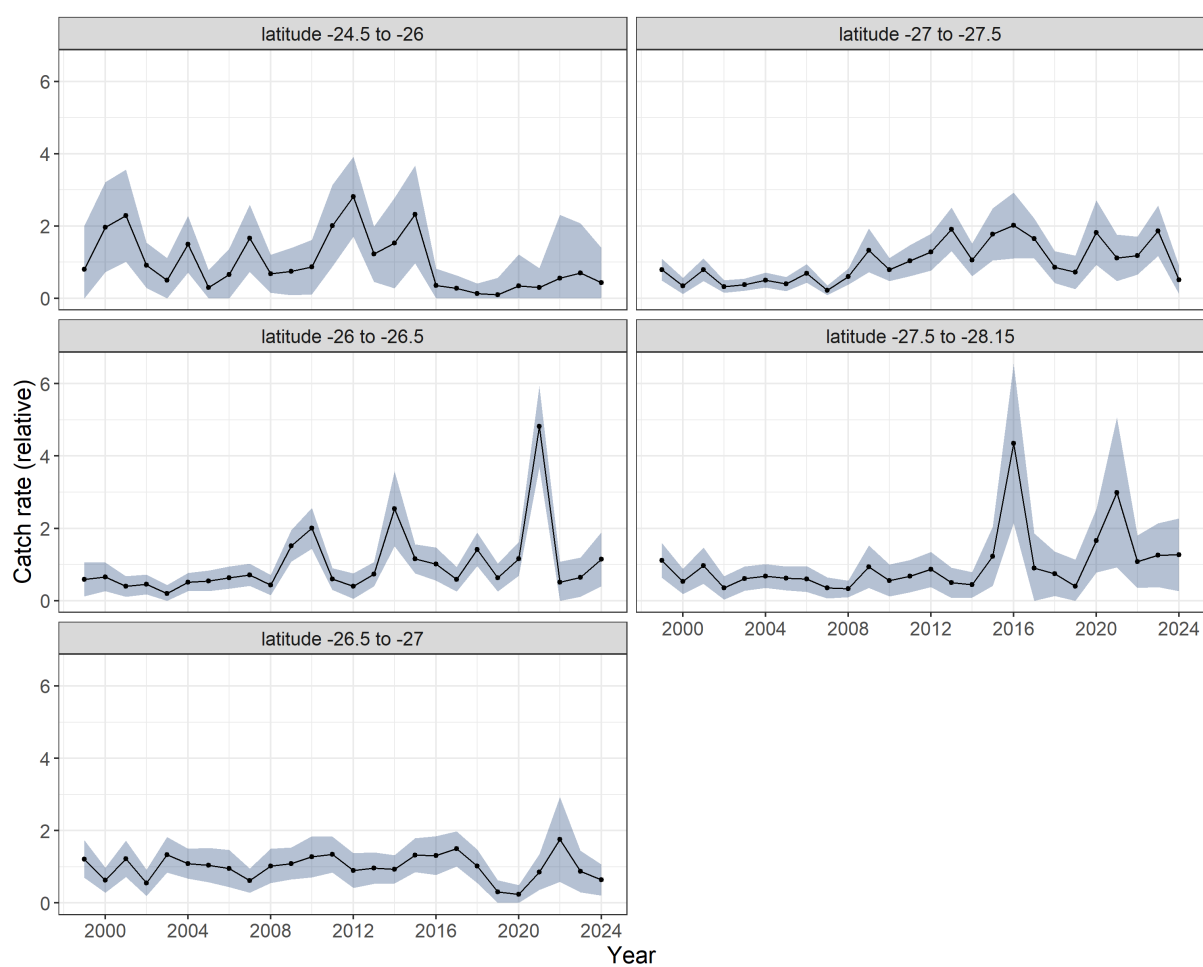


Figure F.36: Alternate standardised catch rate of Qld ocean beach sea mullet by latitude band—shaded ribbon represents 95% confidence intervals

G Model inputs

G.1 Biological data

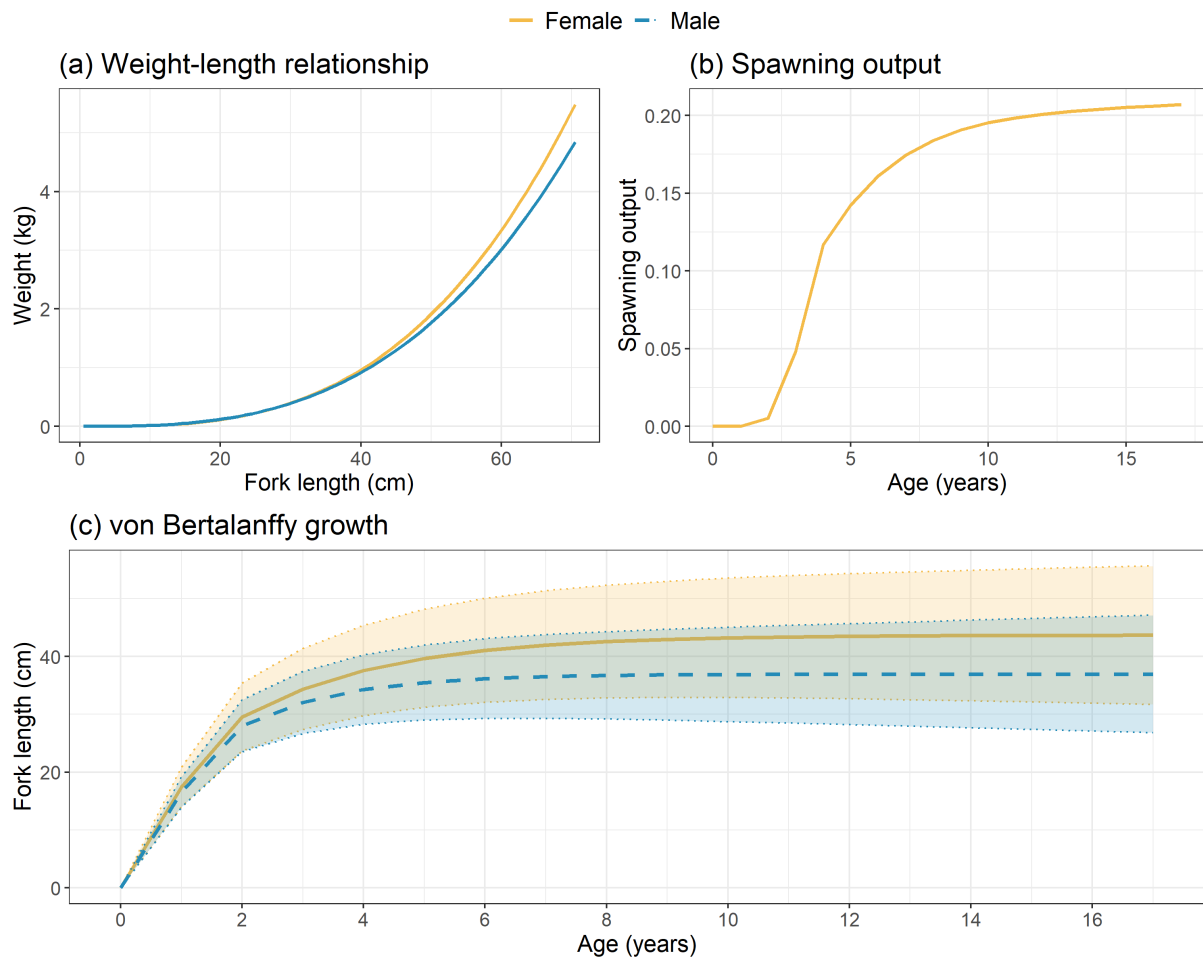


Figure G.1: Biological relationships input to the Stock Synthesis model for Australian east coast sea mullet

G.2 Ageing error

An ageing error matrix was estimated for Stock Synthesis using 2 rereads of Queensland sea mullet otoliths.

The error was modelled using TMB code written for R by Prof André Punt. Methods followed Punt et al. (2008), Heifetz et al. (1999) and Burch and Punt (2023).

The error matrix assumed no bias with linear standard deviation (type 7 error) with age (Burch and Punt 2023). The data were simply structured for twice age-read otoliths. No consideration was given for different years or different people. Multiple reads were generally from the same person. Third or fourth reads on a minor number of otoliths were excluded; data were few and non-random.

The range of ages modelled were 1 to 17 years. The number of data (sample size of reread ages) analysed was 9,048. For analysis, ages were annual age group counts.

The linear type 7 error-model had 2 parameters (minimum and maximum standard deviation SD) to estimate (Table G.1). The maximum gradient for convergence was borderline, but accepted as data trimming was undesirable (Burch and Punt 2023). Figure G.2 illustrated the results of standard deviations by age.

Observed and estimated (fitted) ages were similar, with the slight suggestion of more 4 year olds (Figure G.3).

In discussion of standard deviation models in the TMB code, linear was preferred and understood by monitoring staff. Adding more complexity, as demonstrated in some models by Burch and Punt (2023), would require more data. Further work could research the use of hierarchical GLMs (Lee 2006; VSN International 2022), where more detailed dispersion models could be estimated.

Table G.1: Parameter estimates and standard deviations (SD) for the linear age-error-model.

Variable	Estimate	SD
Min SD age 1+	0.17	0.01
Max SD age 17+	0.69	0.03

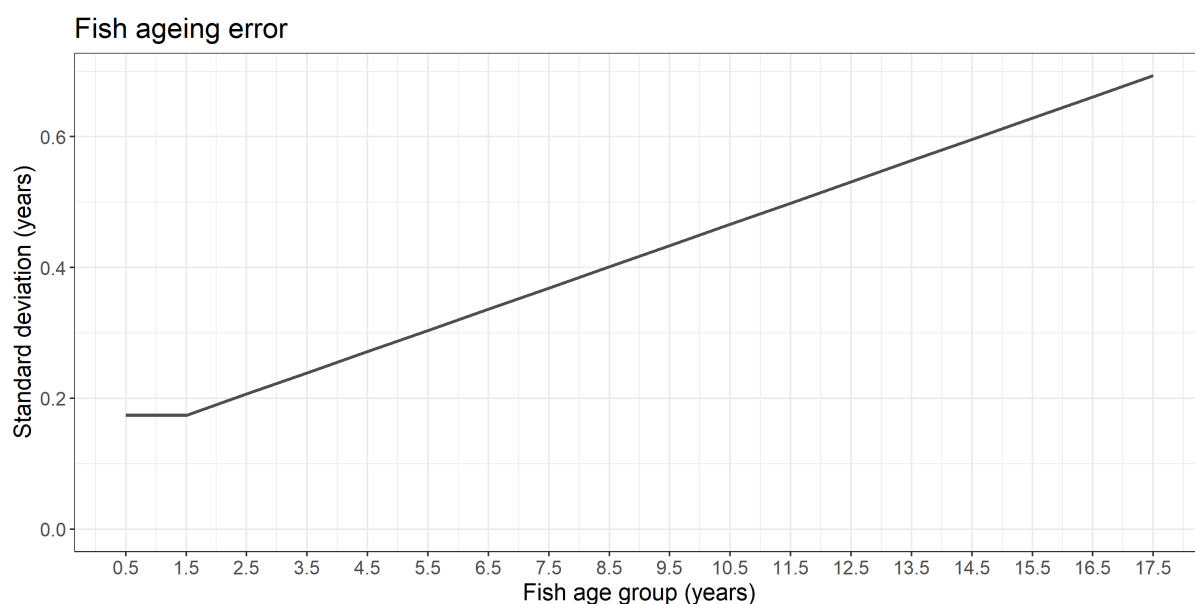


Figure G.2: Linear increase in standard deviation of random age-reading error with fish age for Queensland sea mullet

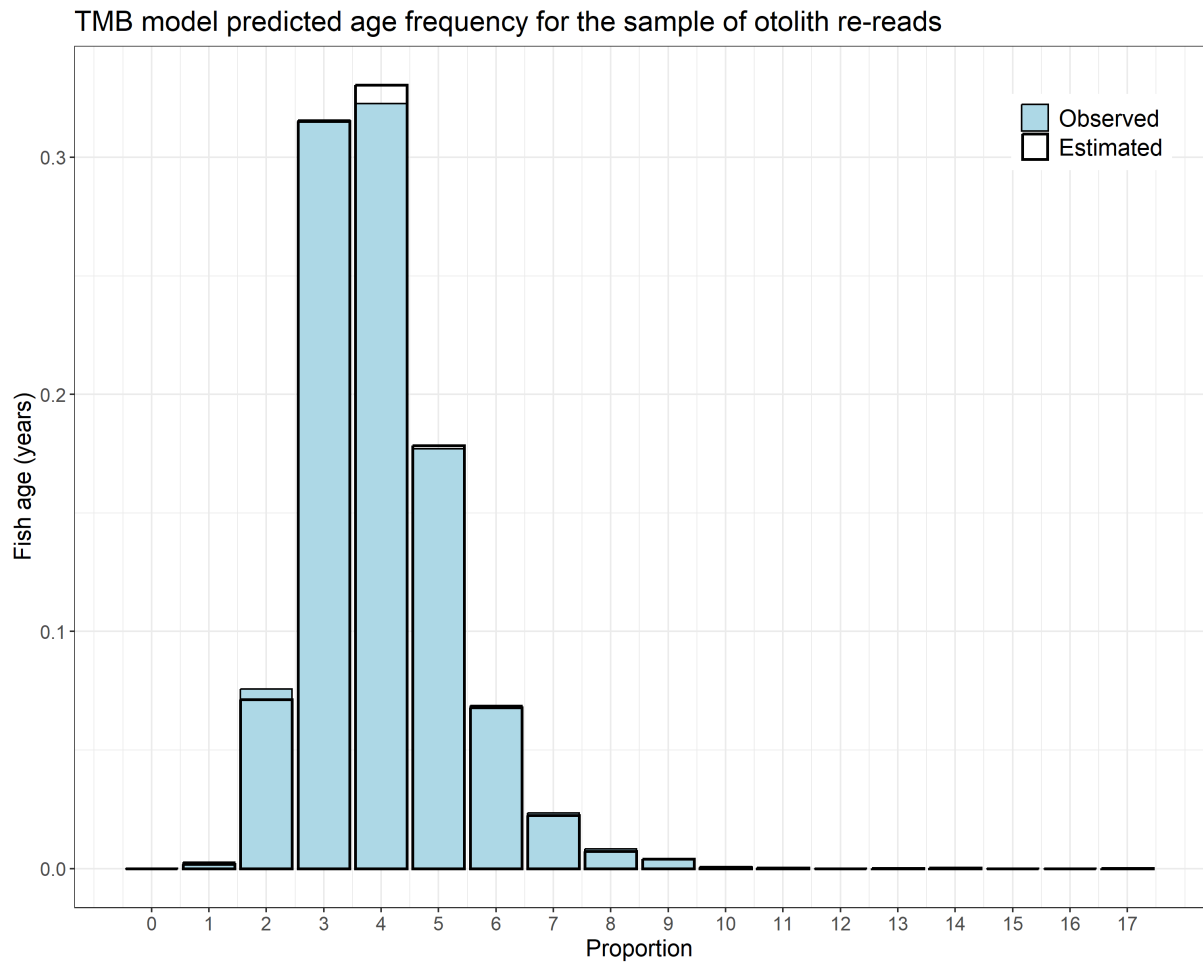


Figure G.3: Comparison of observed and estimated ages over 2 independent otolith re-reads for Queensland sea mullet

H Model outputs

The ensemble model has been derived from the weighted outcomes of 24 scenarios (see Section 2.6.3). Outputs shown in this section show either the derived ensemble outcome, the results from each of the 24 scenarios within the ensemble or the first 8 scenarios of the ensemble as a representative subset. Scenarios 1–8 within the ensemble include all catch rate and vulnerability options with a natural mortality value of 0.33 (natural mortality upper and lower bound scenarios are excluded).

H.1 Diagnostics

H.1.1 Fits to data

H.1.1.1 Catch rates

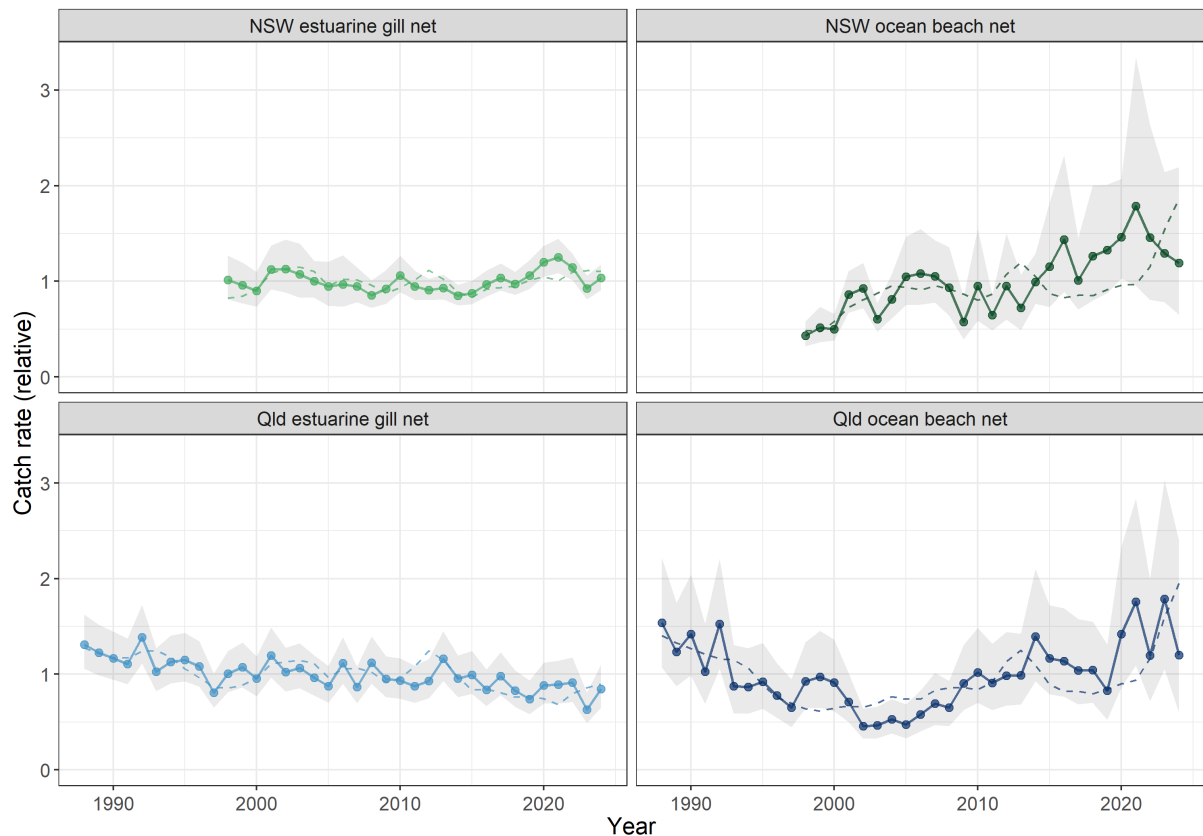


Figure H.1: Ensemble fits to catch rates for Australian east coast sea mullet

H.1.1.2 Length

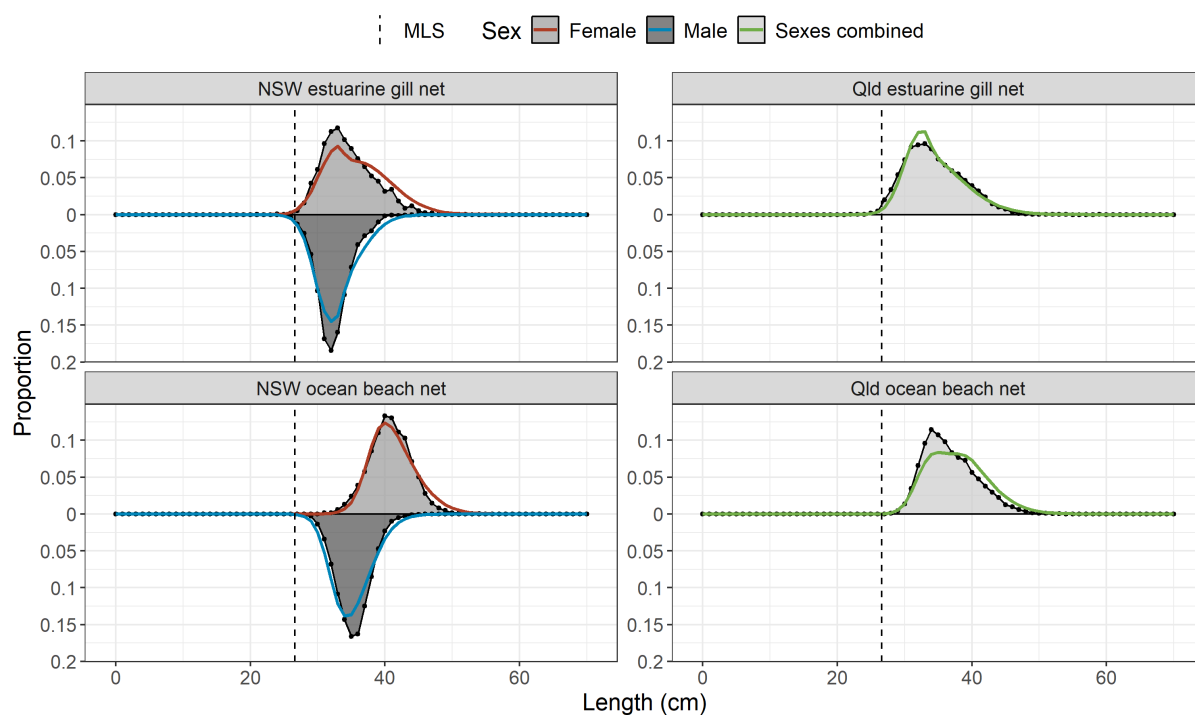


Figure H.2: Ensemble fits to aggregated length data for Australian east coast sea mullet

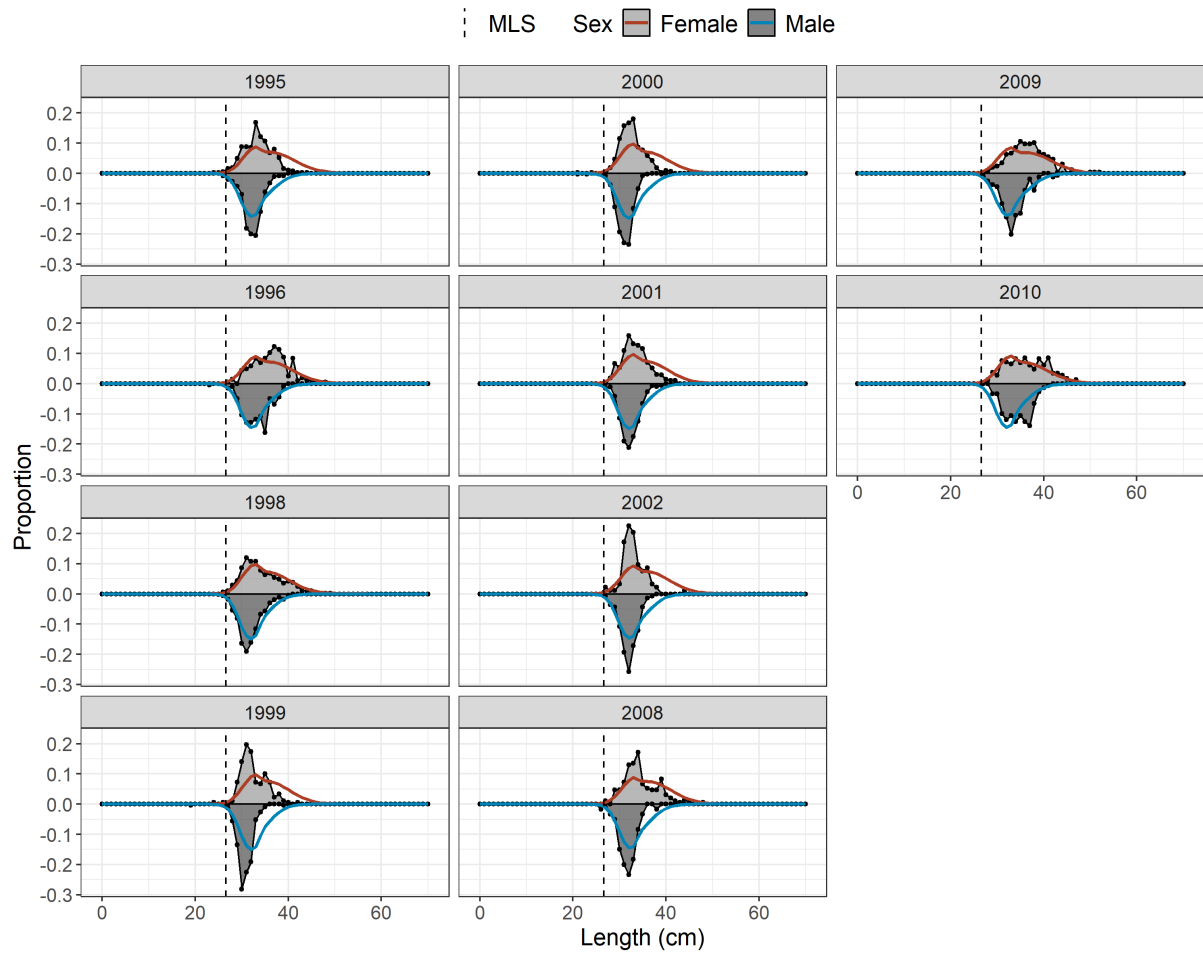


Figure H.3: Ensemble fits to NSW estuarine length data for Australian east coast sea mullet

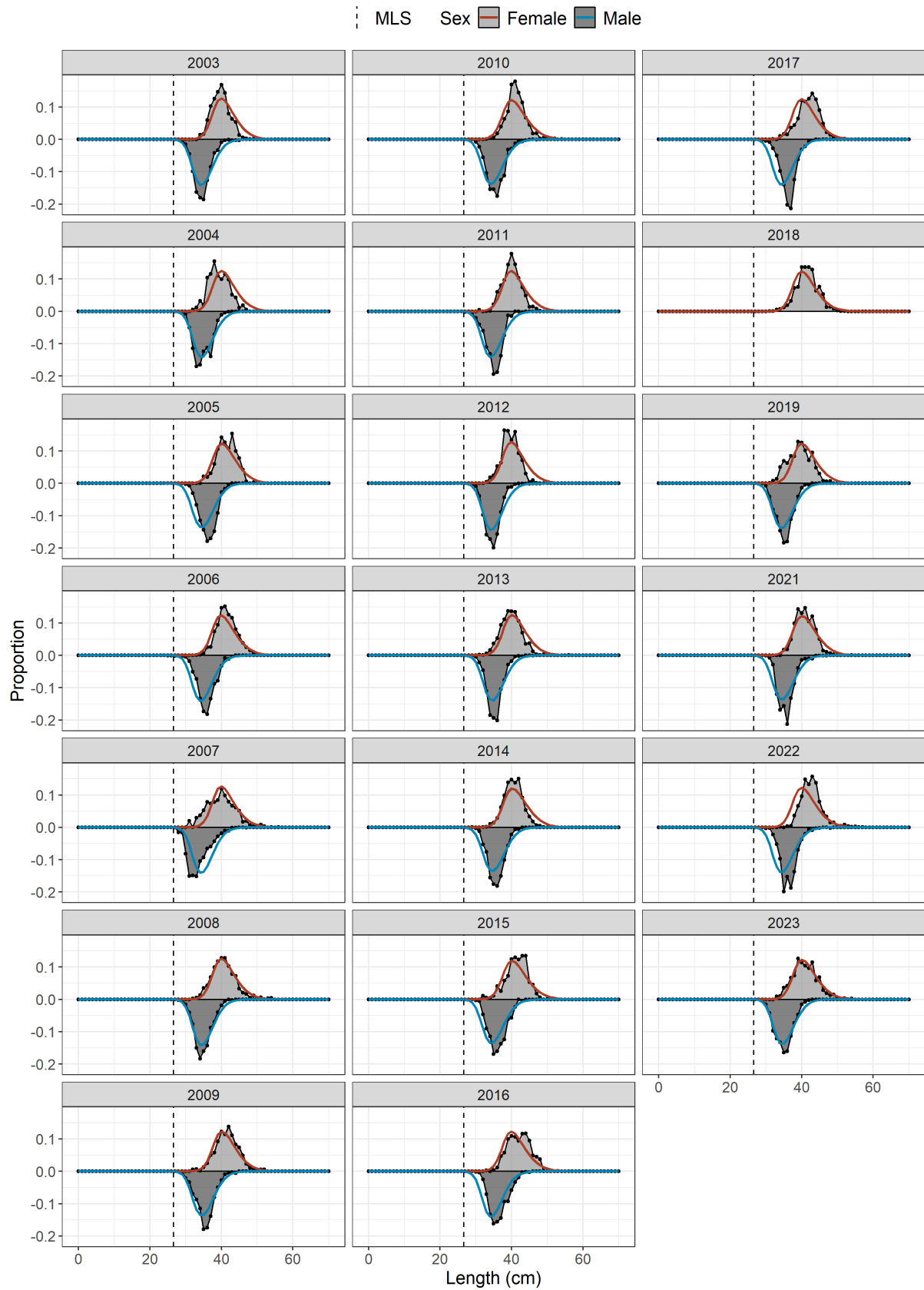


Figure H.4: Ensemble fits to NSW ocean beach length data for Australian east coast sea mullet

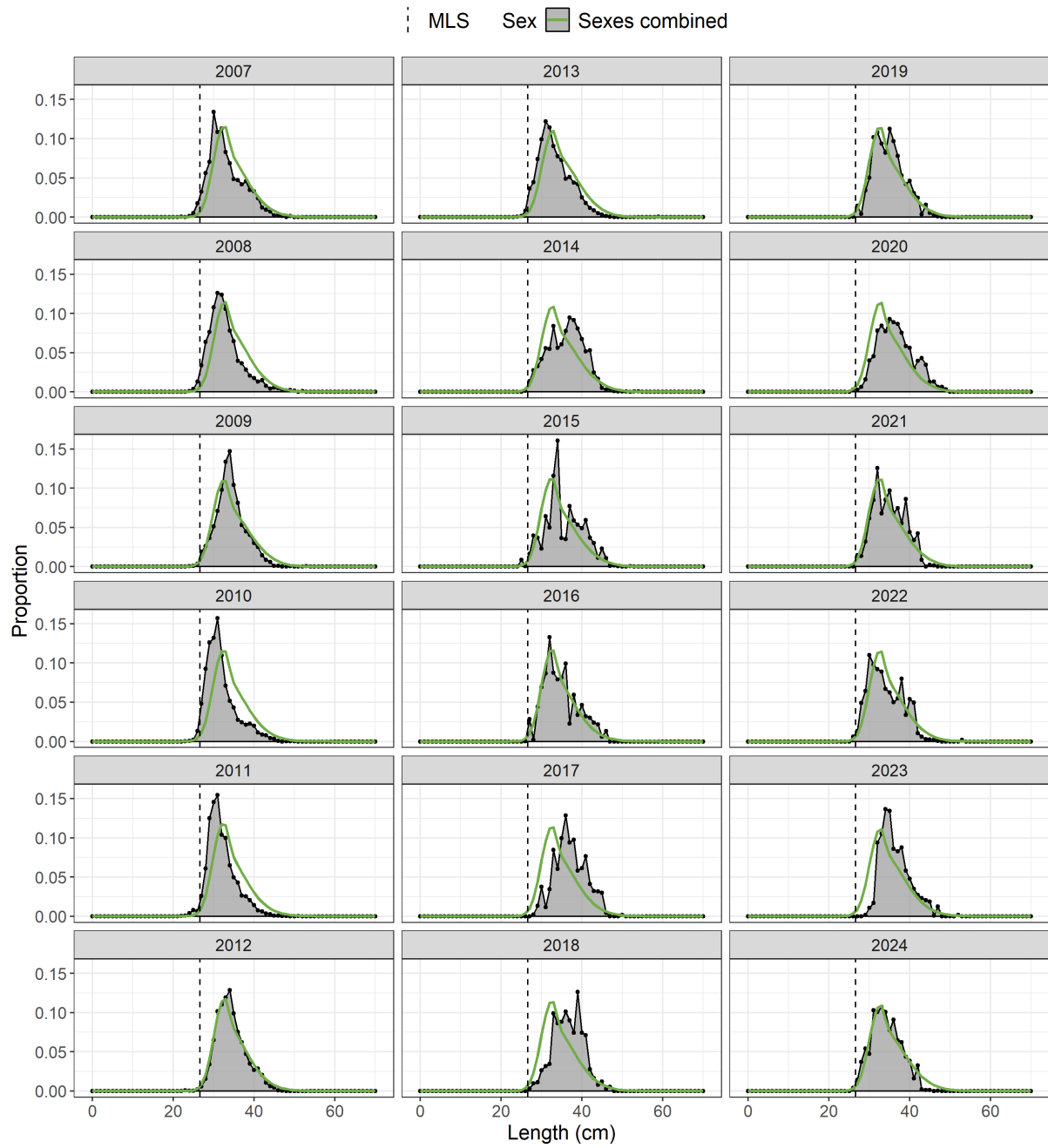


Figure H.5: Ensemble fits to Qld estuarine length data for Australian east coast sea mullet

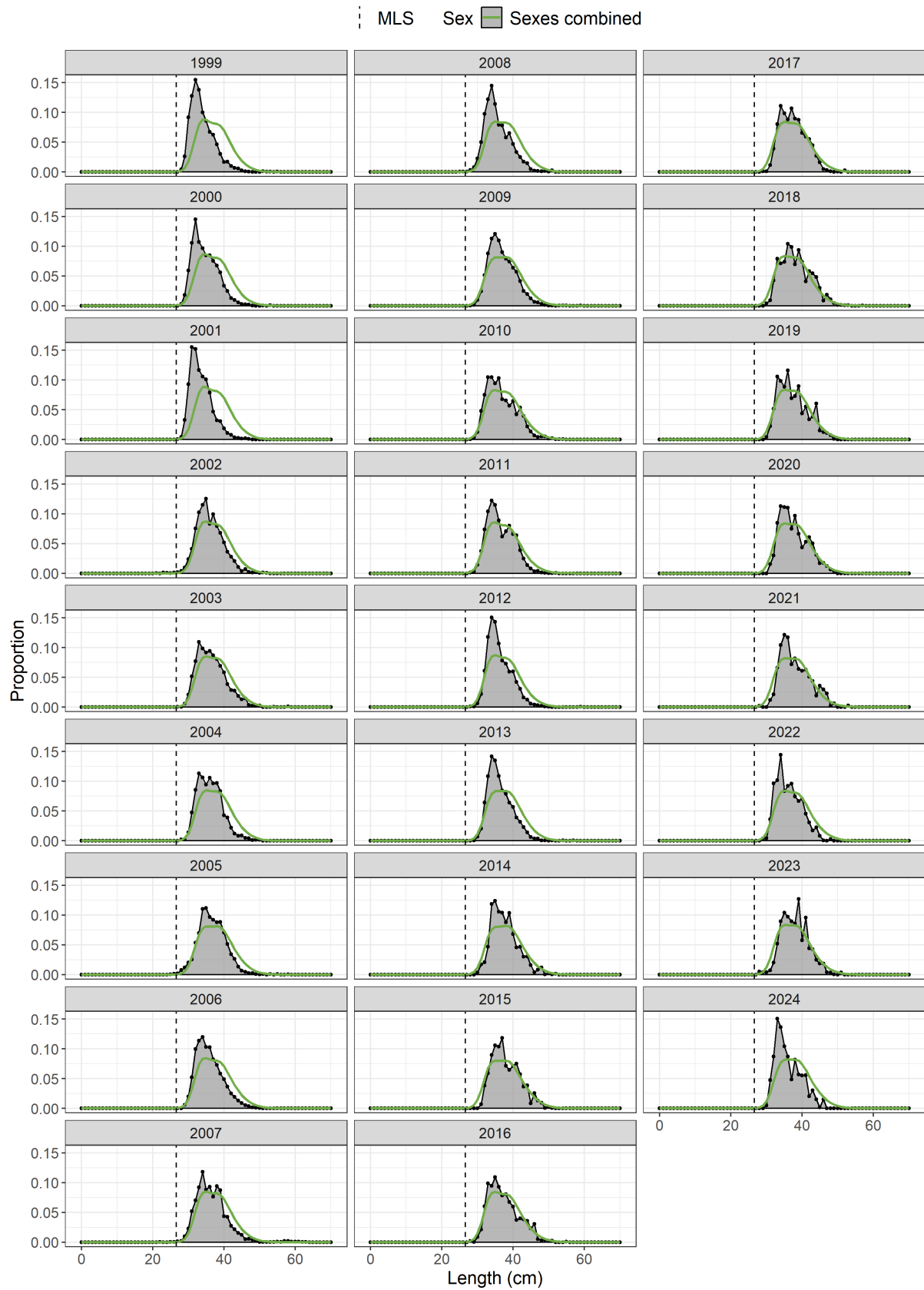


Figure H.6: Ensemble fits to Qld ocean beach length data for Australian east coast sea mullet

H.1.1.3 Age

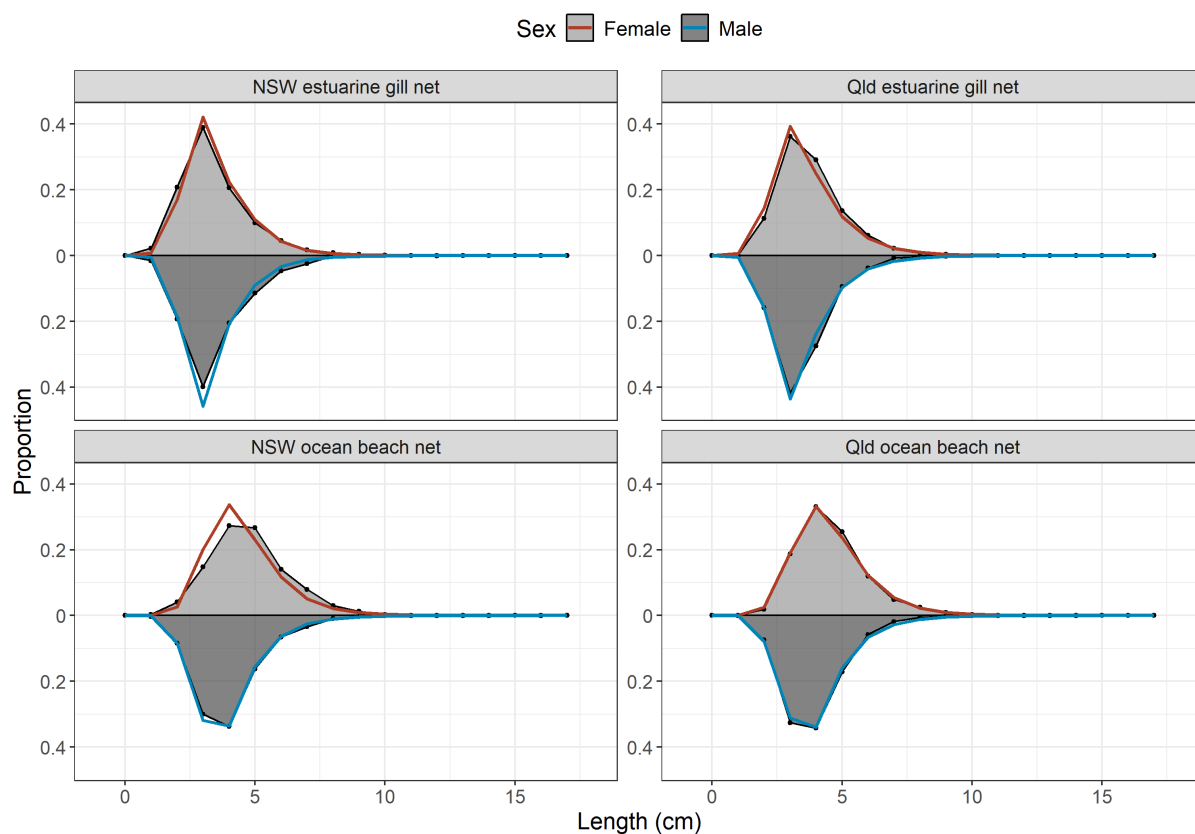


Figure H.7: Ensemble fits to aggregated age data for Australian east coast sea mullet

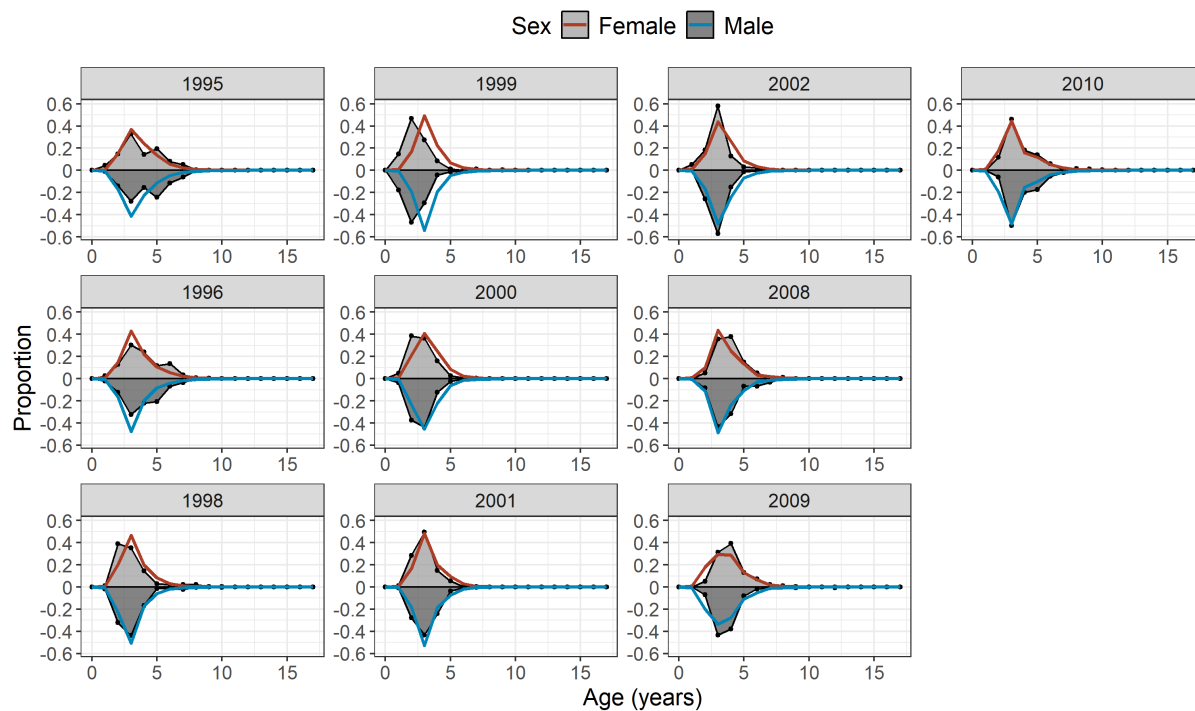


Figure H.8: Ensemble fits to NSW estuarine age data for Australian east coast sea mullet

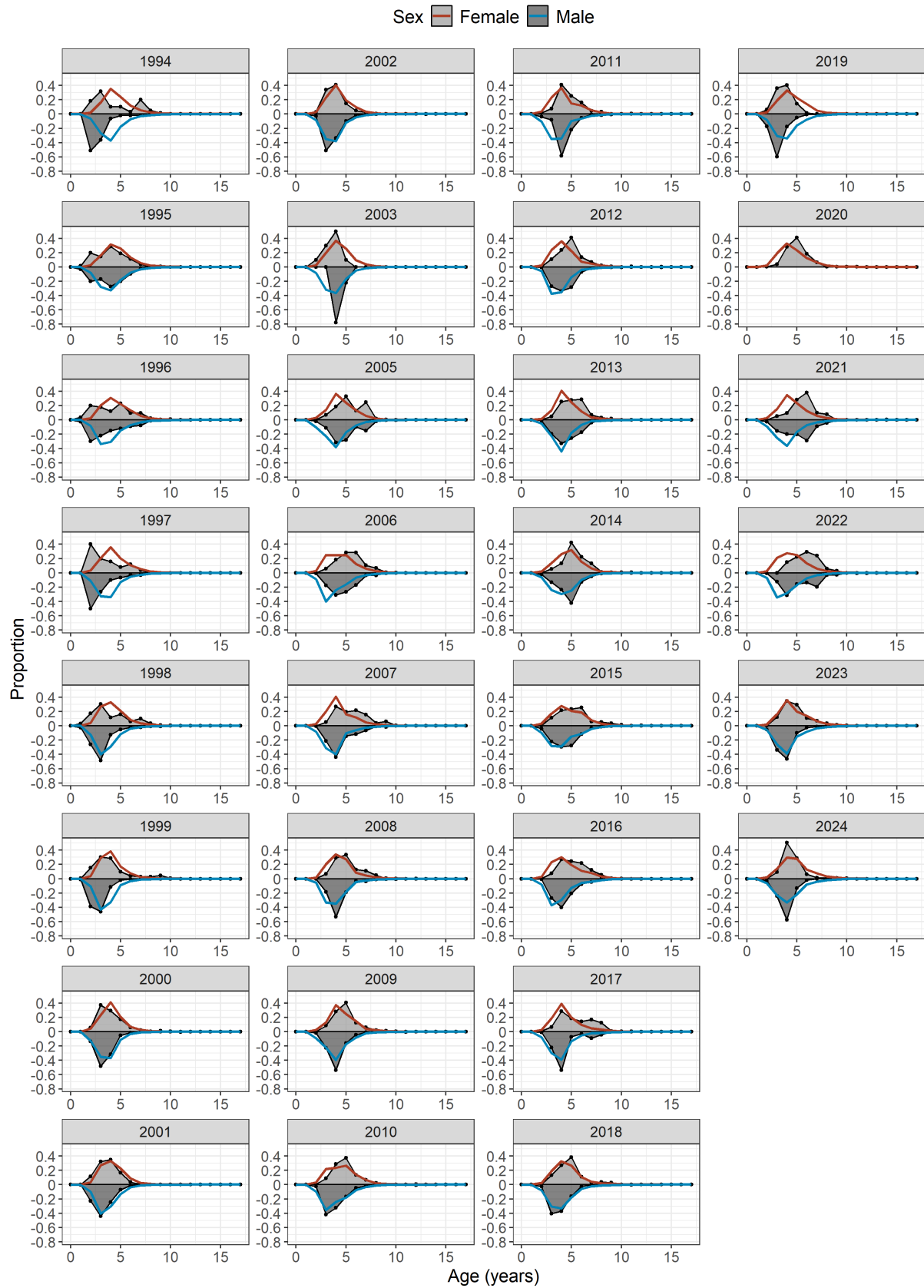


Figure H.9: Ensemble fits to NSW ocean beach age data for Australian east coast sea mullet

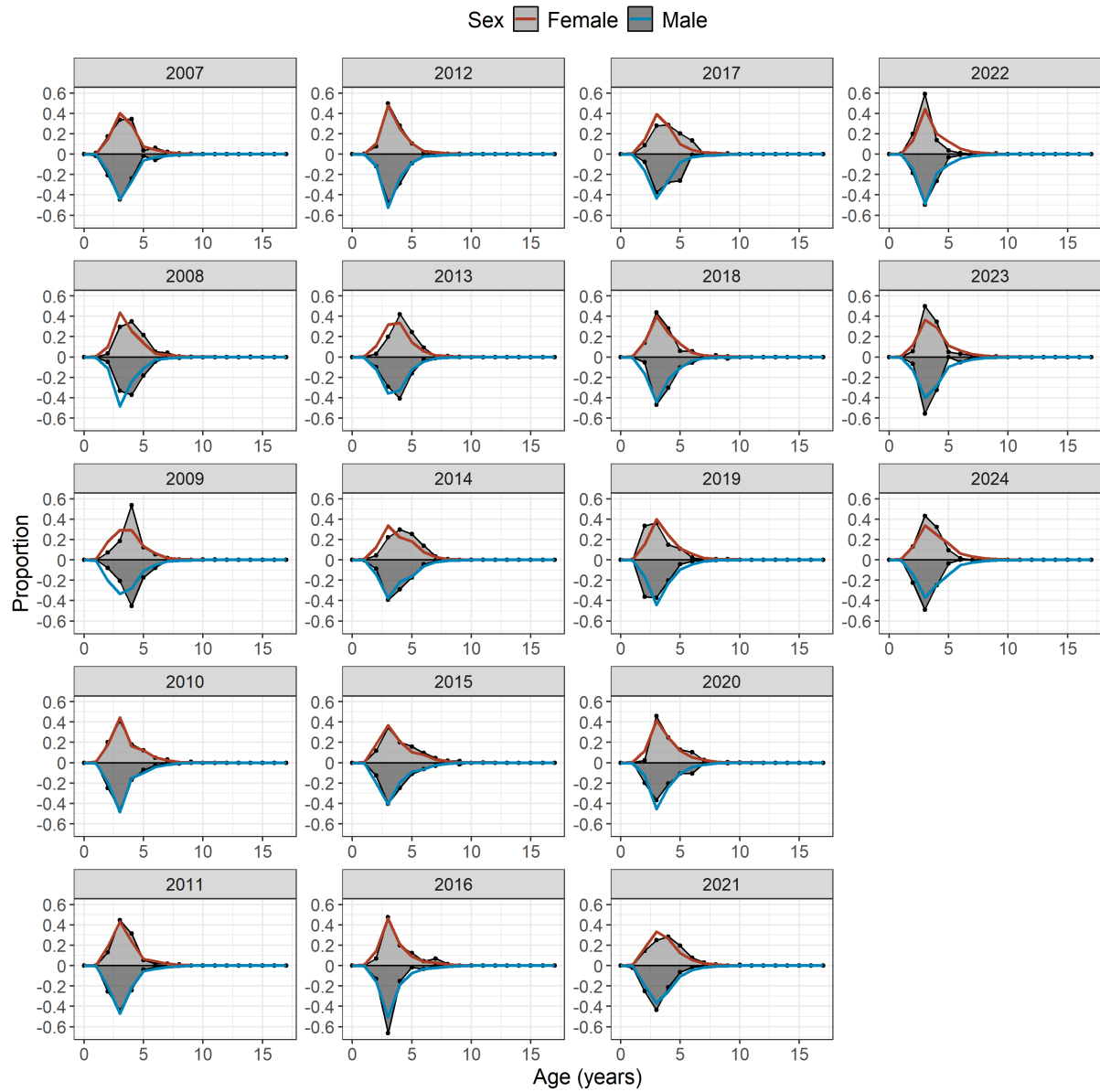


Figure H.10: Ensemble fits to Qld estuarine age data for Australian east coast sea mullet

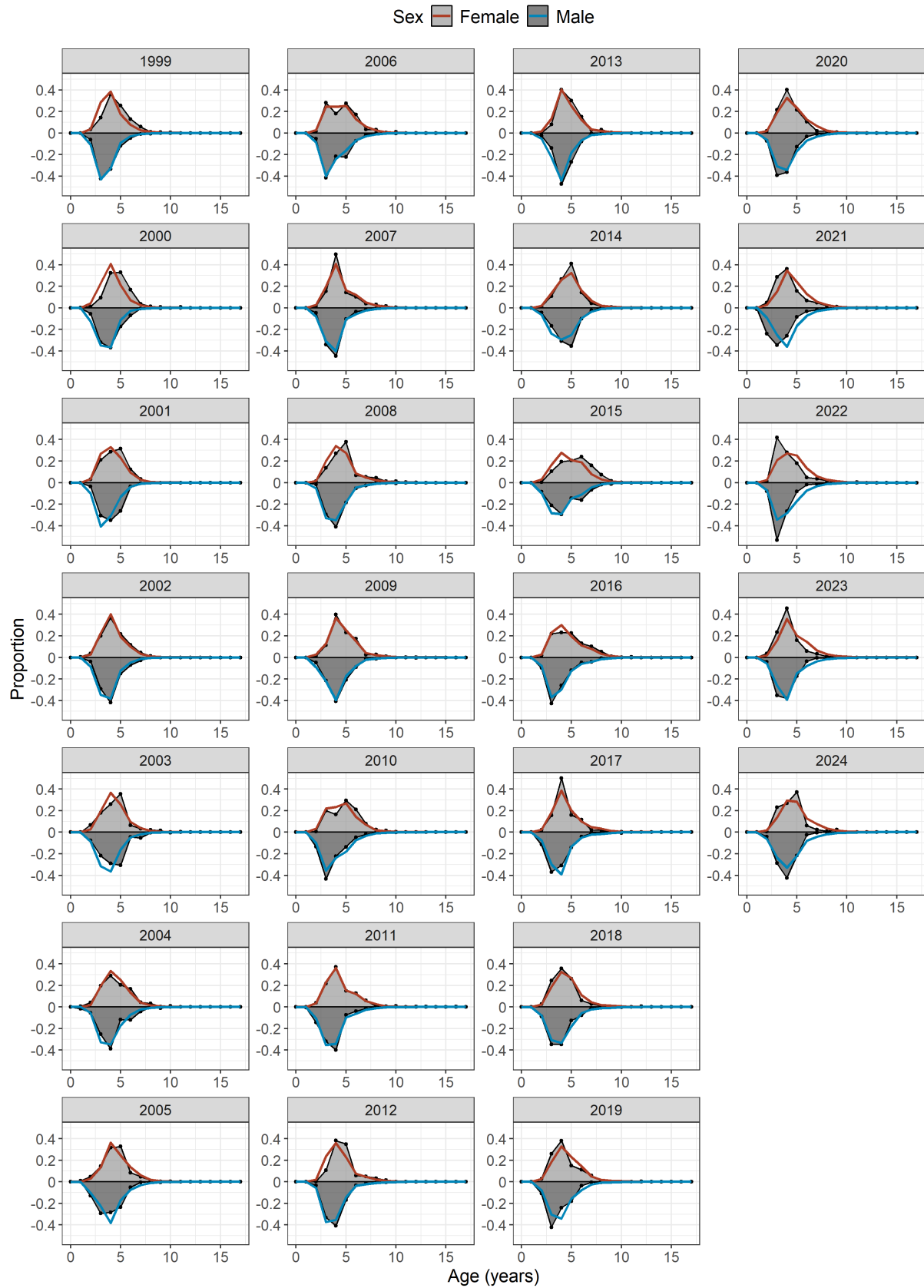


Figure H.11: Ensemble fits to Qld ocean beach age data for Australian east coast sea mullet

H.1.2 Likelihood profiles

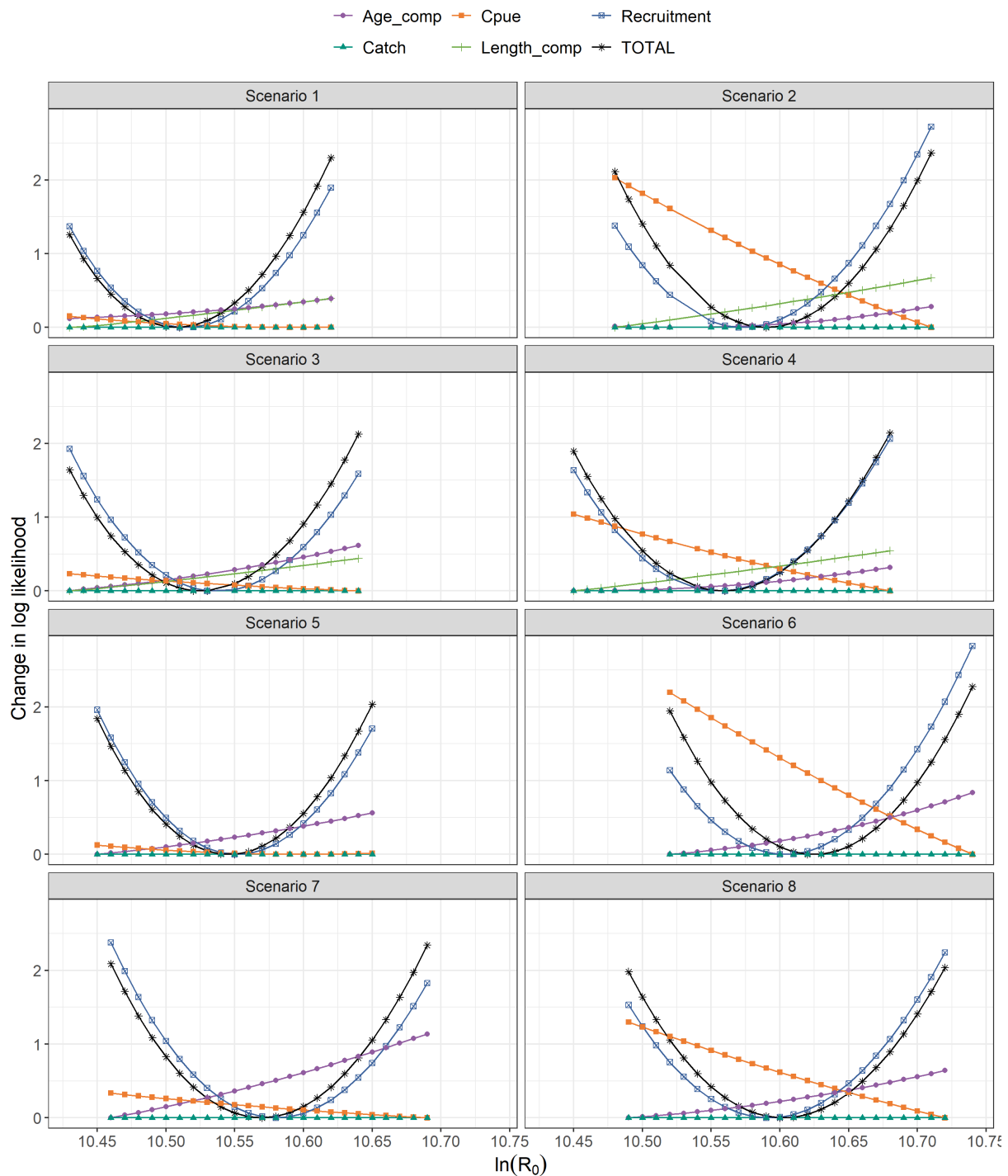


Figure H.12: Likelihood profiles for the parameter $\ln(R_0)$ for Australian east coast sea mullet ensemble scenarios 1 to 8

H.1.3 MCMC

Markov chain Monte Carlo (MCMC) simulations were performed on all scenarios over a total of 500 thousand iterations, with every 100th draw after the first 2,000 saved to investigate the posterior defined by Stock Synthesis. This resulted in a total of 4,980 saved iterations per scenario.

Convergence of the MCMC was monitored using a factor ($\hat{R}$) (Gelman et al. 2004). Effective sample sizes for each estimated parameter was also calculated, indicating the number of independent draws. Success was determined for values $0.99 < \hat{R} < 1.01$ and independent draws > 400 (Vehtari et al. 2020; Monnahan 2024).

Figures H.13 and H.14 show the potential scale reduction factor ($\hat{R}$) and effective sample sizes from the MCMC model for each scenario within the ensemble.

The ensemble was constructed by sub-sampling the iterations from each ensemble scenario according to scenario weightings, resulting in a total of 34,356 iterations (Table H.1, Section 2.6.3).

Table H.1: Scenario MCMC iteration contributions towards the ensemble model

Scenario	Iterations	Weight	Maximised weight	Ensemble iterations
1	4980	0.230	0.396552	1975
2	4980	0.070	0.120690	602
3	4980	0.580	1.000000	4980
4	4980	0.120	0.206897	1031
5	4980	0.230	0.396552	1975
6	4980	0.070	0.120690	602
7	4980	0.580	1.000000	4980
8	4980	0.120	0.206897	1031
9	4980	0.115	0.198276	988
10	4980	0.035	0.060345	301
11	4980	0.290	0.500000	2490
12	4980	0.060	0.103448	516
13	4980	0.115	0.198276	988
14	4980	0.035	0.060345	301
15	4980	0.290	0.500000	2490
16	4980	0.060	0.103448	516
17	4980	0.115	0.198276	988
18	4980	0.035	0.060345	301
19	4980	0.290	0.500000	2490
20	4980	0.060	0.103448	516
21	4980	0.115	0.198276	988
22	4980	0.035	0.060345	301
23	4980	0.290	0.500000	2490
24	4980	0.060	0.103448	516
TOTAL				34356

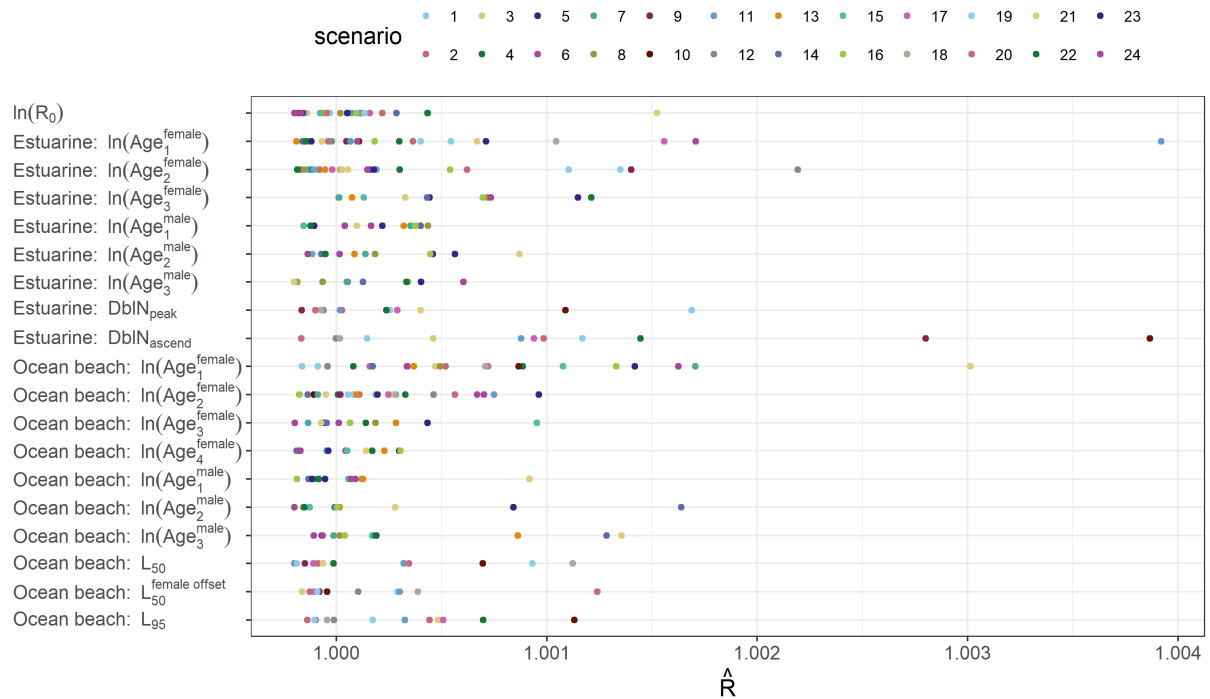


Figure H.13: Potential scale reduction factor, $\hat{R}$ values over each MCMC scenario within the ensemble for Australian east coast sea mullet—model is likely converged if $\hat{R} < 1.01$

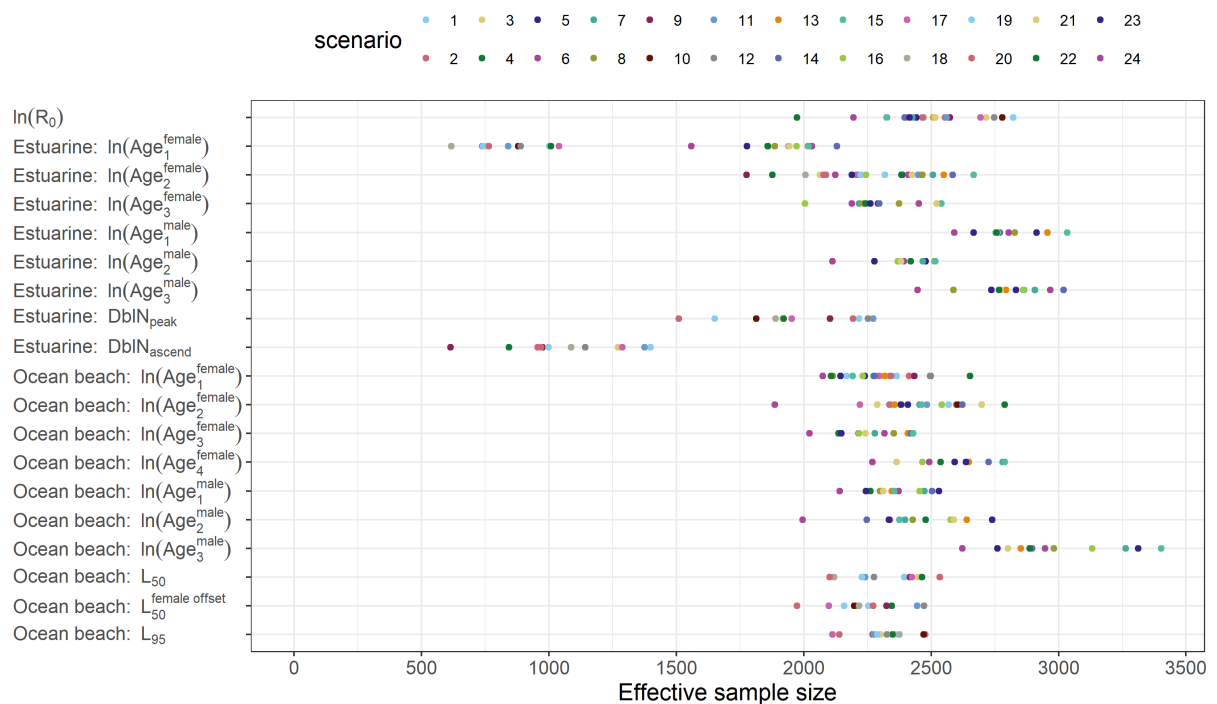


Figure H.14: Potential effective sample size values over each MCMC scenario within the ensemble for Australian east coast sea mullet—effective sample sizes > 400 indicate success

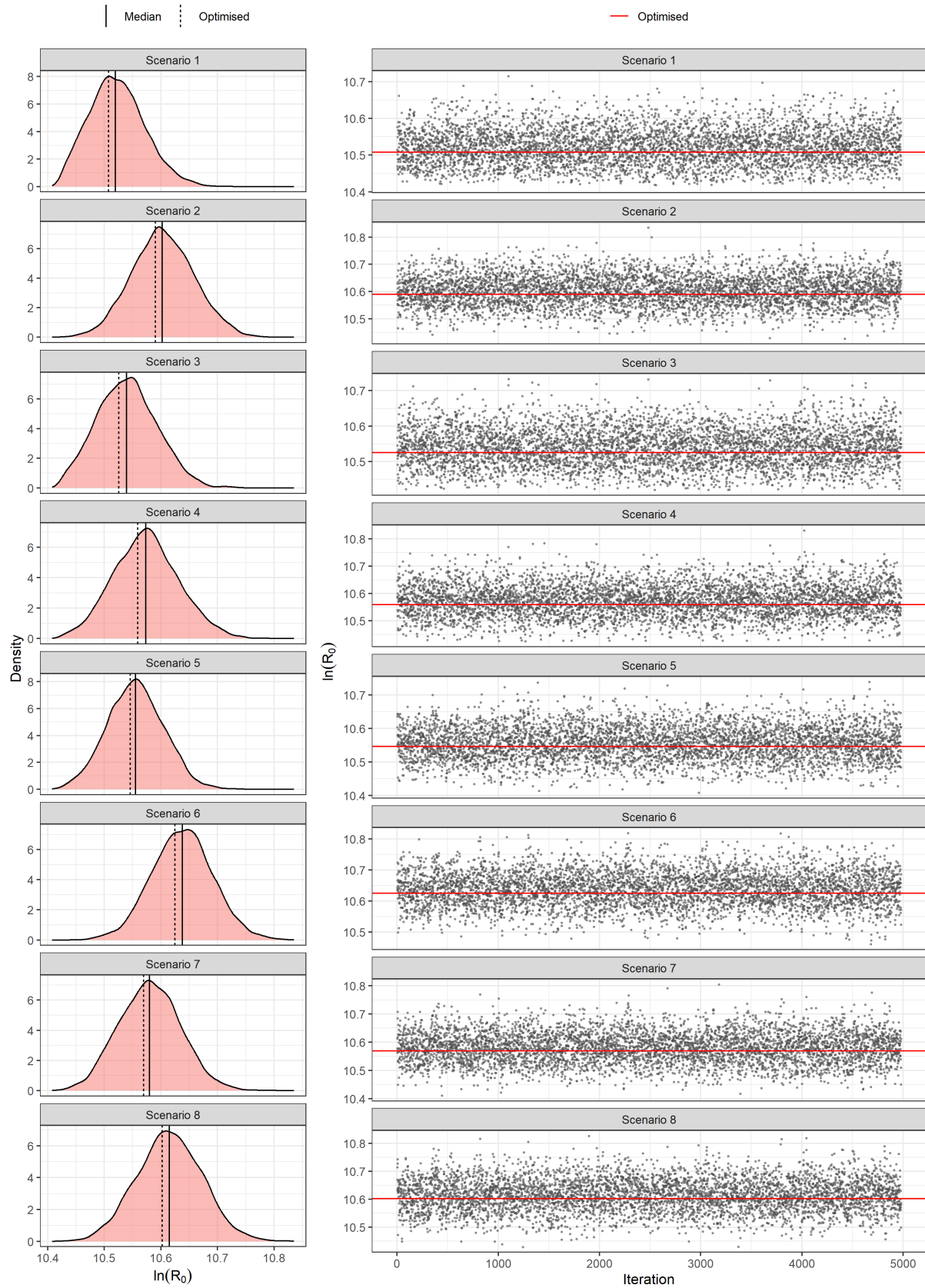


Figure H.15: Posterior density and trace plots of MCMC iterations for the parameter $\ln(R_0)$, ensemble scenarios 1–8, Australian east coast sea mullet—“Median” line shows the median parameter value for MCMC iterations “Optimised” shows the parameter value found from maximum likelihood estimates

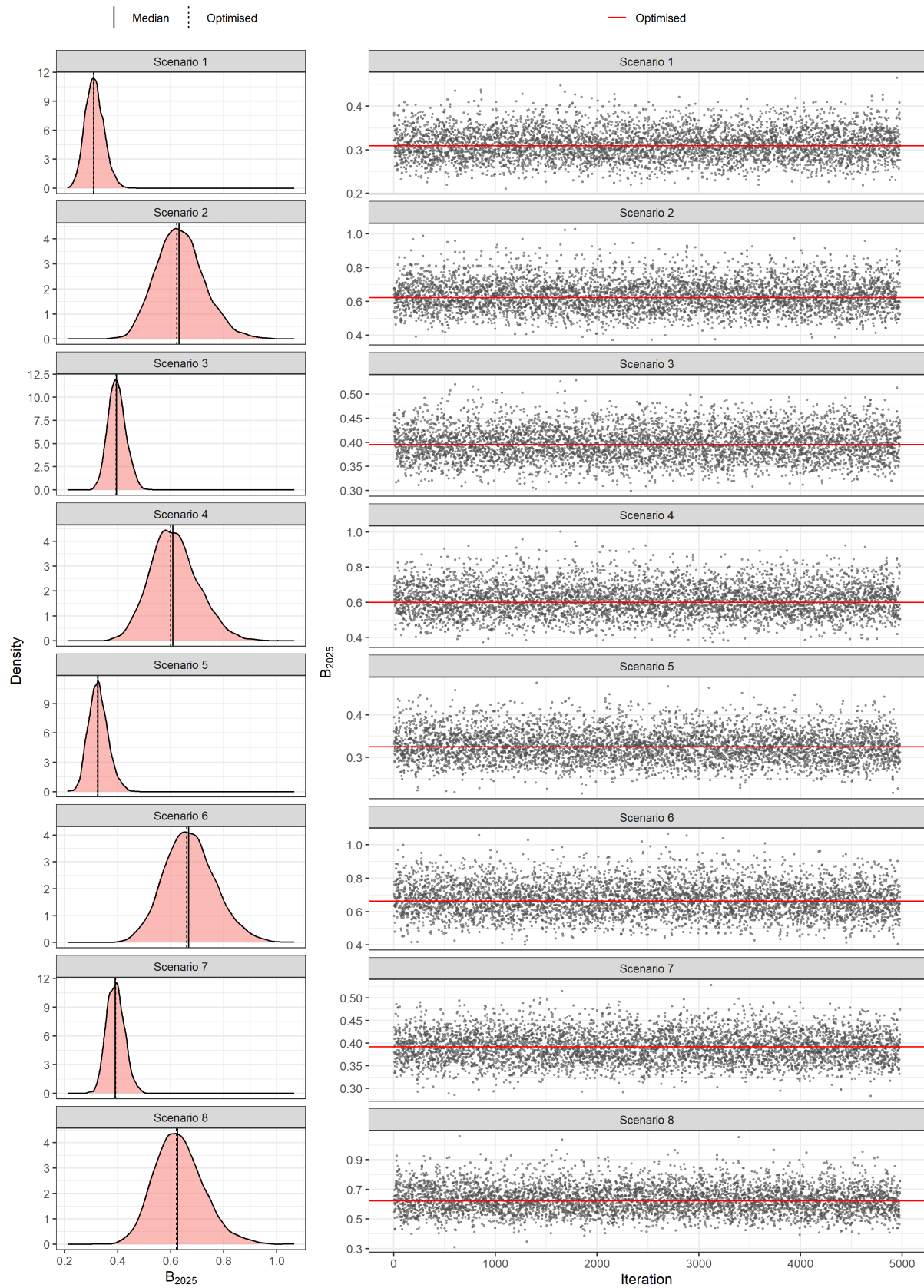


Figure H.16: Posterior density and trace plots of MCMC iterations for 2025 spawning biomass, ensemble scenarios 1–8, Australian east coast sea mullet—“Median” line shows the median value for MCMC iterations “Optimised” shows the value found from maximum likelihood estimates

H.2 Predictions

H.2.1 Parameters

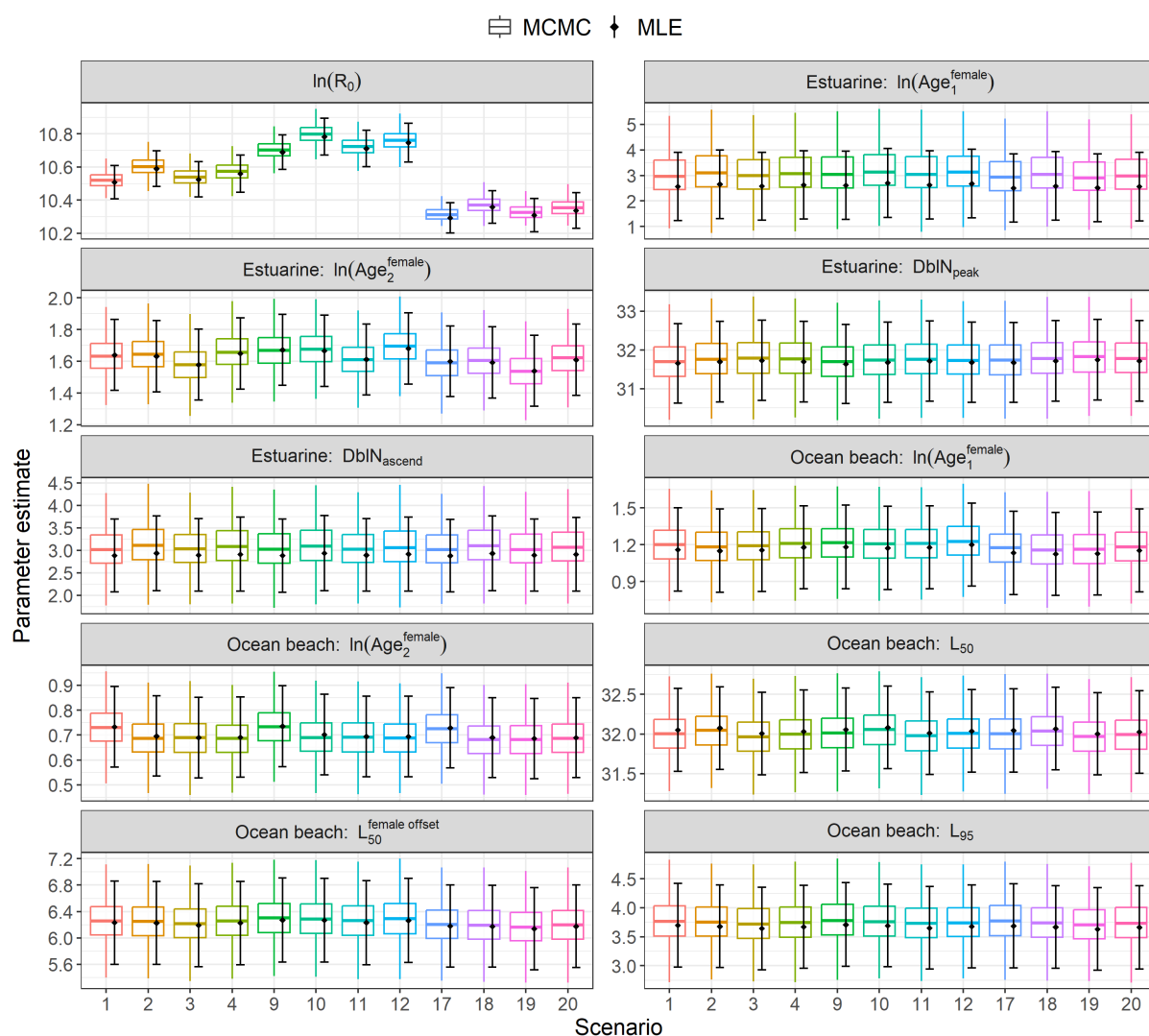


Figure H.17: Comparison of parameter estimates among the age and length vulnerability scenarios included in the ensemble model

⊞ MCMC † MLE

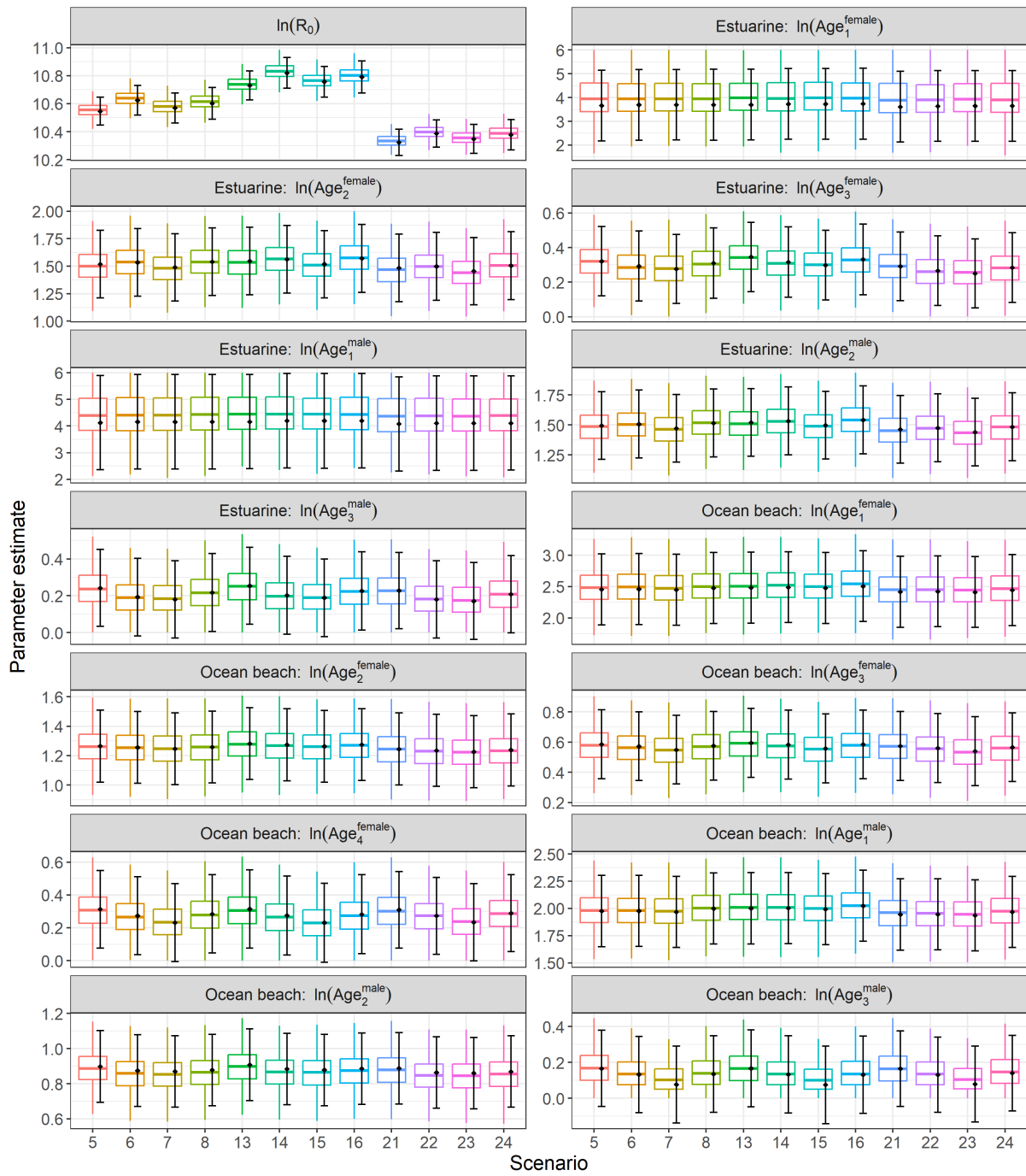


Figure H.18: Comparison of parameter estimates among the age only vulnerability scenarios included in the ensemble model

H.2.2 Stock-recruit curve

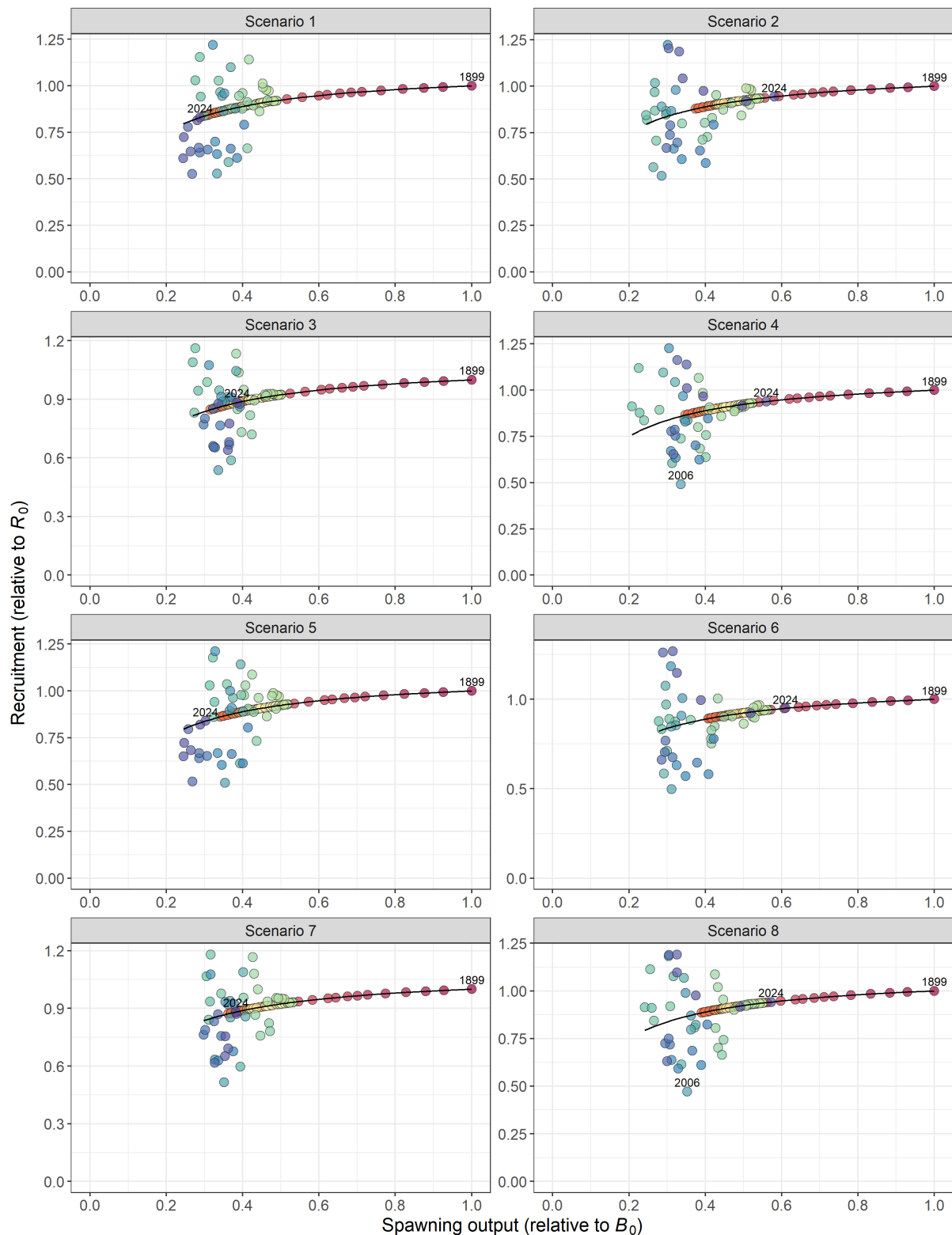


Figure H.19: Stock-recruit curve for Australian east coast sea mullet ensemble scenarios 1 to 8—point colors indicate year, with warmer colors indicating earlier years and cooler colors in showing later years

H.2.3 Fishing mortality

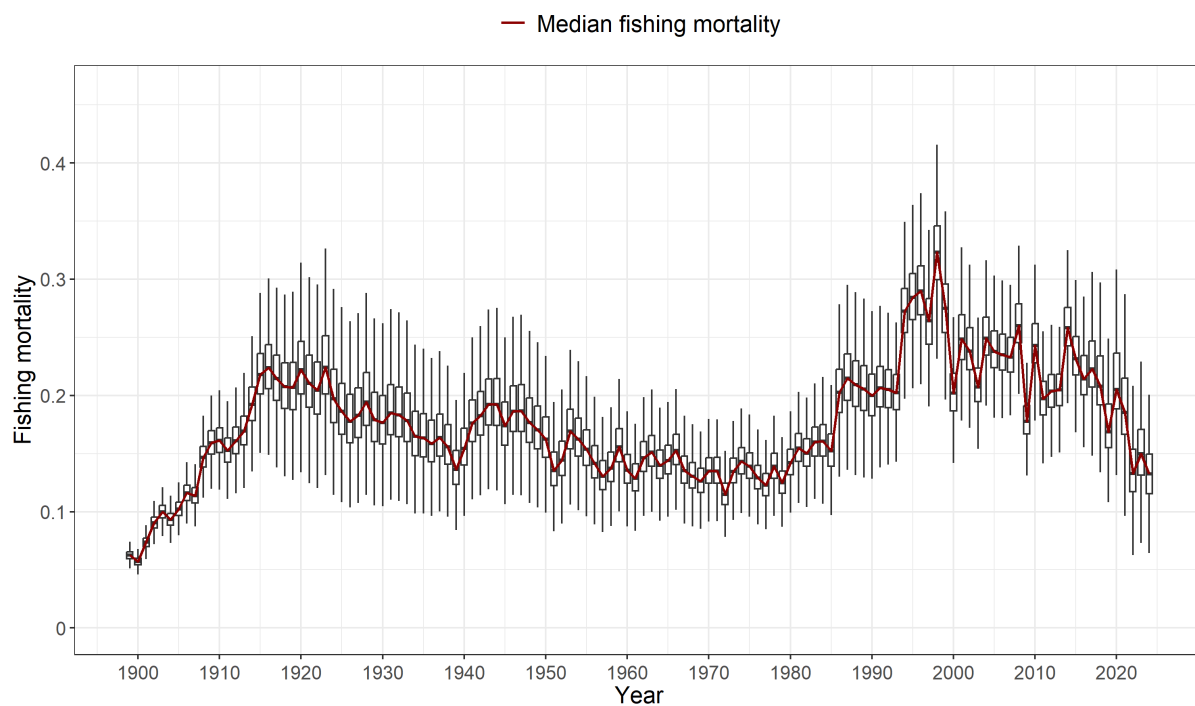


Figure H.20: Time series of fishing mortality from the ensemble model—whiskers represent 95% credible intervals, boxes represent 50% credible intervals and horizontal bars represent medians

H.2.4 Recruitment

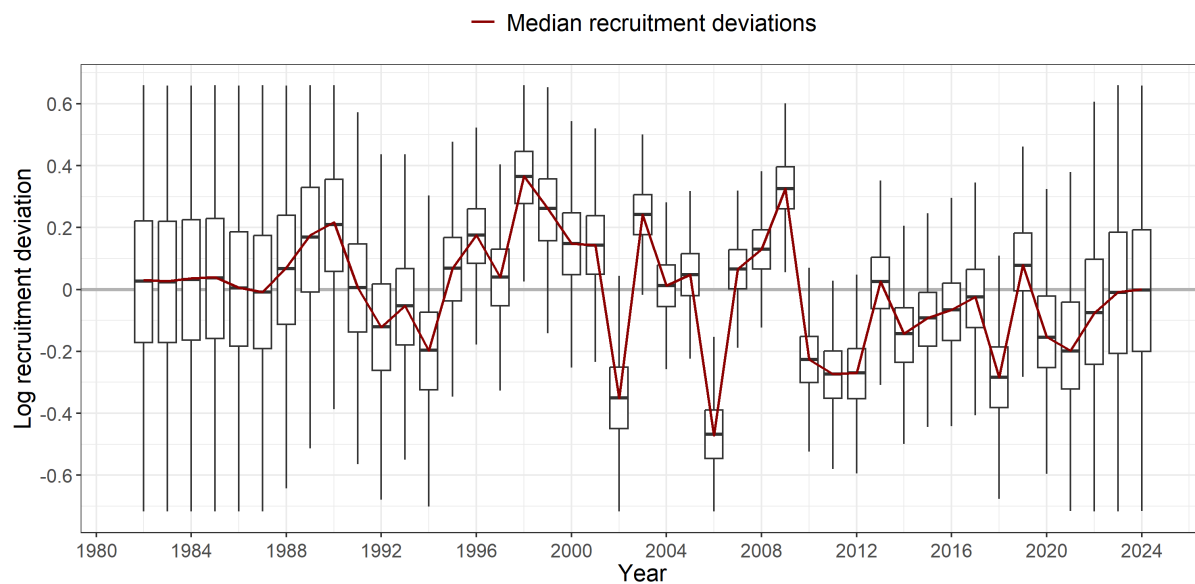


Figure H.21: Recruitment deviations from the ensemble model—whiskers represent 95% credible intervals, boxes represent 50% credible intervals and horizontal bars represent medians

I Bridging analysis

The model used in this assessment differs slightly in formulation to the past assessment (Lovett et al. 2022). For transparency, a bridging analysis has been performed here so that differences between results and decisions made in this assessment can be compared with results from Lovett et al. (2022) (Appendix A).

Changes have been made incrementally to align with the formulation and decisions used for the current assessment. These changes are as follows:

1. **Past model:** The previous assessment model (Lovett et al. 2022) using Stock Synthesis (SS; version 3.30.17.01) and data to the end of 2020.
2. **Maturity:** An older female age-at-maturity schedule was used with full maturity at age 4 years instead of age 3 (see Section 2.5 and Appendices A and G.1).
3. **Growth:** Growth curve settings were updated including:
 - The minimum age parameter was set to $L_{Amin} = 1.5$ years (previously 0.75).
 - Coefficients of variation were estimated from the data prior to modelling and fixed at values of $CV_{old} = 0.14$, $CV_{young}^{female} = 0.10$ and $CV_{young}^{male} = 0.08$. These parameters were previously estimated with a prior of 0.1 for old fish and 0.05 for young fish.
4. **Steepness:** Increased to $h = 0.75$ (previously 0.66).
5. **Natural mortality:** Fixed at a value of $M = 0.33$ for both sexes (previously estimated for both sexes at $M_{female} = 0.312$ and $M_{male} = 0.281$).
6. **Catch rates:** Updated catch rate indices from current data pull and revised methodology (Section 2.4 and Appendix F). Extra standard deviation parameters (previously estimated) were derived during the catch rate standardisation analysis and input to the model as fixed parameters.
7. **Monitoring data:** Updated age and length data from current data pull.
8. **Vulnerability:** Changed age and length vulnerability parameters and setup.
9. **Catch data:** Updated catch estimates from current data pull using earlier assessment approach.
10. **Recruitment variability:** Fixed recruitment variation at $\sigma_R = 0.30$ based on the Stock Synthesis sigma_R_info recommendation. (Previously estimated at $\sigma_R = 0.34$).
11. **Catch reconstruction:** Updated catch reconstruction using new historical estimates and estuarine to ocean-beach method proportions (see Section 2.3 and Appendix A).
12. **Data extension:** Extended the data inputs to include recent years up to the end of 2024.
13. **Data weighting:** Applied updated Francis weights which were not used in the previous assessment.
14. **Final model comparison:** Comparison of results with the final ensemble model.

Across all steps, the spawning biomass trend remains broadly similar over time (Figure I.1). However, the level of spawning biomass in recent years shifts slightly downward as updates were added. The final model sits toward the lower end of earlier model outputs, but still follows the same general trajectory.

The biggest change in spawning biomass estimates comes from updating the female age at maturity (Table I.1).

- The revised model assumes females mature later (full maturity at age 4 instead of age 3).
- This reduces estimated spawning output for younger ages.

This was identified as the main driver of differences between the previous and current assessments.

Other updates (growth, mortality, catch rates, and new data) had smaller, incremental effects in later years (Figure I.1 and Table I.1). The final results represent the combined effect of all updates and remain within the range of plausible model outcomes.

Results from recent years indicated that most of the change in spawning biomass estimates was driven by the revised female age-at-maturity schedule. Additional updates—such as new age and length data and changes to vulnerability—had smaller effects on the results.

Table I.1: Summary of bridging analysis showing stepwise model updates and their influence on spawning biomass estimates.

Step	Effect on results	Importance
1: Past model	Starting point for comparison	Reference
2: Maturity	Reduced spawning biomass	High (main driver)
3: Growth	Small change to spawning biomass	Low
4: Steepness	Minor adjustment to spawning biomass	Low
5: Natural mortality	Small increase in spawning biomass	Low
6: Updated catch rates	Small decrease in final spawning biomass	Low
7: Updated monitoring data	Reduced amplitude of cyclic fluctuations	Moderate
8: Vulnerability	Slight effect	Low
9: Updated catch data	Small effect on spawning biomass	Low
10: Recruitment variability	Slight effect	Low
11: Catch reconstruction	Significant effect on early years, however minor effect on recent years	Low
12: Data extension	Slight reduction in spawning biomass	Low–moderate
13: Data weighting	Small adjustment to results	Low
14: Current model (MLE ensemble)	Slightly lower spawning biomass than earlier model	Summary outcome

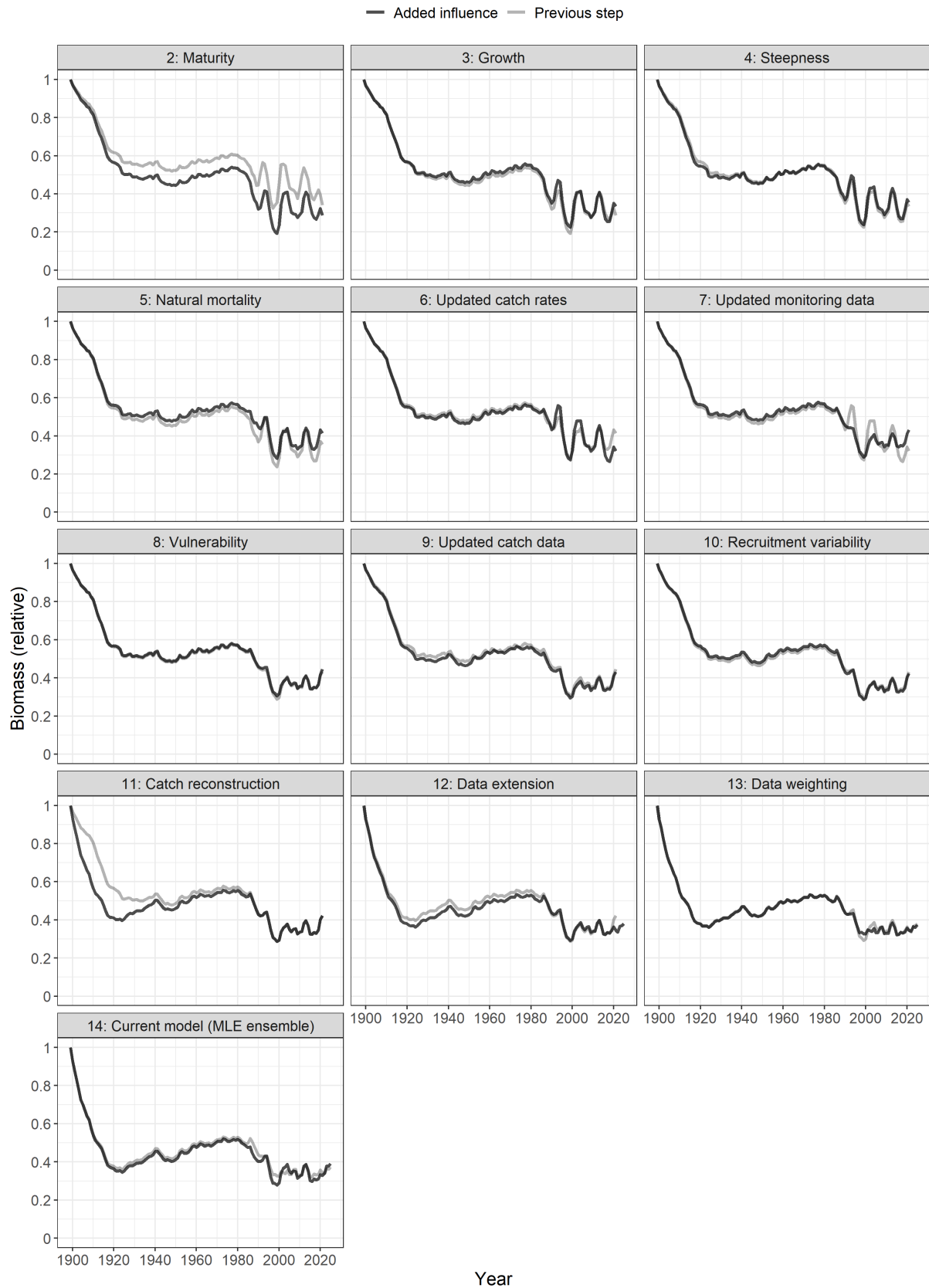


Figure I.1: Iterative changes to spawning biomass from the previous assessment (step 1) to current for Australian east coast sea mullet—results displayed are from maximum likelihood estimation (MLE) models