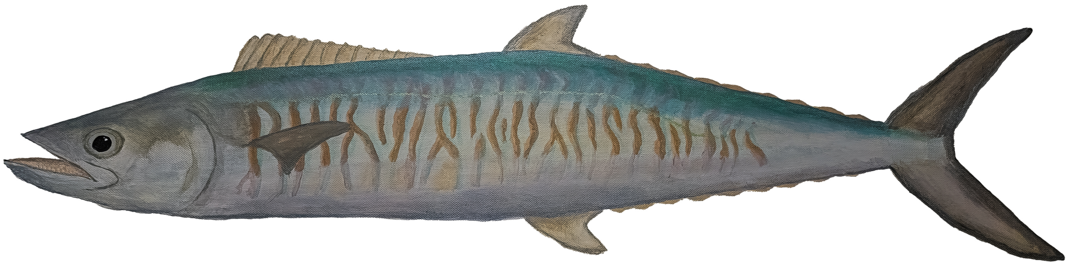

Stock assessment of Australian east coast Spanish mackerel (*Scomberomorus commerson*), with data to June 2024

April 2025

Queensland Government

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The Department of Primary Industries proudly acknowledges all First nations peoples (Aboriginal peoples and Torres Strait Islanders) and the Traditional Owners and Custodians of the country on which we live and work. We acknowledge their continuing connection to land, waters and culture and commit to ongoing reconciliation. We pay our respect to their Elders past, present and emerging.

Contents

Executive summary

Introduction

Spanish mackerel (*Scomberomorus commerson*) is a large pelagic species of fish. On the east coast of Australia they form a single genetic stock, between the Cape York Peninsula in northern Queensland and Newcastle on the New South Wales mid coast. In these waters, Spanish mackerel can live for up to 26 years, grow to over 30 kg in weight and reach maturity between 2 and 4 years of age, as observed in Fisheries Queensland data.

In 2025, a stock assessment was commissioned to establish the current status of the Australian east coast Spanish mackerel stock. This assessment was completed in April 2025 to inform the management of the fishery after management changes were implemented in 2022 and 2023 to address stock declines.

The stock assessment used an age-structured model to determine the spawning biomass at beginning of 2025. The term 'biomass' refers to the total weight of a biological population or stock. 'Spawning biomass' refers to the total weight of mature or reproductively capable individuals within the stock. Estimates of biomass provided in this assessment are presented as the 'spawning biomass ratio', which compares the current spawning biomass to the unfished spawning biomass in 1911, expressed as a percentage.

This stock assessment estimates that the biomass of Australian east coast Spanish mackerel at the beginning of 2025 was between 17% and 62% of unfished levels, with a median biomass estimate of 34% of unfished levels, meaning 34% is the most probable estimate of 2025 biomass.

Several key aspects of this assessment differ from past assessments, including:

- Membership of the project team that guides the assessment was expanded, to include fishery stakeholders (one commercial and one recreational fisher) as well as an independent scientist and a representative from the Great Barrier Reef Marine Park Authority.
- Data provided through the Fisheries Research and Development Corporation (FRDC) funded project 'Addressing the uncertainties in the assessment and management of Queensland east coast Spanish mackerel' (project number: 2021-111).
- The key outputs were constructed as an ensemble across multiple model scenarios, rather than selecting a particular preferred scenario.

The independent reviews of the 2021 assessment, by Dr Neil Klaer in 2021 and Dr Simon Hoyle and Alistair Dunn in 2022, highlighted a concern with the value chosen for steepness. Steepness is a model parameter which indicates how recruitment responds to changes in biomass, influencing the stock's ability to recover from depletion. The Hoyle and Dunn review also critiqued the approach used by the 2021 assessment to tackle catch rate hyperstability. Hyperstability refers to the potential for catch rates to remain stable as biomass drops or increases, in the case of fish that aggregate to spawn (such as Spanish mackerel). All aspects of the independent reviews have been addressed, with detailed responses to each recommendation provided in Section 4.3.

A key advancement in this assessment's modelling approach is that hyperstability is better handled indirectly through emphasising the age-at-length composition data. Additionally, the modelling approach was improved by ensuring uncertainty in steepness is captured through the use of an ensemble. The model structure was also refined to better capture the migratory patterns of Spanish mackerel, by accounting for spatial and seasonal differences in selectivity (the size of fish caught).

Other key improvements include using new research data on shark depredation rates, as well as feedback from experienced Spanish mackerel fishers (gathered via phone survey) to better inform catch history.

Methods

The assessment used an age-structured model with an annual time step, fitted to standardised catch rates, length composition data and age-at-length composition data. The model incorporated Queensland and New South Wales data spanning the period 1911–2024, collected from the commercial, recreational and charter sectors. A full listing of all data inputs and sources is given in Table 2.1, with a description of each in Section 2.1.

All assessment inputs and outputs are referenced on a financial year basis—'2024' means 'July 2023–June 2024'.

Unlike the 2021 assessment, which prioritised reporting on a single 'base case' (or 'most likely') scenario selected from a suite of models, the ensemble approach used here presents the most probable outcome out of all model runs. As discussed in Section 4.3.1, this method avoids reliance on a chosen 'most likely' scenario and is therefore more robust to model misspecification.

Numerous scenarios were run to explore different settings of the natural mortality rate, steepness, fleet structure, catch history, environmental drivers, and fishing selectivity approach. From these exploratory scenarios, an ensemble of 6 final scenarios were chosen for inclusion in summary reporting, covering 3 values of steepness (0.54, 0.69 and 0.81) and 2 different settings of the relative weighting between length composition and age-at-length composition data. Natural mortality was estimated in all six models that made the ensemble. All results were produced from the final ensemble of 6 scenarios, where each scenario was run using a Markov Chain Monte Carlo (MCMC) framework, for 2 million iterations per scenario.

The influence of exploratory scenarios not included in the ensemble is discussed in this report (these scenario results are retained for comparison in Appendix F.

Results

Biomass

The results of this assessment (Table 1 and Figure 1) indicate that at the start of 2025, the biomass was between 17% and 62% of unfished levels, with 95% confidence that the value falls within this range (95% credible interval). The median biomass estimate is 34%, meaning this is the most probable estimate of Spanish mackerel biomass.

The median is preferred as a central tendency measure (over the mean or mode, for example) as it is less prone to the influence of outliers or extreme values, making it a more reliable measure for skewed distributions, such as the probability distribution of 2025 biomass.

We also report the probability of the 2025 biomass falling into 4 categories—below 20%, between 20% and 40%, between 40% and 60%, and above 60%.

Table 1: Stock status indicators for Australian east coast Spanish mackerel

Indicator	Value
Biomass ratio (relative to unfished)	
Median	34%
Range (95% credible interval)	17–62%
Probability below 20%	8%
Probability between 20% and 40%	61%
Probability between 40% and 60%	28%
Probability above 60%	3%

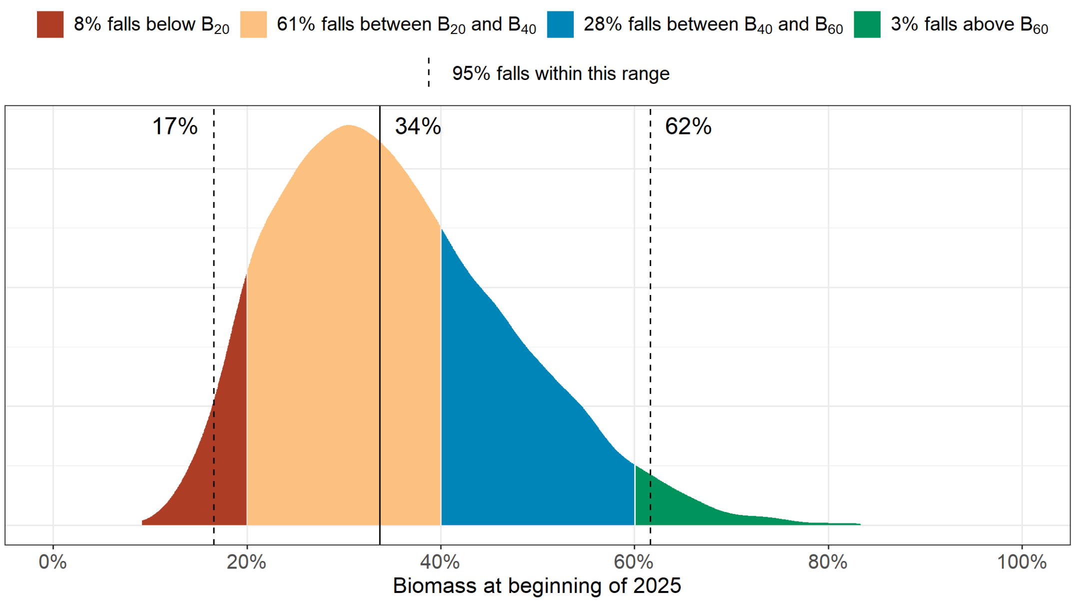

Figure 1: Probability distribution of the biomass ratio at the beginning of 2025 across the full ensemble of scenarios with the credible interval and probability of biomass falling into the four categories indicated

Previous assessments estimated the stock at 39–51% of unfished levels in 2009, 30–50% in 2016 and 17% (14–27%) in 2020.

The biomass trajectory (Figure 2) shows a decline from an assumed unfished level in 1911, potentially reaching as low as 16% by 2003. A period of stock rebuilding followed until 2016, after which biomass declined again from 2016 to 2023. The decline levels off in 2024, followed by an increase in the final year.

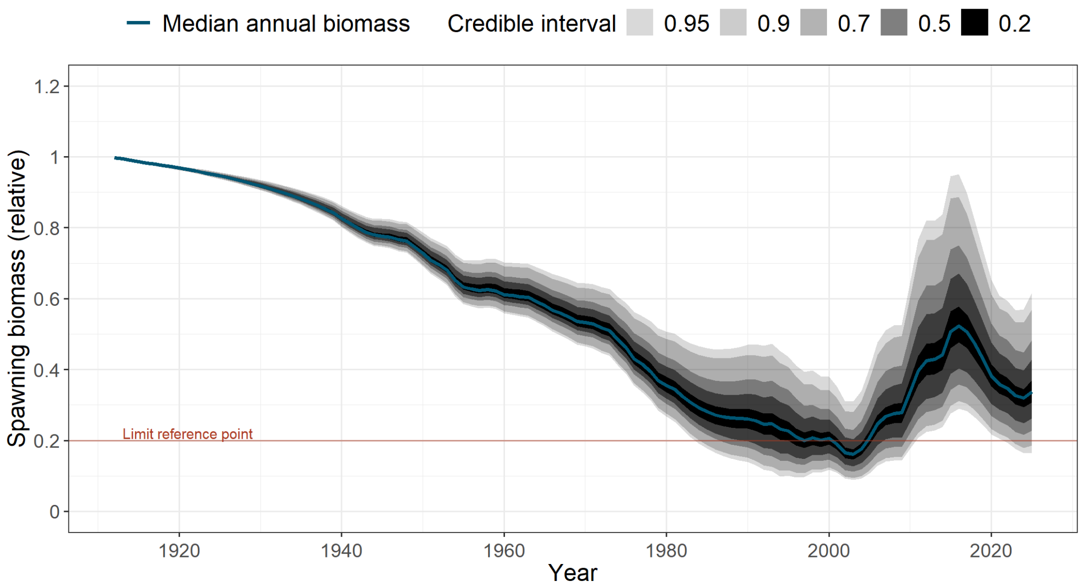

Figure 2: Predicted spawning biomass trajectory relative to unfished levels for Australian east coast Spanish mackerel, from MCMC ensemble scenarios

Catch

Over the last 5 years (2020 to 2024), total catch (all sectors combined) averaged 705 tonnes per year from Australian east coast waters (Figure 3). Approximately 91% of total catch was taken from Queensland waters.

Shark depredation data from FRDC project 2021-111 (collected 2022–2024) was used in the catch reconstruction to account for the additional mortality of fish lost to sharks in Queensland waters. The project recorded depredation rates of 6.02% for commercial trips and 36.58% for recreational trips. In the catch reconstruction, a constant 6.02% rate was applied to the commercial sector. For the recreational and charter sectors, the project team cited a significant recent increase in shark depredation rates, which was supported by responses in Fisheries Queensland's phone survey of Spanish mackerel fishers. As a result, depredation rates for these sectors were set at 12.04% (double the commercial rate) prior to 2009, increasing linearly to meet 36.58% (the rate observed by the research project) by 2024. For full detail on these methods, see Section 2.2.2.

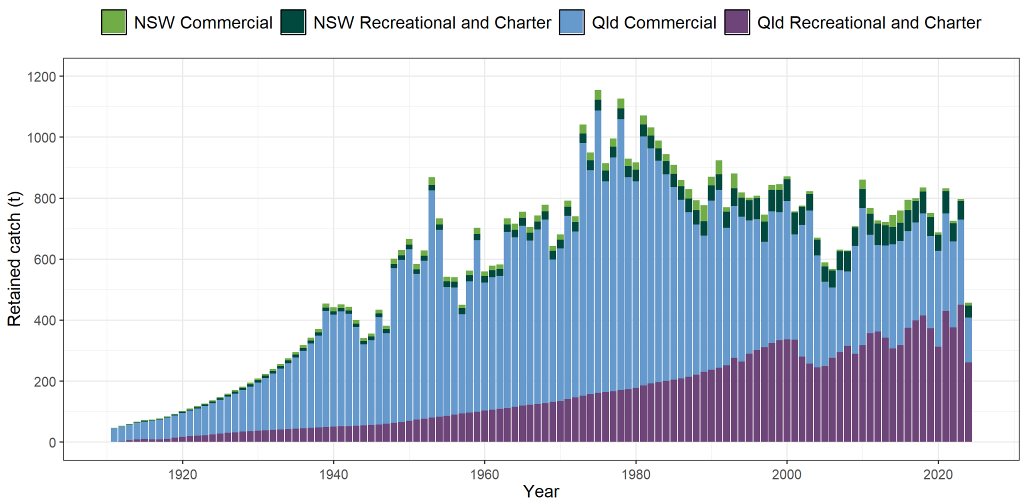

Figure 3: Estimated catch between 1911 and 2024 for Spanish mackerel in the Australian east coast

Catch rates

The commercial catch rates were standardised to estimate an index of abundance of Spanish mackerel through time (Figure 4). Standardisation was based on the kilograms of Spanish mackerel caught per daily fishing operation, which may comprise a primary vessel and multiple dories. The catch rate model included terms for year, month, latitude, lunar phase, wind speed, co-catch of reef fish and an identifier for the fishing operation.

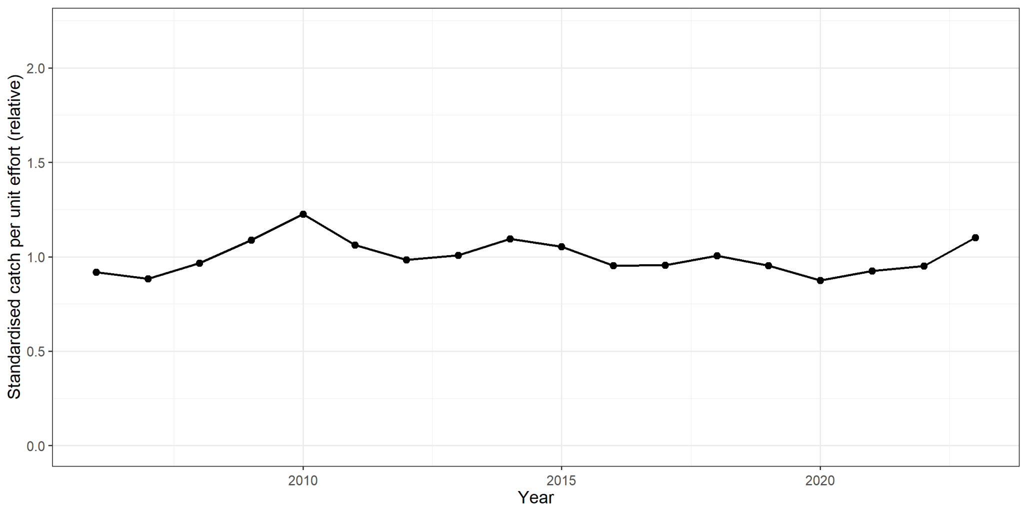

Figure 4: Annual standardised catch rates for Spanish mackerel in the Australian east coast

Length and age

The population model was fit to length composition and age-at-length composition data. The mean (average) age of fish shows a marked increase over the last 20 years (Figure 5).

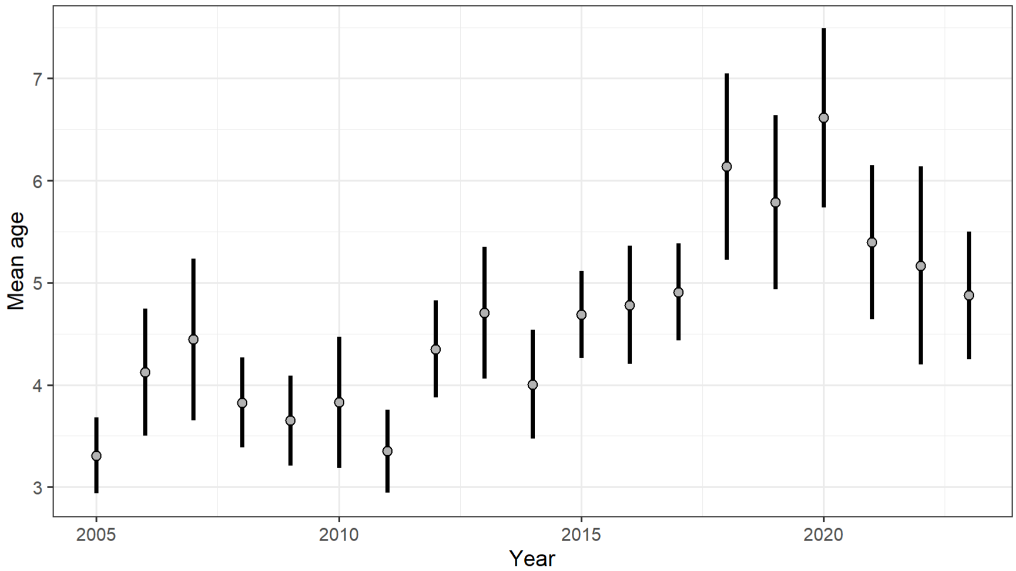

Figure 5: Mean age from conditional age-at-length data over time (aggregated across length bins) for commercial and recreational sectors combined

Key model influences

Key influences in the model were natural mortality rates, steepness and the relative weighting of length and age data and migratory patterns of east coast Spanish mackerel.

Natural mortality and steepness: Natural mortality and steepness were major drivers of biomass outcomes, and their interaction was particularly important. The model was most sensitive to natural mortality, with lower steepness scenarios producing higher natural mortality estimates, which resulted in more optimistic biomass estimates. This highlighted the importance of evaluating these two parameters together.

Relative weighting of length and age data: Adjusting the relative weight of length and age data improved the model's ability to track trends in the mean age of fish over time. By reducing the influence of length composition data, the model was able to fit more closely to age-at-length trends, which were suggestive of a biomass rebuild between 2005 and 2020.

Migratory patterns of east coast Spanish mackerel: Auxiliary analyses of spatial and seasonal patterns in the age and length data (see Section 2.7) confirmed expected seasonal migration patterns and highlighted important structure in these data. These patterns informed the adoption of a spatial model structure (called 'fleets-as-areas'), which improved the model's fit to length compositions, and estimation of selectivity.

Recommendations to improve future assessments

A comprehensive list of recommendations for future work have been made in Section 4.7. At a glance, these are summarised below:

Stock assessment

- **Environmental drivers:** Environmental indices as tested in this assessment had limited influence on model results. Since the empirical use of environmental drivers in stock assessment models is an evolving field, future work should trial alternative methods of incorporation, and use new data equivalent to those collected as part of FRDC project 2021-111, where available.
- **Steepness and natural mortality:** Future assessments should continue to monitor current best practice for the selection of steepness values and the estimation of natural mortality rates.
- **Time-varying selectivity:** Though plausible, time-varying selectivity could not be effectively modelled here, and project team members held mixed or inconclusive views about how realistic this phenomenon may be for east coast Spanish mackerel. We suggest revisiting this topic in future assessments, testing alternative approaches available in Stock Synthesis.
- **Shark depredation:** If updated data on depredation rates become available, they should be included in future assessments.

Monitoring

- **Biological data collection:** Continued collection of age, length, and sex data is critical. These data underpin the model's estimation of key biological processes, especially natural mortality, which was highly influential in this assessment. As time series of these data accumulate, future models will be better equipped to estimate natural mortality internally with reduced uncertainty.

Research

- **Tag-recapture work:** Tagging data from FRDC project 2021-111 helped to inform hypotheses about the relative degree of population mixing, and supported decisions about appropriate model structure. We recommend continued collection of satellite tagging data to obtain a higher sample size of tagged fish, as this would permit the development of models that better account for population mixing and movement.
- **Updates to shark depredation data:** Given indications of rapid change in shark depredation rates, continued research and periodic updates to these estimates are recommended.

Conclusion

This stock assessment was commissioned to establish the status of the Australian east coast Spanish mackerel stock and inform the management of the fishery. The assessment benefited from incorporating recommendations from independent reviews of the 2021 assessment, expanding the project team, and adding new data sources to address knowledge gaps. These factors all contributed to a more robust and responsive model.

This assessment highlights that the stock is unlikely to be at target levels, with a most probable estimate of 34% of unfished spawning biomass. The observed rebuild commencing in the early 2000s appears to be driven by a few strong recruitment years, which produced cohorts of fish that persisted in the population for some time. Reduced fishing mortality during this eriod (due to decreased annual catches) may have allowed these recruitment years to contribute to biomass rebuilding.

These results show that the stock can rebuild when strong recruitment years align with conducive levels of catch. However, this mechanism of rebuild suggests some fragility in stock status, as it depends on the recurrence of strong recruitment events. We recommend that fishery managers consider this mechanism when determining future total allowable catches, to ensure that catch limits do not hinder the potential of future recruitment events to drive further biomass recovery.

Specific recommendations around any particular management proposal would require a separate analysis that takes the current assessment, and models the proposal by projecting forward, taking care to capture the estimated uncertainty in that projection.

Acknowledgements

This stock assessment was capably guided by a project team with an extensive knowledge base and a diverse range of perspectives on the Australian east coast stock of Spanish mackerel. In addition to the Departmental staff involved (including stock assessment scientists, fishery managers, fisheries monitoring staff and data specialists), the team included an independent scientist, two fishing industry representatives and a representative from the Great Barrier Reef Marine Park Authority (GBRMPA). The project team operated under a terms of reference, designed to ensure a transparent and evidence-based approach. The project team members were, in alphabetical order:

- Darren Cameron (GBRMPA)
- Alex Campbell - Stock Assessment (Fisheries Queensland - DPI)
- Sue Helmke - Chair/Fisheries Science Director (Fisheries Queensland - DPI)
- Simon Hoyle - Independent Scientist (Hoyle Consulting)
- Jennifer Larkin - Fisheries Resource Officer (Data) (Fisheries Queensland - DPI)
- Chad Lunow - Fishery Manager (Fisheries Queensland - DPI)
- Tyson Martin - Fisheries Scientist (Fisheries Queensland - DPI)
- Jason McGilvray - Biological monitoring representative (Fisheries Queensland - DPI)
- Ian Meads - Fishery Stakeholder, Recreational and Charter Representative
- Jonathan Mitchell - Fisheries Biologist (Agri-Science Queensland - DPI)
- Peter Stevens - Fishery Stakeholder, Commercial Representative
- Lucas Sumpter - Stock Assessment (Fisheries Queensland - DPI)

The entire team is thanked for contributing their time and knowledge, and engaging constructively over the course of the project.

The project team had additional input from guest attendees representing the Queensland Seafood Industry Association (QSIA) and the New South Wales Department of Primary Industries, whose participation and contributions were appreciated.

The project team also had guest attendees who presented on different aspects of the FRDC funded Spanish mackerel project 2021-111: Dr Ashley Williams (CSIRO) and Dr Sam Williams (Agri-Science Queensland - DPI). Thank you both.

We also thank Dr Susannah Leahy for her work on environmental drivers upon Spanish mackerel recruitment as part of FRDC project 2021-111, which made possible some novel attempts at incorporating environmental influences to a population model for this stock.

The authors acknowledge the significant time commitment of the fishery stakeholder representatives: Ian Meads and Peter Stevens. Their involvement in this project has meant that all aspects of this assessment could be considered not only in a scientific context, but also in the context of their extensive on-water experience. Ian and Peter have both also dedicated their time to assisting with data collection for the FRDC Spanish Mackerel project, which in-turn provided valuable additional data sources to this assessment. Ian and Peter's contributions have set an excellent standard for continued collaboration with industry members to further enhance stock assessments.

Our sincere thanks to the many DPI Fishery Monitoring staff that have participated in the collection and quality assurance of the length, age and sex data for Australian east coast Spanish mackerel, which were integral to this assessment. We also extend our gratitude to all fishers who have voluntarily assisted the collection of biological data. These data always play a crucial role in Queensland stock assessments, though the particularly long and robust time series of biological data available for Spanish mackerel facilitated a number of modelling techniques that were fundamental to achieving the improvements made to the current model. We thank Joanne Langstreth, Peri Subritzky and Olivia Whybird for sharing their intimate knowledge of the data and advising on their usage.

We thank the fishers who gave their time and expertise to respond to the telephone survey conducted to assist this assessment, and we thank the fishery DPI staff who conducted the interviews: John Cavallaro, Chad Lunow, Daniel McInnes and Jamie Nicholson.

We also wish to acknowledge and thank the many fishers, seafood processors and scientists who have contributed to past and current research on the Australian east coast stock of Spanish mackerel.

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Glossary

ACN	Authority chain number
AFMA	Australian Fisheries Management Authority
age	Age within this report refers to age group unless otherwise stated
B	Biomass, total weight of a population or of a component of a population. This assessment refers to spawning biomass, measured by spawning egg production
B_{limit}, B_{20}	Biomass limit reference point, the point below which the risk to the population is regarded as unacceptable under the Sustainable Fisheries Strategy
B_{MSY}	Biomass at maximum sustainable yield
B_0	Mean equilibrium virgin unfished biomass, average biomass level if fishing had not occurred. Virgin state corresponds to the first year assessed in 1911.
BRS	Boat ramp survey
Catch rate	Index of fish abundance, referred to as average (mean) catch rates standardised (adjusted) to a constant vessel and fishing power through time. All references to catch rates were standardised unless specified to be different.
Catchability, q	The ability to catch fish. More formally, it is defined as the probability of catching a fish 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
CKMR	Close-kin mark-recapture
CPUE	Catch per unit effort
DPI	Queensland Department of Primary Industries
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
EC	East coast
Fishery	This stock assessment evaluated Australian east coast Spanish mackerel. The assessment was conducted on the whole (genetic) stock across jurisdictions and included commercial, charter, recreational and research data from both New South Wales and Queensland. The fishery covers all fishing sectors: commercial, charter and recreational.
Fishing year	1 July to 30 June. Also labelled as 'year' within. Fishing years were equal to financial years to group the seasonal and biological patterns of Spanish mackerel. Labelling used the second year in the financial year string. For example the financial year July 2019 to June 2020 was labelled as 2020 fishing year.
FL	Fork length, measured from the tip of fish's nose to the fork in its tail (caudal fork)
fleet	A Stock Synthesis modelling term used to distinguish types of fishing activity. Typically a fleet will have a unique curve that characterises the likelihood that fish of various sizes (or ages) will be caught by the fishing gear, or observed by the survey.
FRDC	Fisheries Research and Development Corporation
FSAs	Fish-spawning aggregations
GBRMPA	The Great Barrier Reef Marine Park Authority
GAM	Generalised additive model
h	Beverton-Holt steepness parameter
ITQ	Individual transferable quota
JL	Jaw length
M	Natural mortality

MCMC	Markov chain Monte Carlo - a statistical simulation method for approximating the final (‘posterior’) distribution of a quantity
MLE	Maximum Likelihood Estimation - a statistical method of estimating the parameters of an assumed probability distribution
MLS	Minimum legal size
MSY	Maximum sustainable yield, the maximum level at which the species can be routinely exploited without long-term depletion
NRIFS	National Recreational and Indigenous Fishing Survey, funded by the FRDC (2000–01)
NSW	New South Wales
Overfished	A fish population with a biomass below the biomass limit reference point (B_{limit})
Overfishing	The condition where a population is experiencing too much fishing and the removal rate is unsustainable, that is, fishing mortality is higher than fishing mortality at maximum sustainable yield. F measured the level of fish harvested by different fishing sectors.
Qld	Queensland
$\boldsymbol{R_0}$	Virgin recruitment
RAP	The Representative Areas Program
Reference point	An indicator of the level of fishing, harvest or size of a fish population, used as a benchmark for interpreting the results of an assessment
RFish	Recreational fishing surveys conducted by Fisheries Queensland (1997, 1999, 2002, 2005)
SM	Fishery symbol used to access the commercial east coast Spanish mackerel fishery
SRFS	Statewide Recreational Fishing Surveys conducted by Fisheries Queensland (2010–11, 2013–14, 2019–20)
SS	Stock Synthesis software for fishery stock assessment
t	Tonnes
TACC	Total allowable commercial catch
TL	Total length, measured from the tip of fish’s nose to the end of its tail lying freely in its normal position
VMS	Vessel monitoring system
Selectivity	Probability of fish to being exposed to fishing mortality. This varies for different sized/aged fish. This is generally a result of fish being present in the fishing area (fishery) and their susceptibility to being caught by the fishing gear.
WW	Whole weight

1 Introduction

Spanish mackerel *Scomberomorus commerson* are a large pelagic fish, recognised as a prized table fish and iconic sports fish. On the east coast of Australia, they are an important target species for all fishing sectors, with substantial annual catches contributed by both the commercial sector and the combined recreational and charter sectors. Spanish mackerel tend to be caught adjacent to submarine features that interrupt current and aggregate bait fish, such as offshore reefs, shoals, islands and prominent coastal headlands. Catches are primarily taken by line fishing techniques with the commercial sector favouring trolling, while the recreational and charter sectors employ a diverse range of line fishing methods, such as bait fishing, use of surface lures, jigging and trolling. They are also a popular target species for recreational spearfishers, with the popularity in this method increasing during recent decades. Net fishing for east coast Spanish mackerel is prohibited.

East coast Spanish mackerel have been observed to live up to 26 years (Fisheries Queensland, unpublished data) and can weigh in excess of 30 kg. They reach sexual maturity between two and four years of age, at lengths greater than the minimum legal size limit of 75 cm.

Spanish mackerel are known to form fish-spawning aggregations (FSAs). Tobin et al. (2013) and Tobin et al. (2014) characterised east coast Spanish mackerel as obligate transient aggregators, meaning a substantial portion of the population migrate to a select few reefs during spawning season. In the fishery's recent history, the most well recognised FSA of Spanish mackerel occurs in waters off Lucinda, Queensland (around latitude 18° south), during October–November (Tobin et al. 2013). Buckley et al. (2017) found that additional aggregations have previously existed elsewhere within the Great Barrier Reef, such as off Cairns and Townsville, but have since been fished to economic infeasibility. Fisheries Research and Development Corporation (FRDC) project 2021-111 documented fisher reports of additional aggregation sites that coincided with suitable hydrodynamic conditions for Spanish mackerel spawning activity. Predictable spawning aggregation patterns make fish populations inherently vulnerable to exploitation (Buckley et al. 2017), with Tobin et al. (2013) noting Spanish mackerel's particular vulnerability due to its temporally and spatially discrete spawning pattern.

East coast Spanish mackerel form a single genetic stock in ocean waters between Cape York Peninsula and northern New South Wales (Buckworth et al. 2007). Buckworth et al. (2007) noted that while some individuals exhibit large scale movements along the east coast, others remain localised. Acoustic tagging work corroborated that some individuals exhibit strong reef fidelity during the spawning season (Tobin et al. 2014). It is unknown what proportion of the population take part in migration for spawning, but partial migrations are a common phenomenon in fish species globally (Chapman et al. 2012). In addition to their aggregation in northern tropical waters during winter and spring, some of the population move to southern waters during summer and autumn to extend their feeding range. This motive was also cited by Tobin and Mapleston (2004), who hypothesised that feeding may be an additional driver for migration, as the latitudinal occurrence of large Spanish mackerel catches varies throughout the year. The spatio-temporal occurrence of catch appears to be a reasonable proxy for migratory patterns, as the seasonal and spatial patterns of fishing follow the predictable locations of schooling fish.

Shark depredation, where a shark preys upon a fish caught by fishing gear before it is landed, is an issue becoming increasingly relevant to research and management in many fisheries internationally (Mitchell et al. 2023). Stakeholders from commercial, recreational and charter sectors alike corroborate the anecdote that rates of shark depredation have increased rapidly in Australian east coast waters during recent history. With markedly increasing participation in recreational fishing (Arlinghaus et al. 2021), the number of Australians discussing and concerned with the topic has also grown. Shark depredation is a complex issue, with Mitchell et al. (2023) highlighting negative biological, economic and social impacts, including increased mortality of target species, loss or damage of catch and fishing gear, and damage to the fishing experience. As of 2024, empirical estimates of shark depredation rates in Queensland east coast waters are available, with data collected by Agri-Science Queensland (ASQ) under FRDC project 2021-111. This assessment has incorporated these data directly to account for the impact of increased mortality upon Spanish mackerel due to shark depredation (Section 2.2.2).

Historically, the Queensland commercial fishing sector has accounted for the largest portion of the east coast Spanish mackerel catch. Commercial fishing for Spanish mackerel commenced in 1911, with fishing operations targeting spawning aggregations on the Great Barrier Reef (Thurstan et al. 2016; Buckley et al. 2017). The reported commercial fleet increased in size from one operation in 1911 to twenty in 1936. This increased to 36 fishing operations in 1937 and to 115 by 1950. Between 1934 and 1947, estimated commercial landings per fishing operation reached up to 540 fish (about 4 t) for a two day fishing trip, with at least 300 t of Spanish mackerel taken commercially in 1938 (Thurstan et al. 2016). Queensland commercial catch peaked in 1975, at an annual take of 927 t. The commercial fishing sector in New South Wales waters is comparatively small, as Spanish mackerel generally only school and feed in New South Wales waters during summer and autumn. New South Wales commercial catch peaked in 1989 at an annual take of 51 t. Since 2004, retained catch from the New South Wales commercial sector has averaged 4.6% of the Queensland commercial sector's take, before accounting for shark depredation. A full history of catch by sector is provided in Section 3.1.2.

In Queensland waters, access to the commercial east coast Spanish mackerel fishery is restricted to holders of an 'SM' fishery symbol. Established on 1 July 2004, this symbol is linked to individual transferable quota (ITQ) holdings. As of November 2024, there were 202 licensed operations (each 'SM' licence symbol identifies the primary line-fishing operation) (Department of Primary Industries 2024). While each licence includes an authorised primary fishing vessel (mothership), the majority of licences are permitted to use between 1 and 7 additional smaller boats (dories or dinghies) each. Of the 202 licences, 147 held ITQ sharing the current annual 165 t total quota (TACC). By comparison, in New South Wales waters the number of commercial fishing operations taking Spanish mackerel has been approximately 50 per year since 1970.

During the last two decades, the proportional catch split by sector has shifted markedly (Table C.2). While total catch has historically been dominated by the commercial sector, the catch share taken by the recreational and charter sectors combined roughly matched commercial take by the mid-2000s, before exceeding it in recent years.

Availability of data on catch and effort from the recreational sector is limited despite the sector's significant contribution to total catch. Measures of recreational fishing in Queensland have been captured by surveys periodically since 1997, with total annual catches estimated by seven surveys between 1997–2020, and fishing effort monitored by the Boat Ramp Survey program from 2016–present (see Table 2.1). More recently, opportunity for voluntary reporting by recreational fishers has been given via the Qld Fishing 2.0 app (Government 2025). Recreational fishing surveys suggest that 14 000–33 000 boat-days per year have been expended catching east coast Spanish mackerel (Higgs 2001; Henry and Lyle 2003; Higgs et al. 2007; McInnes 2008; Taylor et al. 2012; Webley et al. 2015; Teixeira et al. 2021).

Catches of Spanish mackerel taken by Queensland charter vessels were recorded through the logbook system from 1997 to 2024. Measures of historical fishing by charter and recreational operations (i.e. prior to the commencement of charter logbooks and recreational fishing surveys) were not well known or frequently reported.

For all sectors, additional rules apply such as a minimum legal size (MLS), and recreational in-possession limits (bag limits). A MLS of 75 cm (total length) for all kept Spanish mackerel has applied from 1993. Since 1 July 2023, recreational in-possession limits of 1 Spanish mackerel per person, or 2 per boat (with 2 or more people on board) are in effect. A full history of MLS and in-possession limit changes can be found in Table 1.1.

Table 1.1: History of east coast Spanish mackerel management in Queensland and New South Wales

Year	Management	Legislation
Queensland		
18 April 1957	A minimum legal size (MLS) of 18 inches total length (45.72 cm) for Spanish mackerel was introduced on 1 January 1958	*Fisheries Act 1957*
16 Dec 1976	MLS amended to 45 cm	*Fisheries Act 1976*
5 May 1982	Section 35 permits allowing recreational fishers to sell excess catch	
1 Jan 1988	Commercial logbook data collection began	
22 May 1990	Recreational fishers prohibited from selling any of their catch	
25 Jun 1993	MLS increased to 75 cm and recreational possession limit of 10 fish introduced	*Fishing Industry Organisation and Marketing Regulation 1991*
15 July 1994	Amendment to allow twice the in-possession limit for Spanish mackerel, as part of the reef fish provisions, if taken during an extended fishing charter (a continuous duration of 48 hours or more)	*Fishing Industry Organisation and Marketing Regulation 1991*
21 Feb 2003	Investment warning for Spanish mackerel issued	
12 Sep 2003	Amendment to set a recreational possession limit of three fish per person. Introduced a total allowable catch of 619 520 units (1 unit equals 1 kg) and an individual transferable quota management system for the commercial sector. These amendments took effect on 1 July 2004.	*Fisheries Regulation 1995*
1 July 2004	The Great Barrier Reef Marine Park Authority (GBRMPA) revised the reef zonings and expanded the Representative Areas Program (RAP). The zoning process gave consideration for the importance of Spanish mackerel fishing and five key reefs remained open to fishing (Tobin et al. 2014).	*Great Barrier Reef Marine Park Zoning Plan 2003*

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Table 1.1 – *Continued from previous page*

Year	Management	Legislation
28 May 2019	Recreational boat limits set to two times the possession limit to a total of six Spanish mackerel per boat (these boat limits do not apply to charter fishers)	*Fisheries Declaration 2019*
	The total allowable commercial catch (TACC) stands at 578 013 kg following cancellation of units and the 2014 surrender of units bought by the Australian Government as part of the structural adjustment package for the Representative Area Program for the Great Barrier Reef Marine Park introduced in July 2004.	
22 Oct 2022	Amendment to prohibit commercial and recreational fishers from taking or possessing Spanish mackerel in the northern and southern regulated waters during regulated periods. An exception applies for recreational fishers taking part in a licensed charter trip prior to 1 July 2023.	*Fisheries (Spanish Mackerel) Amendment Declaration 2022*
1 Jul 2023	TACC reduced from 578 013 kg to 165 000 kg. Recreational possession limit reduced to one per person or two fish per boat with two or more recreational fishers on board. Possession limit exception for extended charter trips removed.	*Fisheries Legislation (Spanish Mackerel and Bar Rockcod) Amendment Declaration 2023*
	Addition of further regulated periods for the northern Spanish mackerel waters for the period 2023–2025, and clarification that regulated periods for southern Spanish mackerel waters are static. Removal of exception for the possession of Spanish mackerel during regulated period by recreational fishers on licensed charter trips in Spanish mackerel waters.	*Fisheries Legislation (Spanish Mackerel and Bar Rockcod) Amendment Declaration 2023*
New South Wales		
1 Jul 1998	Bag limit of five introduced (comprised all of Spanish mackerel or all of spotted mackerel or partly of each)	*Fisheries And Oyster Farms Act 1935 – Regulation*
3 Sep 2007	MLS of 75 cm total length was introduced in New South Wales	*Fisheries Management (General) Amendment (Prohibited Size Fish and Bag Limits) Regulation 2007 under the Fisheries Management Act 1994*

A number of stock assessments have evaluated the status of Australian east coast Spanish mackerel (O'Neill and McPherson 2000; Hoyle 2002; Welch et al. 2002; Hoyle 2003; Campbell et al. 2012; O'Neill et al. 2018; Tanimoto et al. 2021a). Most recently, Tanimoto et al. (2021a) included data until the 2020 fishing year inclusive, and estimated the stock was at 17% (14–27%) of 1911 levels. An external review was conducted on the 2021 assessment by Neil Klaer (Klaer 2021), with an additional review commissioned by the Queensand Seafood Industry Association (QSIA), conducted by Simon Hoyle and Alistair Dunn (Hoyle Consulting & Ocean Environmental) (Hoyle and Dunn 2023). These reviews made a number of suggestions for future work and highlighted key sources of uncertainty, which have served as focal points in the current assessment.

In 2024, Fisheries Queensland commenced the current body of work resulting in this stock assessment update.

2 Methods

2.1 Data sources

Data sources included in this assessment (Table 2.1) were used to create population model inputs, such as annual retained catch totals, standardised catch rates, discard estimates, length compositions and conditional age-at-length compositions. The assessment period spans 1911 to 2024 inclusive, with data inputs until June 2024 based on available information.

Table 2.1: Data inputs for the assessment

Data	Years	Source	References
Qld commercial	1989–2024	Compulsory commercial logbook database (CFISH) collected by Fisheries Queensland	
	2006–2024	Quota reporting data (catch (kg) by trip of quota species) collected by Fisheries Queensland	
	1937–1981	Historical Queensland Fish Board Data	(O'Neill et al. 2018; Campbell et al. 2012)
Qld recreational	1999, 2002, 2005	Recreational fishing surveys (RFISH) conducted by Fisheries Queensland	(Higgs 2001; Higgs et al. 2007; McInnes 2008)
	2011, 2014, 2020	Statewide Recreational Fishing Survey (SRFS) conducted by Fisheries Queensland	(Taylor et al. 2012; Webley et al. 2015; Teixeira et al. 2021)
	2001	Recreational fishing survey (the National Recreational and Indigenous Fishing Survey, NRIFS) conducted by the Australian Department of Agriculture, Fisheries and Forestry	(Henry and Lyle 2003)
	2016–2024	Boat ramp survey program conducted by Fisheries Queensland	
Qld charter	1997–2024	Logbook data collected by Fisheries Queensland	
NSW commercial	1985–2024	Logbook data collected by New South Wales Department of Primary Industries	

Continued on next page

Table 2.1 – *Continued from previous page*

Data	Years	Source	References
NSW recreational	2001, 2014, 2018	New South Wales recreational fishing survey using similar methodology to the NRIFS	(West et al. 2015; Murphy et al. 2020)
Wind	1989–2023	Weather data collected by Bureau of Meteorology (BOM)	
Lunar	1989–2023	Continuous daily luminous scale of 0 (new moon) to 1 (full moon)	(O'Neill et al. 2014)
Biological	2005–2023	Biological monitoring (age, length, and sex data from the commercial sector) conducted by Fisheries Queensland	
	2005–2023	Biological monitoring (age, length and sex data from recreational sector) conducted by Fisheries Queensland	
Research project	2022–2024	Rates of shark depredation for commercial and recreational sectors in Queensland east coast waters	(Mitchell in prep)
	2022–2024	Rates of post-release mortality	(Mitchell in prep)
	2019–2024	Effort signatures derived using vessel tracking data from the Vessel Monitoring System	(Mitchell in prep)
Telephone survey	2025	Shark depredation and catch history telephone survey responses, collected by Fisheries Queensland	Appendix I

2.1.1 Regions

The spatial extent of the Australian east coast stock of Spanish mackerel is shown in Figure 2.1, bounded at 11° S (Escape River, Queensland) in the north and 34° S (Port Stephens, New South Wales) in the south. One degree latitude bands are shown, where the label indicates the southern extent of each latitude band, and are added to the map for reference. While the previous assessment (Tanimoto et al. 2021a) used these latitude bands explicitly as regional strata in data inputs such as standardised catch rates, this assessment used continuous measures of latitude to allow for finer spatial resolution.

All report commentary refers to Australian east coast fish and does not include adjacent Torres Strait or Gulf of Carpentaria fish stocks.

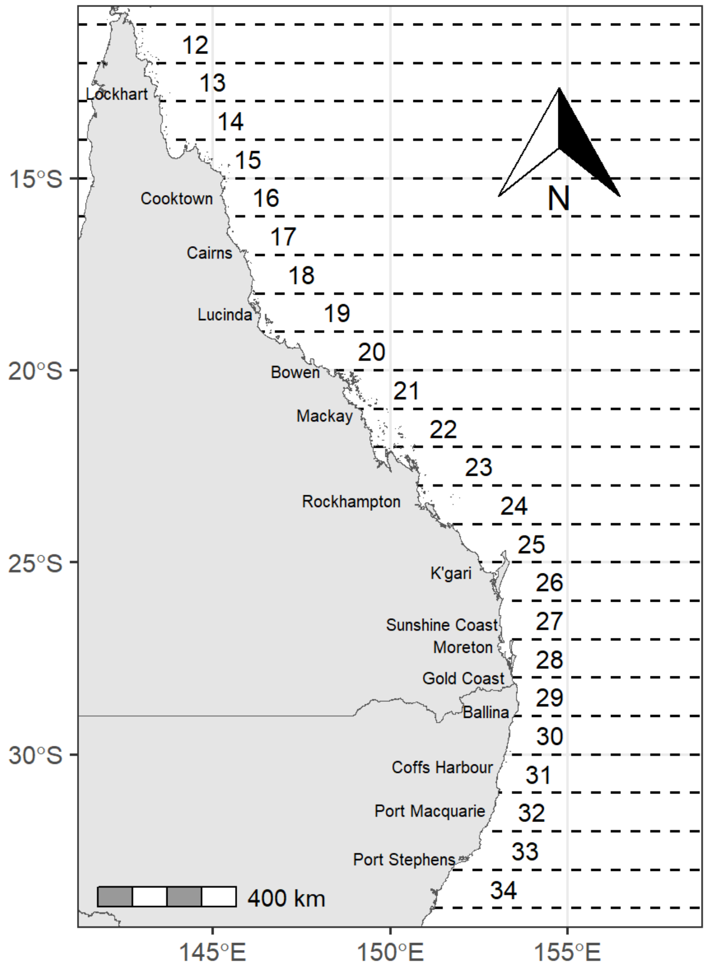

Figure 2.1: Spatial extent of the Spanish mackerel stock in Australian east coast. Numbers indicate latitude bands, where the number represents the latitude at the southern bound of each band.

2.1.2 Commercial sector

2.1.2.1 Catch and effort

The Queensland Fish Board data documented monthly and annual commercial landings of Spanish mackerel for 45 years from 1937 to 1981. The harvest tonnages were originally published in annual reports of the various boards responsible for marketing and distributing fish in Queensland during this period. The data were digitised in the early 2000s. No fishing effort data were available to complement the fish landings data. For the stock modelling, it was assumed the Fish Board tonnages of Spanish mackerel were relatively complete and taken from along Queensland's east coast (Campbell et al. 2012).

Between 1989 and 2024, Queensland commercial catch of Spanish mackerel was recorded through the compulsory logbook system. The data consisted of the daily catch (in kilograms) by species from each fishing operation. The spatial resolution of catch data was based on 6×6 minute latitudinal and longitudinal sites but defaulted to 30×30 minute latitudinal and longitudinal grids where site information was not available.

On 1 July 2004, Queensland east coast Spanish mackerel became a quota regulated fishery (Table 1.1). From the 2005 fishing year to present, catches of Spanish mackerel have been recorded through the quota reporting system. Unload notices are given by trip, and kilograms of Spanish mackerel quota are debited from quota accounts reflecting the total amount of Spanish mackerel caught (converted to whole fish weight). Weights given in unload notices are required to be measured using certified scales (see Fisheries(Commercial Fisheries) Regulation 2019).

Commercial harvest (in kilograms) of Spanish mackerel from New South Wales waters was recorded through compulsory logbook systems from 1985 to 2024. From 1985 to 2009 monthly harvests by species were reported per fishing operation. The procedure changed to daily reports in 2010. The spatial resolution of New South wales commercial catch data was based on one degree latitude bands.

2.1.3 Recreational sector

2.1.3.1 Catch

Recreational surveys provided estimates of the number of fish harvested and discarded, and analysts combined this with demographic information to estimate annual totals for each species (or species group) at state and regional scales. See the references listed in Table 2.1 for more detail.

The statewide methods used telephone surveys of random households to estimate recreational fishing participation, catch and effort. Logbook records were also maintained by a sample of fishing households. Fishing data were demographically weighted to estimate total catches of fish (in numbers) and fishing effort by factors such as key species, seasons and regions.

Surveys conducted in 2001, 2011, 2014 and 2020 had more effective follow-up contact procedures with survey participants, resulting in less dropout of participants compared to the other survey years using RFish methodology (Lawson 2015).

In 2001, 2014 and 2018 statewide surveys of recreational fishing were completed for New South Wales waters. The survey methods were equivalent to those used in Queensland.

2.1.3.2 Effort

Through boat ramp surveys, recreational data were collected by Fisheries Queensland in 18 different regions, extending from Aurukun to the Gold Coast. Fifteen of these regions were along the Queensland east coast, with Cooktown being the northernmost region. Staff trained in the survey protocol, and identifying fish, interviewed recreational fishers at boat ramps during survey shifts. The surveys recorded day and location fished, and for key species, catch (in numbers), discards (in numbers) and measured fork lengths (cm) of retained fish (Northrop et al. 2018; Fisheries Queensland 2017). As boat ramp surveys interview only a subset of recreational fishers, these data cannot be used to estimate total statewide catches. However, the data are indicative of spatial and temporal trends in recreational fishing effort, and patterns of discards. The effort data from boat ramp surveys was used to refine total catch estimates for the years 2016–2019 and 2020–2024, where the most recent SRFS survey was conducted in 2020 (see Section 2.2.1.3 for more detail). Boat ramp surveys were also used to inform recreational discarding behaviour (see Section 2.3).

2.1.4 Charter sector

Catches of Spanish mackerel taken by Queensland charter vessels were recorded through the logbook system from 1997 to 2024. This provided the operator identifier, the date, the location fished, retained catch by species (recorded in kg) and the number of guests on the trip.

2.1.5 Age and length compositions

Age, length and sex data of Spanish mackerel have been collected routinely by Fisheries Queensland to serve as the primary data source for age and length compositions. Details of the age and length sampling are provided in Section 2.6.1, with further information available in Fisheries Queensland (2021) and Sumpton and O'Neill (2004). Various other programs and research projects have also collected similar data for Spanish mackerel, though over shorter periods (for details, see Tobin and Mapleston (2004) and McPherson (1981)).

In 2000–2002, Fisheries Queensland's sampling was focused solely on Spanish mackerel that were commercially fished in the Lucinda area during the spawning season in October/November (Sumpton and O'Neill 2004). From 2005, sampling was increased to be temporally and spatially expansive, covering both commercial and recreational harvests of Spanish mackerel throughout Queensland's east coast waters (Tobin and Mapleston 2004; Campbell et al. 2012). Sampling of age data (otolith collection) has been undertaken since fishing year 2002 (Sumpton and O'Neill 2004). Opportunistic collection of age data from New South Wales (2009–2024) has also been included, however these samples are limited.

2.1.6 Phone survey

Project team meetings throughout this assessment highlighted some challenging topics that would benefit from gathering further information from fishers. A pool of commercial and recreational fishers was surveyed (n = 16), with some questions being specific to the sector the respondent identified with. Thirteen of the sixteen respondents had greater than 30 years of experience when fishing for Spanish mackerel, with the full range of experience among respondents ranging from 10 to 54 years. All questions pertained to their experience when fishing for Spanish mackerel only. Specifically, these topics were:

- The reliability of commercial logbook records during the period 1997–2004 (only asked of commercial operators)
- Shark depredation: what was their experience with shark depredation, and whether they could recall a specific year when they began losing fish to sharks (asked of all fishers)

Fishers were also given the opportunity to make any additional comments they deemed relevant to these topics. Responses to the surveys were used to guide the approaches taken to both retained catch reconstruction (Section 2.2.1) and accounting for shark depredation (Section 2.2.2). The full script of questions contained in the phone surveys can be seen in Appendix I.

2.2 Catch estimates

2.2.1 Retained catch

Catch data from the commercial, charter and recreational sectors were analysed to reconstruct the history of retained catch from 1911 until the end of 2024. Prior to 1911, Australian east coast Spanish mackerel catch was presumed to be negligible. This section describes how these data were combined to create the history of Spanish mackerel catch. All catch is retained (landed) unless stated otherwise. Figure 2.2 shows a graphical overview of the methods used to reconstruct the catch history for this assessment.

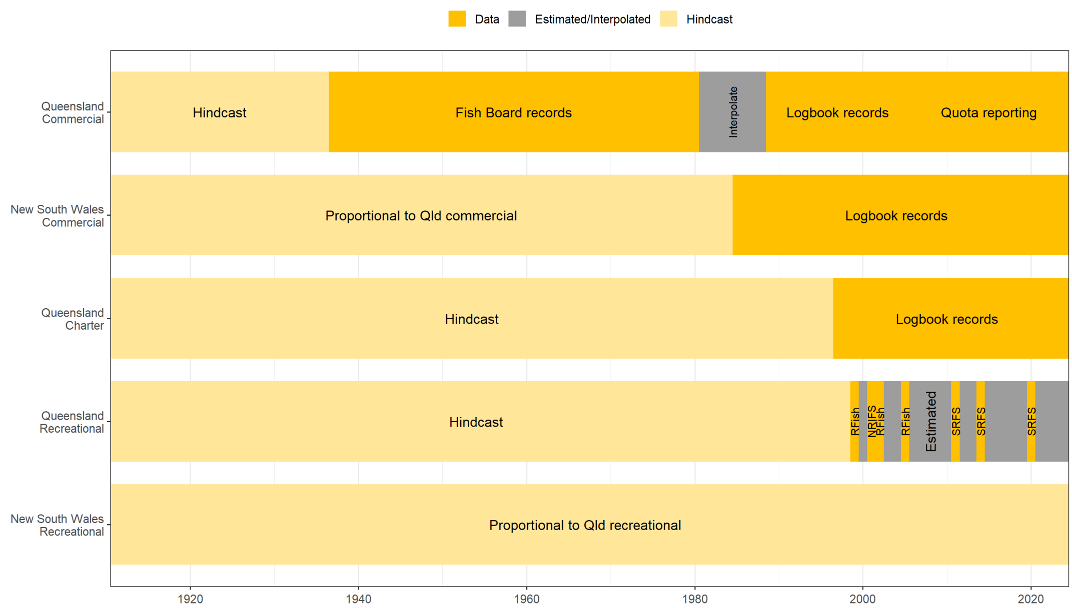

Figure 2.2: Overview of the data sources used to reconstruct the history of Spanish mackerel retained catch

2.2.1.1 Commercial

Members of the project team noted that it was plausible that the investment warning ahead of individual transferable quota (ITQ) allocation in 2004 could lead to over-reporting during the 1997–2004 period. If over-reporting had occurred, this would lead to artificially inflated annual catch totals during this period, followed by a sudden decline following 2004 as quota was implemented. This issue was appraised by the project team, which led to a clearer indication that over-reporting in this period may have occurred. This was then reinforced by commercial fishers' responses to Question 1 in the telephone survey (see Section 2.1.6). The phone survey responses are further detailed in Appendix I.

Project team discussions gave broad agreement that some degree of adjustment would be required for catches in this period, by comparing the 1997–2004 period to a period of equivalent length post-2004.

The project team also acknowledged that some amount of the reduction in catch following 2004 was likely a real effect, as the number of active fishing operations for Spanish dropped from 157 in 1997–2004 compared to 104 in 2005–2012 (see Figure 2.3). Since the number of active fishing operations dropped by 33%, a similar drop in reported catch may be expected. However, raw annual Queensland commercial catches dropped by 59%, across the same periods. This comparison corroborates the possibility of over-reporting during the 1997–2004 period.

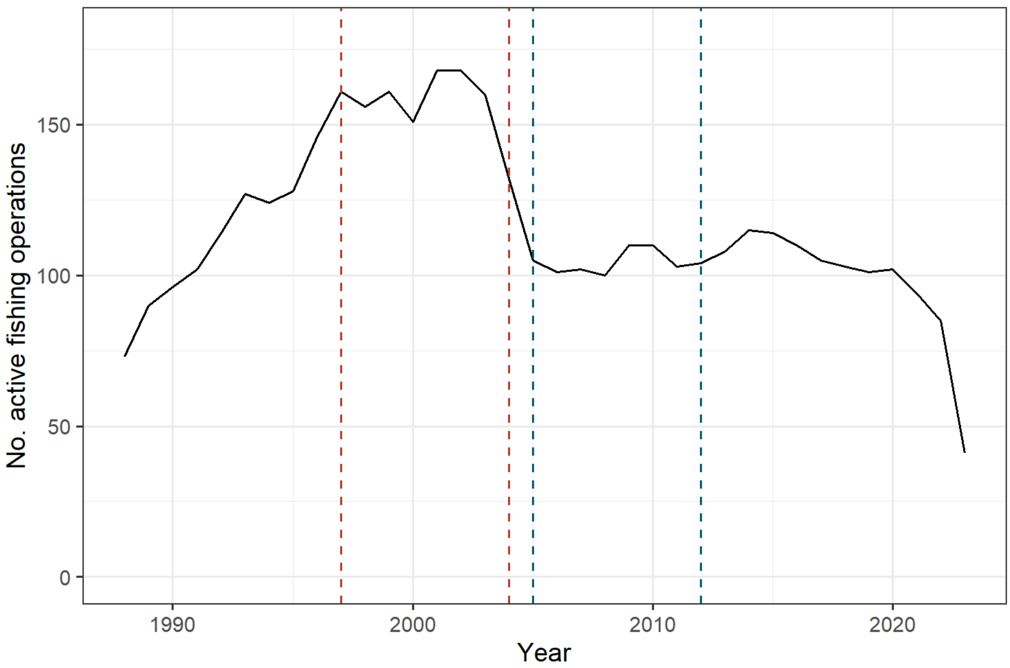

Figure 2.3: Number of active Spanish mackerel fishing operations by year, red and blue dotted lines represent the reference periods (pre-2004 in red, post-2004 in blue) used in the calculation of a scaling factor

Developing an approach to adjust for over-reporting presents a challenge, as both catch and effort measures are assumed compromised during this period, and rendered unusable in any adjustment method. Of the available metrics to compare across 2004, the metric most robust to possible over-reporting was the number of active fishing operations. Hence, an adjustment method was constructed to align the relative change in catch to be proportional to the change in active fishing operations. The method was implemented as follows:

- The average number of active fishing operations, and the average annual catch were calculated for both the pre (1997–2004) and post (2005–2012) periods respectively
- The average catch per fishing operation was produced for both periods. This was done by dividing the average annual catch by the average number of active fishing operations for the pre and post periods respectively.
- A scaling factor was produced using the following calculation:

$$Scale = PostCatch_{operation} / PreCatch_{operation} \tag{2.1}$$

  where:
  - $Scale$ = the resulting scaling factor, equal to 0.61
  - $PostCatch_{operation}$ = average catch per fishing operation (2005–2012), equal to 2,435 kg
  - $PreCatch_{operation}$ = average catch per fishing operation (1997–2004), equal to 3,994 kg
- Finally, the resulting scaling factor of 0.61 is applied to annual catches between the years 1997–2004

The history of Queensland commercial sector catch was reconstructed, using:

- **2007 to 2024:** Quota reporting data
- **2005–2006:** Commercial logbook values
- **1997–2004:** Rescaled commercial logbook values (method defined above)

- **1989–1996:** Commercial logbook values
- **1982–1988:** Linear interpolation
- **1937–1981:** Queensland Fish Board records
- **1911–1937:** A hindcast method, whereby the preceding year's Queensland commercial catch C_{t-1} starting from 1937, was calculated back in time to 1911 by reducing the annual tonnage by the power of 0.985 ($C_{t-1} = C_t^{0.985}$)(Campbell et al. 2012; O'Neill et al. 2018).

The history of New South Wales commercial sector catch was reconstructed, using:

- **1985–2024:** New South Wales logbook values
- **Years prior to 1985:** the geometric mean of the proportion of New South Wales to Queensland commercial harvest between 1985 and 2009 (Campbell et al. 2012; O'Neill et al. 2018). For these years the proportion was 2.7%, showing the magnitude of commercial New South Wales catches was small compared to those from Queensland waters.

2.2.1.2 Charter

As per the previous assessments (Tanimoto et al. 2021a; O'Neill et al. 2018), The history of Queensland charter sector catch was reconstructed, using:

- **1997–2024:** Queensland charter logbook values
- **1911–1997:** A hindcast method, where charter catch was assumed zero in 1911 and increased proportionally to Australian population growth through the time series to reach the catch in 1997

Catch taken by the Queensland charter sector was assumed to be negligible prior to 1937.

2.2.1.3 Recreational

Queensland recreational retained catches of Spanish mackerel were estimated using data from seven statewide surveys (telephone-logbook surveys) (Table 2.1). In years where survey data were not available, catches were estimated using auxiliary data such as annual changes in recreational effort from boat ramp survey (BRS) data, and annual changes in boat registrations in early years. Methods for each period are detailed further below.

In the 1997 RFish survey, all data were recorded as "unspecified mackerel", meaning that species specific data were not available. Hence, data from the 1997 RFish survey was not used in this assessment.

Estimates from the RFish surveys in 1999, 2002 and 2005 had higher participant drop out than surveys in later years. This may bias the mean catch rates and fishing effort upwards and result in an overestimate of recreational fish catches. To account for this bias, the previous stock assessment by Tanimoto et al. (2021a) used a simple ratio method from Leigh et al. (2017) (see Tanimoto et al. (2021a) for further details). This method was applied to reduce RFish catch estimates to better align with the 2001, 2011, 2014 and 2020 surveys. The assumption in applying this scaling was that the RFish estimates were overstated by the same fraction in all survey years in which the RFish methodology was employed. With the exclusion of the 1997 RFish estimate, the rescaling factor was calculated as 0.45 (as opposed to 0.34 in Tanimoto et al. (2021a).

Here, this ratio method was applied with a slight modification, whereby the denominator of the ratio is simply given as the mean of the 1999 and 2002 estimates:

$$c_{2001}/mean(c_{1999} + c_{2002}) \tag{2.2}$$

A recommendation by Hoyle and Dunn (2023) was that 'analysts explore the sensitivity of assessment outcomes to alternative assumptions about recreational catches', where much of the detail about recreational catch estimates in the review focused on the adjustment of RFish estimates. Here, we have excluded the 1997 RFish estimate as it was deemed to have the highest probability of biased estimates, due to the lack of species specification. This assessment also explored multiple approaches to the remaining RFish survey years, whereby the remaining 1999, 2002 and 2005 RFish surveys were either:

- **a.** rescaled using the methods detailed above, or
- **b.** excluded from the assessment, with the hindcast period extended to meet 2001 NRIFS, and a linear interpolation between 2001 NRIFS and 2011 SRFS.

Approach 'b.' was included to appraise the suggestion by Lawson (2015), who stated "the unpredictable and multifaceted nature of the reporting bias observed in the RFish data may preclude any reliable adjustments". Resulting annual catches for this period were comparable between both of the approaches listed above (see Figure C.1 in Appendix C.2). Therefore, the project team opted in favour of retaining the available rescaled RFish estimates, to reduce the length of interpolated periods uninformed by empirical data.

All Queensland recreational surveys (other than the 2011 survey) included some records of "unspecified mackerel", in addition to species-specific records. For each survey, the ratio of known Spanish mackerel to total identified mackerel (Spanish, grey, school, shark and spotted mackerel combined) was applied to the total number of unspecified mackerel, and these were added to the Spanish mackerel catch. This method was applied to kept and released fish separately.

For years where total catch estimates for the recreational sector were not available from surveys, the previous assessment (Tanimoto et al. 2021a) estimated catches for these years using annual commercial catch rates multiplied by mean fishing effort. Commercial catch rates are likely to be impacted by hyperstability, resulting in a less reliable index of abundance (as highlighted in Klaer (2021) and Hoyle and Dunn (2023)). Accordingly, this assessment took a different approach to estimating total recreational catch for these years. The current assessment methods are outlined below. Of the years where survey estimates of total catch were unavailable, the following approaches were taken for years where:

- **Boat ramp survey (BRS) data were available (i.e. 2016–2019, 2021–2024):** Data on the temporal trends of recreational effort from BRS were used inform the pattern of catch. The mean number of Spanish mackerel caught per interview was multiplied by the mean recreational fishing boat trailer count for each year. This gives an index which accounts for both raw recreational catch rates of Spanish mackerel and also total annual effort. This index was produced for each year, before being normalised (where the value of each year was made relative to the value in 2020, which was set to 1.0). Finally, the 2020 SRFS estimate of total recreational catch was multiplied by the annual normalised index values in the years 2016–2019 and 2021–2024.
- **BRS data were not available (i.e. 2000, 2003–2004, 2006–2010, 2012–2013):** A simple linear interpolation between survey years was performed where BRS data were unavailable.

The history of Queensland recreational harvest was reconstructed using:

- **2001, 2011, 2014 and 2020:** were set to equal the values calculated using the NRIFS (2001) and SRFS (2011, 2014 and 2020) surveys and the methods described above.
- **1999, 2002, and 2005:** were set to equal the values from the rescaled RFish estimates and the methods described above.

- **1991–1998:** A hindcast method, where catch increased from 1992 proportionally to the trend in new boat registrations to meet the RFish value in 1999.
- **1911–1990:** A hindcast method, where catch was assumed zero in 1911 and increased proportionally to the Australian population growth through the time series to reach the catch estimate in 1991.

New South Wales recreational harvest:

- was equal to the Queensland recreational harvest rescaled by the ratio of New South Wales to Queensland recreational catch, over the years for which New South Wales data were available. This ratio was 0.26.

The harvest from the recreational surveys was reported in numbers of fish. Hence, the retained catch data from the recreational sector was input into the population model as numbers of fish (unit option = 2 in SS, Methot et al. (2023)). For visualisation purposes, retained catch from all sectors is displayed in plots in terms of weight (tonnes of fish). In plots, recreational catch is converted from numbers to weight by internal processes within Stock Synthesis that make use of the length compositions, selectivity information and weight-length relationship.

2.2.2 Shark depredation

The impact of increased mortality of Spanish mackerel due to shark depredation is quantifiable and can be captured in the model, if data are available. The previous stock assessment by Tanimoto et al. (2021a) made specific recommendation that future Spanish mackerel stock assessments include an investigation on the effect of shark depredation rates. The review completed by Hoyle and Dunn (2023) also recommended testing impacts of shark depredation when estimates of depredation rates became available.

Tanimoto et al. (2021a) trialled an additional scenario which laid some methodological groundwork for incorporating impacts of shark depredation (see Tanimoto et al. (2021a), Appendix F), however empirical data on depredation rates were not available as of 2021. Hence, the scenario was included as an appendix in Tanimoto et al. (2021a) and future work was required before shark depredation methods could be included in the main model ensemble.

In 2024, FRDC project 2021-111 (Mitchell in prep) provided estimates of shark depredation rates in Queensland east coast waters. From 2022–2024, 22 fishers (commercial fishers, recreational fishers and Animal Science Queensland staff) recorded depredation rates while fishing for Spanish mackerel. This provided data on a total of 88 fishing trips (33 commercial, 55 recreational or charter) from various locations on Queensland's east coast.

A key finding from the FRDC data is that depredation rates differed markedly by sector. Of the commercial trips, an average shark depredation rate of 6.02% was obtained, meaning 6.02% of hooked fish were lost to sharks. By contrast, the recreational and charter trips produced a significantly higher average depredation rate of 36.58%. When interpreting this value, it should be considered that possession limits apply to recreational fishing trips, but not to commercial trips. Therefore, it is possible that some portion of the contrast between commercial and recreational rates is attributable to this.

Fisheries Queensland's boat ramp survey (BRS) program has also collected data on depredation experienced by recreational fishers since 6 July 2023. While data on targeted Spanish mackerel trips are limited, and results vary by location and time of year, these data indicate that around 33% of trips experience depredation. At the time of writing, only one year of these data are available, however the BRS program continues to collect these data and a longer time series will be available for future assessments.

Despite the recent availability of data on depredation rates, empirical data is still lacking on the yearly rate of increase in shark depredation, as well as the year or period where rates began increasing. Tanimoto et al. (2021a) assumed shark depredation increased from 2009 onwards, when fishery management introduced Queensland commercial quota for east coast shark and the requirement to hold a commercial shark fishing 'S' symbol. Queensland commercial east coast shark catch decreased following the management changes in 2009 (Queensland annual total east coast shark quota was 600 t per financial year; mean annual shark harvest pre-quota, 2000–2009, was 1190 t; mean annual shark harvest for 2010–2020 was 338 t). There was a belief among some fishers that these changes have directly resulted in higher numbers of sharks and higher depredation rates (Tanimoto et al. 2021a).

In addition, to support the notion of increased shark depredation since 2009, annual nominal levels of otter trawling have roughly halved since 2009, with a decline in bycatch discarding on which sharks may scavenge and feed (Wang et al. 2020; Hill and Wassenberg 2000). As mentioned by Tanimoto et al. (2021a), with less discarded trawl bycatch, one could speculate that sharks may alter their scavenging patterns as needed to consume more fish from offshore line fishing catches.

It is possible however that the same rates of increase have not been experienced by the commercial sector. Prior to the recent FRDC project findings, the only record of shark depredation rates for Spanish mackerel on the east coast was a figure of 7.2% in 1979, for commercial fishers only, in waters between Townsville and Lizard Island on the Great Barrier Reef (McPherson 1981). When compared with the contemporary commercial rate of 6.02%, this is suggestive that rates of depredation experienced by the commercial sector have remained relatively stable over time.

While a potential basis for the temporal increase in shark depredation was given from Tanimoto et al. (2021a), the current assessment project team elected to seek the expertise of commercial and recreational fishers on the matter. Specific questions on shark depredation were included in the phone survey of fishers conducted by Fisheries Queensland (n = 16, see Section 2.1.6). Thirteen of the sixteen respondents had greater than 30 years of experience when fishing for Spanish mackerel, with responses ranging from 10 to 54 years of experience. When asked to recall a year where their experience of losing fish to sharks began to worsen, 14 out of 16 respondents provided a year or year range, with no responses being earlier than the 2000s. Of the 14 responses to this question, 11 responses gave years equal to or more recent than 2009, providing some corroboration for the year 2009 used in Tanimoto et al. (2021a). With the justification given in Tanimoto et al. (2021a) and the results of the phone survey, this assessment assumed shark depredation increased from 2009 onwards.

Within SS, a direct mechanism for incorporating depredation as a separate form of mortality with its own selectivity pattern does not yet exist. Given this, the increased mortality of Spanish mackerel due to shark depredation was accounted for by applying an increase upon the retained catch estimates calculated in Section 2.2.1, using the following method:

- Prior to (and including) 2009, shark depredation rates were set to 6.02% for the commercial sector, and 12.04% for the recreational and charter sectors (assumed double commercial rate). Project team discussion concluded that the difference in fishing practices between the sectors would result in inherently higher depredation rates in the recreational and charter sectors, even prior to recent increases.

- From 2009–2024, a linear increase was implemented in depredation rates for the recreational and charter sectors, from 12.04% in 2009 to 36.58% (Mitchell in prep) in 2024. Commercial depredation rates remain stable at 6.02% throughout this period.
- In any given year, the rate of depredation informed adjustments to the catch estimates as per the following equation:

$$Catch_t = R_t/(1 - d_t) \tag{2.3}$$

where R is retained catch, d is the depredation rate, expressed as a proportion (i.e. 36.58% = 0.3658) and t is the given year.

2.3 Discards and post-release mortality

2.3.1 Discards

For many species, greater than half of the fish caught by recreational anglers are released (discarded) (McLeay et al. 2002). Generally, these released fish are smaller than the MLS which, for Spanish mackerel, is 75 cm total length. However, releasing fish due to being below the MLS is just one reason that fish maybe released. For some species, other factors such as desirability, eating quality, recreational possession limits and practice of catch-and-release fishing can result in legal-sized fish being released.

Commercial discarding of Spanish mackerel was assumed negligible due to the absence of a possession limit for commercial fishers, and the desirability of Spanish mackerel due to their eating quality. Discarding by the commercial sector was therefore assumed negligible and not included in the model. By contrast, boat ramp survey data confirmed that a significant fraction of the recreational catch of Spanish mackerel was released. The project team discussed likely motives for release of legal-sized Spanish mackerel, citing reasons such as reaching recreational possession limits (i.e. 1 per person, 2 per boat since 1 July 2023; 3 per person prior to this), self-imposed lesser catch limits, and the prevalence of sports fishing for Spanish mackerel, which can be on a catch-and-release basis.

Length composition information for discarded fish is not available for Australian east coast Spanish mackerel. In lieu of these data, and due to the numerous reasons for recreational discarding of Spanish mackerel of all sizes (not only MLS), it was assumed that length compositions of discarded fish mirror those of retained fish.

Data on discards from the recreational and charter sectors combined were input into the population model separately from the retained catch, for the years 2016–2024. Estimates of the total quantities of discards were obtained from the Statewide Recreational Fishing Survey (SRFS) in 2020 (Taylor et al. 2012; Webley et al. 2015; Teixeira et al. 2021), and boat ramp survey (BRS) data provided data on the rates and temporal pattern of discarding between 2016 and 2024.

Discard data were input to Stock Synthesis as proportions (i.e. proportion of the total catch that was discarded), which hereafter is synonymous with discard rates. Stock Synthesis then internally converts these data to total discard estimates (in thousands of fish), by evaluating the discard rates in conjunction with retained catch estimates. Data from BRS and the FRDC Spanish mackerel project were combined to create discard data inputs as follows:

- From the BRS data, discard rates per interview were produced, using the totals of kept and released Spanish mackerel for each given interview.
- Mean discard rates were then produced on an annual basis in all years where data were available (i.e. 2016–2024).

- For each year from 2016–2024, the resultant annual discard rates obtained from BRS data were input directly to Stock Synthesis (using discard unit '2', see Methot et al. (2023)). The resulting total discard estimates produced by Stock Synthesis can be seen in Figure 3.23, Section 3.1.8.
- Accompanying the time series of annual discard estimates, the Stock Synthesis discard mortality parameter was fixed at a value of 0.333, informed by findings from FRDC project 2021-111 (Mitchell in prep).

In 2020, a static discard rate was also available from SRFS 2020. This value was used for independent validation of the discard rates obtained from BRS data. Negligible difference was shown, with the 2020 BRS discard rate of 0.32 comparable to the SRFS 2020 derived rate of 0.306, which reinforced the direct usage of discard rates derived from BRS data.

2.3.2 Post-release mortality

Tagging work completed as part of FRDC project 2021-111 (Mitchell in prep) has provided the first available data on post-release mortality rates of Australian east coast Spanish mackerel. A rate of 0.333 was obtained from released, tagged fish in this study (n = 32), which had sufficient data to make a robust assessment of post-release fate (n = 21). The resulting rate is notably lower than the rate of 0.5 assumed in the previous stock assessment in the absence of information. This informed the discard mortality parameter within Stock Synthesis directly, with a fixed value of 0.333 assigned to this parameter.

2.4 Standardised index of abundance

Each statistical observation in the catch per unit effort (CPUE) analysis represented a single day of fishing by a single fishing operation, where a fishing operation may comprise a primary vessel and multiple dories. The response variable, 'logwt', was the log transformed weight of Spanish mackerel caught by that fishing operation. Each observation was constructed with separate fields for the following covariates:

- year: the year during which the fishing operation took place
- month: the month during which the fishing operation took place
- latitude: the latitude of the location in which the most Spanish mackerel were caught for that fishing operation
- lunar: the lunar phase at the time and location of the fishing operation
- wind: whether the average wind speed on that day in that location was greater than 20 kilometers per hour (approx. 11 knots), this was coded as a binary variable (0 or 1)
- rfb ('reef fish binary'): whether any coral trout, red throat emperor or coral reef 'other species' were caught by that fishing operation, this was coded as a binary variable (0 or 1)
- acn ('authority chain number'): the identifier of the fishing operator

The analysis was carried out using the software R (version 4.4.1, R Core Team (2020)).

The form of the model was:

$$\text{logwt} \sim \text{year} + \text{month} + \text{latitude} + \text{month} * \text{latitude} + \text{lunar} + \text{wind} + \text{rfb} + \text{acn} \tag{2.4}$$

A Generalised Additive Model (GAM) approach was taken, using the *mgcv* package (Wood 2012). GAM basis splines for the covariates were specified as follows:

- latitude: cubic regression spline of dimension 10
- month: cyclic cubic regression spline of dimension 10
- lunar: cyclic cubic regression spline of dimension 10
- acn: random effect

The month $*$ latitude term was specified using the tensor product interaction only.

After fitting the model, predictions were made for all levels of year, month, rfb, wind, latitude, as well as reference levels of lunar and acn. These individual predictions were then averaged to form a single prediction for each year. For the latitudinal component, this average was done such that latitudinal bands were weighted proportionally to their habitat area proxy – the largest spatial extent ever fished based on logbook records with fine-scale (site level) data over all years in the model.

The data was filtered prior to analysis according to the following criteria:

- line fishing only
- authority chain number has at least two years of Spanish mackerel catch
- daily logbook records (no 'bulk' reports, where daily quantities cannot be derived)
- latitude and longitude information exists
- year is between 2006 and 2023
- latitude is less than -11 and greater than -30

We elaborate on the rationale for these catch rate modelling decisions, as well as several other approaches that were trialled, in Section 4.3.4.

2.5 Biological relationships

2.5.1 Fork length and total length

All length measurements were provided in either fork length (FL), total length (TL) or jaw length (JL) and the population model was run using FL.

The following conversions by Mackie et al. (2003) and Fisheries Queensland (unpublished) were applied where necessary:

$$TL = 42.74 + (1.06 \times FL) \tag{2.5}$$

$$FL = (TL - 42.74)/1.06 \tag{2.6}$$

$$FL = 2193.05 - 2488.95 \times (0.994^{JL}) \tag{2.7}$$

where TL is total length (mm), FL is fork length (mm) and JL is jaw length (mm).

2.5.2 Maturity

Maturity values input to the model were length-based, following a logistic function (Equation 2.8) with coefficients obtained from Mackie et al. (2005) and Begg et al. (2006). Age-dependent maturity was then calculated from length-dependent maturity within Stock Synthesis using age-length transition matrix (Methot and Wetzel 2013). First mature age was set at 2 years old (Begg et al. 2006), where ages below 2 years had maturity set to zero.

Fractions mature (p) at length were input into the model directly (option type = 6) (Methot et al. 2023). These data were produced by using the following equation:

$$mat = \frac{exp(-10.349 + 0.0128FL)}{1 + exp(-10.349 + 0.0128FL)} \tag{2.8}$$

where mat is maturity and FL is fork length (mm).

2.5.3 Fecundity

The 2023 stock assessment of Torres Strait Spanish mackerel (O'Neill et al. 2024) utilised a fecundity relationship defined by gonad weights, FL and maturity staging data of Torres Strait fish, from Begg et al. (2006). This relationship was deemed an improvement upon the method used in the previous Australian east coast stock assessment (Tanimoto et al. 2021a) and was hence adopted for use in the current assessment.

Female Spanish mackerel gonad weight (kg), FL (cm) and maturity staging data (defined in Table 2.10, page 21, Begg et al. (2006)) were collected from the Torres Strait by:

- Fisheries Queensland in the 2001–2003 fishing years (Begg et al. 2006), and
- FRDC research in the 1999 fishing year (Buckworth et al. 2007).

A gonad-weight – fork-length relationship was used to define increased egg production with fish size. Parameters a and b were estimated from the data using a linear model:

$$log(GonadWeight) = -1 + stage + log(FL) \tag{2.9}$$

where the linear model variables were:

- **GonadWeight**: female Spanish mackerel gonad weight (kg),
- **stage**: intercept for each gonad stage (factor),
- **FL**: fork length in centimetres (variate), and
- **LM family and link function**: Normal and identity link.

From the linear model, parameters: a = exp(stage 6 intercept), and b = slope for log(flcm). This gave values of a = 5.290168E-09 and b = 3.945.

Using the resultant estimates of a and b, the fecundity relationship was defined within Stock Synthesis as the type-2 fecundity equation (Methot et al. 2023):

$$Eggs = a \times L^b \tag{2.10}$$

2.5.4 Weight and length

The length-weight relationship was obtained from Mackie et al. (2003):

$$WW = 3.40 \times 10^{-9} \times FL^{3.12} \tag{2.11}$$

where WW denotes whole fish weight (kg) and FL is fork length (mm).

2.6 Length and age data

2.6.1 Biological monitoring

Fisheries Queensland commenced routine, fishery-dependent biological data collection for Spanish mackerel in 2000. The program's primary objective is to gather representative data about the length, sex and age of retained fish. For commercially caught fish, data are gathered through voluntary cooperation from commercial fishers and fish processors. These businesses facilitate data collection by providing access to fish within the supply chain, measuring or supplying samples from their own catches, and accommodating departmental staff aboard their vessels during fishing operations. Data from recreational and charter catches also involves voluntary cooperation, to allow staff to measure fish at boat ramps, or fishers to provide samples of their own catches that can be processed in the laboratory. The majority of Spanish mackerel samples obtained on Queensland's east coast are contributed by the commercial fishery, though substantial sampling of the recreational sector also occurs. Some data are also available from the charter sector, though sample sizes are limited.

The primary sampling unit is the "catch", which comprises fish from an individual fishing session on a single day or spanning several days, by one fishing operation. The program is designed to collect data from the fishery that is representative of the full spatial extent of the fishery, by setting targets for the number of commercial catches to be sampled in each spatial stratum per year, and for the number of recreational fishing surveys to undertake at key boat ramps throughout a year. For commercially caught east coast Spanish mackerel, the target is 800 fish to be measured per year, from over 160 catches. This target is divided among the sampling regions, based on regional sample size analysis and recent harvest reported in commercial fishing logbooks.

Fishing sector, catch date, location and fishing method are recorded for each catch. Location can be reported at various spatial resolutions, including monitoring region, 30x30 minute CFISH grid reference, or to the specific marine location (e.g. reef name). This recording preserves the confidentiality of the exact fishing location if the fisher wishes, whilst enabling the data collected to be aggregated to a suitable spatial scale.

Fish size is recorded as fork length (in mm, nose to caudal fork) whenever accurate measurement is feasible. In cases where the fish is damaged (e.g. frayed caudal fins) or incomplete (e.g. head only), alternate measures are taken. In these cases, total length (nose to end of tail) or jaw length (tip of the upper jaw to the end of the maxilla) measurements are taken as required. Where a catch has been identified as size biased, it is flagged for exclusion from analyses where representative length frequency data are needed.

When a catch is very large or access is limited by time constraints, a subsample of the catch is measured. The proportion of the catch measured is recorded.

Where possible, macroscopic examination of gonads is undertaken to determine sex, relying on colour, structure and texture of the gonad. Fish are classified as male, female, or unknown sex.

Otoliths (fish ear bones) are used to estimate the age of a fish. Each year, the program aims to collect otoliths from retained fish in every observed length class within every geographic area. To prevent oversampling of frequently retained length classes, or locations with higher availability, the number of otoliths collected per 1 cm length class in each area is capped at 20 fish. Otoliths are first dried and stored, before being immersed in baby oil and placed distal (concave) side up, to be examined using a microscope. To estimate the age of each fish, a trained reader assigns an increment count and an edge type. Age is calculated based on capture date, increment count, edge type, the expected timing of new increments, and the assumed nominal birth date of all fish in the stock. Each year, readers undergo refresher training and testing on a reference collection of otoliths, before undertaking the current year's otolith reading. Annual reads are tested for repeatability of increment and edge assignment.

Each year, both the number of catches sampled and the quantity of biological data collected vary. Sampling is heavily influenced by participation from fishers and processors, as well as by logistical considerations regarding access to the fish. The form in which fish are sold (e.g. whole, gilled and gutted, filleted) also significantly influences what data can be collected. All of these factors vary between years, seasons and regions.

During the early years of the program (2000–2002), sampling was focused solely on Spanish mackerel that were commercially fished in the Lucinda area during the spawning season in October/November (Sumpton and O'Neill 2004). From 2005, sampling was increased to be temporally and spatially expansive, covering both commercial and recreational harvests of Spanish mackerel throughout Queensland (Tobin and Mapleston 2004; Campbell et al. 2012).

2.6.2 Alternative data sources

Some early length and age data were also available from historical sampling events conducted independently of Fisheries Queensland's contemporary biological monitoring program. The feasibility of integrating these early data in this assessment was explored, but ultimately they were not included. A description of these datasets and the rationale for their non-inclusion is provided in Appendix G.

2.6.3 Input to the population model

Given this model's reliance on age and length information to inform stock dynamics, in lieu of contrast in the index of abundance, spatial and temporal filtering of age and length data were necessary to ensure consistency in sampling patterns over time.

Length and age samples from latitudes 16° S (Bloomfield, Queensland) to 28° S (Queensland/New South Wales border) were included in the model. Sample sizes of data from north of 16° S were very small, hence these data were excluded due to their capacity to introduce bias or spurious influence to the age and length compositions. Data from 2005–2023 were included in the length and conditional age-at-length compositions. As mentioned in Section 2.6.1, biological sampling during the 2000–2004 period was not temporally or spatially comprehensive. In 2024, available samples were scarce and the spatial distribution of these samples differed markedly from the 2005–2023. Hence, length and age data from the 2000–2004 period and 2024 were excluded to maintain consistent spatial and seasonal sampling patterns from year to year.

For conditional age-at-length compositions, only length and age data of specified sex (male or female) were included, with fish of unknown sex (sex not able to be determined from sample) excluded. Given the sex-specific growth patterns exhibited by Spanish mackerel, it was important that the sex-specific growth curves were produced only from samples where the sex was known.

In the case of length compositions, length data of all sexes (male, female, unknown) were included, and input to the model as pooled (Sex = 0 means combined male and female, see page 61 of Methot et al. (2024)). A large proportion of the available length samples are obtained from whole fish, where sex cannot be determined. Length data were input to the population model in two-centimetre length bins.

2.6.4 Data weighting

This assessment prioritized fitting the age-at-length data to resolve the 2021 model's inability to capture the trend in mean age over time, as highlighted by Hoyle and Dunn (2023). The relative magnitudes of effective sample sizes (ESS) between length and conditional age-at-length compositions were used as a mechanism to allow the model freedom to do this.

Initial sample sizes were based on the sampling unit of a 'catch', described in Section 2.6.1. Scenarios were created with varying degrees of down-weighting (via reduced ESS) applied to length compositions, to prioritise fitting closely to age compositions and temporal trends in the mean age of fish. The degree of down-weighting of length compositions relative to conditional age-at-length compositions was a key axis of uncertainty which was preserved in the ensemble for sensitivity testing (see Section 2.8.5). Scenarios in which the length composition data had an ESS equal to 50% (half the weight) and 25% (quarter of the weight) of the age-at-length ESS were included in the final ensemble.

Exploratory scenarios were also run with equal weighting applied to both length and conditional age-at-length compositions respectively. Model fits to the temporal trends in the mean age of fish were notably degraded in these runs. Poor convergence was also observed in these scenarios, due to the inherent data conflict between length and conditional age-at-length compositions, as suggested by Hoyle and Dunn (2023). As such, scenarios with equal ESS weights for both length and conditional age-at-length compositions were not included in the final ensemble, but were retained as exploratory scenarios (see Appendix F).

2.7 Spatiotemporal patterns in age and length

Given the migratory patterns of Spanish mackerel and tendency to form spawning aggregations, the project team hypothesised that spatial and seasonal structure would be present in the age and length data. Spatial and seasonal patterns in the age and length data were explored using GAMs (Generalised Additive Models) prior to population model optimisation. This provided insight into structure in the biological data, and hence informed the structure of the population model.

In order to model the spatial structure effectively, the catch location of each sample was required as a continuous latitude. Since the spatial resolution of the catch location field varies as described in Section 2.6.1, a consistent method of extracting latitude information from these catch locations was required. The following process was undertaken to obtain continuous measures of latitude for age and length samples:

- For each individual catch location reported in the age and length data, a list was created of 30x30 minute grid cells that comprise that location. Depending on the inherent resolution of the original catch location, this may be just one grid, or it may be multiple.
- From the resultant groupings of grids, a continuous latitude and longitude point was sampled at random. This informed the latitude and longitude fields associated with each sample.
- The subsequent models were constructed and run multiple times, to investigate whether spatial and seasonal trends were sensitive to the random sampling process. Bias due to the random sampling of spatial data from within catch locations was not observed.

2.7.1 Age response model

A GAM was constructed to explore spatial and seasonal patterns in the age of Spanish mackerel. The form of the age-response model was

$$Age \sim Sex + te_{Month} + te_{Latitude} + ti_{Month,Latitude} + Year \tag{2.12}$$

where:

- **Sex** was the sex of fish (male or female)
- **Month** was the calendar month
- **Latitude** was continuous latitude, sampled as per methods in the above section
- **Year** was the fishing year

2.7.2 Length response model

A GAM was constructed to explore spatial and seasonal patterns in the length of Spanish mackerel. The form of the length-response model was:

$$FL \sim Sex + te_{Month} + te_{Latitude} + ti_{Month,Latitude} + Year + Sector \tag{2.13}$$

where:

- **FL** was the fork length of fish (in cm)
- **Sex** was the sex of fish (male or female)
- **Month** was the calendar month
- **Latitude** was continuous latitude, sampled as per methods in the above section
- **Year** was the fishing year
- **Sector** was the fishing sector (either commercial or recreational/charter combined)

2.7.3 Age-at-length model

A GAM was constructed to explore spatial and seasonal patterns in the age-at-length of Spanish mackerel. In this case, age was still the response variable, but length was included as a model term. The form of the age-at-length model was:

$$Age \sim Sex + te_{FL.Sex} + te_{Month} + te_{Latitude} + ti_{FL,Latitude} + Year \tag{2.14}$$

where:

- **FL** was the fork length of fish (in cm)
- **Sex** was the sex of fish (male or female)
- **Month** was the calendar month
- **Latitude** was continuous latitude, sampled as per methods in the above section
- **Year** was the fishing year

2.8 Population model

2.8.1 Description

The software Stock Synthesis (SS) (Methot and Wetzel 2013; Methot et al. 2024), version 3.30.22.1, was used for the population model. A full technical description of Stock Synthesis is given in Methot et al. (2024).

2.8.2 Model structure

Biological monitoring data indicated a growth difference between the sexes with females growing larger than males. The population model was therefore set up as a two-sex model.

The spatio-temporal modelling of Queensland east coast age and length data (detailed in Section 2.7) indicated spatial and seasonal variation in the availability of fish of particular size classes (see Section 3.1.4). These findings suggest that patterns of realised selectivity are dependent on latitude and season, and they would differ between spatio-temporal strata for the Queensland portion of the stock. The population model was hence set up as a 'fleets-as-areas' model, to allow necessary flexibility to fit the contrasting patterns in selectivity, and more appropriately capture seasonal patterns of migration and aggregation exhibited by Australian east coast Spanish mackerel.

With the exception of the New South Wales sectors, which form just two fleets according to sector (see Table 2.2 below), each Queensland fishing sector (Commercial, Recreational and Charter (combined)) was split into three fleets according to the spatio-temporal quadrants shown in Figure 2.4. These quadrants correspond to different combinations of fishery area and season, capturing different portions of the stock's annual migration pattern. Quadrant four contributes very little catch and consequently has minimal age and length data available. Accordingly, only the first three quadrants were used to define fleets in the model, and any catch from quadrant four was allocated to quadrant one to ensure fishing mortality from quadrant four was accounted for. The abbreviations 'Q1', 'Q2' and 'Q3' used in the fleet labeling (Table 2.2) are synonymous with quadrant one, quadrant two and quadrant three respectively. Finally, the abundance index data were included as a survey fleet. The resultant fleets included in the population model, as well as the area and season they correspond to, are listed in Table 2.2.

The full results of the spatio-temporal modelling work can be found in Section 3.1.4.

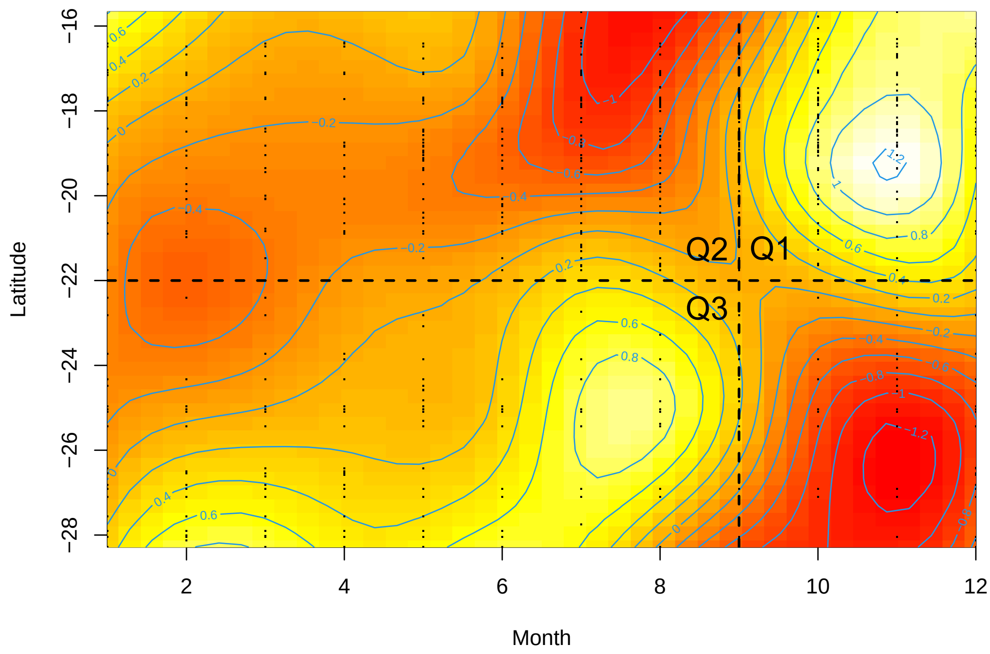

Figure 2.4: Heatmap produced of modelled age by latitude and month, produced from equation 2.12. White indicates a positive response (increased age) and red indicates a negative response (decreased age). Dashed lines indicate the month and latitude of separation for the fleets-as-areas model structure. Labels indicate the resulting quadrants used in fleet designation.

Table 2.2: Structure of fleets included in the population model

Fleet	Fleet label	Sector	Region	Season
1	QldCommercialQ1	Qld Commercial	North of 22° south	During spawning season (Sept-Dec)
2	QldRecCharterQ1	Qld Recreational & Charter	North of 22° south	During spawning season (Sept-Dec)
3	NSWCommercial	NSW Commercial	NSW waters from 28° to 34° south	Year round
4	NSWRecCharter	NSW Recreational & Charter	NSW waters from 28° to 34° south	Year round
5	QldCommercialQ2	Qld Commercial	North of 22° south	Outside spawning season (Jan-Aug)
6	QldCommercialQ3	Qld Commercial	South of 22° south	Outside spawning season (Jan-Aug)
7	QldRecCharterQ2	Qld Recreational & Charter	North of 22° south	Outside spawning season (Jan-Aug)
8	QldRecCharterQ3	Qld Recreational & Charter	South of 22° south	Outside spawning season (Jan-Aug)
9	Index	Qld Commercial	Whole stock	Year round

2.8.3 Model assumptions

The main assumptions underlying the model included:

- Fish swim freely and mix instantaneously throughout Australian east coast waters. In reality, the time-scale of mixing is unknown, but obviously slower.
- The Australian east coast can be considered a single stock with no immigration or emigration.
- At finer spatial scales demographic structure can be handled through spatial/seasonal stratification and weighting of input data.
- The fishery began from an unfished state in 1911.
- The fraction of fish that are female at birth is 50% and fish do not change sex during their life.
- Growth occurs according to the von Bertalanffy growth curve.
- Length at age follows a single growth curve (by sex). In reality, length at age may depend on environmental conditions, such as annual and spatial variation in food supply.
- The weight and fecundity of Spanish mackerel are parametric functions of their size.
- The first mature age is 2, after which the proportion of mature fish depends on size.
- Fishing selectivity of Spanish mackerel is a function of length, and not age.
- Expected annual recruitment is a Beverton-Holt function of stock size.
- The instantaneous natural mortality rate M is constant and does not depend on size, age, sex, or year.
- Catch rates, once spatially weighted, are proportional to whole-Australian east coast abundance, and inform proportionally on the annual change in abundance of legal-sized Spanish mackerel.
- Discards of commercially caught Spanish mackerel are negligible

2.8.4 Model parameters

Model parameters are listed in Table 2.3. Years in which recruitment deviations were estimated were chosen based on the reach of influence from cohorts of fish contained in the available years of age data. Efforts were also made to ensure that the time series of recruitment deviations did not begin or end suddenly with a large value, as this may cause results to depend on the choice of recruitment deviation years to an unacceptable degree. The reasoning outlined above resulted in recruitment deviations being estimated for years 1992–2022.

Table 2.3: Parameters included in the population model

Symbol	Description	Value
M	Natural mortality	Estimated with prior (Hamel and Cope 2022)
L_{minF} L_{minM}	Mean fork length of fish at minimum age (male & female, in cm)	Estimated
L_{maxF} L_{maxM}	Mean fork length of fish at maximum age (male & female, in cm)	Estimated
K_{F} K_{M}	Von Bertalanffy growth coefficient (yr^{-1}) (male & female)	Estimated
$\mathrm{SD}_{\mathrm{youngF}}$ $\mathrm{SD}_{\mathrm{youngM}}$	Standard deviation of fork length at minimum age (male & female, in cm)	Estimated
$\mathrm{SD}_{\mathrm{oldF}}$ $\mathrm{SD}_{\mathrm{oldM}}$	Standard deviation of fork length at maximum age (male & female, in cm)	Estimated
h	Beverton-Holt stock recruitment steepness	0.54, 0.69, 0.808 (Thorson 2020)
$\ln R_0$	Log of number of recruits when unfished (1911)	Estimated
σ_R	Standard deviation of natural log recruitment	0.6
L_{p1}	Beginning size for the plateau (FL, in cm)	Estimated
L_{p2}	Width of plateau (as logistic)	Estimated
L_{p3}	Ascending width (value in $ln(width)$)	Estimated
L_{p4}	Descending width (value in $ln(width)$)	Estimated
L_{p5}	Selectivity at start bin (as logistic)	-20
L_{p6}	Selectivity at last bin	Estimated
recdev	Recruitment deviations between 1985 and 2022	Estimated

Initially, plausible values for the natural mortality rate (M) were explored by fixing the parameter at three different values informed by methods from Hamel and Cope (2022). The central value was set equal to $5.4/Amax$, where Amax was set to the age class of the oldest fish observed in the biological monitoring data (Age class = 25), giving a value of M = 0.216. Hamel and Cope (2022) gave a standard deviation value of 0.31 (log-scale), and by taking the 25th and 75th percentiles of this distribution, values of 0.175 and 0.266 were obtained as plausible upper and lower bounds of M respectively.

Once model estimation was stable using these fixed values, estimation of M was attempted using the prior from Hamel and Cope (2022) (median of $5.4/Amax$ where $Amax$ = 25, and a standard deviation of 0.31 (log-scale)). The range of resulting model estimates of M appear to represent the Hamel and Cope (2022) prior distribution well, and are similar to fixed values obtained from taking the 25th and 75th percentiles of the distribution. As described in Punt (2023), it is best practice to estimate M within the model where possible, with a prior based on information external to the assessment. Hence, we deemed the estimation of M favourable, and all scenarios included in the final ensemble estimated M. Comparison of model outputs with both fixed and estimated M is provided in Appendix F.

As highlighted by the review of the 2021 assessment by Hoyle and Dunn (2023), Beverton-Holt stock recruitment steepness (h) is difficult to estimate reliably, and a common approach for h is to represent uncertainty by considering a range of values and report on them all. Accordingly, h was also fixed at a range of different values in this assessment. However, little information is available in the literature for this species, and a logical starting point is required to set up a plausible range of h values.

The previous stock assessment used a value of steepness (h = 0.45) obtained from the meta-analysis by Thorson (2020), using the estimate associated with the genus level (Scomberomorus) (Tanimoto et al.

2021a). The Thorson (2020) paper provided steepness estimates at not only the genus level, but also at the broader family level (Scombridae). While using a value associated with the genus may present as a more precise approach for the species (*S. commerson*), very few estimates of h are available in the FishLife database (Thorson 2020) at the Scomberomorus genus level. This low sample size introduces potential for bias and uncertainty in these estimates. By contrast, a much greater number of estimates of h are available at the family level (Scombridae), and a median value of h = 0.69 is provided. The higher sample size of estimates associated with the Scombridae family provides more confidence, and serves as a more appropriate basis from which to test the model's sensitivity to different values of steepness.

Specifically, the review of the 2021 assessment by Hoyle and Dunn (2023) recommended trialling a range of steepness values from 0.45 to 0.95, and referenced the Scombridae family estimate from Thorson (2020) as a more robust starting point than the genus level estimate. In this assessment we have used the value associated with the Scombridae family, h = 0.69, as a central value of steepness. The final ensemble also included values of h = 0.54 (chosen by taking 0.15 as the size of a step downwards from the central value large enough to explore a significantly different region of parameter space) and h = 0.808 (chosen by reflecting the difference between h=0.69 and h=0.54 symmetrically around the central value on the appropriate transformed scale). Prior to forming the final ensemble, we completed MLE model runs across a comprehensive range of steepness values (from 0.3 to 0.99) to gauge the sensitivity of the model to h. We found that the range of 0.54 to 0.808 well represented the variability present in model outcomes due to h, with values outside of this range either not providing any further information to the model, or, at the extremes, failing to converge.

A dome-shaped selectivity pattern (double normal, pattern 23 (Methot et al. 2023)) was estimated for each fleet, with the exception of fleet 8 (QldRecCharterQ3) which assumed asymptotic selectivity (logistic, pattern 1 (Methot et al. 2023)). Fleets 3 and 4 (NSWCommercial, NSWRecCharter) were set to mirror selectivity from fleets 1 and 2 (QldCommercialQ1 and QldRecCharterQ1). Six parameters were estimable for the double normal curve, with all estimated except initial selectivity (selectivity at smallest length bin, fixed at 0.0).

Standard deviation of natural log recruitment (σ_R) was fixed at 0.6, as per recommendation 7 from Hoyle and Dunn (2023). This is an increase from the value of 0.35 in the previous assessment. Recruitment deviations between 1985 and 2022 improved fits to composition data and abundance indices as variability in recruitment annually allowed for changes in the population on shorter time-scales than fishing mortality alone.

2.8.5 Ensemble

Six model scenarios were included in the final ensemble to determine the model's sensitivity to different parameter values and assumptions (Table 2.4).

In addition to testing multiple values of steepness (h), an axis of uncertainty preserved in the final ensemble for sensitivity testing was the degree of ESS down-weighting applied to the length composition data, to allow for better fits to age-at-length compositions. Two levels of length composition down-weighting (relative to conditional age-at-length compositions) were included in the final ensemble (for further detail, see Section 2.6.4).

Table 2.4: Scenarios included in the ensemble to test sensitivity to parameter values and assumptions

Scenario	h	Length weighting (ESS)
1	0.54	50% of age ESS
2	0.69	50% of age ESS
3	0.808	50% of age ESS
4	0.54	25% of age ESS
5	0.69	25% of age ESS
6	0.808	25% of age ESS

2.8.6 Exploratory sensitivity scenarios

Collectively, recommendations from the 2021 stock assessment and the subsequent reviews (Klaer 2021; Hoyle and Dunn 2023) highlighted a number of unmodelled influences, knowledge gaps (due to lack of available data), and suggestions for modelling approaches that may impact results. While many of these aspects were incorporated into the models that comprise the final ensemble, many of these scenarios did not significantly affect results, and were therefore excluded from the final ensemble. We report on the influence of these factors nonetheless, and results of these scenario runs can be seen in Appendix F. A full list of these scenarios and the methods used to construct them are given below.

- **Environmental drivers:** Environmental drivers that may affect the stock size of Spanish mackerel were listed as an unmodelled influence in the 2021 stock assessment by Tanimoto et al. (2021a), and appraisal of environmental drivers was noted as an informative piece of future work. As part of the FRDC project 2021-111, Leahy et al. (in review) investigated key environmental drivers of recruitment variability of east coast Spanish mackerel.

  The full list of potential environmental drivers and further details on their mechanisms of influence can be found in Leahy et al. (in review). The four most influential metrics identified by Leahy et al. (in review) were trialled as candidates for inclusion as an environmental driver, linked to R_0:

  1. **Peak flows out of the Herbert river during spawning season:** Particularly high flows from the Herbert River (most adjacent major river to the Lucinda aggregation) are disruptive to Spanish mackerel spawning and were shown to have a negative association with year class strength Leahy et al. (in review). Index provided as normalised log-transformed values since 1983.
  2. **Median winter sea-surface temperature (June, July, August):** Cooler winter sea-surface temperatures were shown to have a positive association with year class strength Leahy et al. (in review). Index provided as normalised log-transformed values since 1992.
  3. **Mean summer sea-surface temperature (September to March):** Cooler sea-surface temperatures and higher rainfall during summer of the year before spawning have a positive association with year class strength Leahy et al. (in review). Index provided as normalised log-transformed values since 1993.
  4. **Nominal CPUE of banana prawns (January to May):** Higher CPUE of banana prawns during the inshore juvenile stages of the life-cycle of Spanish mackerel had a positive association with year class strength Leahy et al. (in review). Index provided as normalised values since 1988.

  In each case, the time series of the given variable was input to Stock Synthesis as an environmental index and incorporated via an environmental linkage to R_0 (input of 204 in element 14 of SR_LN(R0) parameter line, see page 204 of Methot et al. (2023)). This allowed the stock-recruitment curve to deviate from year to year, influenced by any trends present in the chosen environmental variable. Qualitatively, the influence of this linkage can be evaluated by examining plots of the stock recruitment curve and comparing the magnitude or trend of resulting deviations in the curve during years where the environmental index data are available. Of the four indices listed above, index 1 had the most notable influence upon the stock recruitment curve over time, though the impact of any of the given indices was minor.

Impacts on biomass ratio and recruitment deviations were evaluated for a scenario using index 1. Biomass ratio in the early period of the recruitment deviations series (~1985–1995) showed some minimal impact (see Figure F.1 in Appendix F). Early recruitment deviations have an inherently larger standard error, as a result of being less informed by the age data, which commences considerably later, in 2005. Presumably, this impact (albeit minimal) upon biomass ratio occurred during these years as the environmental index explained some variability during years where recruitment deviations were less certain. Despite this, following the introduction of the age and length data, no noticeable impact was seen upon recruitment deviations or biomass ratio outcomes. Final model outputs were impacted negligibly by the inclusion of an environmental index linked to R_0, and hence the project team elected to exclude these runs from the final ensemble.

- **Time-varying selectivity:** The review by Hoyle and Dunn (2023) mentioned time-varying length selectivity as a possible mechanism to explain decreasing trends in the mean length of fish over time. The exploratory spatio-temporal modelling of length and age data (see Section 2.7) showed some degree of decline in the mean length of fish sampled over time (Figure C.4), which warranted investigation into the possibility of time-varying selectivity. When split by sector, this decline was evident for the recreational and charter sectors, while lengths sampled from the commercial sector remained relatively stable. The likelihood of the presence of time-varying selectivity was discussed with the project team, with varying feedback. The project team noted that motives do exist for fishers to avoid larger fish. For commercial fishers, some markets enforce their own maximum weight limits on Spanish mackerel they accept, due to risk of ciguatoxins. For all sectors, avoiding larger fish is also a plausible strategy to allow fishers to land more fish in areas with high rates of shark depredation. The project team agreed that, if there was a time-varying selectivity effect, it would be characterized by the avoidance of larger fish.

  To test this, scenarios were run using an Stock Synthesis technique called a 'trend' (element 13 of the parameter line set to -2, see page 209 of Methot et al. (2023)) implemented on the parameter controlling the width peak selectivity (the width of the 'dome'), for the double normal selectivity pattern (henceforth referred to as SelP2). Allowing this to vary meant that the width of the 'dome' formed by the double-normal selectivity pattern could vary with time. If the hypothesis of avoidance of larger fish is true, this should mean the dome narrows over time.

  Switching this functionality on invokes three extra parameters for estimation - the initial value of SelP2 (at the beginning of the trend), the period of time (in years) over which this trend occurred, and the final value of SelP2 (at the end of the trend). The period of time was fixed to 2003–2024 (beginning one year before commencement of length data) to match the period of time of the spatio-temporal modelling of length data, where some trend was observed. The initial and final values of SelP2 were estimated freely, allowing the model flexibility to estimate the direction of trend (positive or negative) as well as the magnitude.

  Introducing the time-varying selectivity mechanism to the model resulted in varied and non-intuitive impacts upon model outputs. Hence, alongside inconclusive project team discussion about the potential for time-varying selectivity, these scenarios were excluded from the final ensemble.

- **Fixed values of natural mortality (M):** As described in Section 2.8.4 above, models were initially run with a range of fixed natural mortality estimates obtained from the prior distribution given in Hamel and Cope (2022), before estimating M in final ensemble scenarios. While M estimation was deemed an improvement to the model, exploratory runs were retained with the three original fixed values of M for comparison.

- **Equal data weighting between length and age-at-length compositions:** A scenario with no down-weighting of length compositions relative to age-at-length compositions (equal weighting) was trialled, and retained in the exploratory scenarios. Figure F.3 shows a comparison of the equal-weighting scenario against the ESS weighting scenarios from the final ensemble.

- **Fish Board data adjustment:** Previous Queensland stock assessments of various species have raised the possibility that the Queensland Fish Board data (1937–1981) are an under-representation of true retained catch totals. The justification given was that the Fish Board only accepted fish landed through main ports, and may not include catches of fish from more remote regions.
  If the Queensland Fish Board data are indeed an underestimate, it is unclear by how much and no data are available to verify this. Hence, a scenario was constructed with the existing Fish Board data inflated by a factor of 1.25, to test the model's sensitivity to a significant (and hypothetical) degree of underestimation.
  This scenario showed some minor contrast to other scenarios in terms of biomass ratio in the 1970s and 1980s (see Figure F.1 in Appendix F). However, it showed no notable impact in recent model outputs or final biomass ratio outcomes. The project team agreed that this sufficiently tested the model's sensitivity to the possibility of higher historical catch totals, and the scenario was not included in the final ensemble.

- **Decadal CPUE:** The 2021 stock assessment included an additional abundance index, using commercial mean decadal relative catch rates from Thurstan et al. (2016), from 1941 to 2013. The review by Hoyle and Dunn (2023) suggested that this index not be used unless adjustment was made for the rate of recall bias associated with the decadal catch rates based on interviews of fishers (for more details on the recall bias adjustment, see Hoyle and Dunn (2023)).
  In this assessment, we trialled including the decadal CPUE index both with and without the recall bias adjustment. In both cases, the inclusion of this index had no discernible impact upon biomass ratio outcomes (Figure F.1 in Appendix F) and scenarios including the decadal CPUE index were not included in the final ensemble.

3 Results

3.1 Model inputs

3.1.1 Data availability

Model inputs are described for Australian east coast Spanish mackerel. All single model outputs in this section relate to Scenario 2 as the ensemble reference scenario (as defined in Table 2.4). Biomass trajectories from exploratory scenarios are presented in Appendix F and full model results from all ensemble scenarios are presented in Appendix E.

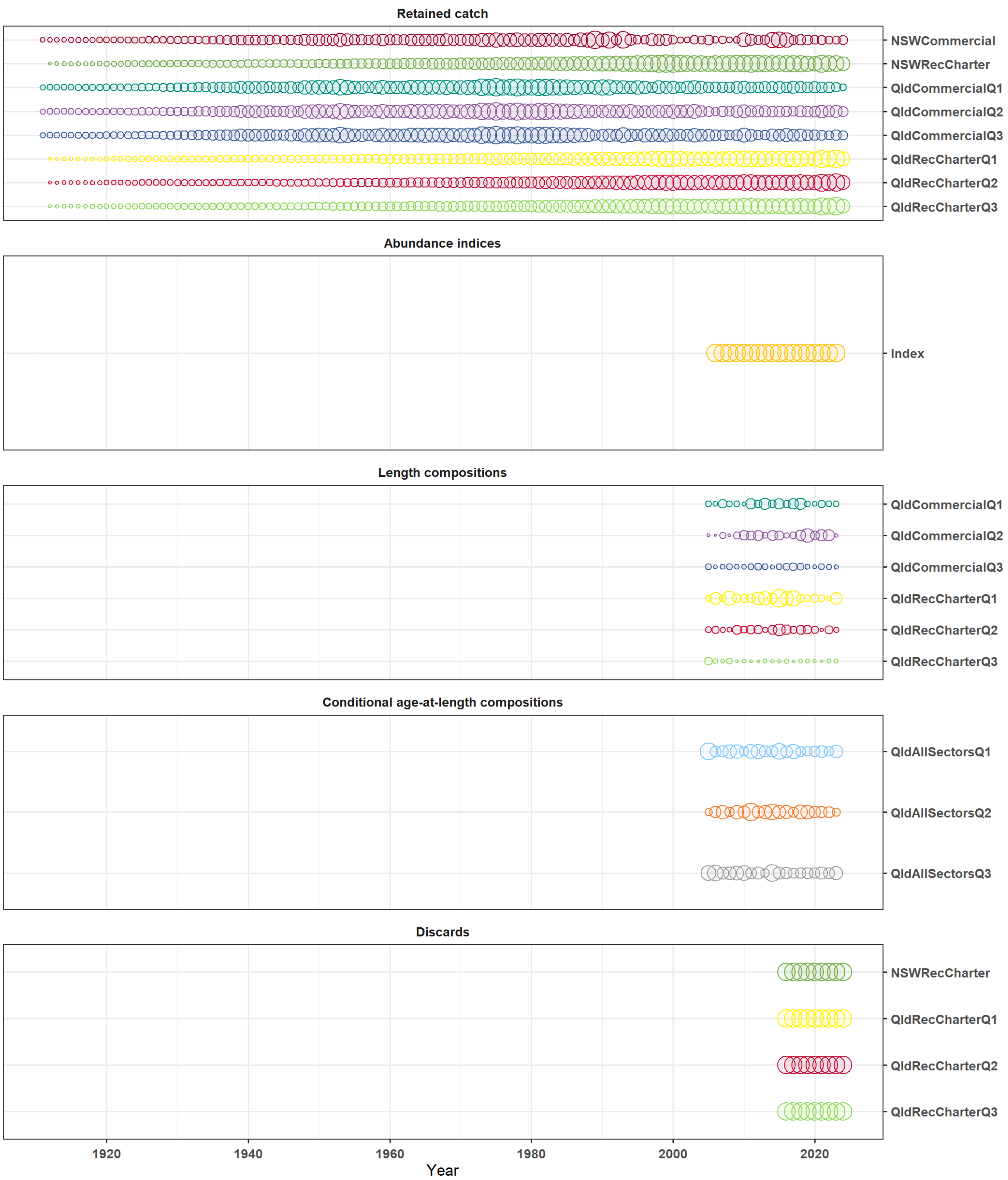

Figure 3.1: Data presence by year for each category of data type for Australian east coast Spanish mackerel

3.1.2 Catch estimates

Time series of Spanish mackerel catch are shown by fishing sector (Figure 3.2) and by fleet (Figure 3.3). Annual catches were estimated using data sources and methods described specific to each sector, as described in Section 2.2. These catch estimates include the shark depredation adjustments outlined in Section 2.2.2. These estimates do not include discard mortality, as discard estimates and discard mortality rates are input to Stock Synthesis separately.

Historically, the overall catch was mainly taken by the Queensland commercial sector. From 2005 this changed, with estimates of catch from the Queensland recreational and charter sectors (combined) exceeding the Queensland commercial take (Table C.2). Since 2005, catch taken by the Queensland recreational and charter sectors has continued to increase, while Queensland commercial take has remained relatively stable (Figure 3.2).

These estimates indicate that total annual catches (all sectors combined) on Australia's east coast increased consistently since 1911, reaching a peak in the mid 1970s of 945 t. Since the 1980s, the reported total catch gradually declined to around 800 tonnes in the period 1990–2004. Total catch notably dropped from 2005–2009 following major reform to the fishery in the 2004 fishing year (see Table 1.1), and the 2004 rezoning of the GBRMP. By 2010, total catch had rebounded, and remained at around 700–750 t until 2023. In July 2023, the commercial TACC was reduced from 578 t to 165 t, and the recreational in-possession limit was reduced to 1 fish per person, 2 per boat (with 2 or more people on board). Subsequently, a markedly lower estimate of total catch (459 t) was observed in 2024.

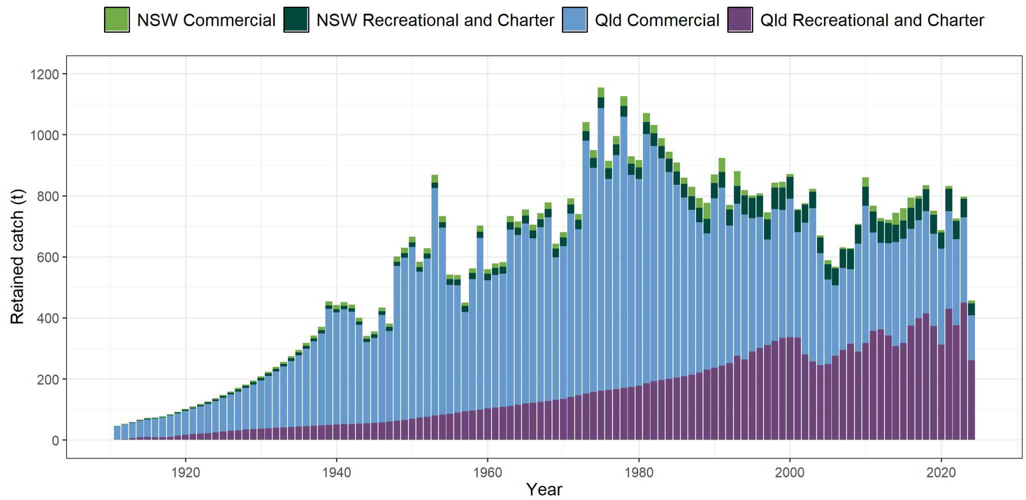

Figure 3.2: Estimated catch of Australian east coast Spanish mackerel by sector, between 1911 and 2024

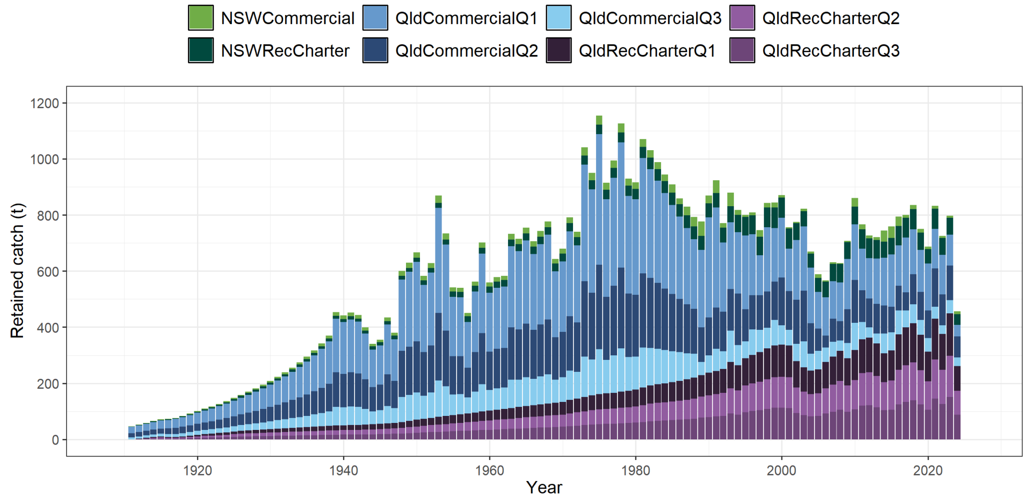

Figure 3.3: Estimated catch of Australian east coast Spanish mackerel by fleet, between 1911 and 2024

Table 3.1: Catch per sector in a subset of years between 1970 and present, expressed in tonnes with annual percentages

Year	Qld Commercial	Qld RecCharter	NSW Commercial	NSW RecCharter
1970	500 t (74%)	132 t (19%)	18 t (3%)	28 t (4%)
1980	678 t (74%)	175 t (19%)	24 t (3%)	37 t (4%)
1990	554 t (64%)	234 t (27%)	28 t (3%)	50 t (6%)
2000	452 t (52%)	330 t (38%)	9 t (1%)	71 t (8%)
2004	367 t (55%)	240 t (36%)	7 t (1%)	50 t (8%)
2005	276 t (47%)	245 t (42%)	13 t (2%)	50 t (9%)
2006	230 t (41%)	271 t (48%)	4 t (1%)	56 t (10%)
2007	269 t (43%)	290 t (46%)	6 t (1%)	61 t (10%)
2008	244 t (39%)	311 t (50%)	3 t (0%)	66 t (11%)
2009	353 t (50%)	285 t (41%)	5 t (1%)	60 t (9%)
2010	449 t (52%)	314 t (37%)	32 t (4%)	61 t (7%)
2011	323 t (42%)	353 t (46%)	18 t (2%)	69 t (9%)
2012	284 t (39%)	360 t (50%)	10 t (1%)	70 t (10%)
2013	301 t (42%)	341 t (47%)	11 t (2%)	66 t (9%)
2014	341 t (46%)	308 t (41%)	40 t (5%)	57 t (8%)
2015	342 t (45%)	317 t (42%)	41 t (5%)	59 t (8%)
2016	317 t (40%)	375 t (47%)	33 t (4%)	70 t (9%)
2017	321 t (40%)	401 t (50%)	10 t (1%)	71 t (9%)
2018	335 t (40%)	419 t (50%)	14 t (2%)	73 t (9%)
2019	303 t (40%)	377 t (50%)	13 t (2%)	64 t (8%)
2020	314 t (45%)	318 t (46%)	9 t (1%)	53 t (8%)
2021	320 t (38%)	438 t (52%)	10 t (1%)	74 t (9%)
2022	283 t (39%)	381 t (52%)	7 t (1%)	61 t (8%)
2023	280 t (35%)	454 t (57%)	8 t (1%)	61 t (8%)
2024	147 t (32%)	261 t (57%)	10 t (2%)	39 t (9%)

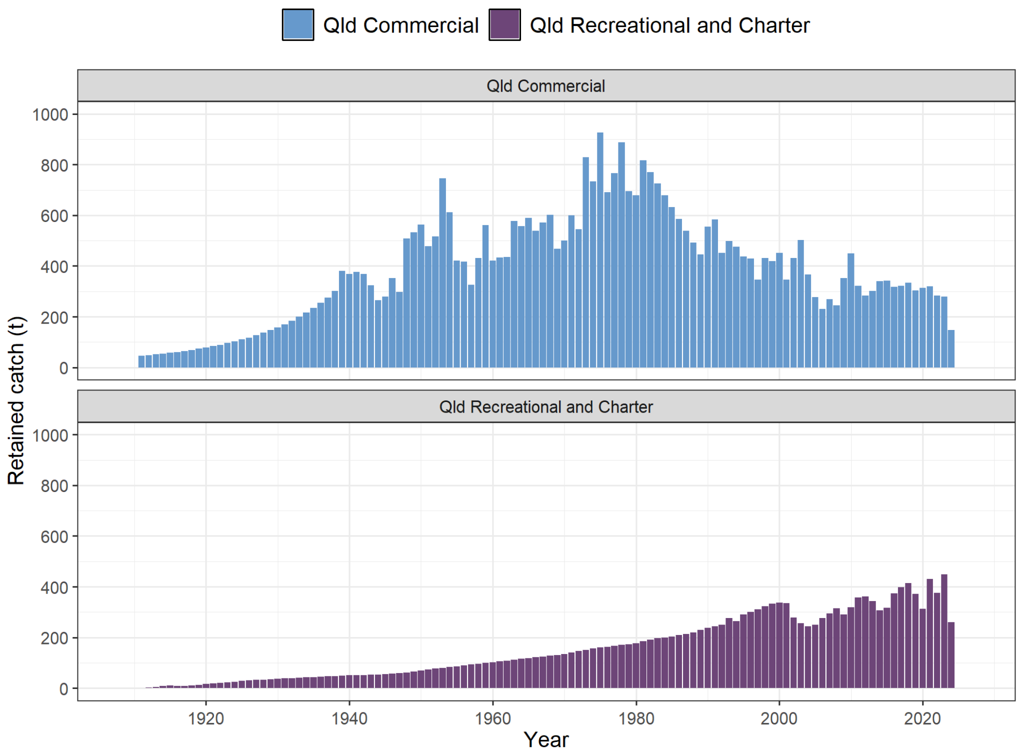

Figure 3.4: Estimated catch by the Queensland commercial sector (QldCommercialQuad1, QldCommercialQuad2 and QldCommercialQuad3 fleets) and Queensland recreational and charter sectors combined (QldRecCharterQuad1, QldRecCharterQuad2 and QldRecCharterQuad3 fleets) between 1911 and 2024

Spatial patterns of retained catch from the commercial sector for periods 1989–2004 and 2004–2024 are shown in Figure 3.5 and Figure 3.6 respectively. The few grids that comprise the Lucinda aggregation grounds contribute a disproportionate amount of the total retained catch. This has remained consistent throughout the time series of logbook data (i.e. 1989–2024).

Some spatial contraction of catch is evident when comparing the spatial distribution of catch in the former and latter portions of the logbook timeseries (i.e. 1989–2024) (Figure 3.5, Figure 3.6). In particular, catches in north Queensland waters between 15° and 20° south were distributed more broadly throughout the region in years prior to 2004 then appear to contract, favouring the Lucinda aggregation grounds and grids offshore from Bowen.

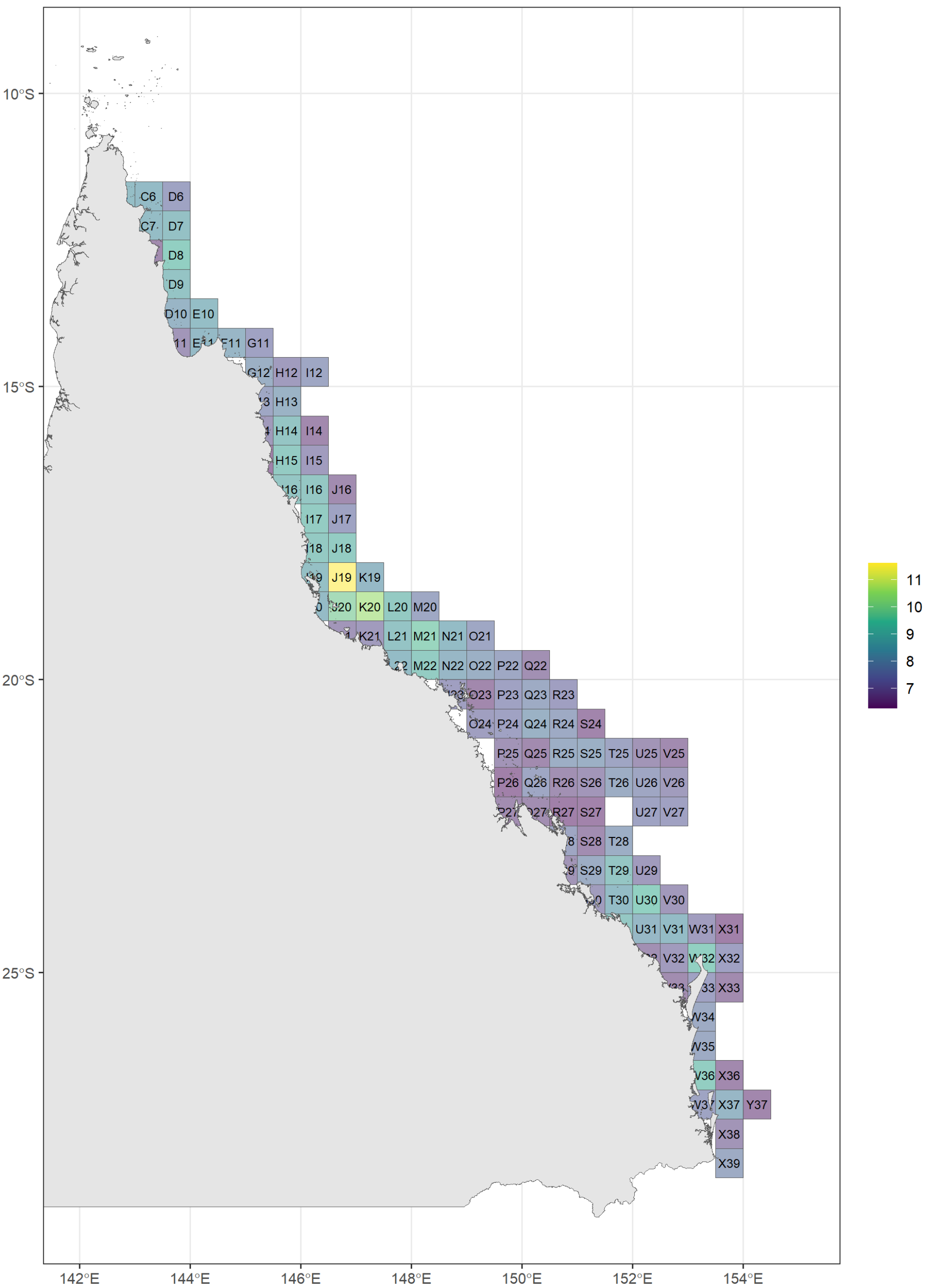

Figure 3.5: Mean annual retained catch by grid for years 1989 - 2004, expressed as the logarithm of catch in kilograms (log kg).

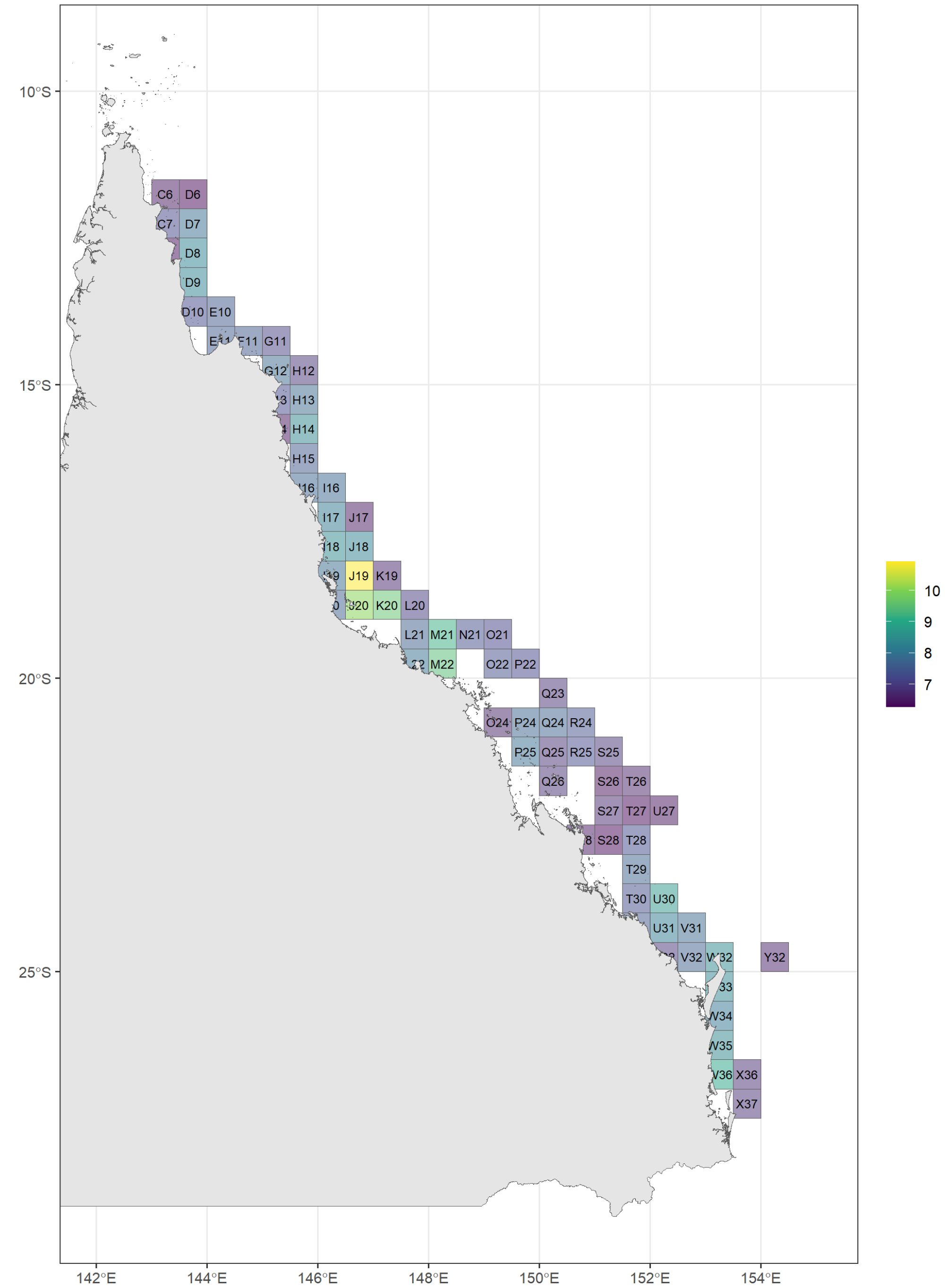

Figure 3.6: Mean annual retained catch by grid for years 2004 - 2024, expressed as the logarithm of catch in kilograms (log kg).

3.1.3 Standardised indices of abundance

Overall, the index shows little contrast over the time series (Figure 3.7). This result is not unexpected, due to the tendency for hyperstability in this fishery as described in Section 2.4. The catch rate index was given a standard error of 0.3 to allow the population model freedom to fit more closely to biological data inputs (see Section 4.3.4 for the rationale). Model fits to the index shown in Section 3.2.2 (Figure 3.24). Model diagnostics were satisfactory and can be found in Appendix B.

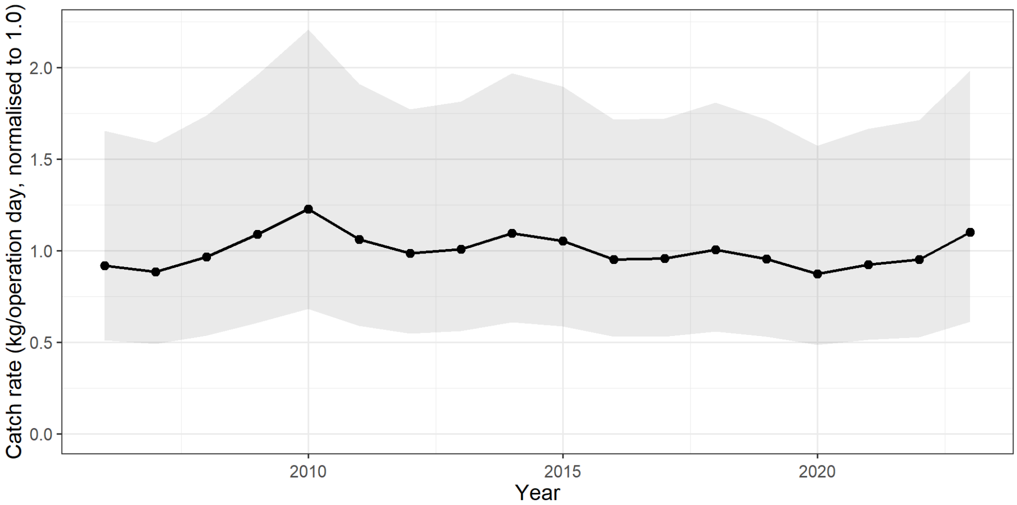

Figure 3.7: Annual standardised catch rates for Australian east coast Spanish mackerel between the years of 2006 and 2023 (Standard error = 0.3)

3.1.4 Spatiotemporal patterns in age and length

Results from the age response model (Figure 3.8) indicate a strong influence of both latitude and month upon the age of fish. The pattern shown in this plot is consistent with the known migratory patterns of Spanish mackerel, displaying the movement of mature, spawning-age fish from southern latitudes early in the year, to the spawning grounds (evidenced in Figure 3.8 by a ’white-hot’ circle).

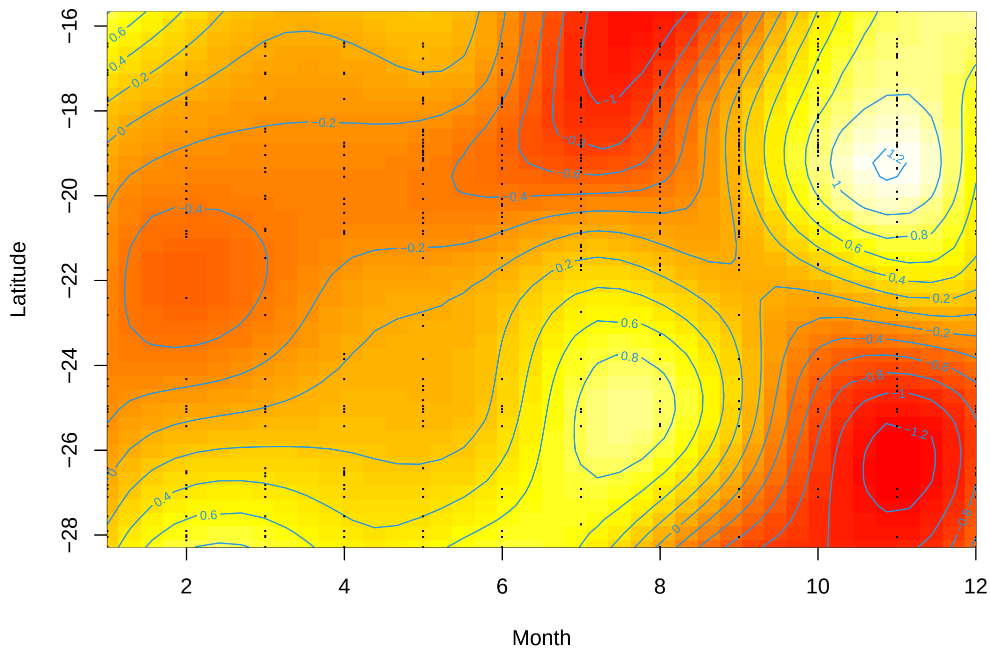

Figure 3.8: Modelled age by latitude and month, produced from equation 2.12. White indicates a positive response (increased age) and red indicates a negative response (decreased age).

Results from the age-at-length model (Figure 3.9) show some spatial variation in the age-at-length of fish by latitude. Some contrast is shown at lengths of above 130 cm fork length, with younger ages at length further north. This may be related to spatially varying growth, or to differing migration behaviour by sex. It warrants further investigation in future.

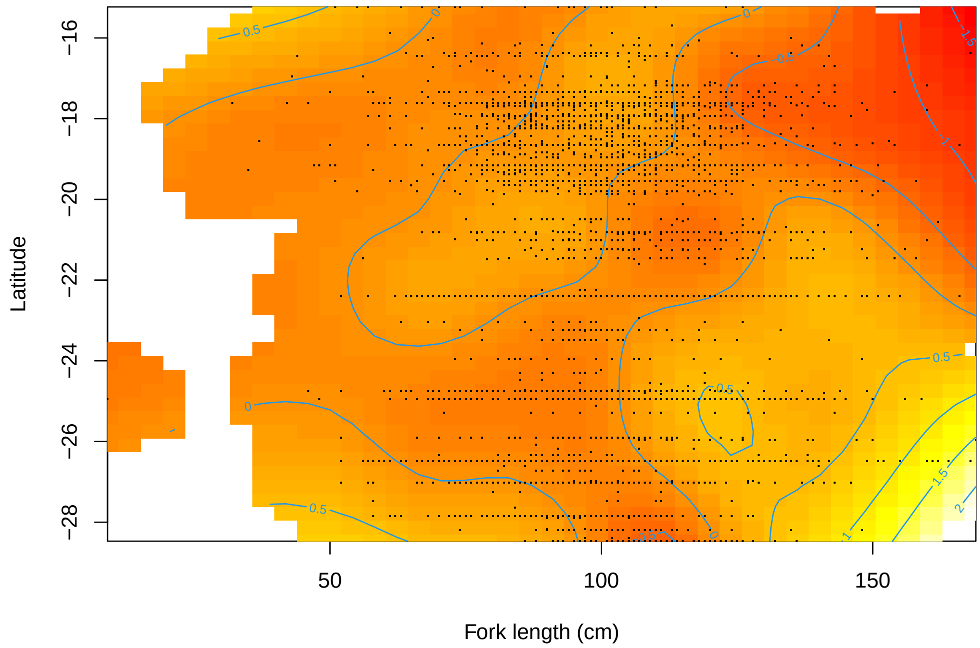

Figure 3.9: Modelled age by latitude and fork length, produced from equation 2.14. White indicates a positive response (increased age) and red indicates a negative response (decreased age). Some cells at small length classes have missing data.

Patterns observed in the results from the length-response model were similar to results from the age-response model, though less clear (Figure 3.10). Given the complex spatial and season patterns of selectivity (see Section 2.7), it is not surprising that less spatio-temporal signal can be inferred from the results of the length-response model.

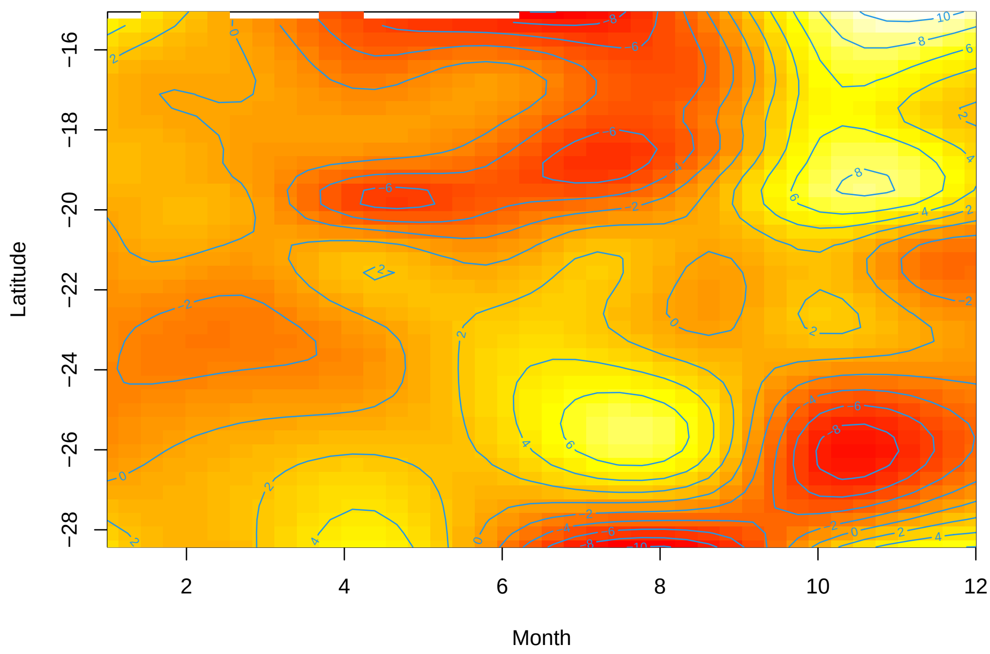

Figure 3.10: Modelled length by latitude and month, produced from equation 2.13. White indicates a positive response (increased length) and red indicates a negative response (decreased length).

3.1.5 Age-at-length

The age data were input to the population model as conditional age-at-length data compositions by fleet, including data from 2005–2023 (Figure C.6–Figure C.11 in Appendix C.5). Trends were evident in mean age over time, and differed by fleet. In particular, quadrant 1 exhibited a notable increase in mean age between the years 2011–2020 (Figure 3.11). Quadrant 2 showed a gradual increase in mean age between years 2005 and 2015 (Figure 3.12), while mean age in quadrant 3 remained steady before and after a marked drop in 2014 and 2015 (Figure 3.13). These trends were a focal point when optimizing the population model to fit closely to age-at-length data.

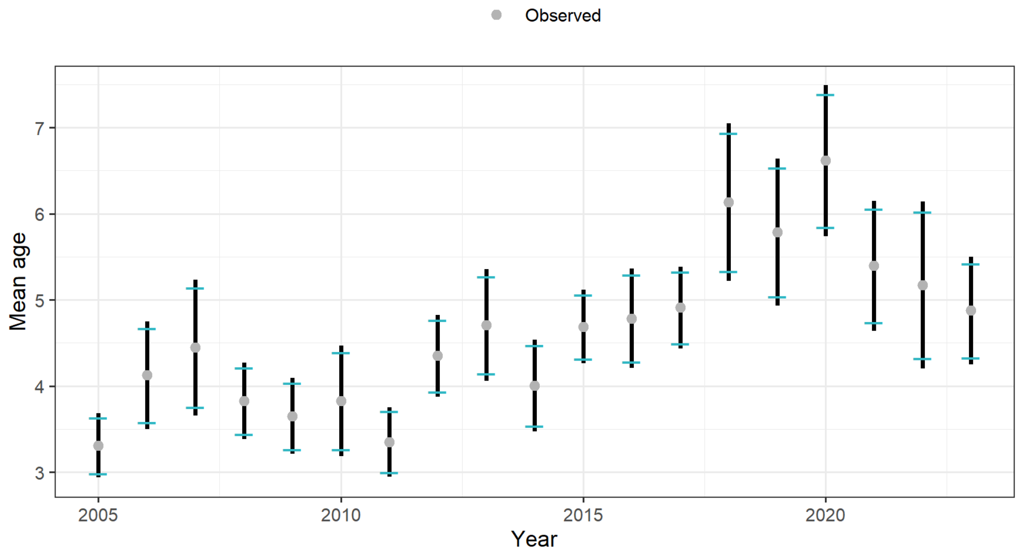

Figure 3.11: Mean age over time (aggregated across length bins) for fleet 1 (QldCommercialQ1). 95% confidence intervals based on current sample sizes: blue intervals (with capped ends) show result of further adjusting sample sizes based on suggested multiplier (with 95% interval) for conditional age-at-length data

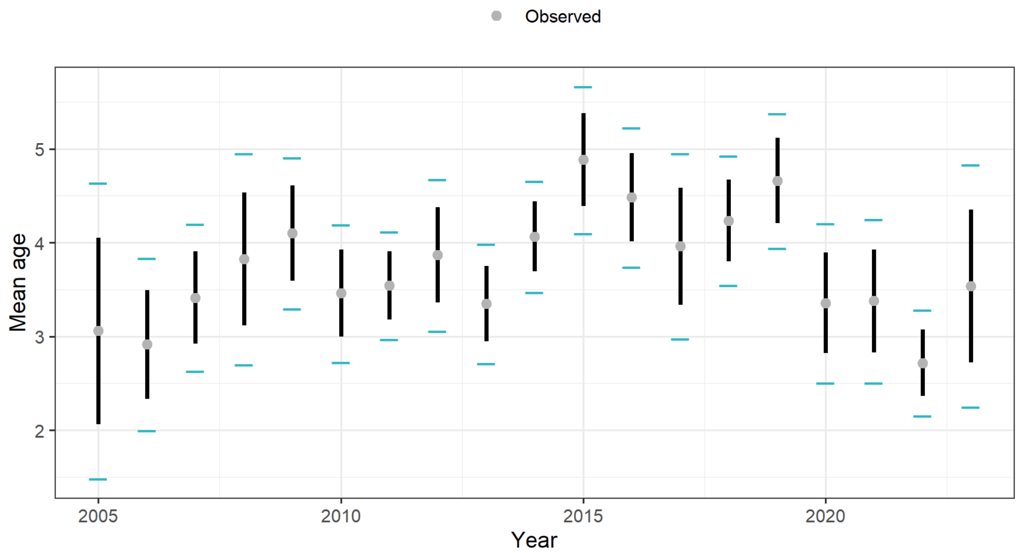

Figure 3.12: Mean age over time (aggregated across length bins) for fleet 5 (QldCommercialQ2). 95% confidence intervals based on current sample sizes: blue intervals (with capped ends) show result of further adjusting sample sizes based on suggested multiplier (with 95% interval) for conditional age-at-length data

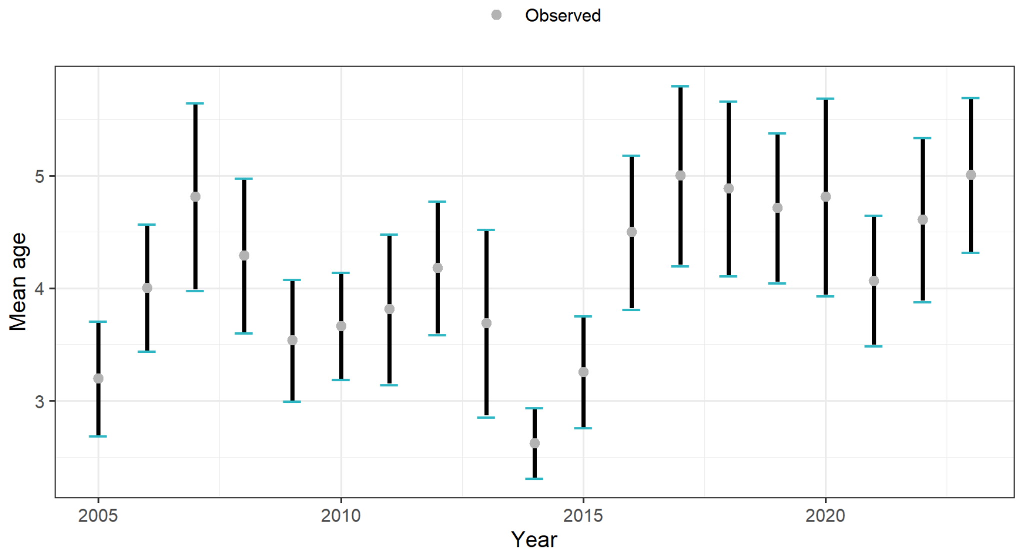

Figure 3.13: Mean age over time (aggregated across length bins) for fleet 6 (QldCommercialQ3). 95% confidence intervals based on current sample sizes: blue intervals (with capped ends) show result of further adjusting sample sizes based on suggested multiplier (with 95% interval) for conditional age-at-length data

3.1.6 Age compositions

While age information was input to the model as conditional age-at-length data, annual age frequencies were constructed for visualisation purposes (Figure 3.14 to Figure 3.19). In 2014, a particularly strong year class can be seen as one-year old fish, and this cohort remains visible in the data until 2020. This is most pronounced in the age compositions of female fish. 2014–2020 corresponds to the most pronounced period of increase in the mean age of fish sampled from quadrant 1 and quadrant 3 (Figure 3.11, Figure 3.13).

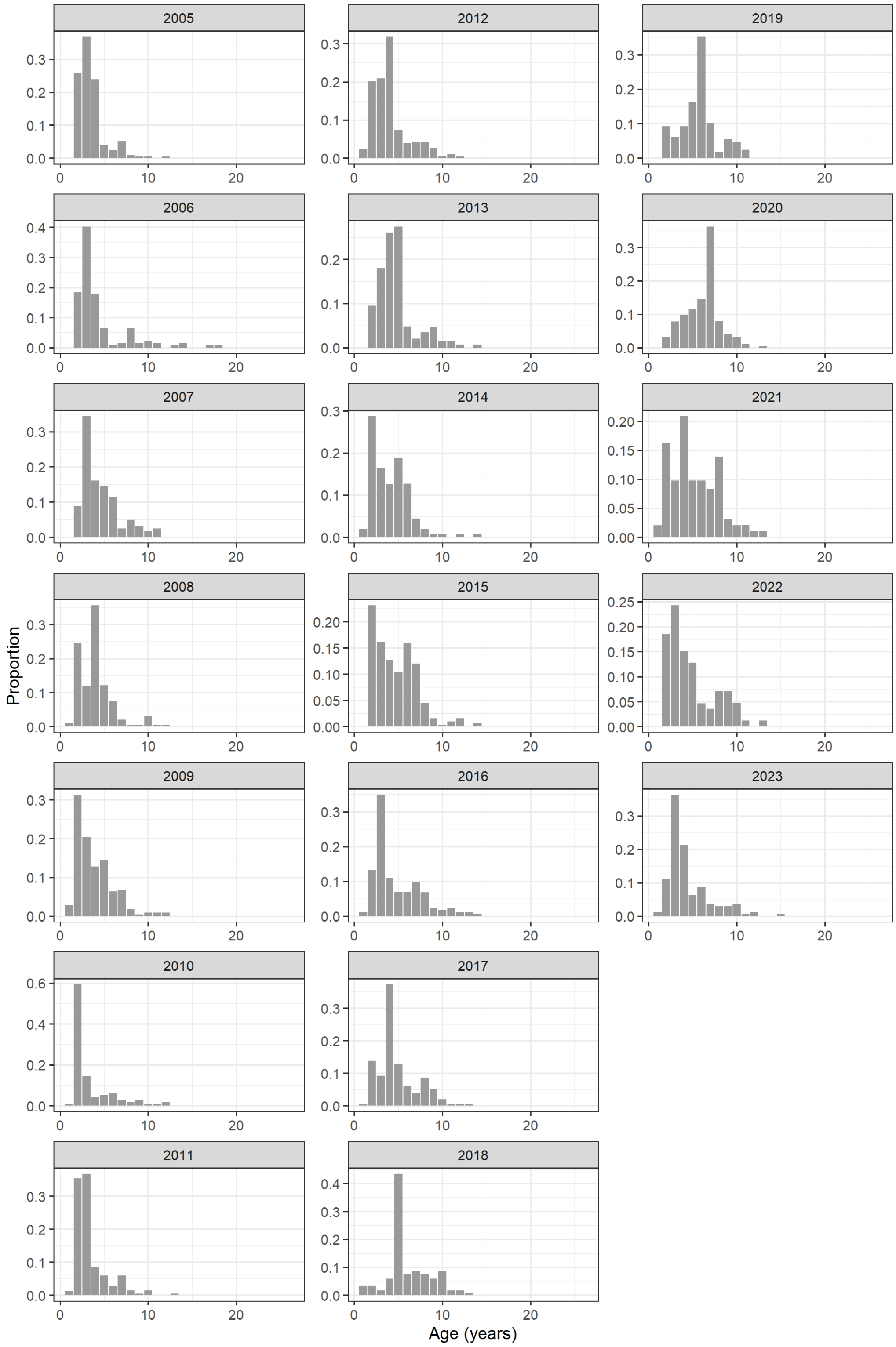

Figure 3.14: Annual age compositions of female Spanish mackerel for Fleet 1 (QldCommercialQ1)

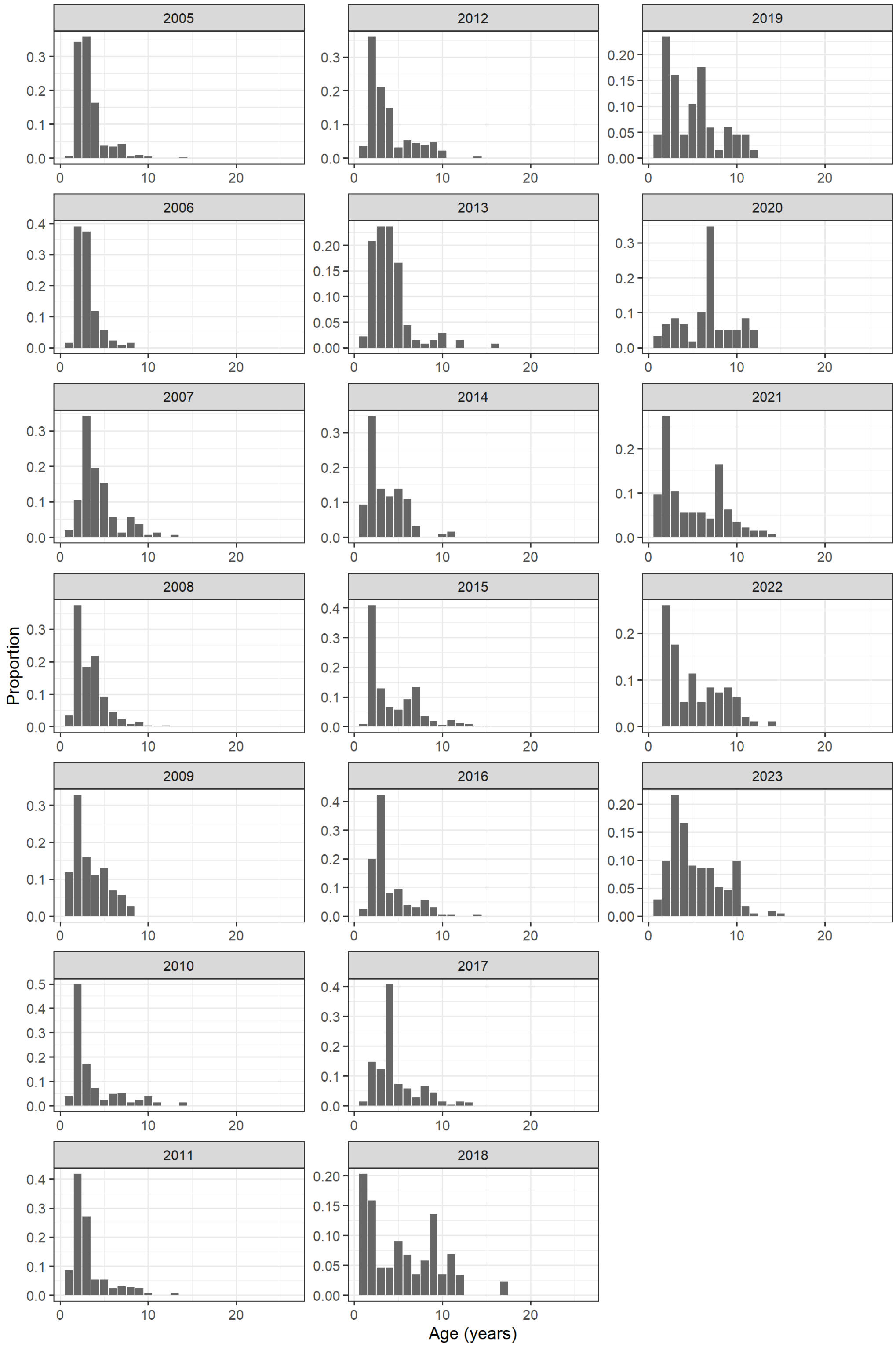

Figure 3.15: Annual age compositions of male Spanish mackerel for Fleet 1 (QldCommercialQ1)

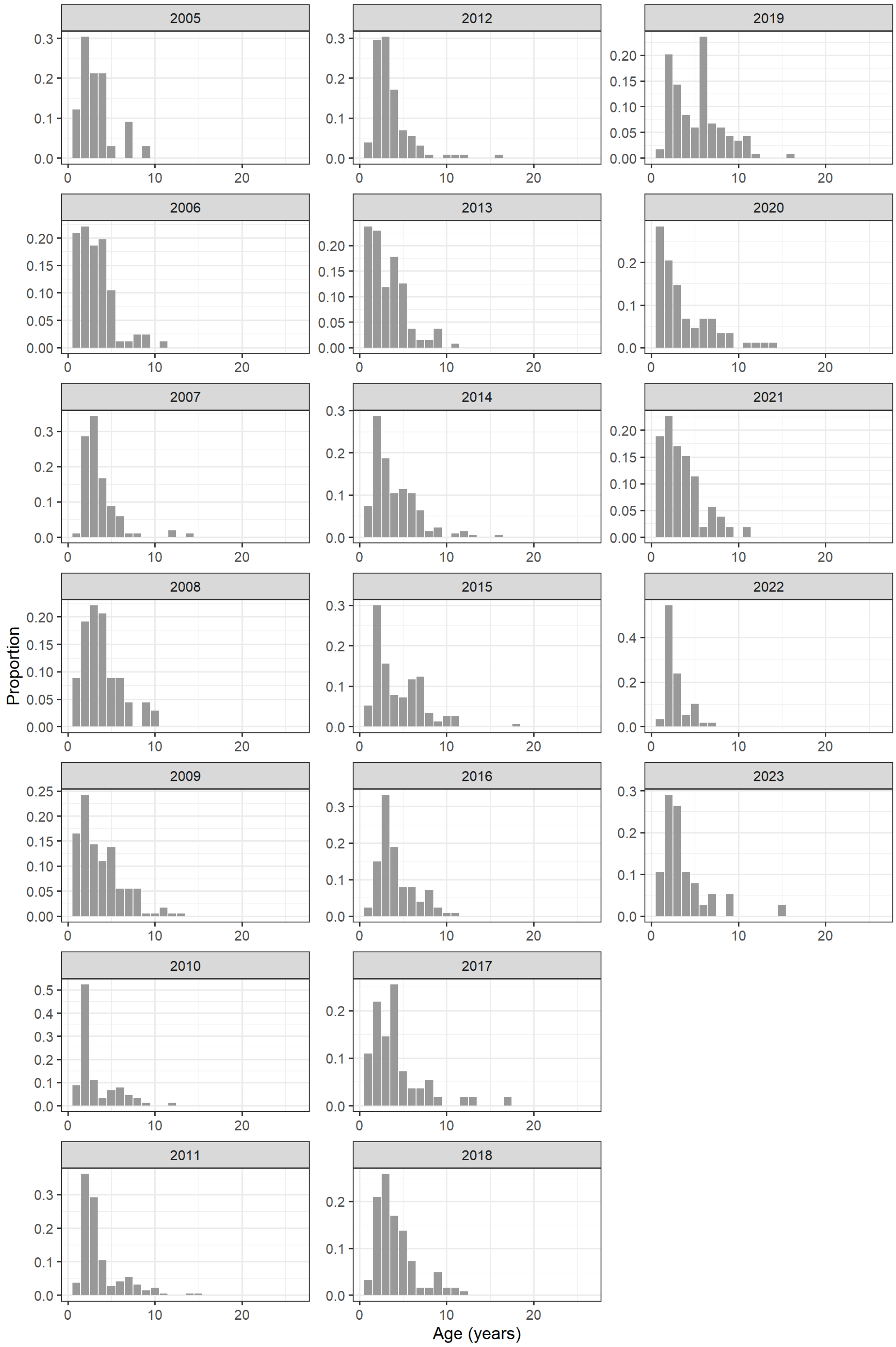

Figure 3.16: Annual age compositions of female Spanish mackerel for Fleet 5 (QldCommercialQ2)

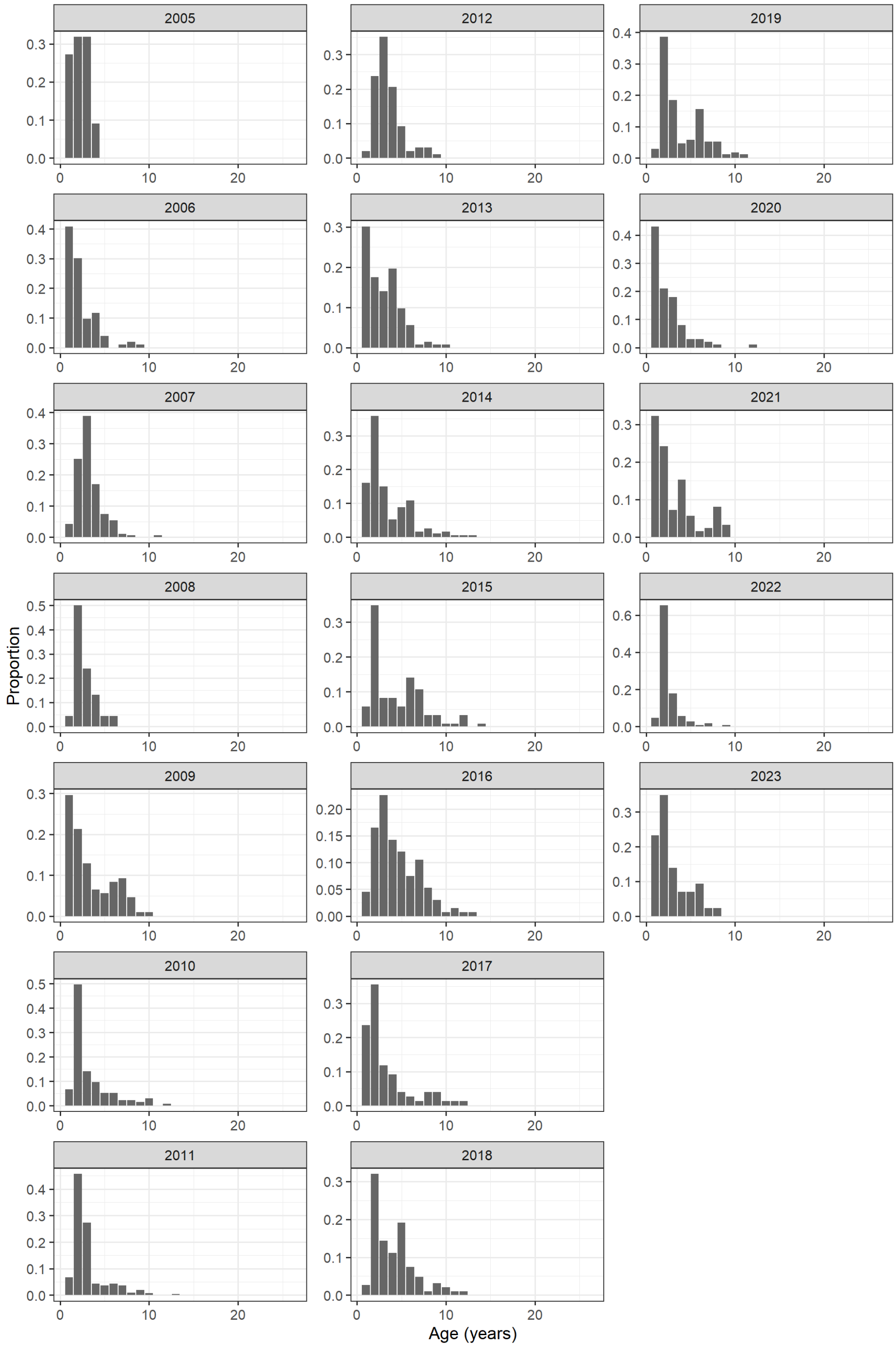

Figure 3.17: Annual age compositions of male Spanish mackerel for Fleet 5 (QldCommercialQ2)

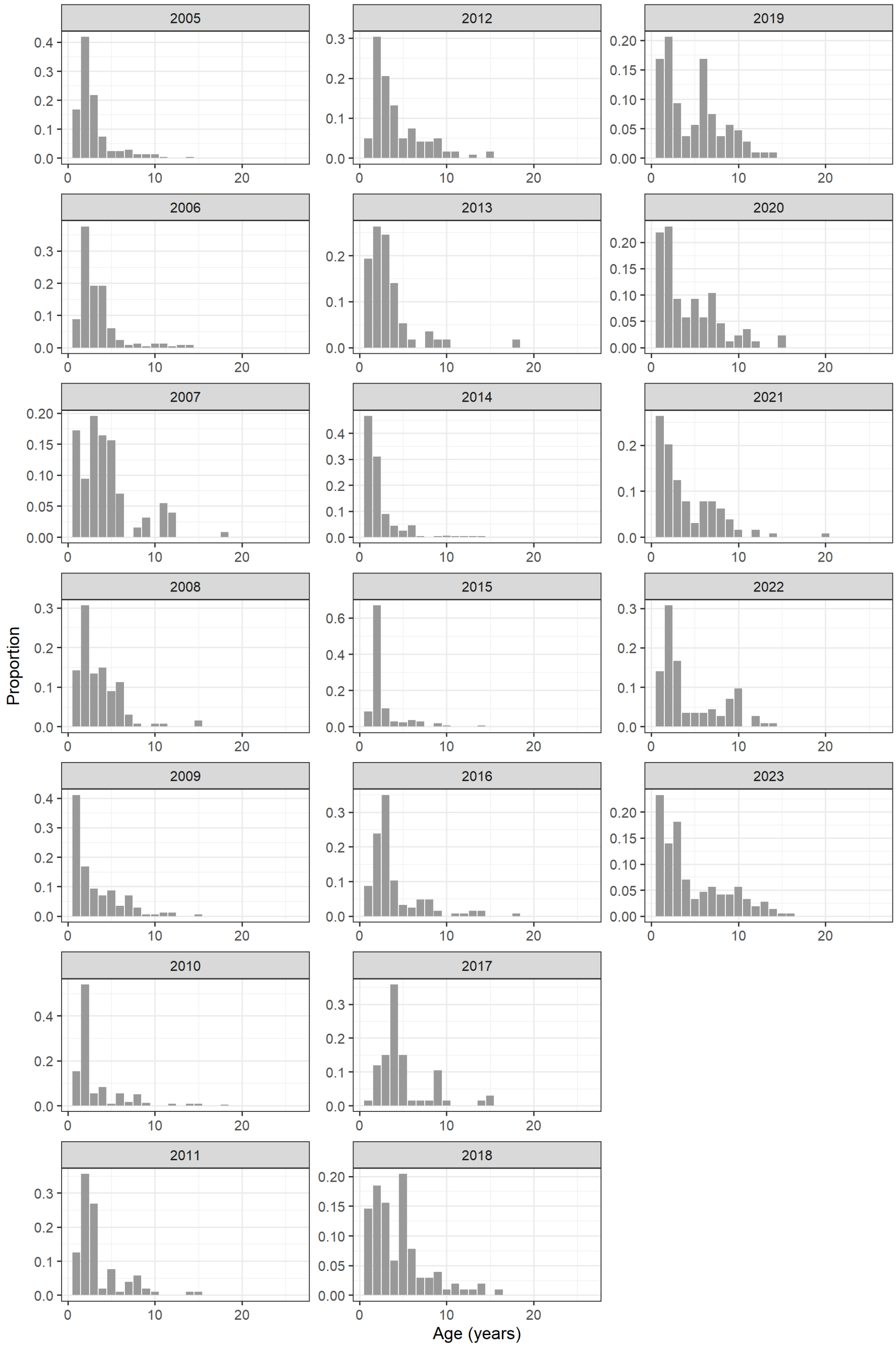

Figure 3.18: Annual age compositions of female Spanish mackerel for Fleet 6 (QldCommercialQ3)

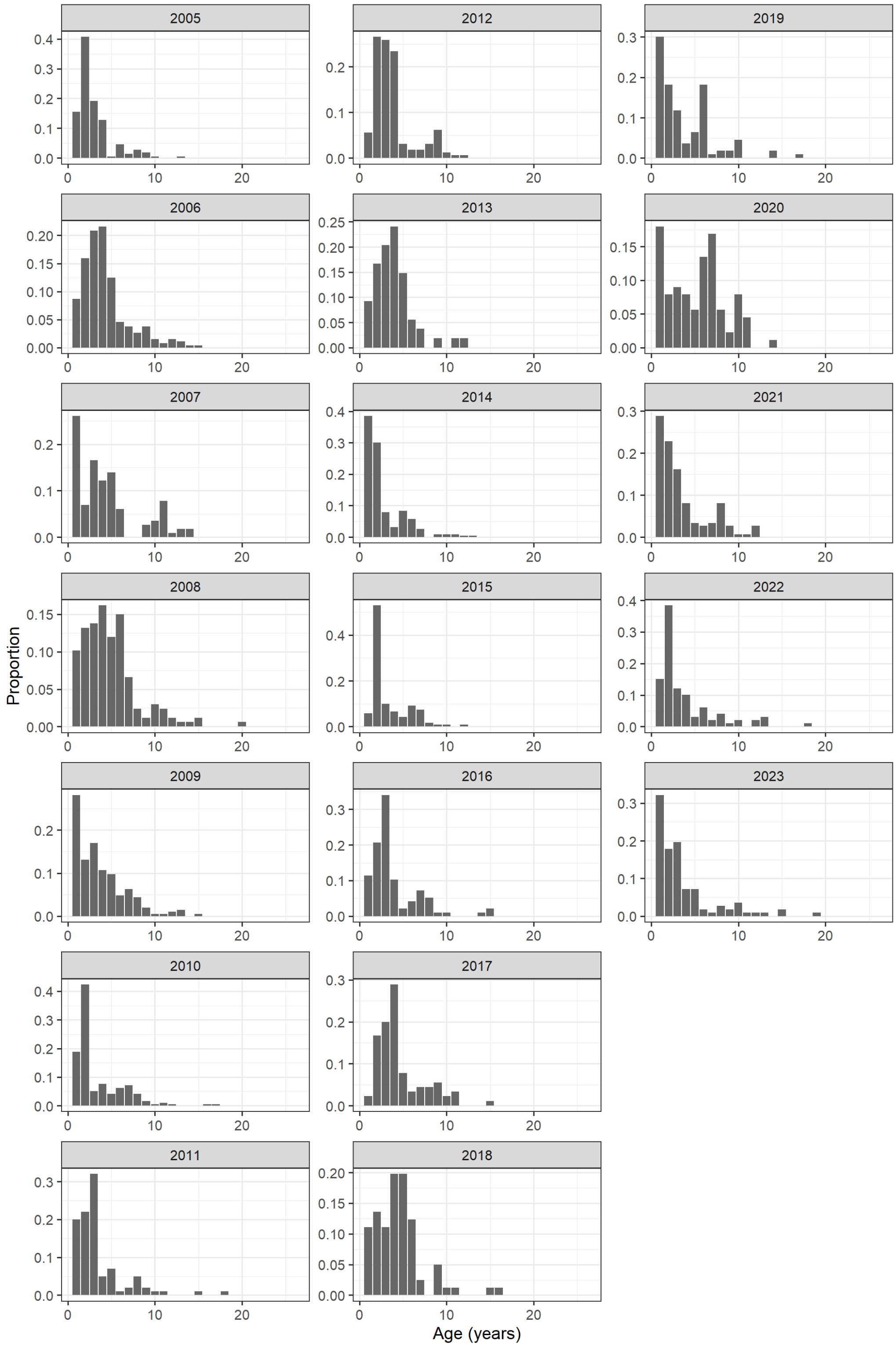

Figure 3.19: Annual age compositions of male Spanish mackerel for Fleet 6 (QldCommercialQ3)

3.1.7 Length compositions

Length compositions of Australian east coast Spanish mackerel are shown by fleet, aggregated across time (Figure 3.20) and annually by sector (Figures 3.21 and 3.22). The length compositions differ considerably by fleet (Figure 3.20), suggesting that selectivity patterns differ by both quadrant and sector.

Differences across quadrants result from the spatial and seasonal patterns in the availability of particular size classes of Spanish mackerel, due to their migratory behaviour (Figure 3.10). For explanation of the spatial and seasonal bounds of the quadrants, refer to Table 2.2 in Section 2.8.2. This effect can be seen when examining subplots for quadrant 1 and 2 for the Queensland commercial sector (see Figure 3.20). Quadrants 1 and 2 are the same spatial area (in different seasons), yet the length compositions are markedly different. In quadrant 1 (north of 22° south during spawning season), catches and samples are primarily from the Lucinda aggregation. Schooling fish participating in spawning tend to be of a similar size distribution to one another (Kasumyan and Pavlov 2023). Given the majority of fish are taken from the spawning aggregation in quadrant 1, this will mean the selectivity pattern of this fleet will favour the size classes common to the aggregation, which are likely to be spawning adults. By comparison, the quadrant 2 length composition exhibits a peak at smaller size classes, in the absence of migratory spawning fish.

Sectoral differences in selectivity arise from the different fishing practices, fishing gear and motives for catching Spanish mackerel between commercial and recreational sectors. This effect can be seen when comparing commercial and recreational subplots contained in Figure 3.20. Length compositions from the three recreational fleets are broader than the commercial equivalents for each quadrant, with the largest individuals typically caught by the recreational sector. Commercial fishers have economic reasons for avoiding larger fish, such as market-imposed size restrictions due to risk of ciguatera poisoning, and the ability to avoid shark depredation when fighting small to average sized fish. Conversely, motives and fishing practices of recreational fishers vary broadly, with some fishers targeting large trophy-sized fish, while others target any fish above MLS.

Collectively, the spatial, temporal and sectoral structure in the length data exhibited in Figure 3.20 and the influences listed above helped to inform the decision to set up the population model as a 'fleets as areas' model, allowing for the estimation of different selectivity patterns by quadrant.

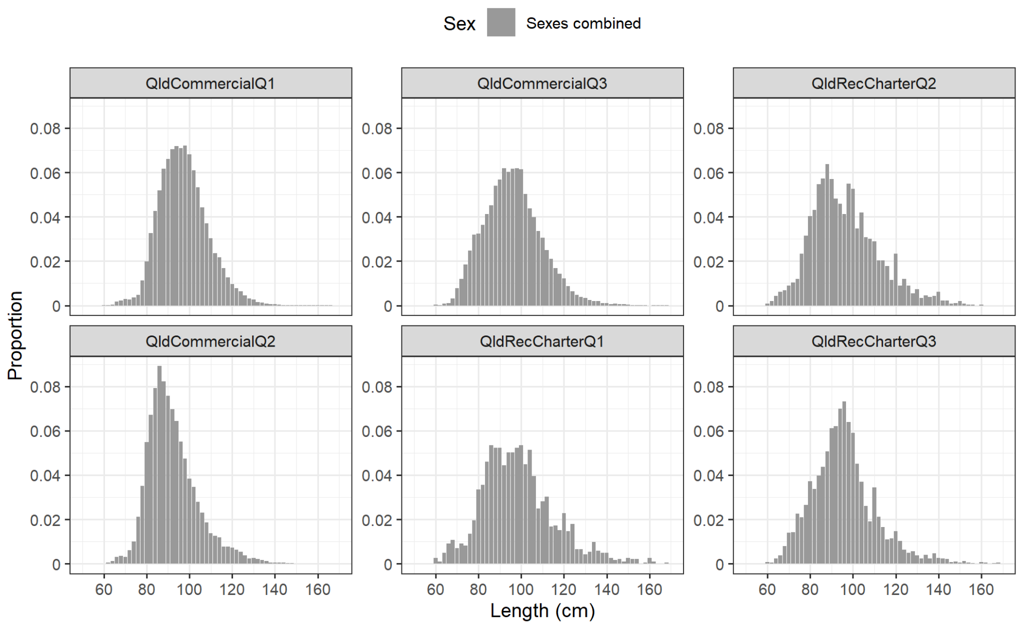

Figure 3.20: Length compositions of Spanish mackerel, aggregated across time (2005–2023) by fleet

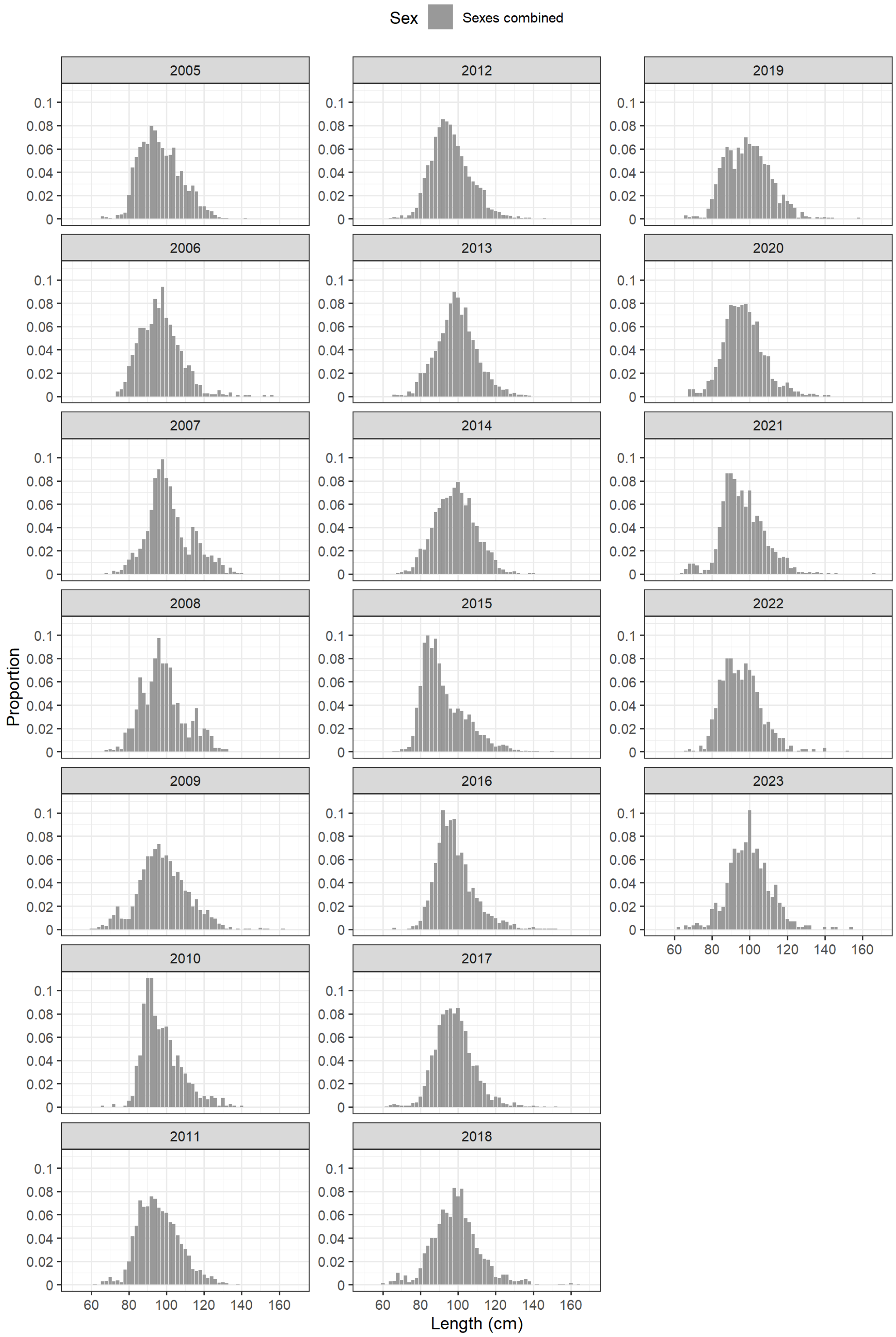

Figure 3.21: Annual length compositions of Spanish mackerel caught by the Queensland commercial sector

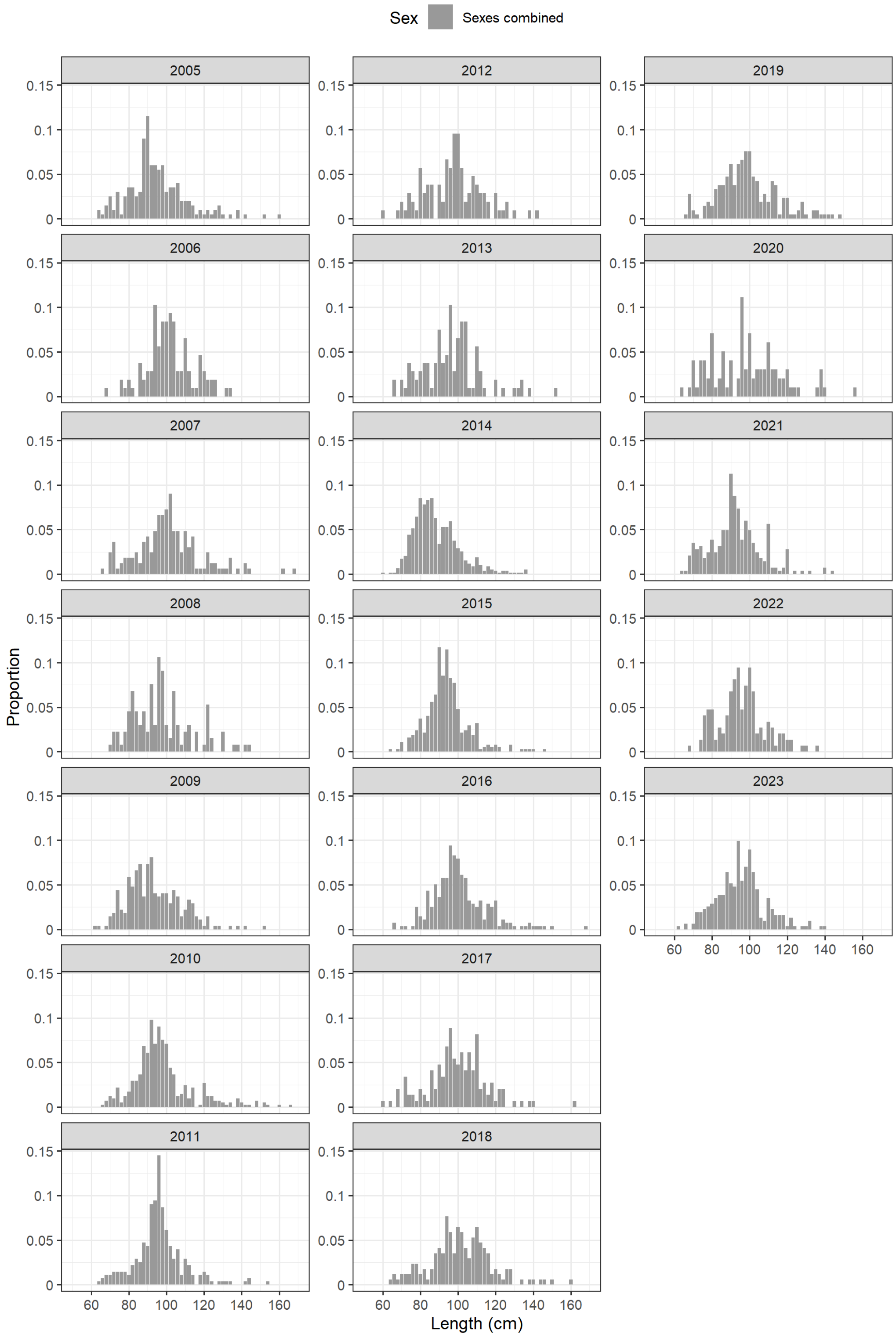

Figure 3.22: Annual length compositions of Spanish mackerel caught by the Queensland recreational sector

3.1.8 Discards

Estimates of discard rates by the Queensland recreational fleets as input into the model are shown in Figure 3.23. Discard rates were estimated at a statewide level based on the availability of data, and hence the rates applied to each quadrant are mirrored.

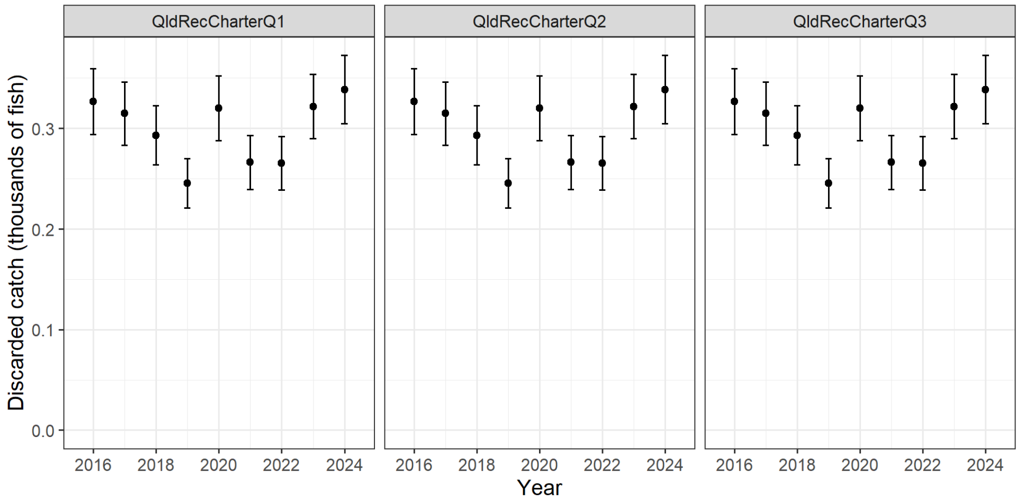

Figure 3.23: Recreational discard estimates for Australian east coast Spanish mackerel

3.1.9 Other model inputs

Fixed biological relationships are plotted in Appendix C (Section C.6, Figures C.12–C.14). These include the length–weight relationship, maturity at age, and individual spawning output (maturity multiplied by fecundity) by both age and length.

3.2 Model outputs

3.2.1 Model parameters

Parameter estimates across the ensemble are listed in Table 3.2.

Symbol	MCMC median	MCMC 2.5%	MCMC 97.5%
Natural mortality	0.2	0.2	0.3
Length at minimum age (female)	75.4	73.3	77.6
Length at maximum age (female)	138.01	134.11	141.88
VonBert growth coefficient (female)	0.2	0.2	0.2
SD of length at minimum age (female)	0.1	0.1	0.1
SD of length at maximum age (female)	0.07	0.06	0.08
Length at minimum age (male)	69.9	68.2	71.5
Length at maximum age (male)	114.2	112.6	115.8
VonBert growth coefficient (male)	0.32	0.29	0.36
SD of length at minimum age (male)	0.1	0.1	0.1
SD of length at maximum age (male)	0	0	0
Log of number of recruits when unfished	5.94	5.53	6.57
Selectivity plateau start, Fleet 1	96.8	91.4	103.1
Selectivity plateau width, Fleet 1	-14	-24.5	-2.5
Selectivity asc. width, Fleet 1	5.43	4.71	6.12
Selectivity desc. width, Fleet 1	5.6	3.4	7.3
Selectivity at max length, Fleet 1	0.3	0	0.6
Selectivity plateau start, Fleet 2	107.68	89.05	137.54
Selectivity plateau width, Fleet 2	1.4	-23.7	14.3
Selectivity asc. width, Fleet 2	7.4	5.8	9.2
Selectivity desc. width, Fleet 2	6.13	3.14	8.84
Selectivity at max length, Fleet 2	0.8	0.5	1
Selectivity plateau start, Fleet 5	89.3	84.7	94.1
Selectivity plateau width, Fleet 5	-14.03	-24.33	-3.26
Selectivity asc. width, Fleet 5	5.2	4.4	6
Selectivity desc. width, Fleet 5	4.7	3.2	5.8
Selectivity at max length, Fleet 5	0.24	0.13	0.4
Selectivity plateau start, Fleet 6	97.3	85.3	110.5
Selectivity plateau width, Fleet 6	-11.3	-24.4	11.3
Selectivity asc. width, Fleet 6	6.22	4.92	7.65
Selectivity desc. width, Fleet 6	6.1	3.2	8.7
Selectivity at max length, Fleet 6	0.4	0	0.9
Selectivity plateau start, Fleet 7	92.11	66.81	126.32
Selectivity plateau width, Fleet 7	-6.2	-24.2	13.8
Selectivity asc. width, Fleet 7	6.3	4.3	8.9
Selectivity desc. width, Fleet 7	5.95	3.15	8.87
Selectivity at max length, Fleet 7	0.7	0.1	1
Selectivity plateau start, Fleet 8	99	90.2	118
Selectivity plateau width, Fleet 8	-11.62	-24.33	13.15
Selectivity asc. width, Fleet 8	6.5	5.8	8.2
Selectivity desc. width, Fleet 8	4.3	3.1	8.6
Selectivity at max length, Fleet 8	0.6	0.11	0.95

Table 3.2: Summary of parameter estimates for Spanish mackerel from the ensembled scenarios. MCMC Median is median parameter value from robust MCMC scenarios. MCMC 2.5% and 97.5% indicates 95% credible interval. Fleet definitions are listed in Table 2.2.

3.2.2 Model fits

Plots of model fit to standardised catch rate, mean age over time, length-composition and age-composition by fleet are shown from Figure 3.24 to Figure E.15.

By applying broad standard errors (SE = 0.3) to the CPUE index, the model fits to the index were deliberately down-weighted. This was done to allow the model greater flexibility to fit closely to trends in the age-at-length data, and avoid fitting closely to a CPUE index likely impacted by hyperstability. As a result, model fits to the CPUE index were intentionally less precise (Figure 3.24).

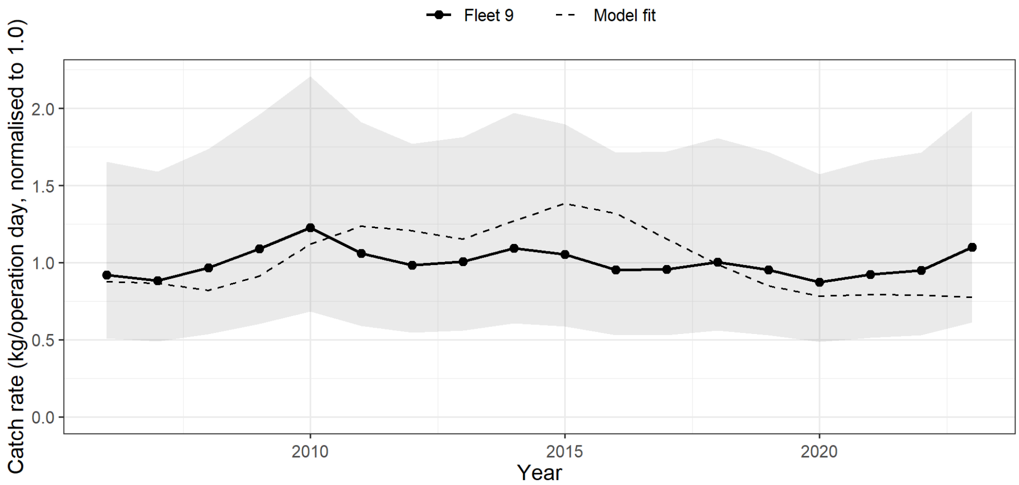

Figure 3.24: Model fits (dotted line) to standardised catch rates for Australian east coast Spanish mackerel between the years of 2006 and 2023

Overall, the mean age plots (Figure 3.25) show reasonable fit to the age-at-length data. Some tendency remains to over-predict ages in the early period, and under-predict recent ages at length. In interpreting the quality of fit in the three subplots, it is important to consider that the absolute value of the predictions are constrained at the level of the entire population, meaning that predictions at the fleet level may be able to match the trend, but not the magnitude.

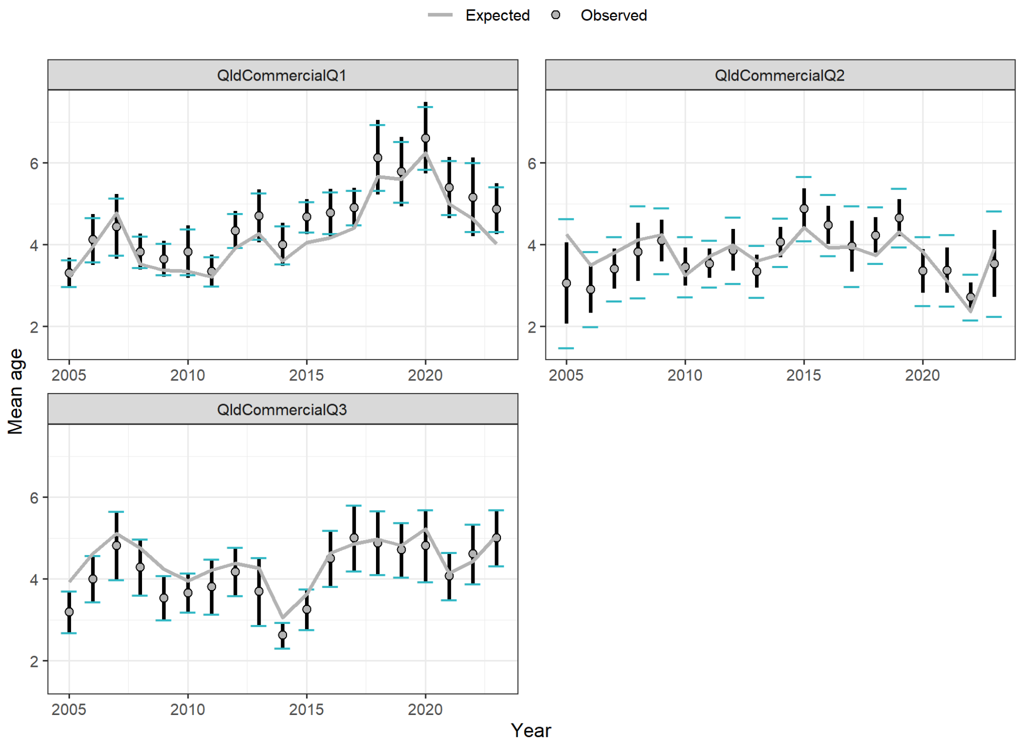

Figure 3.25: Model fits to mean age from conditional data (aggregated across length bins) with 95% confidence intervals based on current sample sizes: blue intervals (with capped ends) show result of further adjusting sample sizes based on suggested multiplier (with 95% interval) for conditional age-at-length data

Model fits to annual length composition data by fleet are given in the plots below (Figures 3.26 to 3.31). In general, fits to length composition data were reasonable despite statistical down-weighting using ESS. Annual sample sizes in early years of the data were low, meaning the relative ESS (and therefore weight) apportioned to these years was comparatively low. This translated to some lack of fit in these years, which can be observed across all fleets.

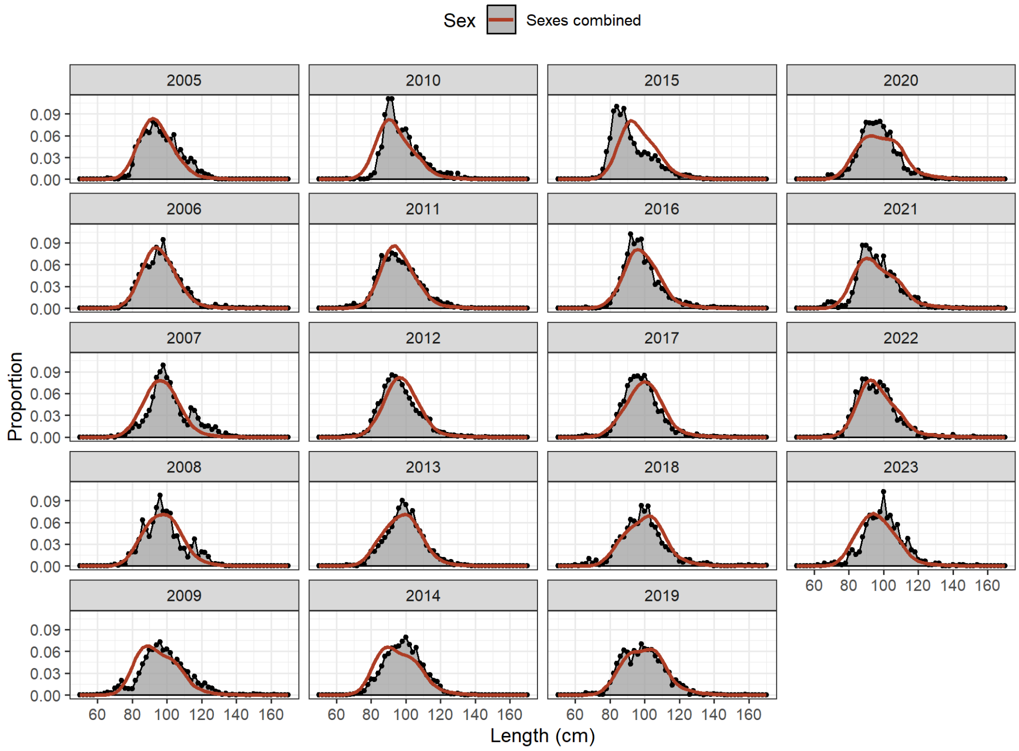

Figure 3.26: Model fits to length structures for Fleet 1, based on maximum likelihood estimation—the grey area and black line represent data inputs and the red and blue line represents the model fits for female and male, respectively

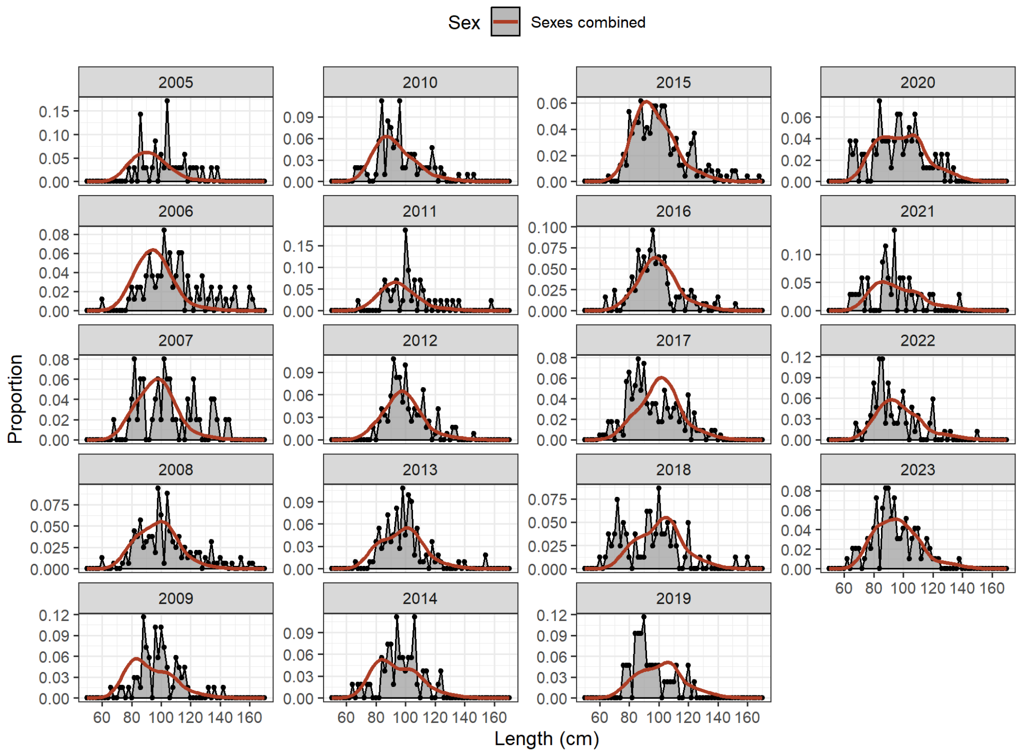

Figure 3.27: Model fits to length structures for Fleet 2, based on maximum likelihood estimation—the grey area and black line represent data inputs and the red and blue line represents the model fits for female and male, respectively

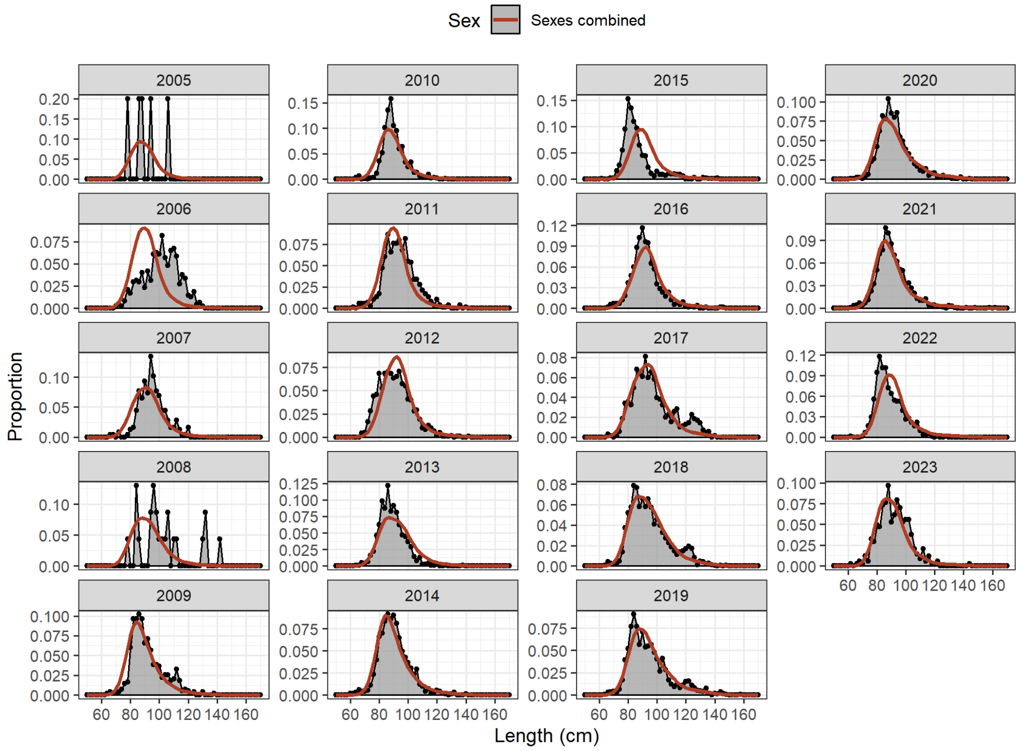

Figure 3.28: Model fits to length structures for Fleet 5, based on maximum likelihood estimation—the grey area and black line represent data inputs and the red and blue line represents the model fits for female and male, respectively

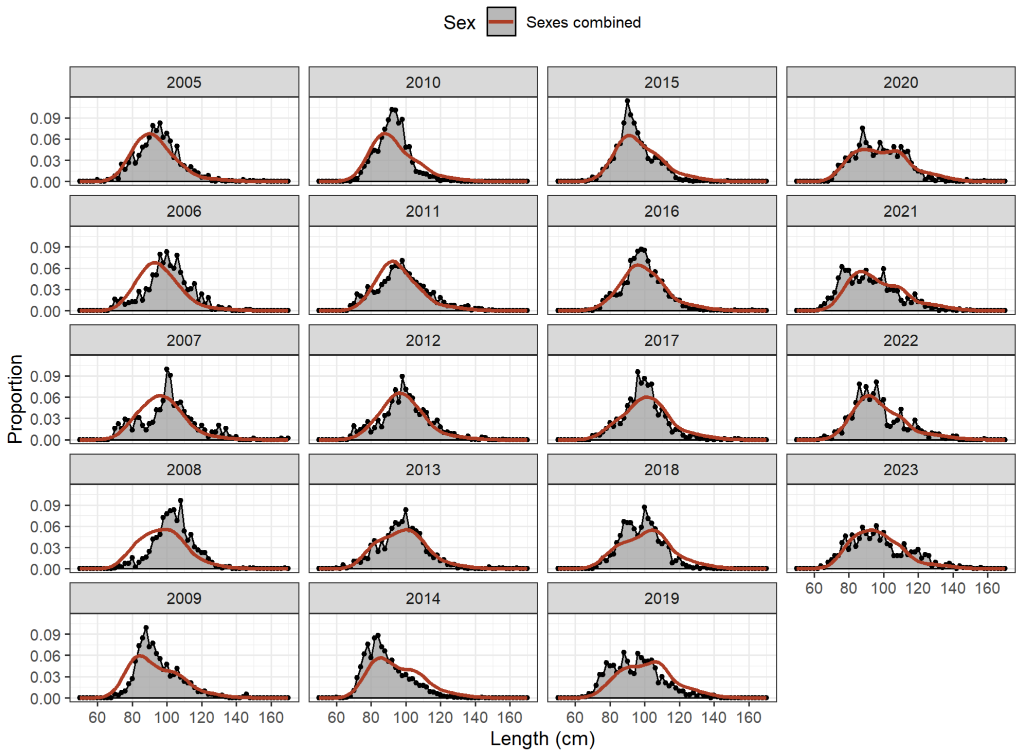

Figure 3.29: Model fits to length structures for Fleet 6, based on maximum likelihood estimation—the grey area and black line represent data inputs and the red and blue line represents the model fits for female and male, respectively

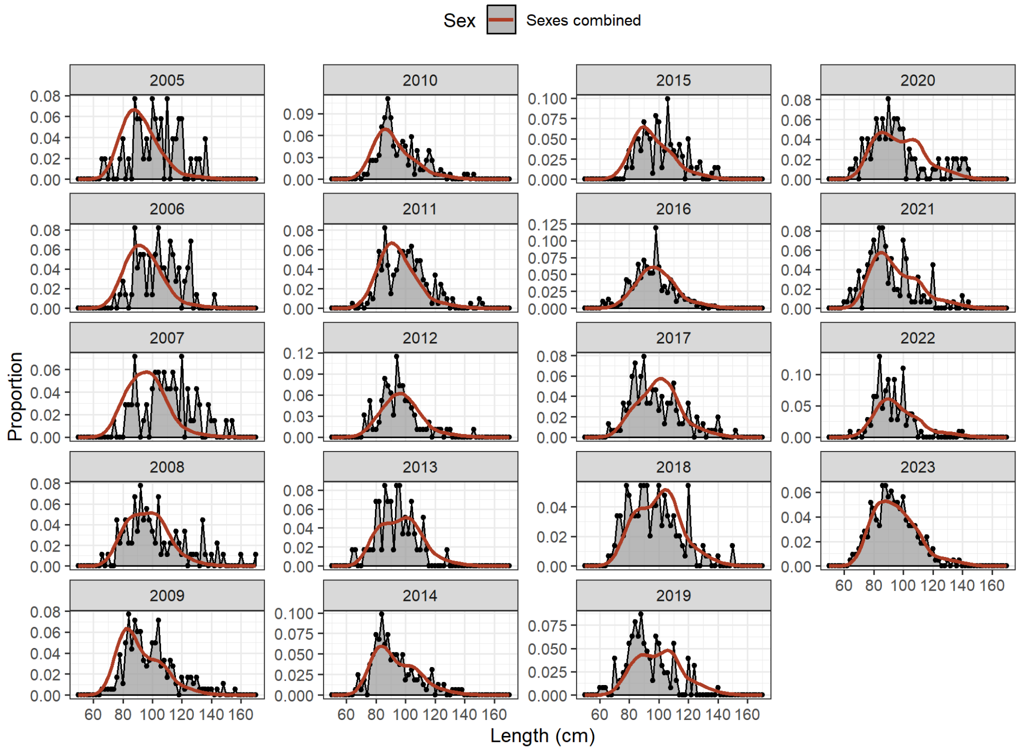

Figure 3.30: Model fits to length structures for Fleet 7, based on maximum likelihood estimation—the grey area and black line represent data inputs and the red and blue line represents the model fits for female and male, respectively

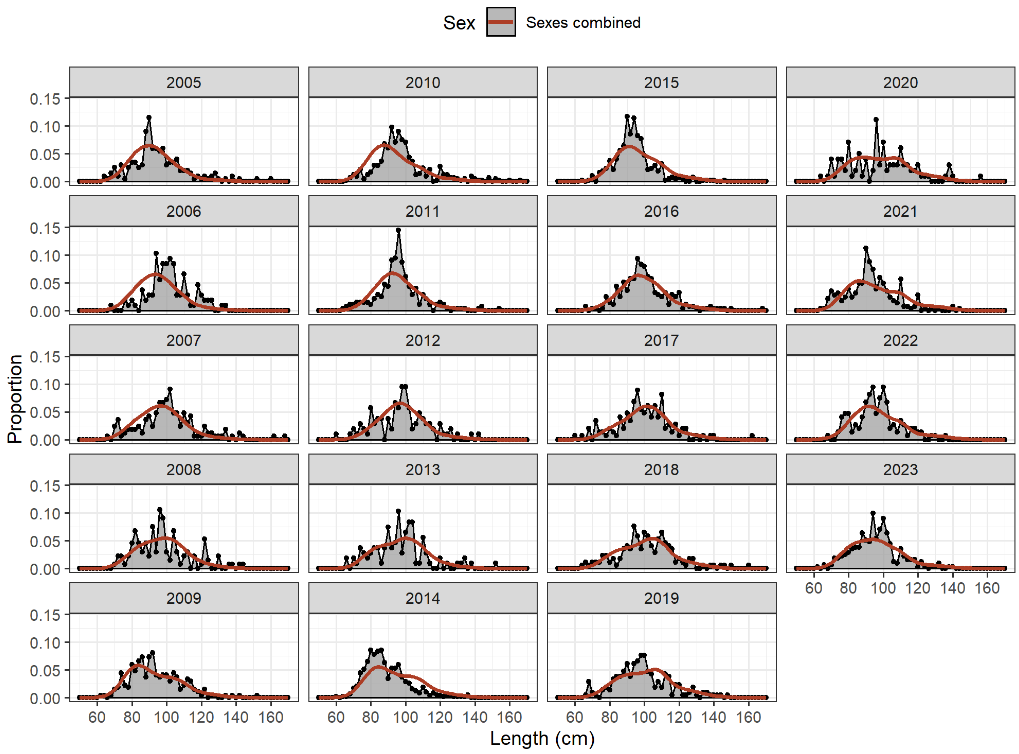

Figure 3.31: Model fits to length structures for Fleet 8, based on maximum likelihood estimation—the grey area and black line represent data inputs and the red and blue line represents the model fits for female and male, respectively

Age data were input to the model as conditional age-at-length data, rather than age-only composition data derived outside the model. For model verification, goodness-of-fit plots to resulting age compositions were included for visualisation purposes, however the age-only composition data were not used as part of the model fitting (Figures 3.32 to 3.37).

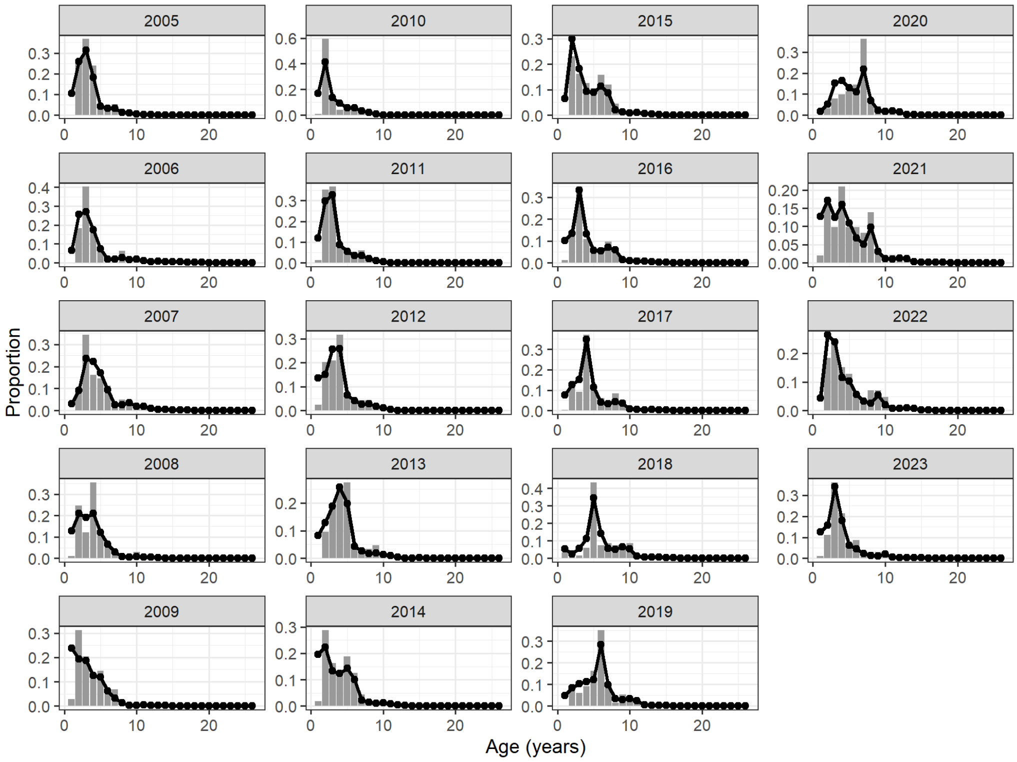

Figure 3.32: Model fits to annual age compositions of female Spanish mackerel for Fleet 1

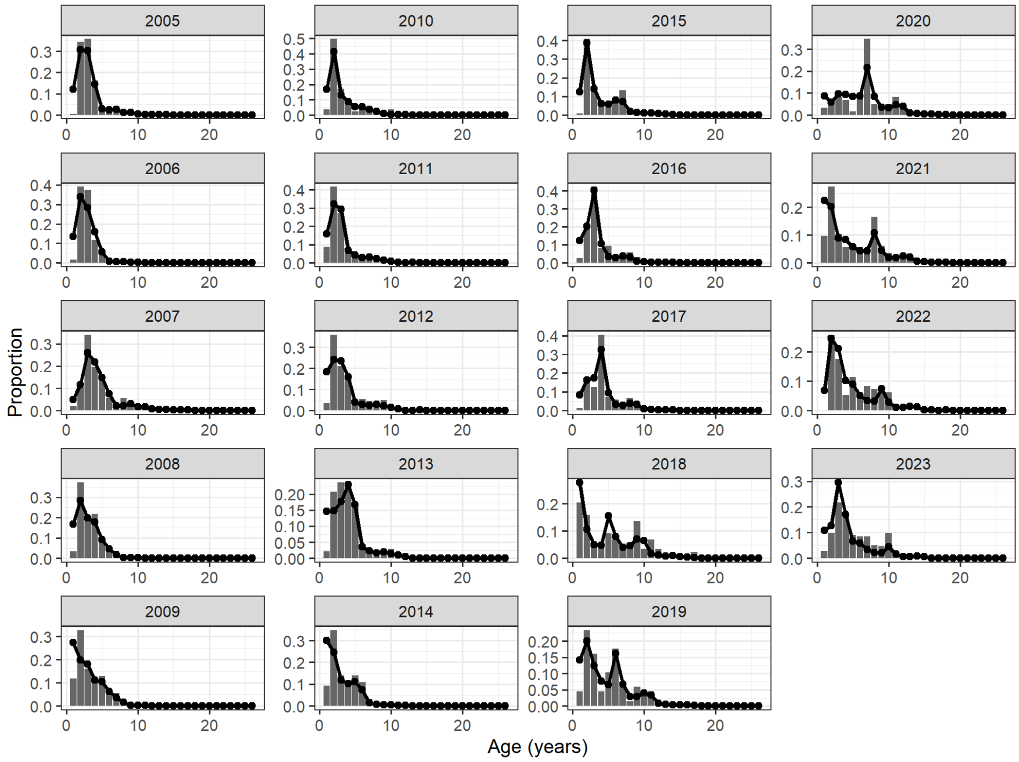

Figure 3.33: Model fits to annual age compositions of male Spanish mackerel for Fleet 1

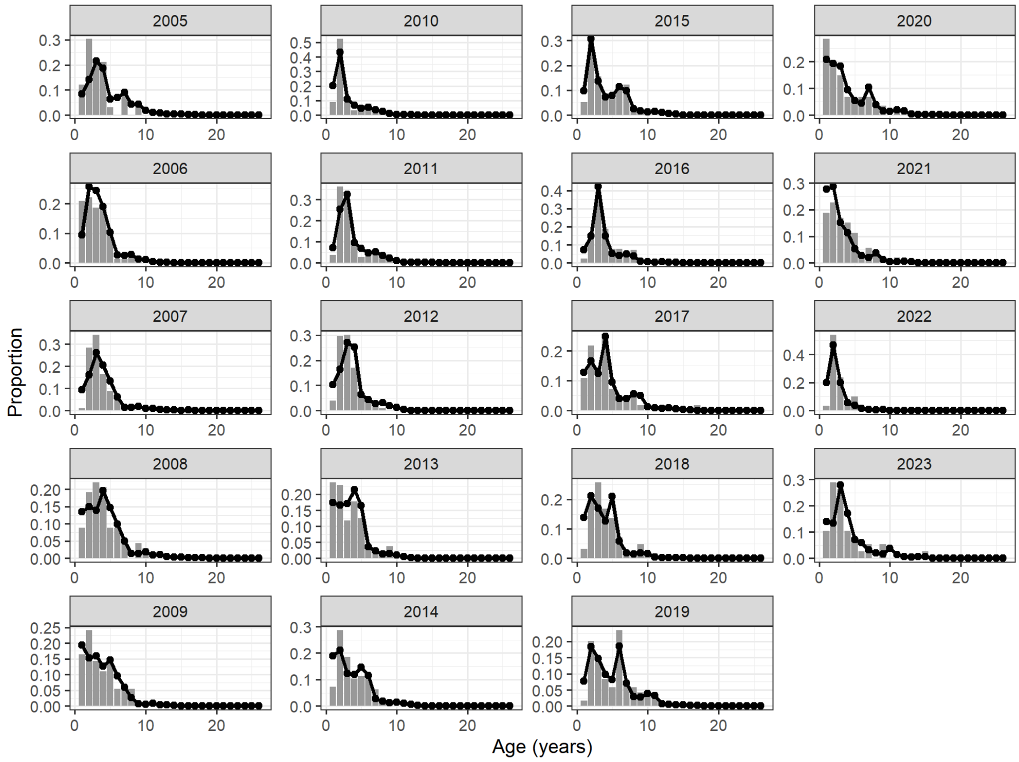

Figure 3.34: Model fits to annual age compositions of female Spanish mackerel for Fleet 5

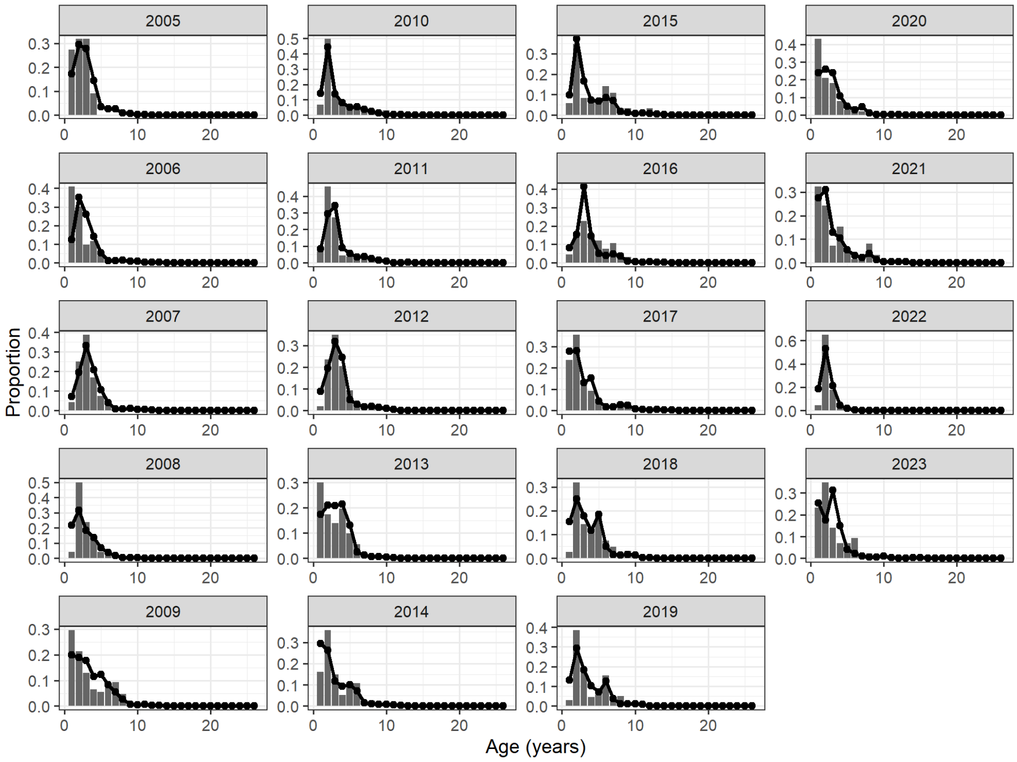

Figure 3.35: Model fits to annual age compositions of male Spanish mackerel for Fleet 5

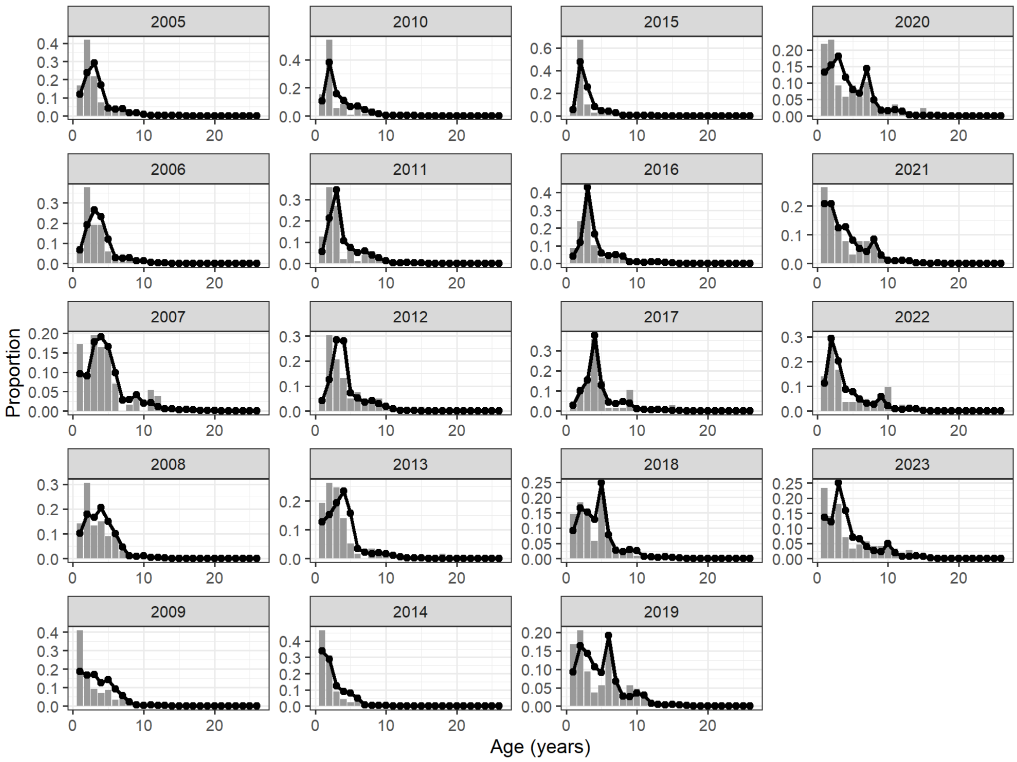

Figure 3.36: Model fits to annual age compositions of female Spanish mackerel for Fleet 6

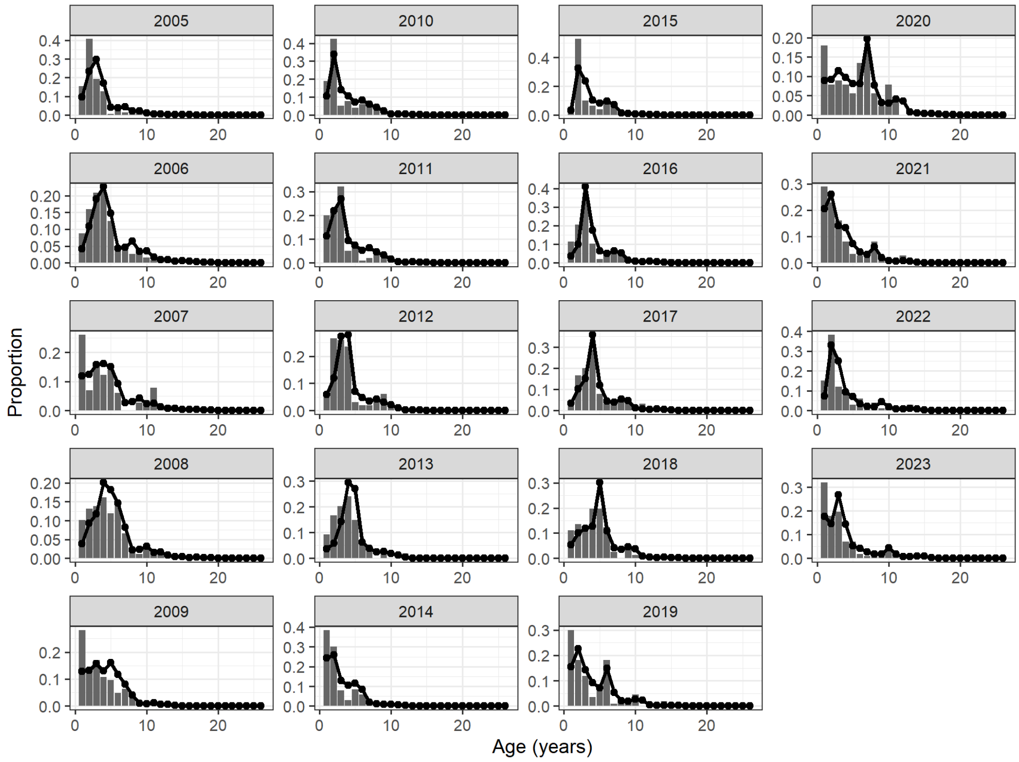

Figure 3.37: Model fits to annual age compositions of male Spanish mackerel for Fleet 6

3.2.3 Selectivity

Parameters for length-based selectivity to fishing were estimated within the model (Table 3.2). The resulting selectivity functions (Figure 3.38) represent the relative proportion of Spanish mackerel of a given length that can be caught by the fishing gear deployed by a fleet (ranging from zero to 100%). Estimated patterns of selectivity differed by fleet.

Freely estimating the parameters of the double normal curve (explained in Section 2.8.4) provided the model the flexibility to estimate either dome-shaped or asymptotic selectivity for each given fleet as warranted by the data. All recreational fleets and fleet 6 (QldCommercialQ3) utilised this flexibility and conformed to an asymptotic selectivity pattern (Figure 3.38), while fleets 1 and 5 (QldCommercialQ1 and QldCommercialQ2) formed a dome-shaped selectivity pattern.

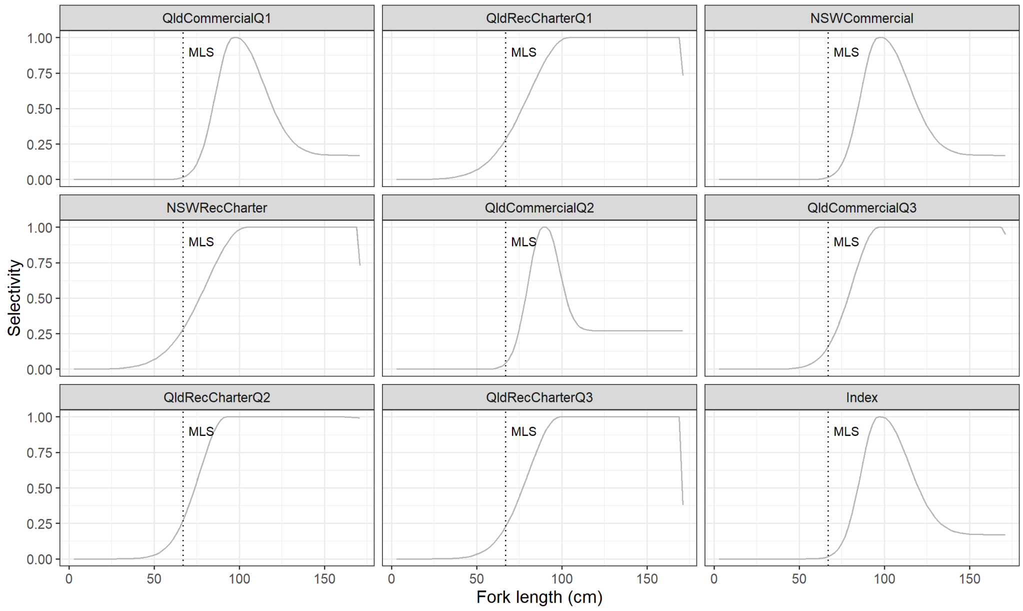

Figure 3.38: Model estimated length-based selectivity in 2025 for the representative MLE model—the dashed line shows the current minimum legal size of 75 cm in fork length (approximately 67 cm)

3.2.4 Growth curves

The von Bertalanffy growth curve, including coefficients of variation of old and young fish, was estimated within the model for both males and females (Table 3.2, Figure 3.39).

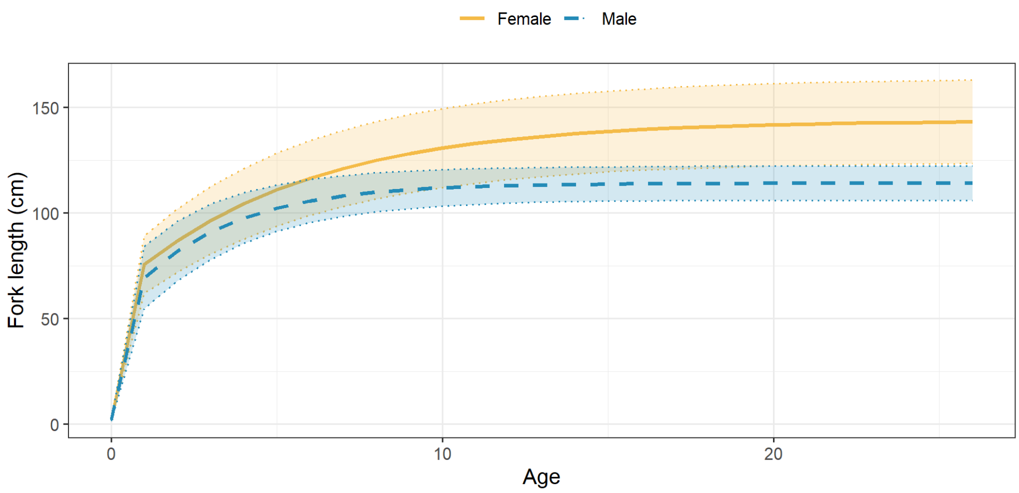

Figure 3.39: Estimated growth of Spanish mackerel (95% confidence intervals) for the representative MLE model (scenario 2)

3.2.5 Biomass

The time series of estimated spawning biomass ratio (relative to an unfished state) from all scenarios listed in Table 2.4, are shown in Figures 3.40 (Markov chain Monte Carlo results) and 3.42 (maximum likelihood estimates and MCMC results) and Table 3.3 and Table 3.4.

The final ensemble produced a probability distribution of 2025 biomass ratio (Figure 3.41). This figure differs from the way final outputs were presented in Tanimoto et al. (2021a) and instead follows the presentation style of Campbell et al. (2024). Tanimoto et al. (2021a) presented a 'base case' with an uncertainty range. A 'base case' means that the project team was asked for a preferred (or most likely) scenario from the larger suite of scenarios. As we elaborate upon in Section 4.3.1, an ensemble approach directly represents all uncertainty considered in the final suite of scenarios, by bringing them into a single output distribution.

While the 'base case' approach used in Tanimoto et al. (2021a) presents biomass results from a 'most likely' scenario as chosen by project team members, the ensemble approach can show the most probable biomass outcome from the scenario suite with all scenarios considered in concert. Figure 3.41 shows this, displaying the relative probability of different final biomass ratio outcomes. Rather than the 'most likely' biomass outcome that would be given by a 'base case' approach, the median biomass is given as a measure of central tendency for 2025 biomass outcomes. The median is preferred as a central tendency measure (over the mean or mode, for example) as it is less prone to the influence of outliers or extreme values, making it a more robust measure for skewed distributions, such as the probability distribution of 2025 biomass.

A tabular summary of stock status indicators relating to biomass outputs is given in Table 3.3.

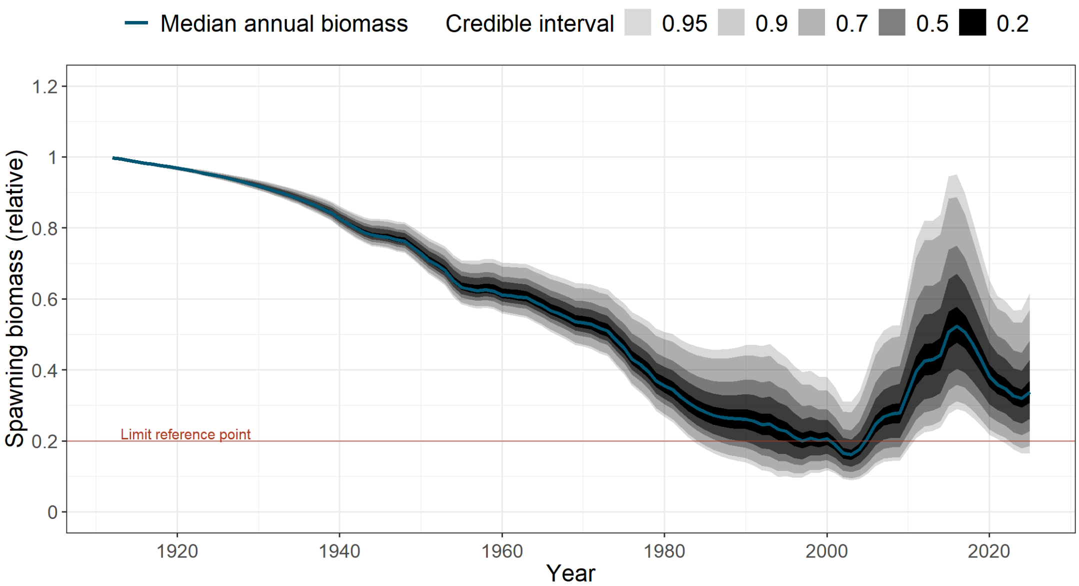

Figure 3.40: Predicted spawning biomass trajectory relative to unfished for Spanish mackerel in the Australian east coast, from MCMC ensemble scenarios

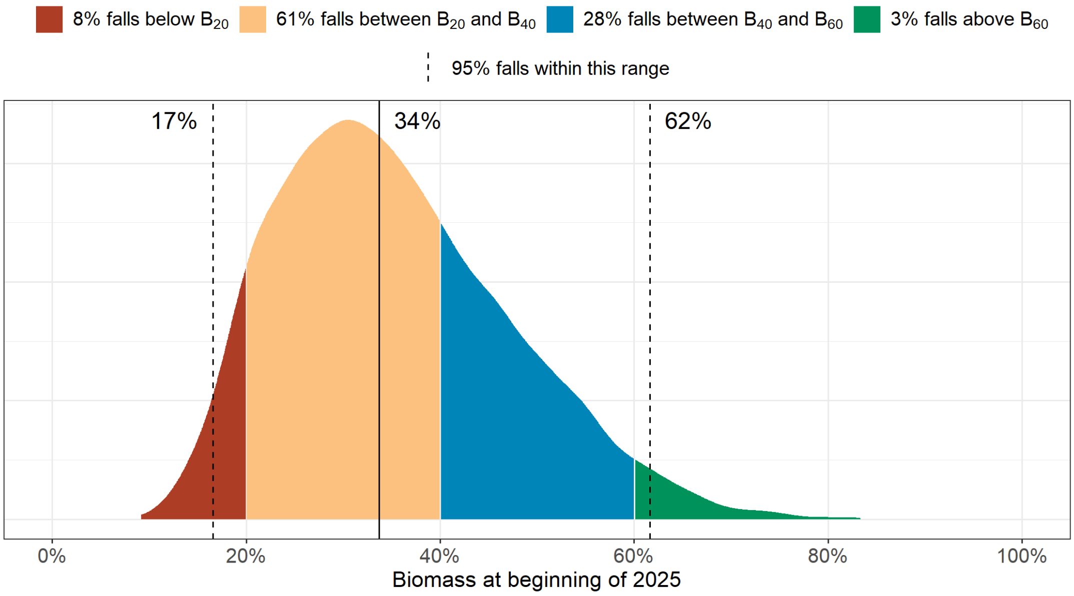

Figure 3.41: Probability distribution of the biomass ratio at the beginning of 2025 across the full ensemble of scenarios with the credible interval and probability of biomass falling into the four categories indicated

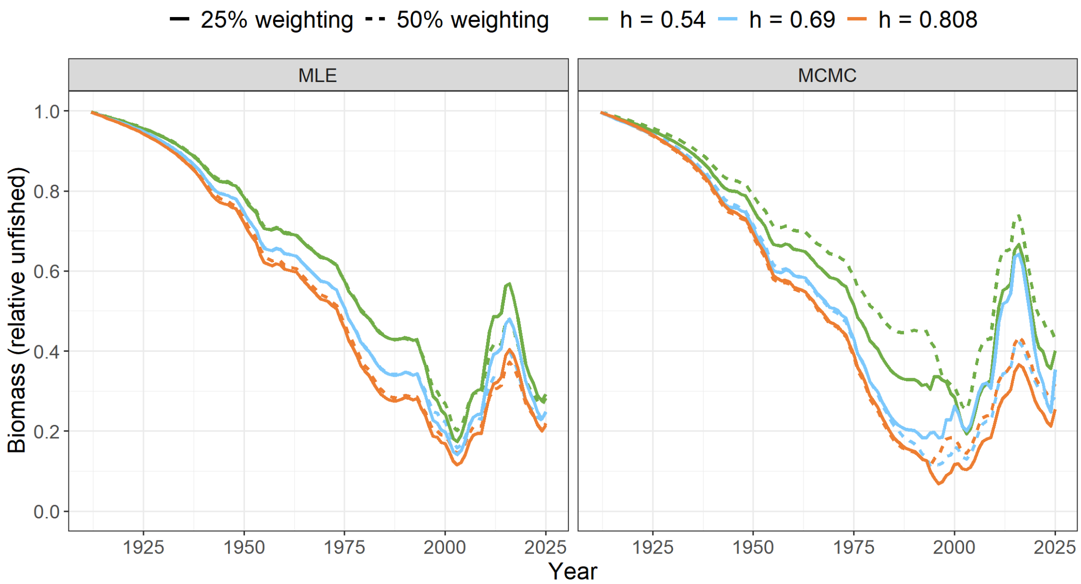

Figure 3.42: Estimated spawning biomass trajectory relative to unfished levels for Australian east coast Spanish mackerel from 1911 to 2025 for all scenarios. The right panel displays the "MCMC median" (i.e. iteration that produced the median value for biomass at the beginning of 2025) and the left panel is the optimised maximum likelihood estimate (MLE)

Table 3.3: Stock status indicators for Australian east coast Spanish mackerel

Indicator	**Value**
Biomass ratio (relative to unfished)	
Median	34%
Range (95% credible interval)	17–62%
Probability below 20%	8%
Probability between 20% and 40%	61%
Probability between 40% and 60%	28%
Probability above 60%	3%
Mean of MLE scenarios	25%

In the following table, biomass ratio outcomes at the beginning of 2025 are given by scenario, for both maximum likelihood estimation (MLE) and Markov chain Monte Carlo (MCMC) model runs (Table 3.4). For MCMC runs, the biomass outputs shown here are relevant to the scenario providing the median 2025 biomass from each run's MCMC distribution. For a list of the six scenarios and their given parameter settings, refer to Table 2.4.

Table 3.4: Summary of model outcomes for all scenarios.B_{2025}% is the most likely biomass in 2025 relative to unfished in 1912 with the 95% confidence interval for maximum likelihoods estimations and 95% credible interval for MCMC estimations.

Scenario	**MLE**			**MCMC**		
	B_{2025}%	$B_{2025,lower}$%	$B_{2025,upper}$%	B_{2025}%	$B_{2025,lower}$%	$B_{2025,upper}$%
1	0.28	0.10	0.46	0.43	0.25	0.66
2	0.25	0.08	0.41	0.29	0.18	0.42
3	0.22	0.08	0.36	0.32	0.16	0.58
4	0.29	0.12	0.47	0.40	0.23	0.63
5	0.25	0.10	0.40	0.35	0.17	0.63
6	0.22	0.08	0.35	0.26	0.14	0.54

4 Discussion

4.1 Stock status

Stock status at the beginning of 2025 was estimated to be between 17% and 62% of unfished (95% credible interval over the MCMC ensemble), with a median biomass estimate of 34%. The probability that the biomass was below 20% at this time was estimated to be 8%. The biomass trajectory indicates a decline from an assumed unfished state in 1912 to potentially as low as 16% in 2003, before a period of rebuild.

4.2 Key influences

4.2.1 Natural mortality and steepness

A key influence upon the 2021 assessment noted by the previous assessment authors, as well as reviewers (Klaer (2021) and Hoyle and Dunn (2023)) was steepness (h). While h remained influential in this assessment, the updated modelling approach highlighted the sensitivity of the model to natural mortality (M). This assessment also reinforced the importance of evaluating these two parameters in tandem due to their interaction, rather than in isolation.

As mentioned in Section 2.8.4, the model was initially constructed using a range of fixed values for M (0.175, 0.216, 0.266) and here, the direct impact of M upon biomass outcomes was clearly evident. Scenarios in the final ensemble estimated M using a prior (Hamel and Cope 2022). As a result, the direct relationship between M and biomass became less distinguishable, as M and h were allowed to interact, preventing the isolated effect of M from being observed. However, a clear comparison of different fixed M values and their impact upon biomass outcomes can be seen in Figure F.2, where we explore the original three fixed M models. The comparative impact of M and h can also be compared in Figure F.2, showing that biomass outcomes are more sensitive to natural mortality than steepness across the range of plausible values explored.

In the final ensemble, steepness (h) has a notable impact on biomass, but higher values of steepness (h) are not necessarily associated with more optimistic biomass outcomes. As the given value of h changes by scenario, the resulting estimates of M differ. Specifically, final ensemble scenarios with lower values of h tended to produce higher estimates of M. Given the impact of M upon biomass, these low h scenarios resulted in higher estimates of 2025 biomass, likely as a consequence of this interaction (Figure 3.42).

4.2.2 Relative weighting of length and age data

In the review of the previous stock assessment, Hoyle and Dunn (2023) highlighted a lack of fit to age-at-length data, namely the 2021 model's inability to fit to the trend of mean age over time. The reviewers commented on a likely conflict between the length composition and conditional age-at-length datasets. Increases shown in the mean age of fish over time, particularly during 2011–2020 in quadrant 1 (Figure 3.11), are suggestive of rebuild. As the 2021 assessment (Tanimoto et al. 2021a) placed a relatively high weighting on both the CPUE index and length compositions, fits were poor to this increase in mean age over time, and it did not translate to a rebuild in biomass ratio.

As detailed in Section 2.6.4, scenarios were created with varying degrees of down-weighting (via reduced ESS) applied to length compositions, to prioritise fitting closely to age compositions and temporal trends in mean age. Here, we found that as the ESS for length compositions was reduced (see Table 2.4), the model became more responsive to trends in mean age (Figure 3.42). In particular, scenarios with an ESS set at 25% of the conditional age-at-length ESS were the most responsive (Figure 3.42). These scenarios exhibited a greater degree of rebuild before 2020, followed by more rapid declines after 2020 as the mean age of fish decreased. A comparison between both length composition weightings in the ensemble, as well as an exploratory 'equal-weighting' scenario is provided in Figure F.2.

While the degree of ESS down-weighting on length compositions notably influenced biomass outcomes, particularly the model's responsiveness to trends in mean age, its impact on 2025 biomass estimates was relatively modest compared to the influence of h and the resulting estimates of M (Figure 3.42). Nevertheless, the relative weighting of length and age data remained a key influence upon biomass outcomes, and played an important role in improving the model's ability to fit the conditional age-at-length data.

4.2.3 Migratory patterns of east coast Spanish mackerel

The existence of partial migration of Spanish mackerel in east coast waters is well documented (Tobin et al. 2014; Buckworth et al. 2007; Tobin and Mapleston 2004; McPherson 1981). While the general migration patterns are understood, knowledge of the precise timing and spatial extent remains limited. The specific latitude-by-month timing has not been described in the literature, despite fishers effectively tracking these movements. The lack of broad scale tagging data likely contributes to this gap.

In this assessment, we carried out auxiliary analyses (see Section 2.7) to better understand east coast Spanish mackerel migratory patterns and refine the model's spatial and seasonal structure. Figure 3.8 provides a clear visualization of migration patterns by mapping the expected mean ages of fish by latitude and season, averaged across years. Figure 3.10 shows similar patterns, albeit less clear, in the expected mean lengths of fish by latitude and season, averaged across years. These figures confirm the expected migratory behaviour but also explicitly indicate the timing of changes in age and length patterns at specific latitudes. These insights helped us to define spatio-temporal quadrants with distinct selectivity, permitting the adoption of a 'fleets and areas' (FAA) model structure.

The project team agreed that the FAA approach improved upon a spatially and seasonally aggregated model as used in Tanimoto et al. (2021a). and was therefore implemented across all ensemble scenarios. It was therefore implemented across all ensemble scenarios. The resulting fleet-specific length compositions, selectivity patterns, and trends in mean age underscored the importance of capturing these migration dynamics. Accounting for these migratory patterns improved the model fit to length composition data, by accounting for spatio-temporal variation in length selectivity.

4.3 Response to review recommendations

Two external reviews of the 2021 stock assessment (Tanimoto et al. 2021a) were conducted, first by Klaer (2021) and then by Hoyle and Dunn (2023).

Initial response to the review by Klaer (2021) was given by the previous assessment authors at the time of publication, in Tanimoto et al. (2021b). However a key topic noted in Klaer (2021) was the previous assessment's rationale for the choice of a lower central steepness value (h = 0.45), which was re-appraised in this assessment (see Section 2.8.4). Tanimoto et al. (2021b) cited the 2021 model's poorer fit with higher steepness values as reinforcing evidence for the lower central value. Here, we acknowledge and uphold the perspective of Hoyle and Dunn (2023), that the relatively poorer model performance with higher steepness values in the previous assessment is not by itself sufficient evidence for a lower central value of steepness. Hence, as we have noted in Section 2.8.4, this assessment instead favours the family level estimates from Thorson (2020), with a central value of h = 0.69 used for steepness. Moreover, following the significant changes made to the population model structure in this assessment, it was shown that steepness is less influential here than in the 2021 model, with natural mortality (M) contributing equally, if not more, to overall uncertainty. A more detailed discussion about natural mortality and its interaction with steepness is provided above in Section 4.2.

The review by Hoyle and Dunn (2023) contained a range of critiques of the 2021 model and suggestions for the following assessment, which were distilled into 8 key recommendations at the end of the report. In this assessment, significant modelling exploration and model refinement has occurred in alignment with the recommendations from Hoyle and Dunn (2023). Our actions in response to these recommendations are detailed below.

4.3.1 Recommendation 1

"We note that the model shows signs of misspecification and recommend that these issues should be resolved before the model is used in the development of management advice"

The risk of model misspecification were mitigated in the assessment by employing the following strategies:

- **Scientific and industry representation on project team.** Changes were made to the inclusivity of project team membership. The project team guiding this stock assessment included an independent scientist (Dr. Simon Hoyle), a GBRMPA representative and two fishing industry representatives, from the commercial and recreational sectors respectively. This ensured an extensive knowledge base and diverse range of perspectives on the key influences upon the Australian east coast Spanish mackerel stock.
  Wherever possible, thorough appraisal of influences upon the stock, alternate modelling approaches and parameter settings were carried out by the project team. These discussions resulted in either improvements to the population model to account for these influences or, where applicable, the construction of suitable sensitivity tests (for scenarios explored outside the ensemble, see Section 2.8.6).

- **Ensemble approach.** The previous stock assessment relied on the project team to choose one preferred scenario as the 'base case'. This decision is typically made by presenting ranges of plausible settings for key model parameters, and asking project team members to choose the most plausible suite of settings to comprise a 'base case' scenario. One inherent risk in choosing a base case is that model outcomes rely heavily upon user-defined parameter settings, rather than considering all possible combinations of plausible parameter settings in concert. This means that the 'base case' process introduces a higher risk of model misspecification.
  In this assessment, we used the ensemble approach to reporting model outcomes. The project team members were asked to agree upon a plausible range of scenarios, rather than one preferred base case. Project team members were presented with a list of scenarios with crossed plausible scenarios of all key parameter values (e.g. h and M) and key modelling decisions (e.g. relative weighting on age/length data). The result of this process was an agreed list of plausible scenarios, with no one scenario given any more relative weighting than the others. This approach is inherently

more robust to model misspecification, as it considers a range of options for key parameters and modelling decisions.

- **MCMC modelling:** The 2021 assessment reported results from a maximum likelihood estimation (MLE) modelling approach. The Markov chain Monte Carlo approach is a more robust way to estimate parameters (conditional on MCMC convergence) because it is able to explore parameter space globally and thereby overcome issues with local minima. It is also practically important in forming the ensemble as once an MCMC chain of estimates has been generated for any given scenario, the ensemble can be formed simply by considering all chain estimates across all scenarios.

4.3.2 Recommendation 2

"We recommend that analysts resolve indications of model instability and poor fit to the data: residual trends in the age structure, historical CPUE data, and length composition data which suggest data conflict; a growth curve that estimates unrealistically low length at age; an unusual pattern of multiple optima in likelihood profiles; and instability in model fitting."

We addressed recommendation 2 by actioning the following:

- **Prioritising fitting to the age data.** A modelling ethos that permeated through many aspects of this assessment was the priority of fitting well to the trends in the age data. Hoyle and Dunn (2023) highlighted the likelihood of conflict between datasets (i.e. between the CPUE, age structure, and length composition data). It is not uncommon for different datasets to have different influences upon the stock (i.e. implying recovery or depletion), and hence 'disagree with one another', so to speak. This can occur when a model assumption is broken, such as when CPUE is hyperstable and fails to track abundance, fishing selectivity changes through time, or fish behaviour is more complex than represented by the model. In this position, modelers must make important decisions regarding which datasets are more reliable, and give more relative weight (i.e. more influence) to these datasets to ensure the model follows the most reliable account of the population dynamics.
  In the 2021 assessment by Tanimoto et al. (2021a), tight standard errors were given to the CPUE index, hence giving a high relative weighting to CPUE. For length and age data, the 2021 assessment applied suggested Francis tuning values (Francis 2011) for multiple iterations, which resulted in length data being up-weighted by comparison to the age data. Overall, the 2021 model prioritised influence from CPUE and length composition data and as a result, Hoyle and Dunn (2023) noted that the overall fit to the age structure data was poor, with residual trends present. While the standardised catch rates method in the 2021 assessment employed numerous strategies in attempts to account for the inherent hyperstability in CPUE indices, the review noted that hyperstability had not been appropriately dealt with, and perhaps with the available data this is not achievable.
  In the current assessment, we determined that our most reliable available data source for inferring population dynamics were the age-at-length data. A long time series of age data are available (2005–2024), with good annual sample sizes and a structured sampling program to ensure (as far possible) the consistency of spatial and seasonal sampling patterns from year to year. Temporal trends in the mean age of fish were present by fleet (Figure 3.11; Figure 3.12; Figure 3.13), with the increasing trend shown by fleet 1 suggestive of rebuild (Figure 3.11). We concluded that fitting closely to a CPUE index that exhibits hyperstability due to the species' predictable aggregating behaviour was prone to risk, especially given the presence of complexities in the effort data that

are hard to resolve. Accordingly, a conservatively large standard error value of 0.3 was applied to the CPUE index (Figure 3.7), in order to allow the model to track temporal signals in mean age. Further, length composition data are prone to extraneous influences such as selectivity effects, so for the purpose of examining temporal trends to infer dynamics of the population, age-at-length data are more robust. Hence, more relative weight was given to the age-at-length composition data by applying varying degrees of down-weighting (through ESS values) to the length composition data (Table 2.4). A detailed description of data weighting methods is given in Section 2.6.4).

  Additionally, adopting a 'fleets-as-areas' model structure allowed the model to achieve better fits to length composition data and spatially and seasonally dependent selectivity patterns, despite the relative down-weighting. This ensured that, even with lower ESS values, adequate quality of fit was achieved to length composition data.

  By implementing the methods above, improved fits to age compositions (Figures 3.14 to Figure 3.19) and mean age over time (Figure 3.25) were obtained in this assessment without unreasonably compromising fits to length composition data (Figures 3.20, 3.20, 3.20) or selectivity estimation (Figure 3.38).

- **Removing the historical decadal CPUE data from Thurstan et al. (2016).** Additional scenarios were run to test the model's sensitivity to the inclusion of the historical decadal CPUE series (see Section 2.8.6 for further detail). Ultimately, these data were not included in the scenarios comprising the final ensemble due to a lack of influence on model outcomes. Therefore, any issues experienced in the 2021 assessment regarding lack of fit to these data were not encountered here.

- **Improving growth curve.** The growth curve estimated in this assessment shows higher length at age than the growth curve estimated by the 2021 stock assessment. A marked increase was observed in the asymptotic fork length at maximum age (i.e. L_{Amin} parameter) for females (Females = 138.01 cm, Males = 114.20 cm) as compared with the 2021 assessment (Females = 130.19 cm, Males = 114.18 cm). We also note a greater degree of separation of the sex-wise growth curves, as the model has better captured sex-dependent growth. Excluding length and age samples of unknown sex from the conditional age-at-length compositions, and only including male or female specified samples greatly improved growth curve estimation, especially with regard to capturing sex-dependent growth. The introduction of a double-normal, or 'dome-shaped' selectivity pattern also increased estimates of L_{Amin}. While also noting the impact of ubiquitous changes to the population model, we attribute the growth curve improvements to these changes.

- **MCMC and ensemble approach.** As discussed above in response to recommendation 1, the use of an MCMC generated ensemble approach was important in addressing issues with local optima and model instability.

4.3.3 Recommendation 3

"Reducing uncertainty about the degree of mixing among areas is a high priority. Available information about Spanish mackerel behaviour should be used to develop hypotheses about population structure, and to design a research programme. Analysts should allow for the implications of incomplete mixing in their data preparation and selection of stock assessment methods."

We addressed recommendation 3 by employing the following approaches:

- **Evaluating FRDC project satellite tagging data.** As part of the recent FRDC Spanish mackerel project (Mitchell (in prep), unpublished data), satellite tagging work was carried out in Queensland east coast waters. 32 fish were tagged in waters off Mackay, Lucinda and the Sunshine Coast, with movement information available from 27 of these individuals. Findings from the tagging work suggested that the degree of movement exhibited by Australian east coast Spanish mackerel is highly variable, with some fish exhibiting site fidelity, while others moved great distances. Of the 27 individuals, only two fish moved 10 km or less. The maximum distance travelled by a tagged fish was 625 km (over 60 days at liberty), with other fish also travelling distances in excess of 100 km (Mitchell in prep). Across all tagged fish, the mean distance travelled was 66.4 km, the mean time at liberty was 11.05 days, and the mean distance per day was 13.99 km.

These data have provided a valuable preliminary indication of Spanish mackerel movements, which was unavailable for the 2021 stock assessment. While the results of the tagging work showed highly variable amounts of movement, they highlighted the capacity of Spanish mackerel to move significant distances. Given the relatively small sample size of tagged fish (n = 32), information on Spanish mackerel movement remains limited. However, to observe multiple individuals travelling distances in excess of 100 km out of such a small sample implies that movements of this scale are not uncommon among the population, along with fish exhibiting some degree of site fidelity.

This information, while preliminary and sample-limited, is consistent with the assumption that partial migration occurs in the Australian east coast Spanish mackerel stock. A mixture of movements and site fidelity complicates the modeling and increases uncertainty, as it implies that mixing is less than complete. Nevertheless, understanding this has helped us understand stock structure and assist in developing an appropriately structured population model.

- **Demonstrating spatial extent of Spanish mackerel migratory patterns.** Auxiliary modelling work was conducted, with the main purpose of identifying spatial and seasonal patterns in age and length of Australian east coast Spanish mackerel. For more detail on these findings specifically relating to spatio-temporal patterns, see the response to recommendation 5 below (Section 4.3.5). However, the results shown in Figure 3.8 reflect the movement of older (spawning age) fish, and in turn give an indication of the spatial extent of the migratory patterns shown by Spanish mackerel. The spatial extent of this migratory pattern supports the occurrence long range movements, corroborating the assumption inferred from the FRDC satellite tagging data.

4.3.4 Recommendation 4

CPUE: review and update approach to the development of the CPUE index, including but not limited to the following:

a *Explore and characterize the catch and effort data, including factors associated with targeting, to identify patterns likely to affect CPUE.*

b *Change approach to weighting by latband, to weight by the product of relative habitat area (or an appropriate proxy) and density rather than by catch or the number of records.*

c *Review the fishing power estimates and their relevance for the fishing methods included in the CPUE index before using them in the base case assessment model. Consider whether search-related factors should be included in the catch rate or the probability model.*

d *Produce indices without data from the Latitude 19 area where spawning schools concentrate and hyperstability is most likely to affect CPUE.*

e *Allow for the effects of targeting on catch rates. Run models that standardize the CPUE of vessels that exclusively target Spanish mackerel.*

f *Drop runs that include the probability model until issues with it have been addressed.*

g *Produce a separate document with a comprehensive overview of the CPUE methods, results and diagnostics.*

Through iterative data exploration and analysis, as well as extensive project team discussion, it was ultimately decided that optimal way to handle CPUE was to down-weight its importance in the population model fitting process. This was motivated by concerns about the potential of hyperstability and fishery management changes to mask signal, as well as data quality and data resolution concerns. This exploration and discussion focussed on the biological monitoring data that indicated overall higher reliability and signal, in particular in the age-at-length data. Thus age-at-length fits in the final models were significantly prioritised over CPUE fits. Notwithstanding this, the CPUE index was improved by addressing sub-points a–f of recommendation 4.

a Thorough exploration and characterisation of catch and effort data has been carried out. The influence of targeting behaviour upon catch rates was appraised in this assessment by incorporating targeting covariates in the model, based on the presence or absence of bycatch species as indicators of targeting intent (see also Section 2.4). The final covariate used in the model was denoted as rfb or 'reef fish binary'. While a broad range of species and their relevance were explored, rfb was a simple binary variable indicating whether coral trout, red-throat emperor or other coral reef finfish species (contained in the reef OS quota group) were present in a given catch, alongside Spanish mackerel. This approach served as a quantitative method of distinguishing catches from Spanish mackerel specialists (unlikely to contain reef fish), as opposed to non-specialists such as coral trout fishers, whose catches are likely to comprise few Spanish mackerel but high quantities of reef fish. Project team discussion highlighted that the majority of this influence could be explained purely by the presence or absence of coral trout alone, as a proxy by which to isolate non-targeted catches from coral trout boats. However, it is acknowledged that some reef fish specialists do not target coral trout (in favour of reef OS quota species) and may take Spanish mackerel as bycatch. Hence, red-throat emperor and the reef OS quota group of species (including saddletail snapper, red emperor, crimson snapper, spangled emperor) were included in the calculation of rfb. Early catch rates models were explored which filtered data to include only records from fishers who exclusively caught Spanish mackerel. This approach was not adopted for the final catch rates model. The justification for this was two-fold. Firstly, in filtering strictly for fishers who exclusively catch Spanish mackerel, the available sample size of data is greatly reduced, and is biased heavily towards the Lucinda aggregation grounds with otherwise poor spatial representation. A trade-off is present, whereby recommendation 4e to focus exclusively on specialists narrows the spatial focus to the aggregation, but recommendation 4d suggests removing data from the spawning aggregation due to its propensity for hyperstability. Secondly, the predicted catch rates of the specialist exclusive model showed no significant change in trend. As a result, the project team favoured the approach of using the targeting covariate rfb in the model.

b This assessment applied a spatial weighting method to standardised catch rate predictions. In the absence of empirical data on the relative amounts of Spanish mackerel habitat throughout Queensland east coast waters, the chosen proxy used was 'fishable area' (see Section 2.4 for how 'fishable area' is defined). An additional consideration in the use of fishable area for prediction weighting was any temporal change in the relative fishable area. The amount of fishable area available to fishers changed from 2004 onwards, due to the revision of reef zonings and expansion of the Representative Areas Program (RAP) by GBRMPA. This change, and its potential impact upon catch rates was accounted for by the truncation of the CPUE time series to 2006–2023.

c Tanimoto et al. (2021a) incorporated fishing power estimates obtained from Buckley et al. (2017) and Thurstan et al. (2016), applied as an offset in the standardised catch rates model. Hoyle and Dunn (2023) highlighted concerns raised by industry relating to the relevance of using these fishing power estimates (based on interviews of commercial and recreational fishers) for the commercial CPUE index. Further, Hoyle and Dunn (2023) recounted comments from industry that commercial Spanish mackerel fishers typically target Spanish mackerel in well-known, predictable locations at predictable times, which is not surprising given their predictable aggregation behaviour described by Buckley et al. (2017) and Tobin et al. (2013). These comments imply that advancements in available fishing technology and gear have not notably enhanced commercial fishers' ability to search and locate Spanish mackerel schools, and hence may not have translated to an increase in fishing power for the commercial sector. In this assessment, the relevance of incorporating fishing power offsets to commercial CPUE indices was raised with the project team. The project team agreed that, in the context of the commercial sector, fishers have continued to target Spanish mackerel in the same locations and times as they have prior to profound advancements in fishing gear and technology. However, it was noted that these technological advancements may have had a significant impact upon recreational catch rates, though CPUE data from the recreational sector are unavailable for analysis. Following these discussions, the fishing power offset applied in Tanimoto et al. (2021a) based on estimates from Buckley et al. (2017) was not included in the commercial standardised catch rates model in this assessment.

d During the exploratory phases of catch rate modelling, models excluding data from the Lucinda aggregation grounds were explored. This was trialled via multiple filtering methods, such as filtering out catch records from latitude band 19, or filtering out the key grids that comprise the aggregation only. Trends in the resulting CPUE series exhibited negligible change. Our interpretation of this result is that hyperstability is exhibited across most of the spatial extent of the fishery, rather than an effect localised to the spawning aggregation grounds. This is perhaps unsurprising, as migrating fish en route to, or departing the spawning grounds will arrive in predictable locations at predictable times of year, and spatio-temporal patterns of catch track this (Tobin and Mapleston 2004). A visual indication of this is shown in Figure 3.8. A significant loss of sample size was also observed in excluding data from the aggregation, as the majority of catch is taken from the Lucinda aggregation grounds (Figures 3.5; 3.6). Further, the authors noted concerns that excluding data from the spawning aggregation grounds would also incur a significant loss of specialist Spanish mackerel fishers from the dataset - which would contradict the notion on page 6 of Hoyle and Dunn (2023) that specialists are more likely to catch Spanish mackerel at a rate that reflects abundance. On balance of the above information, data from the Lucinda aggregation grounds were not excluded from the catch rates model in this assessment.

e While extensive attempts to improve the probability model were made during early catch rates modelling work, the project team deemed the method unable to effectively account for hyperstability and nor to handle exogenous influences in 2004, regarding the major reforms to the fishery and the GBRMP rezoning. Accordingly, the team decided not to use the probability model for the construction of the CPUE index in this assessment. The presence of hyperstability in CPUE data was primarily addressed by placing priority on signal in the age-at-length data, and giving a lesser relative weight to the CPUE index.

f Not done due to relative unimportance of CPUE, as noted above. A full description of methods, results and diagnostics can be found in this report, and the companion document.

Several other considerations were relevant to the construction of the final catch rate model and resulting index of abundance:

- **Shorter time series:** A shorter time series for the catch rate analysis was used in this assessment. The review by Hoyle and Dunn (2023) raised concerns with the catch rates used in the previous assessment (Tanimoto et al. 2021a), such as the inability of the catch rate model to appropriately standardize the management changes that occurred in 2004, citing the GBRMP rezoning as one such change. The catch rate time series from Tanimoto et al. (2021a) exhibited a step down following 2004, which the reviewers deemed more likely to be a product of management changes and fisher behaviour than a signal of abundance. A thorough list of approaches were trialled in attempts to standardise for extraneous influences in 2004 and include the full time series of catch rates. Ultimately, the project team deemed that the structural changes to the fishery in 2004 would render catch rates incomparable prior to, and post 2004. As a result, the standardised catch rates model was run over data from 2006–2023, to achieve the most temporally consistent index of abundance.

- **Great Barrier Reef Marine Park (GBRMP) rezoning:** In 2004, the GBRMPA revised the reef zonings and expanded the Representative Areas Program (RAP), introducing no-take areas or 'green zones'. In this assessment we trialled use of a 'fishable area offset' in early catch rates model development, which captured the relative amount of area that was 'fishable' prior to, and post 2004. In the absence of measures of true habitat area, 'fishable area' is the closest available proxy, though it does not capture the amount of closed area that was suitable Spanish mackerel habitat or operationally viable fishing ground. Accurate measures of habitat area would be required to viably implement this. Further, anecdotal information suggests the GBRMP rezoning had significant influence upon fisher behaviour in the following years. It is unclear how many fishers lost favoured fishing ground to the rezoning, and how many years it took the fleet to adapt post 2004. The spatial shift in the fishery and its impact upon catch rates is complex, and in the absence of accurate habitat information, the project team concluded that comparison of catch rates before and after the rezoning may lead to spurious results.

- **Reliability of logbooks 1997–2004:** The project team noted that it was plausible that the 1997 investment warning ahead of individual transferable quota (ITQ) allocation in 2004 could lead to over-reporting during the 1997–2004 period. This has been supported to some extent through anecdotal evidence. If over-reporting occurred, it would contaminate measures of both catch and effort during this period and may artificially inflate catch rates prior to 2004. This could have contributed to the marked step down seen in the catch rates time series from Tanimoto et al. (2021a). This issue was taken to the project team, which led to a clearer indication that over-reporting in this period may have occurred. This was then reinforced by commercial fishers' responses to Question 1 in the telephone survey (see 2.1.6).

- **Major change to fishing fleet:** The number of fishers actively fishing for Spanish mackerel greatly reduced following the introduction of quota and GBRMP rezoning in 2004. Project team discussions cited that likely causes for fishers exiting the fishery were quota allocation and whether they obtained an 'SM' symbol, permitting them to continue taking Spanish mackerel. It is plausible then that the subset of fishers who remained post 2004 are likely to be specialists, with a disproportionate amount of the dropout attributed to non-specialist Spanish mackerel fishers. A fundamental temporal change in the demographic of fishers such as this furthers the incomparability of catch rates prior to, and post 2004.

4.3.5 Recommendation 5

"Auxiliary analyses: Explore the long-term monitoring length and age data set to identify spatial, season and sectoral effects on age and length composition of the catch. Check for evidence of spatial patterns in length-at-age, and spatial and temporal patterns in age-at-length."

We addressed recommendation 5 by conducting the following auxiliary analysis:

- **Modelling of spatio-temporal patterns in age and length.** Auxiliary modelling work detailed in Section 2.7 explored spatial and seasonal patterns in age and length data throughout Queensland east coast waters (equivalent age and length data from the New South Wales portion of the stock was unavailable). Spatial and seasonal patterns were observed in both the age and length data (see Figures 3.8, 3.9, 3.10), with these findings directly informing our selection of stock assessment methods, namely our choice to adopt a 'fleets-as-areas' model structure.

4.3.6 Recommendation 6

"Catch and related issues:

- *a. Review approaches used to develop time series of recreational catch; and explore sensitivity of assessment outcomes to alternative time series.*
- *b. When preliminary estimates of depredation rates become available, we recommend testing their effects in the assessment."*

We addressed recommendation 6 by employing the following approaches:

- **Revisions to recreational catch reconstruction methods.** In the body of the review by Hoyle and Dunn (2023), the reviewers elaborated on recommendation 6a by specifically mentioning the handling (and adjustment) of RFish survey estimates (1997, 1999, 2002 and 2005) in reconstructing the time series of recreational catch. This was largely due to uncertainty around the appropriate degree of adjustment for the RFish estimates (based on suspected recall bias), which was significant in the 2021 assessment (a factor of 0.34). The review also suggested that this assessment explored alternative assumptions about recreational catches.
  In this assessment, we excluded the 1997 RFish estimate as the data did not specify mackerel species, only containing estimates of 'unspecified mackerel'. Without the 1997 estimate, the calculated rescaling factor was 0.45. We also tested the sensitivity of the model to removing the RFish estimates altogether, anchoring the hindcast period to the 2001 NRIFS survey estimate and using linear interpolation in the period 2002–2010. Resulting annual catches for this method were comparable to retaining the rescaled RFish estimates as per methods outlined in Section 2.2.1.3. Therefore, it was decided to retain the available rescaled RFish estimates, to reduce the length of interpolated periods uninformed by empirical data. For full details, see Section 2.2.1.3.
  Further to this, an improvement was made to the method for interpolating catches between 2014 and 2020 SRFS estimates, and for extrapolating from 2020 to 2024. This method utilizes information on temporal trends in recreational effort targeting Spanish mackerel, available from boat ramp survey (BRS) data in the years 2016–2024. A full description of the method is given in Section 2.2.1.3.

- **Including FRDC shark depredation data in main ensemble scenarios.** Since the last stock assessment, estimates of shark depredation rates in Queensland east coast waters have become available, courtesy of the FRDC Spanish mackerel project (Mitchell in prep). These findings

showed that shark depredation rates differed greatly between sectors, with the commercial and recreational sectors experiencing depredation rates of 6.02% and 36.58% respectively. A method was developed in this stock assessment to account for the increased mortality on Spanish mackerel attributed to shark depredation, with a detailed description of this method given in Section 2.2.2.
The effects of incorporating shark depredation data were tested, and the project team elected to include the resulting adjustment for shark depredation in all final ensemble scenarios.

4.3.7 Recommendation 7

"Input parameters:

- *a. For steepness, we recommend applying a range of values from 0.45 to 0.95, with a median value close to the 0.69 FishLife estimate for Scombridae.*
- *b. For recruitment variability, the commonly assumed value of 0.6 should be used when fitting the model to estimate recruitments, instead of 0.35.*
- *c. For natural mortality we recommend (i) updating the prior mean to M=5.4/Amax, based on Hamel and Cope (2022), who identified a modelling error in the approach of Then et al (2015); (ii) replacing constant M at age with the biologically well-justified Lorenzen approach of setting M inversely proportional to body length (Lorenzen, 2022); and (iii) fixing M in the model at a range of values across the prior, rather than estimating it in the model.*
- *d. We recommend applying the Schnute-Richards (1990) growth curve rather than the von Bertalanffy."*

To summarise our response to recommendation 7, we implemented the changes suggested above directly, with the exception of the Schnute-Richards growth model where the desired improvements to the growth curve were achieved by use of alternate methods. More detail on our response to recommendation 7 is given below:

- **Updated range of steepness (h) values.** The final ensemble scenarios explored steepness values of 0.54, 0.69 and 0.808 with a central value of 0.69, informed by 0.69 FishLife median estimate for Scombridae (Thorson 2020). During preliminary model runs prior to forming the ensemble, model runs were completed with steepness values applied from 0.3 to 0.99, to thoroughly explore the sensitivity of the model to h. A full explanation of the exploration into steepness and the justification for the chosen values in the final ensemble is given in Section 2.8.4.
  As per recommendation 7a in Hoyle and Dunn (2023), this assessment explored applying a range of values broader than the recommended 0.45 to 0.95, and the ensemble contained a range of steepness values with a median value set to 0.69.

- **Updated recruitment variability value.** The suggested value of 0.6 was adopted directly, with a fixed δ_R value applied in all scenarios comprising the ensemble.

- **Updated approach to M, based on Hamel and Cope (2022).** Recommendation 7c from Hoyle and Dunn (2023) suggested that natural mortality be fixed, rather than estimated in the model. As per methods described in Section 2.8.4, initial model runs explored fixed natural mortality (M) values of 0.175, 0.216 and 0.266, informed by the prior given in Hamel and Cope (2022). Once model estimation was stable using these fixed values, estimation of M was attempted using the prior from Hamel and Cope (2022) (median of $5.4/Amax$ where $Amax$ = 25, and a standard deviation of 0.31 (log-scale)). A combined approach of estimating M using the prior from Hamel and Cope (2022), along with MCMC estimation was found to be a preferable method for exploring uncertainty in M. The resulting estimates of M explored a similar range of the Hamel and Cope (2022) prior when compared with three initial fixed values (M = 0.19–0.27, see estimates by scenario in Appendix E). The Lorenzen curve approach was not implemented but should be considered in future.

- **Growth curve improvements.** As described in the response to recommendation 2 above (Section 4.3.2), marked improvements to the growth curve were achieved in this assessment. Some model runs were explored using a Schnute-Richards growth curve as per recommendation 7d, however after implementing changes described in response to recommendation 2, the von Bertalanffy growth model achieved improved fits and performance was comparable between growth models. Given the Schnute-Richards growth model requires estimation of an additional parameter (b) and performance was comparable, we opted to retain the less computationally intensive von Bertalanffy growth model.

4.3.8 Recommendation 8

"Model structure: Update the approach to modelling selectivity to better fit the composition data: separate the commercial and recreational fisheries; consider spatial and/or seasonal structure; non-asymptotic selectivity, particularly for the commercial fishery."

All aspects of recommendation were explored and deemed as improvements, before being applied in the final ensemble. The following actions were taken:

- **Separating sectors.** This stock assessment split fishery sectors into separate fleets, before further separating fleets by spatial and season strata to comprise the final 'fleets-as-areas' fleet structure. Estimated selectivity patterns differed markedly between sectors (Figure 3.38). See Section 2.8.2 for a detailed explanation of the final fleet composition.

- **Adopting a 'fleets-as-areas' model structure.** The auxiliary modelling work undertaken to explore spatio-temporal patterns in age and length (Section 2.7) was instrumental in informing the decision to adopt a 'fleets-as-areas' model structure. As described in Section 2.8.2, findings from these models indicated spatial and seasonal variation in the availability of fish of particular size classes. Therefore, patterns of realised selectivity are dependent on latitude and season, and would differ between spatio-temporal strata for the Queensland portion of the stock.
  Given this evidence, estimating one stock-wide selectivity pattern per sector would likely underestimate the structure in the data and result in poorer fits to the length composition data. Upon adopting a 'fleets-as-areas' model structure with the spatial and season splits detailed in Table 2.2, the model estimated notably different selectivity patterns by fleet (Figure 3.38) and fits to the length composition data improved.

- **Non-asymptotic selectivity patterns.** As per the rationale described in Section 3.1.7, selectivity patterns are inherently different between sectors, as well as across spatial and temporal strata. For instance, the commercial sector in quadrant 1 (fleet 1, Table 2.2 is likely to exhibit non-asymptotic or 'dome-shaped' selectivity, with a truncated range of sizes being selected. This is because this fleet primarily targets schooling fish participating in the spawning aggregation with the objective of maximising catch, and these fish tend to be of similar sizes to one another (Kasumyan and Pavlov 2023). This biases the pattern in realised selectivity to favour these common size classes and select for relatively less large individuals, giving a more truncated, non-asymptotic selectivity pattern. By contrast, the recreational sector in quadrant 3 (fleet 8, Table 2.2) is more likely to

exhibit an asymptotic selectivity pattern. This is because quadrant 3 comprises the 'off-season' with regards to spawning, and targeting practices of recreational fishers vary broadly, with some fishers targeting large trophy-sized fish, while others target any fish above MLS. In addition to this, data from quadrant 3 also contains the largest individuals in the observed length composition data. To accommodate the finding that selectivity is likely to vary across fishery sectors, spatial and seasonal strata, a flexible method of estimating selectivity by fleet was applied. As detailed further in Section 3.2.3, we applied a double-normal curve with six estimable parameters, all of which were estimated except initial selectivity (selectivity at smallest length bin, fixed at 0.0). The exception to this was fleet 8, which was estimated as an asymptotic curves for the reasons detailed above. This flexibility allowed the model to estimate a non-asymptotic, or asymptotic selectivity pattern, as the fleet-wise length composition data warranted. As can be seen in Figure 3.38, the model used this flexibility and estimated a wide range of selectivity patterns by fleet.
Upon evaluation of the improvements made in the approach to selectivity, the above changes were implemented in all models comprising the final ensemble.

4.4 Performance of the population model

Parameter estimation occurred using two methodologies across six scenarios: maximum likelihood estimation (MLE) and Markov chain Monte Carlo (MCMC) estimation. For MCMC estimation, each scenario was run with 2,000,000 iterations, taking 72–96 hours of computation time, using the standard Stock Synthesis algorithm. Final gradient diagnostics for all six MLE scenarios were satisfactory (final gradients 0.0001 or lower), with the exception of scenario 6 (high h, 25% length ESS) which exhibited a final gradient of 2.34, indicating lack of convergence. Since final ensemble results were derived from MCMC outputs, scenario 6 was retained and model performance was re-evaluated in the context of MCMC diagnostics. The trace plots by scenario in Appendix E indicate some level of non-convergence due to the R_0 parameter, however overall convergence appears reasonable. The trace plots also show that, in the case of each scenario, any pattern in the R_0 parameter reflects the pattern shown by M, reiterating the influence of M upon biomass and overall uncertainty. In general, a degree of non-convergence for both MLE and MCMC is not surprising given the lack of contrast present in the data and the down-weighting of standardized catch rates.

MCMC posterior density plots for scenario 6 (Figures E.165 to E.169) show some bimodality in estimates of M and R_0 and as such, notable trends persist in the scenario 6 trace plots for these parameters (Figures E.170 to E.174). Despite this, the posterior density distribution of 2025 biomass (labelled 'Bratio_2025') given by scenario 6 remains unimodal (Figure E.169). Based on the scenario 6 MCMC outputs, we trialled excluding scenario 6 from the ensemble, but found a negligible impact on the central tendency of the 2025 biomass distribution. In the interest of preserving the intended sensitivity tests of h and length composition ESS in full, scenario 6 was retained in the final ensemble.

The MCMC outputs exhibited a broader range of 2025 biomass estimates than the MLE outputs (Figure 3.42). This outcome was anticipated when allowing the estimation of M and all selectivity parameters within MCMC, as estimating a greater number of influential parameters increases the possibility of MLE estimation converging to local minima. Using MCMC to explore the uncertainty in M and selectivity parameters was necessary, and ensured this uncertainty was propagated into the final biomass estimates.

Fits to age-at-length data, particularly the fit to mean age over time (Figure 3.25) were notably improved in this assessment, due to the lesser relative weights given to the CPUE index and length composition data. In the 2021 stock assessment, these fits were a particular area flagged for improvement by Hoyle and Dunn (2023). The model fits the trend of the mean age observations much better than the 2021 assessment, particularly in quadrant 1 where the most significant increase in mean age is observed.

Despite these improvements, some tendency remains to over-predict ages in the early period, and/or under-predict recent ages. At the same time, scenarios generally show the opposite trend in fit to the length frequency data, tending to underestimate sizes early and overestimate late. Age and size are linked, and the conflicting signals from these two data types causes internal conflict in the model. We have responded by reducing the statistical weight given to the length frequency data, assigning multiple alternative levels of ESS weighting, as described in Section 2.6.4. We found that reducing statistical weight on length frequency data degraded their fit marginally, while improving the fit to age frequency data. Due to the particularly high initial sample sizes of available length composition data, there was some capacity to reduce statistical weights on length composition data before a notable degradation of their fit was observed.

The contrasting trends in age and size may be caused by time-varying size selectivity. A potential mechanism for this may be if the commercial fleet continued to target fish of marketable size while the average size and age in the population increased. However, attempts to model time-varying selectivity were unsuccessful on this occasion. Some recommendations regarding time-varying selectivity have been made for future assessments in Section 4.7.

The fit to the CPUE was deliberately down-weighted by applying broader standard errors (SE = 0.3), allowing the model greater flexibility to fit closely to the age-at-length data, as described above. Accordingly, the model fit to CPUE was less precise than in the 2021 assessment, though not to an unacceptable degree (Figure 3.24). Despite down-weighting of length composition data (Section 2.8.4), fits to the length composition data were sound, though the goodness-of-fit to these data decreased proportionally to the different degrees of down-weighting in the ensemble (Table 2.4). Fits to length composition data were aided by the updated approach to selectivity estimation. Specifically, using a 'fleets-as-areas' model structure better accounted for the spatial and seasonal variation in realised selectivity (see Section 2.8.2), and estimating non-asymptotic selectivity patterns (for most fleets) improved fits, particularly for the commercial sector.

4.5 New research from FRDC project 2021-111

Under FRDC project 2021-111 (Mitchell in prep), novel data were collected for east coast Spanish mackerel to fill key knowledge gaps flagged by recommendations in Tanimoto et al. (2021a) and Hoyle and Dunn (2023). Multiple aspects of this stock assessment benefited from these data sources, which are listed with descriptions of their usage below:

- **Satellite tagging data.** The satellite tagging data collected by FRDC project 2021-111 contained valuable information on two elements of uncertainty from the previous stock assessment. These data provided estimates of post-release mortality rates which were previously unavailable, with Tanimoto et al. (2021a) assuming a rate of 0.5 in the absence of empirical data. The updated estimate of 0.333 was incorporated directly into the population model for all scenarios in the final ensemble. In addition to this, data on the distances travelled by tagged Spanish mackerel helped to inform appropriate modelling assumptions regarding the likely degree of mixing. More detail on this application of these data is given in response to recommendation 3 from Hoyle and Dunn (2023) (Section 4.3.3).

- **Shark depredation.** Access to data on shark depredation rates was a priority listed in the recommendations from the 2021 stock assessment (Tanimoto et al. 2021a), and their inclusion in future assessments was recommended by Hoyle and Dunn (2023). From 2022–2024, the project gathered shark depredation information from 88 fishing trips (33 commercial, 55 recreational or charter) from various locations on Queensland's east coast (for details see Section 2.2.2). Access to these data allowed this stock assessment to account for the additional mortality on Spanish mackerel due to depredation, which has not been possible in prior east coast Spanish mackerel assessments. The project team favoured including the shark depredation adjusted catch estimates for all scenarios included in the final ensemble.

- **Environmental drivers.** Four select environmental influences were flagged as potential environmental drivers of Spanish mackerel recruitment by Leahy et al. (in review), as part of FRDC project 2021-111. Using methods described in Section 2.8.6, the influence of these indices upon recruitment (via use of the R_0 parameter) was explored, with the most influential of the four environmental indices further explored in a population model scenario. While this scenario was not included in the final ensemble due to a negligible impact upon biomass results, the results of this model are reported on in Section 2.8.6 and the results in terms of resultant biomass trajectory can be seen in Figure F.1. Some recommendations of approaches to environmental drivers for future stock assessments have been made (Section 4.7).

- **Findings from close-kin mark recapture (CKMR) pilot.** The primary objective of the CKMR pilot study was to estimate appropriate sample sizes for a full CKMR program in the future (for more detail, see Mitchell (in prep)). However, genetic analysis (using single nucleotide polymorphisms (SNPs)) conducted as part of this pilot has served to reconfirm prior assumptions that east coast Spanish mackerel are a single genetic stock. While unpublished at the time of writing, these data were presented in the second project team meeting by authors of Mitchell (in prep).

- **Effort signatures from vessel tracking data.** Effort signatures analysis (see Mitchell (in prep) for more detail) highlighted an inverse relationship between time spent trolling and catch of coral trout. This supported the hypothesis that the presence/absence of coral trout alongside Spanish mackerel catch could be used to distinguish Spanish mackerel specialists from non-specialists. This hypothesis led to the construction of the reef fish binary term in the catch rate model (Section 2.4).

4.6 Unmodelled influences

Aspects of spatial complexity not covered by the fleets-as-areas approach remain a key source of uncertainty. Some recommendations for the collection of satellite tagging data on a larger scale have been made for future research projects (Section 4.7). Collection of a sufficiently large sample size of these data may enable future assessments to model movement explicitly.

4.7 Recommendations

4.7.1 Stock assessment

- **Revisit approach to environmental drivers.** As described in Section 2.8.6, the inclusion of four different environmental driver candidates did not have a notable impact upon model results. In this assessment, the environmental index candidates were incorporated using Stock Synthesis' built-for-purpose environmental link functionality, via an environmental linkage to R_0 (input of 204 in element 14 of SR_LN(R0) parameter line, see page 204 of Methot et al. (2023)).

We acknowledge that different methodologies for incorporating environmental drivers area available, and this area of work is continually in development throughout the stock assessment community. For example, the utility of including environmental indices more directly as 'survey' indices could be explored, though this would require robust assumptions about the chosen environmental index. The newly available data from Leahy et al. (in review) on potential environmental drivers for this stock is a valuable resource, and we recommend that future assessments explore alternative approaches to incorporating these data as they arise.

- **Continue to monitor updates to best practice for selection of h and M values.** The selection of appropriate values of steepness (h) and methods for estimating natural mortality (M) were guided by recommendations from Hoyle and Dunn (2023) and current best practice from the literature on these topics (Hamel and Cope 2022; Punt 2023). A detailed explanation of the basis for the selected values used in this assessment is given in Section 2.8.4. We note that currently accepted good practices in stock assessment regarding h and M are subject to change with future research, and authors of future assessments should ensure they appraise the most recent literature regarding the selection of appropriate values.
- **Revisit time-varying selectivity.** In this assessment, the project team discussed the plausibility of time-varying selectivity in the east coast Spanish mackerel fishery. While discussions about the most plausible mechanism were somewhat inconclusive, a temporal trend in length data was observed in our auxiliary modelling of length data (see Figure C.4). We attempted to model time-varying selectivity, using methods described in Section 2.8.6, though attempts were largely unsuccessful. While using a 'trend' (element 13 of the parameter line set to -2, see page 209 of Methot et al. (2023)) may be a plausible modelling mechanism to capture time-varying selectivity, other methods are available in Stock Synthesis. We recommend that future assessments revisit the topic of time-varying selectivity, and trial alternate modelling mechanisms where available.
- **Incorporate updated shark depredation data, if available.** If updated estimates of shark depredation rates by sector in Australian east coast waters become available in the future, the next assessment should incorporate these.

4.7.2 Monitoring

- **Continued collection of length and age data.** The age, length and sex information collected by Fisheries Queensland's biological monitoring program has been fundamental to this stock assessment. Age and length data are used to inform fishery-dependent processes like selectivity, as well as fishery-independent processes like growth, mortality and recruitment. In this assessment, these data played a more influential role in informing fishery-independent processes, in lieu of informative CPUE information.

  Natural mortality (M) was shown to be a highly influential parameter upon biomass results in this assessment. As per the methods outlined in Hamel and Cope (2022) for calculating M, which were recommended by Hoyle and Dunn (2023), appropriate values of M can be obtained by using the equation $M = 5.4/Amax$. This means that appropriate values of natural mortality are highly influenced by the maximum observed age of fish in the biological monitoring data.

  At the time of writing, sample sizes of aged fish, as well as spatial and seasonal coverage of age-based sampling are good. As detailed in Section 2.8.4, after exploring a range of fixed M values, we deemed estimation of M to be possible when applying a prior corresponding to the prior distribution given by Hamel and Cope (2022). In future, as data time series (particularly ageing data) accumulate, and as modeling approaches for spatial structure and data weighting improve, assessments will be better able to estimate natural mortality internally (Maunder et al. 2023), reducing uncertainty around M estimation. Hence, continued age sampling is crucial to informing appropriate estimates of M, an influential parameter for this stock.

We recommend the continued collection of age, length and sex data, as the quality of future stock assessments of Spanish mackerel is contingent upon these data.

4.7.3 Research

- **Continued tag-recapture work.** Satellite tagging data from Mitchell (in prep) provided an early indication of the capacity of Spanish mackerel to travel long distances. Despite small sample sizes, these data helped to inform hypotheses about the relative degree of mixing, and decisions about model structure. As highlighted in Section 4.6 above, spatial complexities beyond those handled by fleets-as-areas are present. Future data on the movement of Spanish mackerel by area, sex, age and size would improve understanding of movement and population dynamics. Fully spatial models with movement between areas may not be the objective, but better understanding of movement dynamics would permit development of models that account for these important processes, providing more precision and less bias (Goethel et al. 2024). We recommend that, where feasible, the collection of satellite tagging data be continued to obtain a higher sample size of tagged fish, by which stock assessment scientists could consider attempting a spatial model.

- **Future updates to estimates of shark depredation.** The newly available estimates of shark depredation rates from the FRDC Spanish mackerel project (Mitchell in prep) were a valuable resource in this assessment, for quantifying the degree of additional mortality upon Spanish mackerel by sector, attributed to sharks. These results, paired with project team discussions and phone survey responses (Section 2.1.6) regarding shark depredation, highlighted that rates of depredation are likely changing, potentially rapidly. Therefore, we recommend future research of an equivalent or similar nature to update the estimates of shark depredation for use in future assessments.

4.7.4 Management

This assessment highlights that the stock is unlikely to be at target levels, with a most probable estimate of 34% of unfished spawning biomass, and a high probability (61%) of falling between 20 and 40% of unfished spawning biomass.

The rebuild exhibited since the early 2000s appears to be attributable (at least in part) to a few strong recruitment years, which produced strong cohorts of fish that were visible in the population for some time (as detailed in Section 3.1.6). One particular cohort drove a persistent increase in the mean age of fish, visible in both quadrant 1 and quadrant 3 (Figures 3.11; 3.13). It is possible that reduced rates of fishing mortality (F) since the early 2000s have allowed the influence of these strong recruitment events to propagate through the population, and translate to a rebuild in biomass.

Model improvements made in this assessment allowed for better responsiveness to recruitment trends. This improved the model's ability to capture recruitment-driven changes in the population and highlighted this period of rebuild more clearly. In contrast, this mechanism may have been masked in the previous assessment (Tanimoto et al. 2021a) due to hyperstability in the CPUE index.

The mechanism for rebuild outlined above suggests some fragility of stock status, as it is dependent on the recurrence of strong recruitment events. It appears that annual catches in the recent history of the fishery are more conducive to allowing for recruitment-driven rebuild. Appraisal of this mechanism by fishery managers is important when considering the assignment of total allowable catches.

Specific recommendations around any particular management proposal would require a separate analysis that takes the current assessment, and models the proposal by projecting forward, taking care to capture the estimated uncertainty in that projection.

4.8 Conclusions

This stock assessment was commissioned to establish the status of the Australian east coast Spanish mackerel stock and inform the management of the fishery. Relative to an assumed unfished state in 1911, biomass was estimated to be between 17% and 62% with a median biomass of 34% at the beginning of 2025. This result was generated over an ensemble of six scenarios. Some recommendations for future assessment and monitoring have been made.

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A Project Team decisions and recommendations

Project teams form an important part of the stock assessment process by providing guidance from experts from various disciplines relevant to the stock assessment. This approach ensures scientific validation and increases transparency.

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

A.1 Defining fishable area

The tagging study found Spanish mackerel spend time at depths up to 70 meters. Fishable area was calculated between coastline and 100 m contour (proxy for continental shelf) that falls between 2 m and 50 m of depth. Fishable area post 2004 was calculated as fishable area minus green zones.

Decision: The project team agrees the range of depth used to estimate fishable area. (Meeting 1, 12 July 2024)

A.2 Stock structure

The FRDC project stems from the last stock assessment where there was a range of recommendations for new data to be collected, including assessing mortality from shark depredation and also post release mortality, investigating environmental factors and how they might be affecting the population, and trying to find new ways to enhance the resolution of fishing effort data.

The close-kin mark-recapture (CKMR) and tagging study revealed that the Torres Strait, East Coast and Papua New Guinea stocks are clearly distinguished while there is an indication of small level of long-term mixing between East Coast and Torres Strait. The CKMR indicated fairly complete long-term mixing within East Coast. The project is currently extended to investigate short-term mixing and to estimate absolute spawning biomass, mortality and connectivity.

Decision: The project team confirmed that the model treats Australian east coast Spanish mackerel as a single stock. (Meeting 2, 9 August 2024)

A.3 Model structure

The author team proposed a spatio-temporal model (i.e. nine fleets by Sector/Area/Time) as the base structure of the model. (Meeting 5 and the follow up email circulated on 28 January 2025)

Decision: The project team agreed on the spatio-temporal model approach as the base model structure.

A.4 Length and age

The author team proposed to reduce emphasis on length data to prioritise age-at-length data (Meeting 5 and the follow up email circulated on 28 January 2025)

Decision: The project team accepted to upweight age-at-length data. The final ensemble included a 50% and a 25% weighting of length compared to age-at-length.

A.5 Unsexed length data

See note below 'Adjustment during project team review' in the 'Steepness and natural mortality' section.

A.6 Selectivity

The author team proposed a dome-shape selectivity for commercial and recreational sectors, except for one recreational fleet (Fleet 8, QldRecCharterQ3) which has asymptotic selectivity. (Meeting 5 and the follow up email circulated on 28 January 2025)

Response: The project team agreed on dome-shape selectivity for both commercial and recreational sectors.

A.7 Catch history

Recommendation: Fisheries Queensland to seek views from a larger group of fishers who have historical knowledge and experience in the Spanish mackerel fishery. (Meeting 4, 22 October 2024)

Response: In January 2025, the telephone survey was conducted by Fisheries Queensland to seek insights from experienced fishers. Details of of the questionnaire is provided in Appendix I.

The author team proposed to adjust catch history between 1997 and 2004 using proportional decline in active licence holder, unless the phone survey suggested otherwise (Meeting 4, 22 October 2024, Meeting 5 and the follow up email circulated on 28 January 2025)

Decision: Project team supported this proposal (emailed responses to follow up email circulated on 28 January 2025) and telephone survey provided support for retaining the proportional decline approach.

The author team proposed to make no adjustment to FishBoard data. (Meeting 5 and the follow up email circulated on 28 January 2025)

Response: Project team supported this proposal (emailed responses to follow up email circulated on 28 January 2025).

A.8 Shark depredation

The author team proposed to consider shark depredation rate of 6% (constant) for commercial sector, and linear increase of 12 to 36.58% over the period 2009–2024 for recreational sector, unless the telephone survey suggests otherwise. (Meeting 5 and the follow up email circulated on 28 January 2025)

Response: The project team agreed on the proposed shark depredation effect and recommended to cap the effect at 36.58 (or 40%) for recreational sector for future projection. (email feedback received on 28 January 2025)

Majority of fishers responded to the telephone survey indicated that shark depredation had increased over time. Some answered that the shark depredation got worsen since around 2009, which align with the time period that the model included shark depredation effects.

Decision: ensemble models to include this approach to shark depredation, with the report also including an exploratory model with recreational depredation held fixed at the commercial rate.

A.9 Steepness and natural mortality

The author team proposed three levels of steepness (h = 0.54, 0.69, 0.808) and three levels of natural mortality (M = 0.216, 0.189, 0.247) to be included in the final ensemble approach. (the follow up email circulated on 28 January 2025)

Decision: Project team supported this proposal (emailed responses to follow up email circulated on 28 January 2025).

Adjustment during project team review: During the review phase, concerns were raised around two issues:

- Exclusion of length composition data where the sex of fish was unknown
- The range of values chosen for natural mortality

Following significant additional modelling and investigation, the author team proposed the following amendments:

- All length composition data, whether male, female or sex unknown, to be included as a single ”sex unknown” data set. (Age-at-length remaining sex specific).
- Natural mortality is estimated. (This removes the need for the M axis of the ensemble grid.)

These proposals were discussed with and confirmed by external project team members by phone call 20/3/2025.

A.10 Environmental drivers

As environmental drivers had little impact on the model, the author team proposed not to include them in the final ensemble models. (followup email sent on 28 January 2025)

Response: The project team had no objection against not including environmental drivers in the final ensemble models. (the followup email circulated on 28 January 2025)

A.11 Decadal catch rates

The model exploration revealed that historical decadal catch rates did not noticeably affect trend in biomass, nor final biomass ratio (Section F). The author team suggested not to include historical decadal catch rates in the final ensemble scenarios. (Project followup email sent on 28 January 2025)

Response: The project team had no objection against not considering decadal catch rates in the final ensemble model, however, one member questioned whether it affects future projection and forecasting. (Meeting 5 and the followup email sent on 28 January 2025)

B Diagnostics for standardised indices of abundance

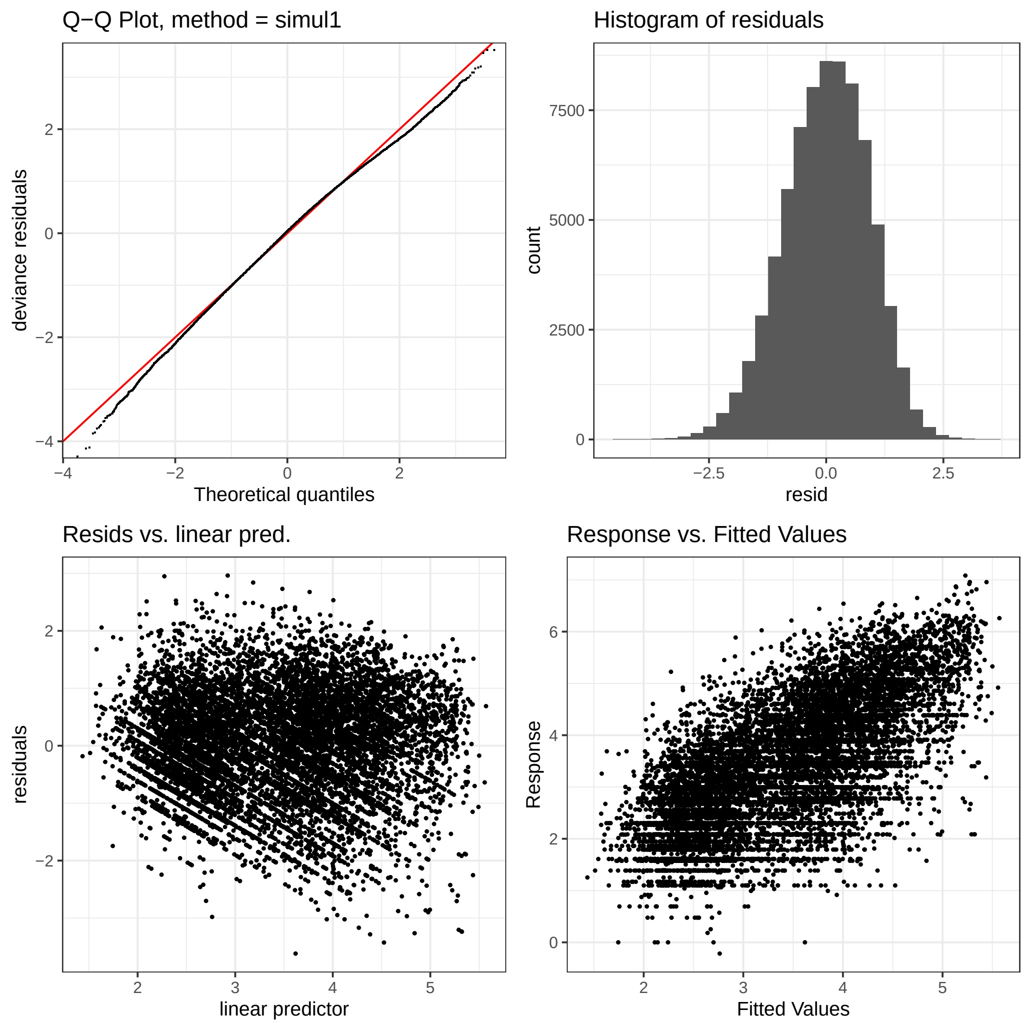

Figure B.1: Analysis of residuals for the catch rate model

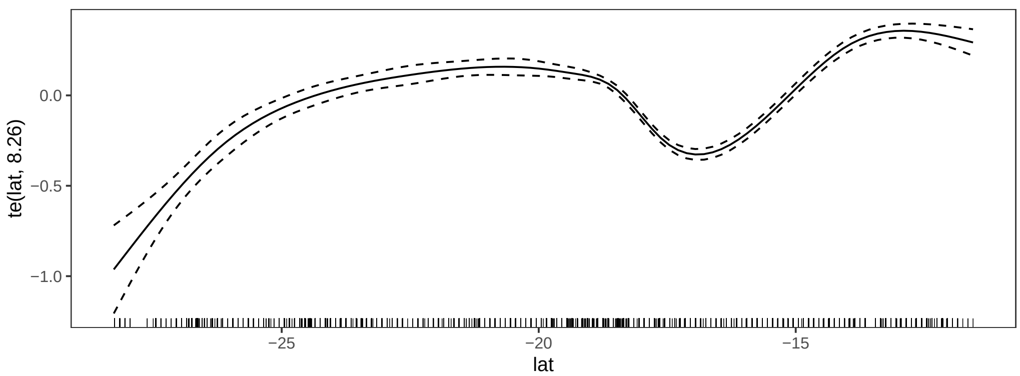

Figure B.2: Catch rate model effect plot - latitude effect

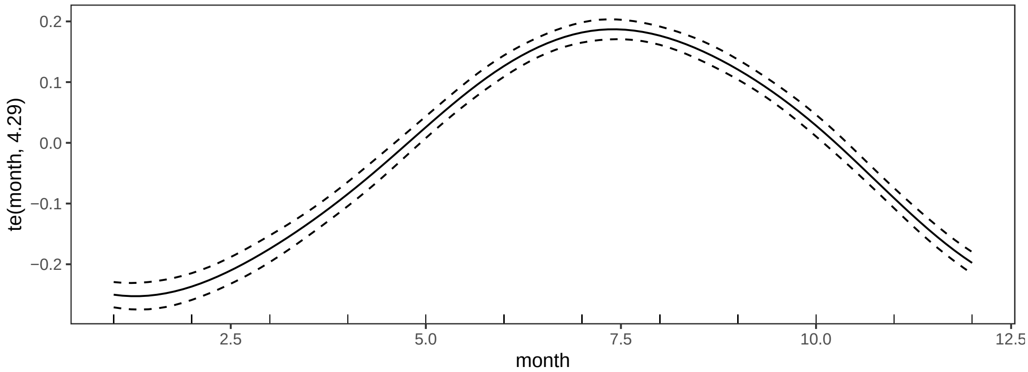

Figure B.3: Catch rate model effect plot - month effect

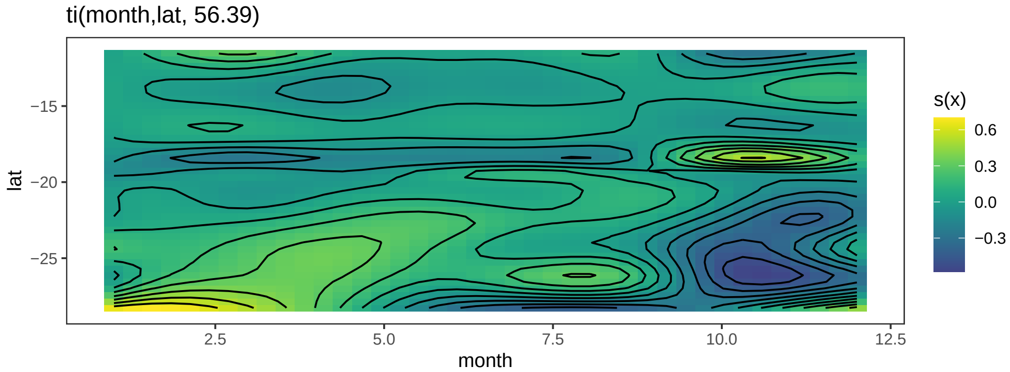

Figure B.4: Catch rate model effect plot - month-latitude interaction effect

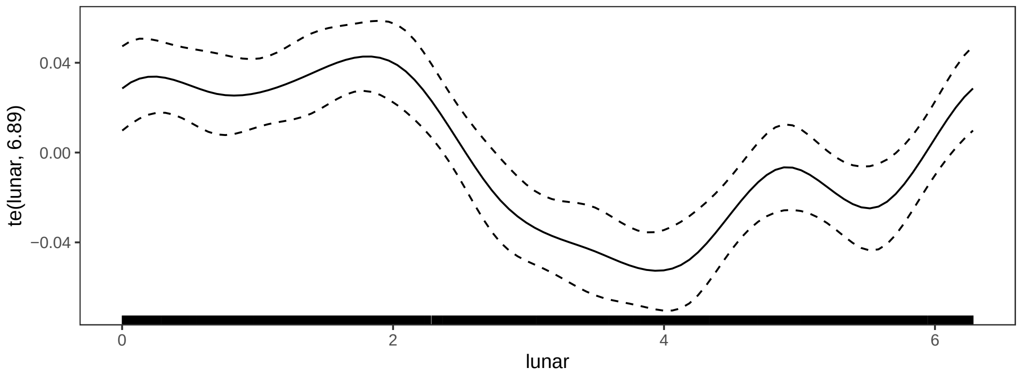

Figure B.5: Catch rate model effect plot - lunar effect

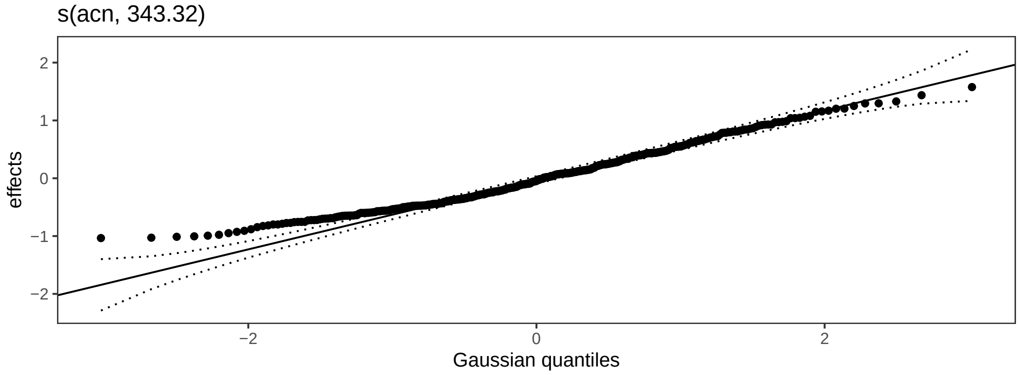

Figure B.6: Catch rate model effect plot - fisher effect

C Model inputs

C.1 Initial weighting of length and age data

Weighting of length and age data, as input into the model, are shown in Table C.1.

Year	Age	Length: Scenarios 1, 2, 3		Length: Scenarios 4, 5, 6	
		Commercial	Recreational/Charter	Commercial	Recreational/Charter
2005	268	35	28	17	8
2006	229	35	33	14	12
2007	199	28	31	13	9
2008	193	29	50	11	20
2009	267	48	57	16	18
2010	210	65	70	25	20
2011	301	57	55	26	21
2012	234	76	42	33	17
2013	164	56	36	23	16
2014	321	76	76	32	24
2015	278	70	91	31	31
2016	194	58	84	22	32
2017	180	55	72	21	31
2018	176	68	47	27	17
2019	177	66	40	27	12
2020	146	49	35	18	14
2021	182	71	48	28	13
2022	135	37	41	15	15
2023	178	25	69	9	23

Table C.1: Annual weighting of length and age data sample sizes

C.2 Queensland recreational catch comparison

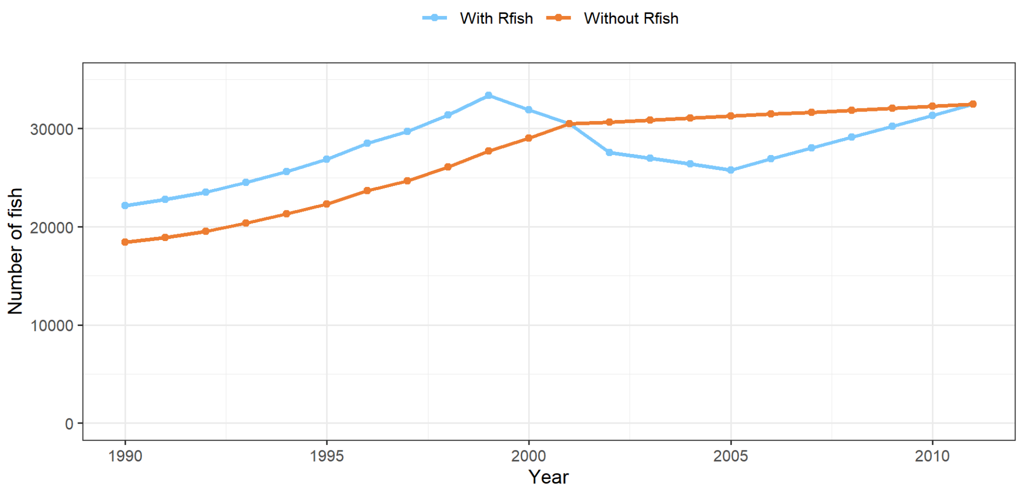

Figure C.1: Recreational catch estimates with and without RFish survey data between 1990 and 2011

C.3 Components of catch - retained catch and shark depredation

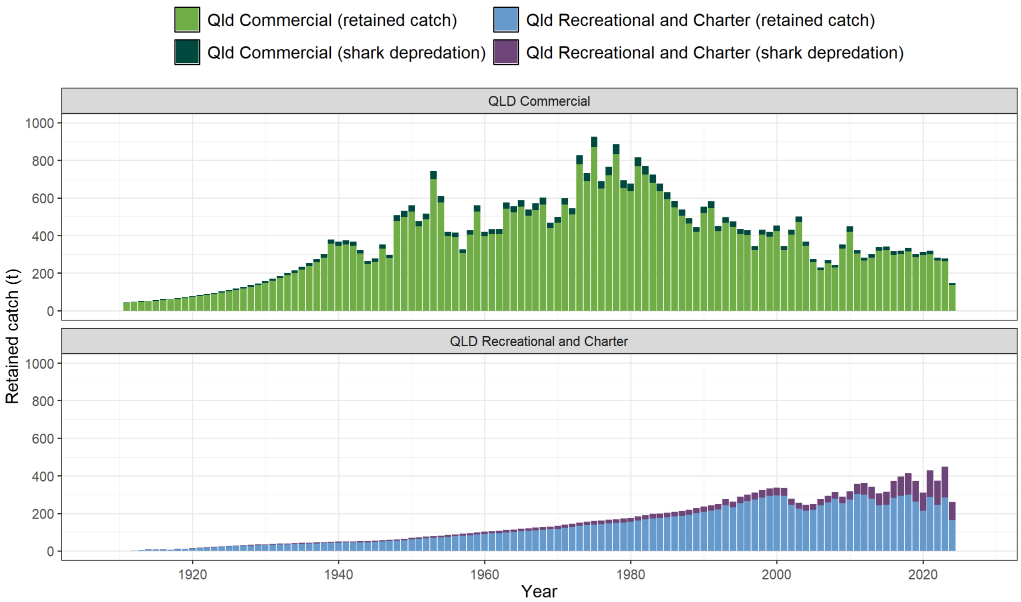

Figure C.2: Estimated catch by Queensland sectors, split into retained catch and shark depredation components between 1911 and 2024

Table C.2: Retained catch (no adjustment applied for shark depredation) per sector between 2004 and present, expressed in tonnes with annual percentages

Year	Qld Commercial	Qld Recreational/Charter	NSW Commercial	NSW Recreational/Charter
2004	345 t (56%)	211 t (34%)	7 t (1%)	50 t (8%)
2005	260 t (48%)	215 t (40%)	13 t (2%)	50 t (9%)
2006	217 t (42%)	238 t (46%)	4 t (1%)	56 t (11%)
2007	253 t (44%)	255 t (44%)	6 t (1%)	61 t (11%)
2008	229 t (40%)	273 t (48%)	3 t (0%)	66 t (11%)
2009	332 t (51%)	251 t (39%)	5 t (1%)	60 t (9%)
2010	422 t (54%)	271 t (34%)	32 t (4%)	61 t (8%)
2011	303 t (44%)	298 t (43%)	18 t (3%)	69 t (10%)
2012	267 t (41%)	297 t (46%)	10 t (2%)	70 t (11%)
2013	283 t (44%)	276 t (43%)	11 t (2%)	66 t (10%)
2014	320 t (48%)	244 t (37%)	40 t (6%)	57 t (9%)
2015	322 t (48%)	246 t (37%)	41 t (6%)	59 t (9%)
2016	298 t (43%)	284 t (41%)	33 t (5%)	70 t (10%)
2017	302 t (44%)	297 t (44%)	10 t (1%)	71 t (11%)
2018	315 t (45%)	302 t (43%)	14 t (2%)	73 t (10%)
2019	285 t (45%)	266 t (42%)	13 t (2%)	64 t (10%)
2020	295 t (51%)	218 t (38%)	9 t (1%)	53 t (9%)
2021	301 t (44%)	293 t (43%)	10 t (2%)	74 t (11%)
2022	266 t (46%)	248 t (43%)	7 t (1%)	61 t (10%)
2023	263 t (42%)	288 t (46%)	8 t (1%)	61 t (10%)
2024	139 t (39%)	165 t (47%)	10 t (3%)	39 t (11%)

C.4 Spatiotemporal patterns in age and length

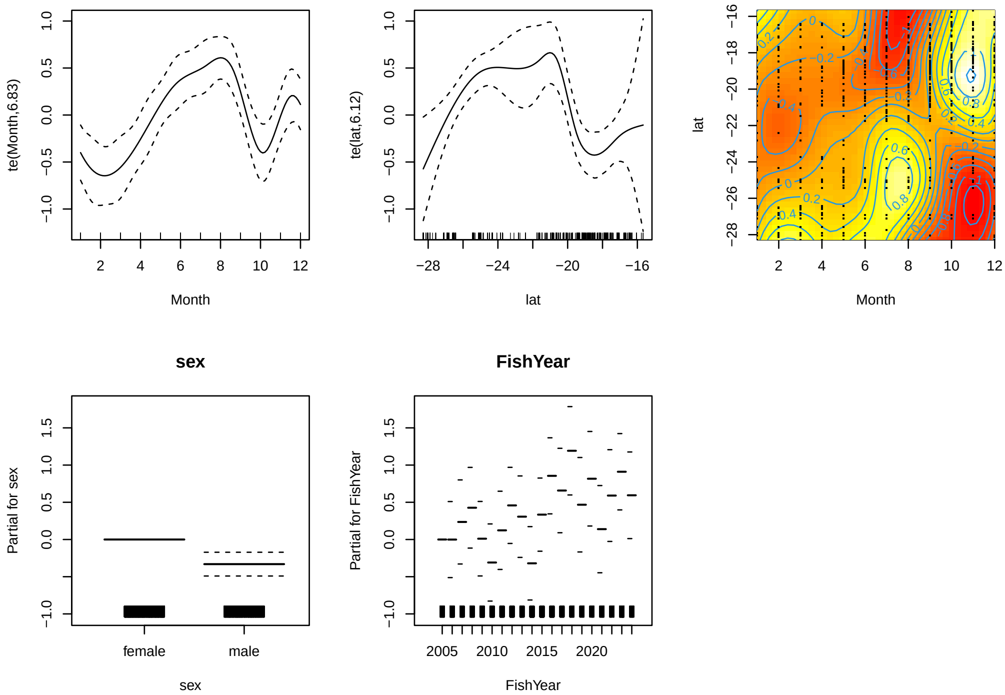

Figure C.3: GAM model terms in the age-response model. For the latitude and month interaction subplot, white indicates a positive response (increased age) and red indicates a negative response (decreased age).

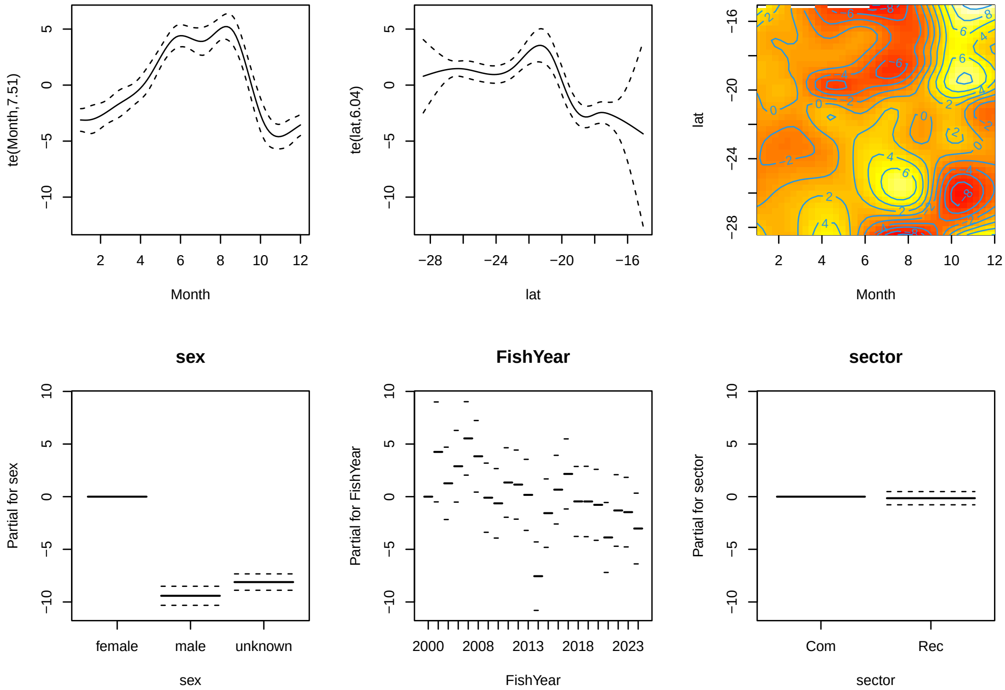

Figure C.4: GAM model terms in the length-response model. For the latitude and month interaction subplot, white indicates a positive response (increased length) and red indicates a negative response (decreased length).

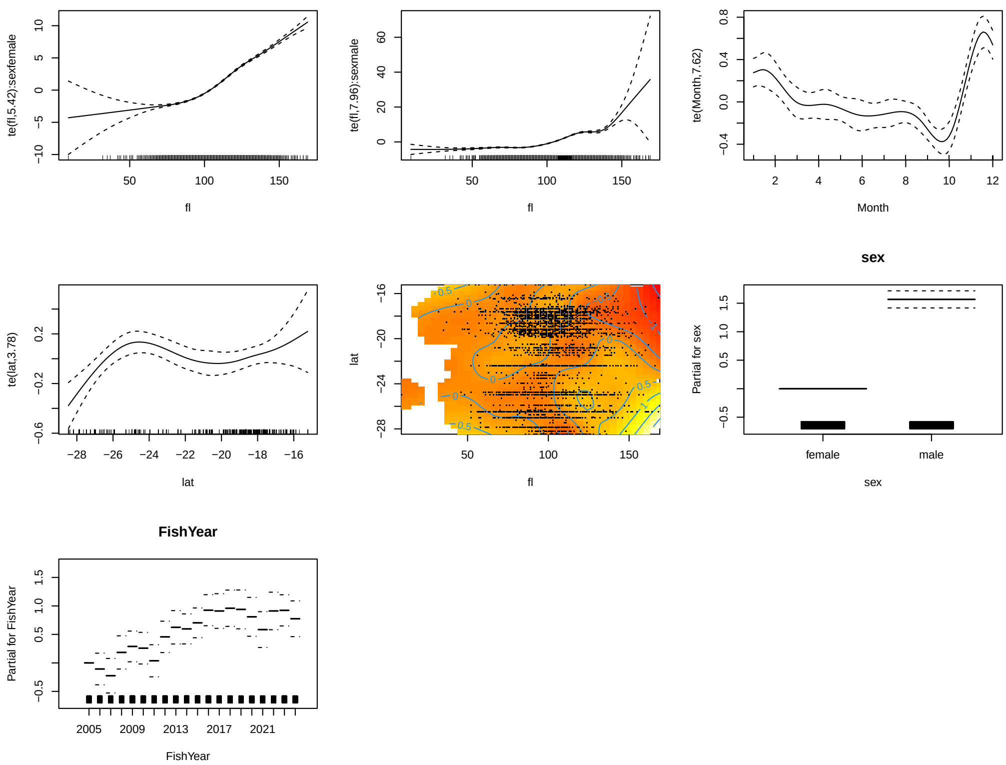

Figure C.5: GAM model terms in the age-at-length model. For the latitude and fork length interaction subplot, white indicates a positive response (increased age) and red indicates a negative response (decreased age).

C.5 Conditional age-at-length

Age data were input to the population model in the form of conditional age-at-length data (Figure C.6–C.11).

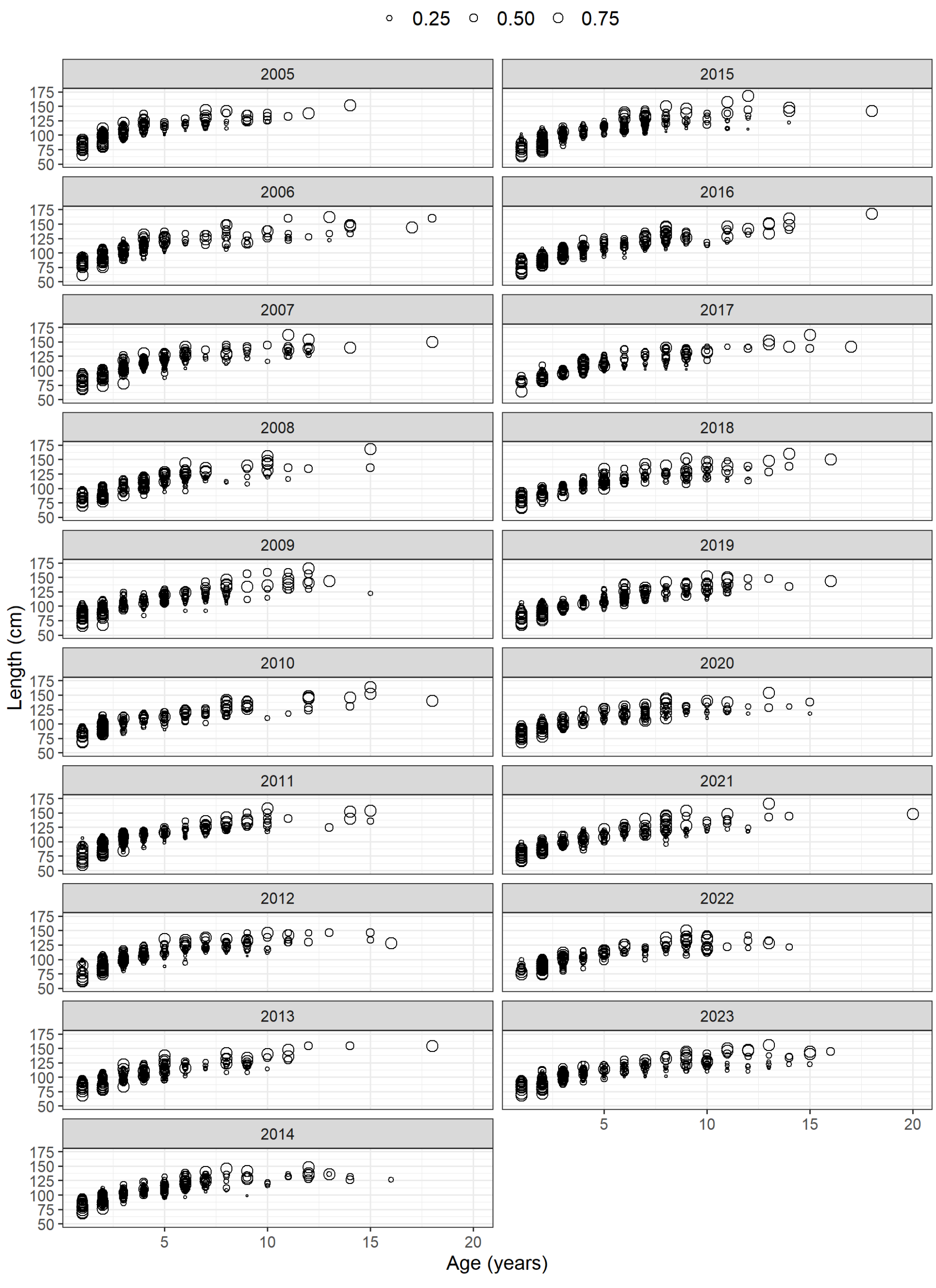

Figure C.6: Conditional age-at-length compositions for female Spanish mackerel in Fleet 1 (QldCommercialQ1)—circle size is proportional to relative sample size in each bin across rows (i.e. for a given length bin)

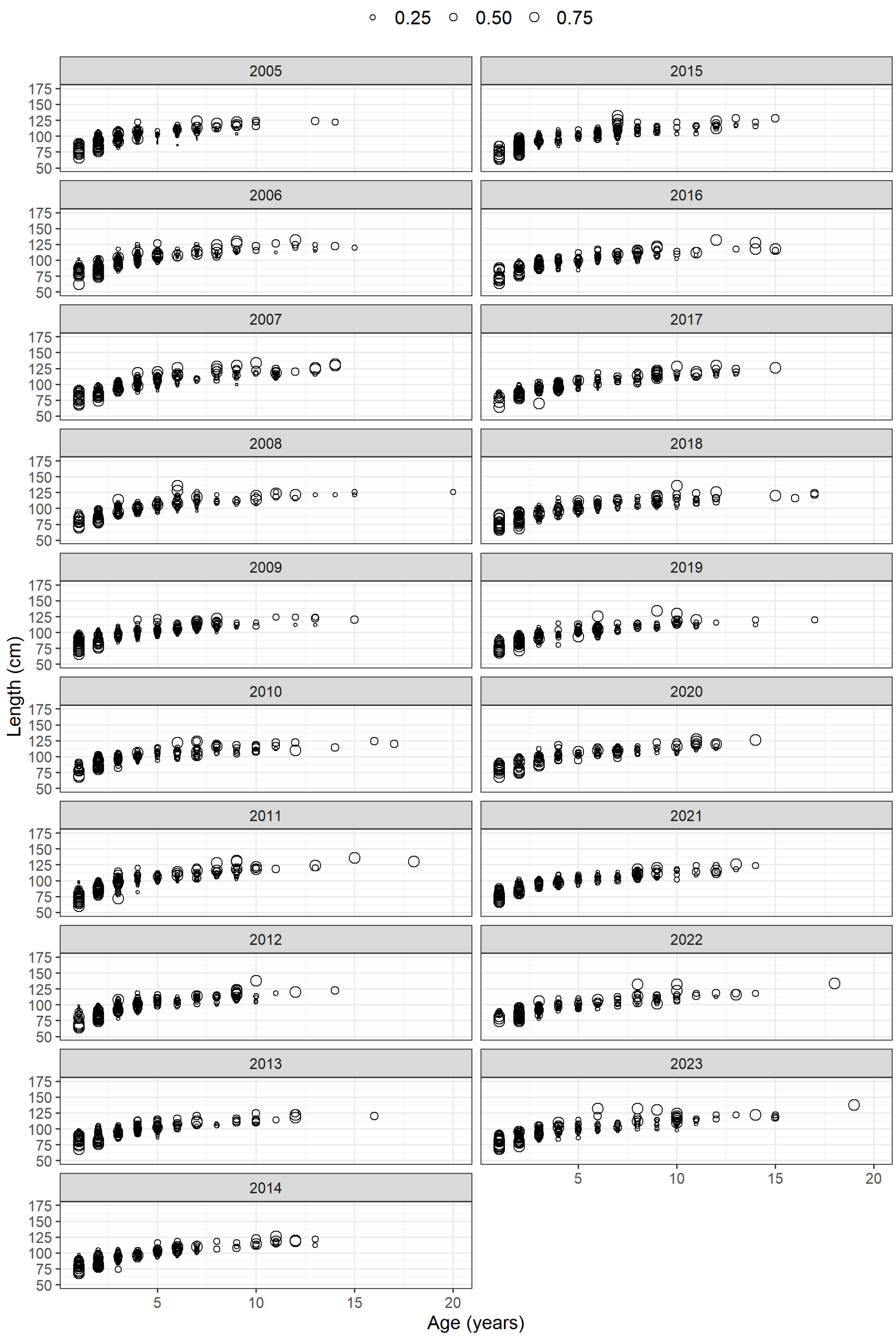

Figure C.7: Conditional age-at-length compositions for male Spanish mackerel in Fleet 1 (QldCommercialQ1)—circle size is proportional to relative sample size in each bin across rows (i.e. for a given length bin)

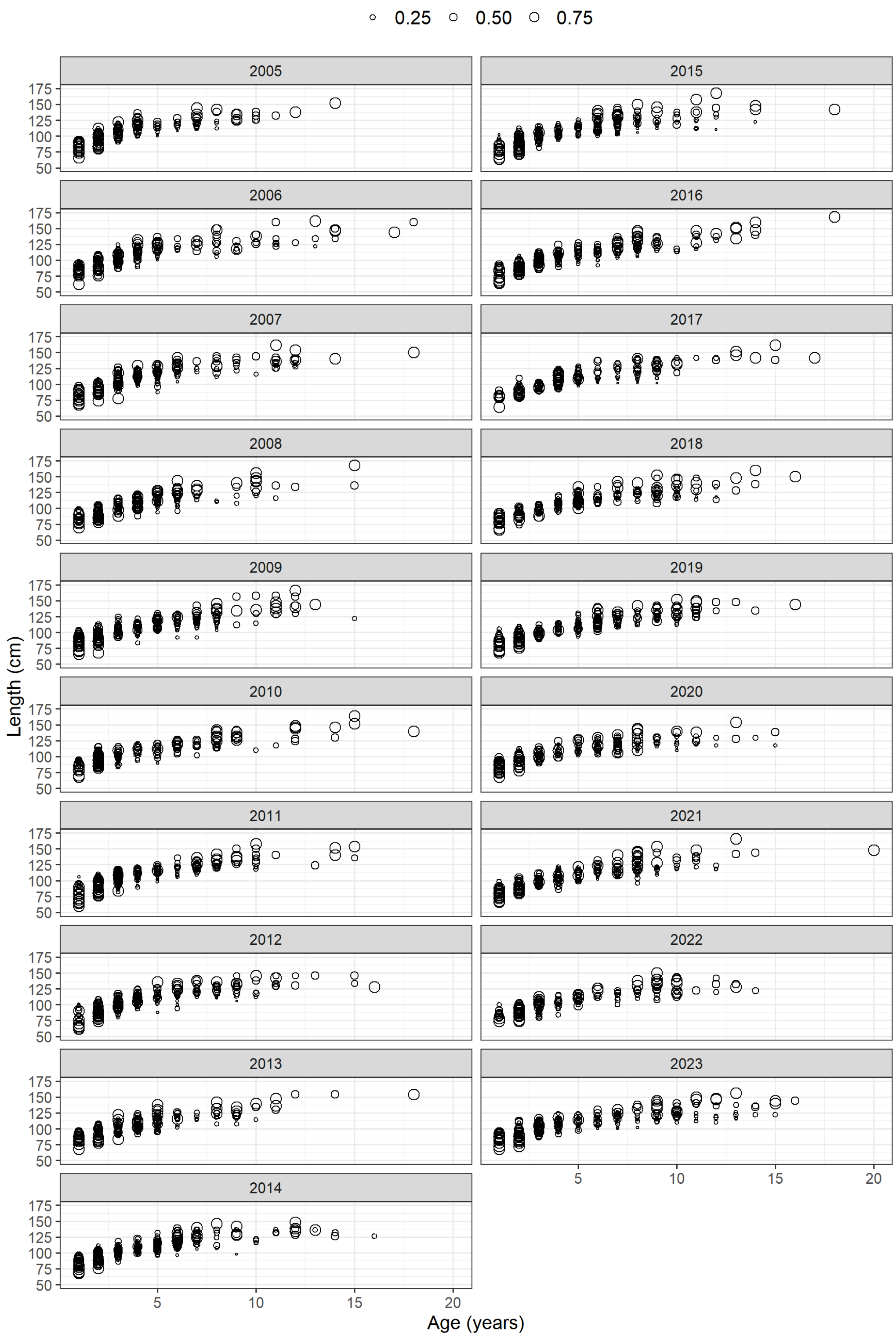

Figure C.8: Conditional age-at-length compositions for female Spanish mackerel in Fleet 5 (QldCommercialQ2)—circle size is proportional to relative sample size in each bin across rows (i.e. for a given length bin)

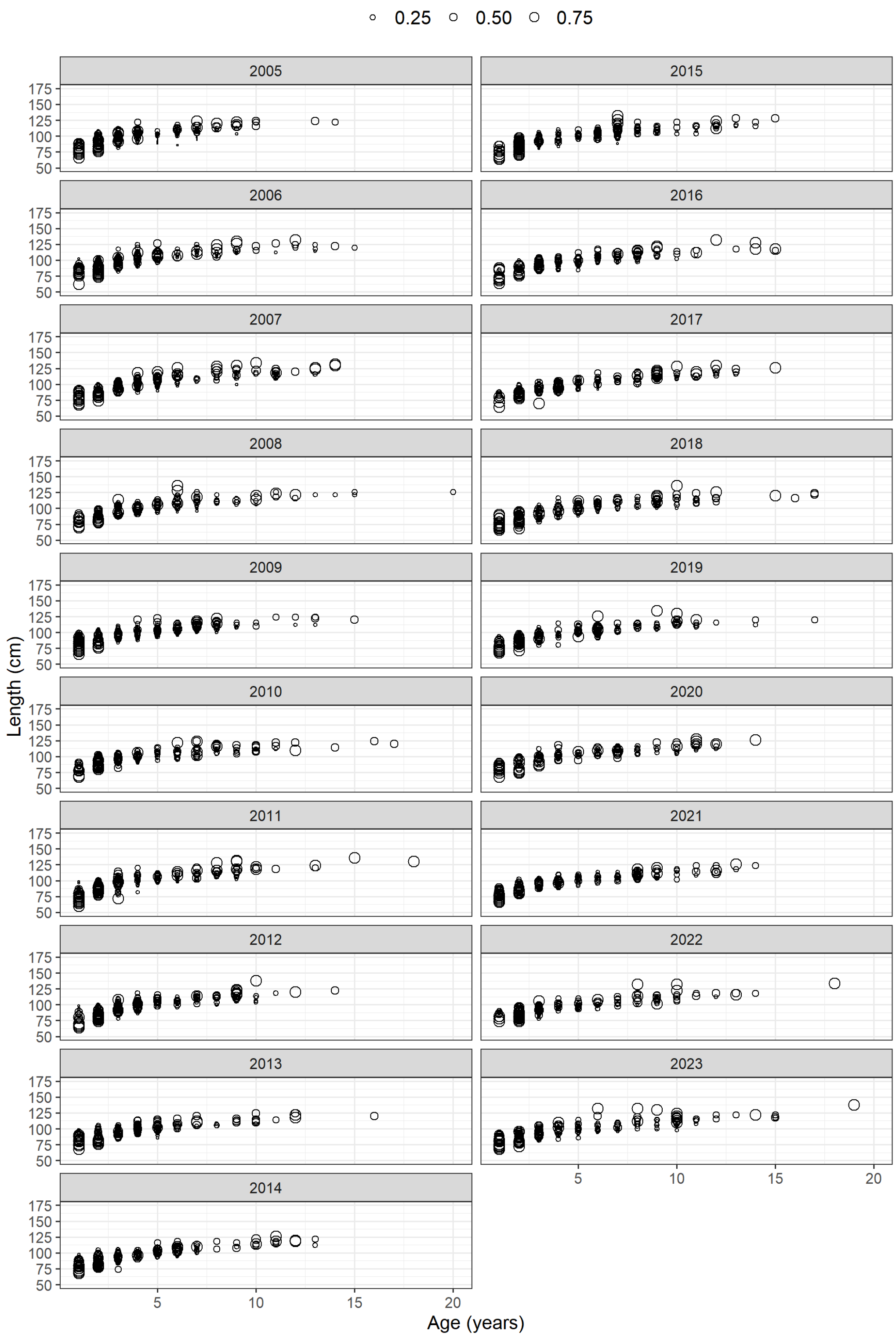

Figure C.9: Conditional age-at-length compositions for male Spanish mackerel in Fleet 5 (QldCommercialQ2)—circle size is proportional to relative sample size in each bin across rows (i.e. for a given length bin)

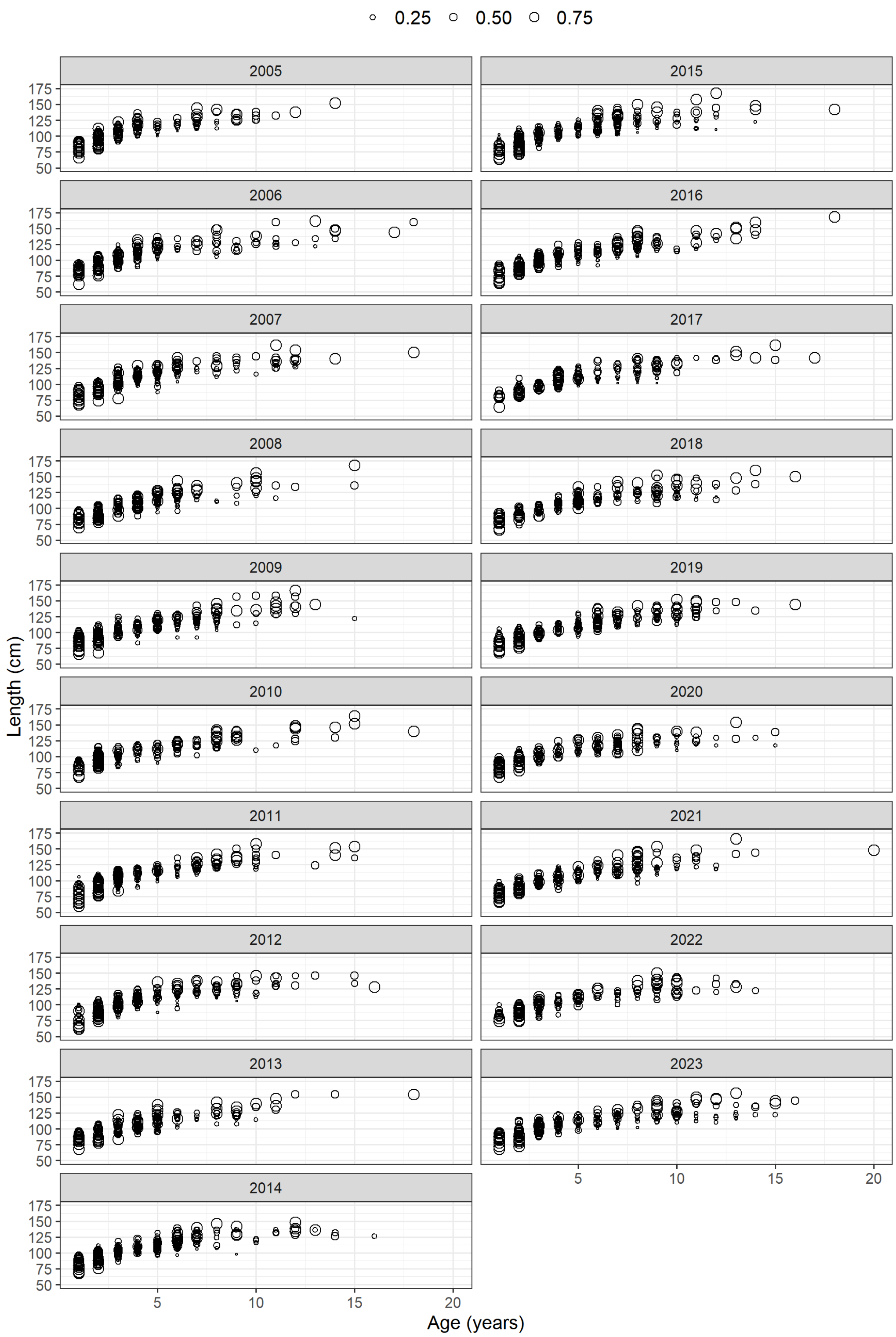

Figure C.10: Conditional age-at-length compositions for female Spanish mackerel in Fleet 6 (QldCommercialQ3)—circle size is proportional to relative sample size in each bin across rows (i.e. for a given length bin)

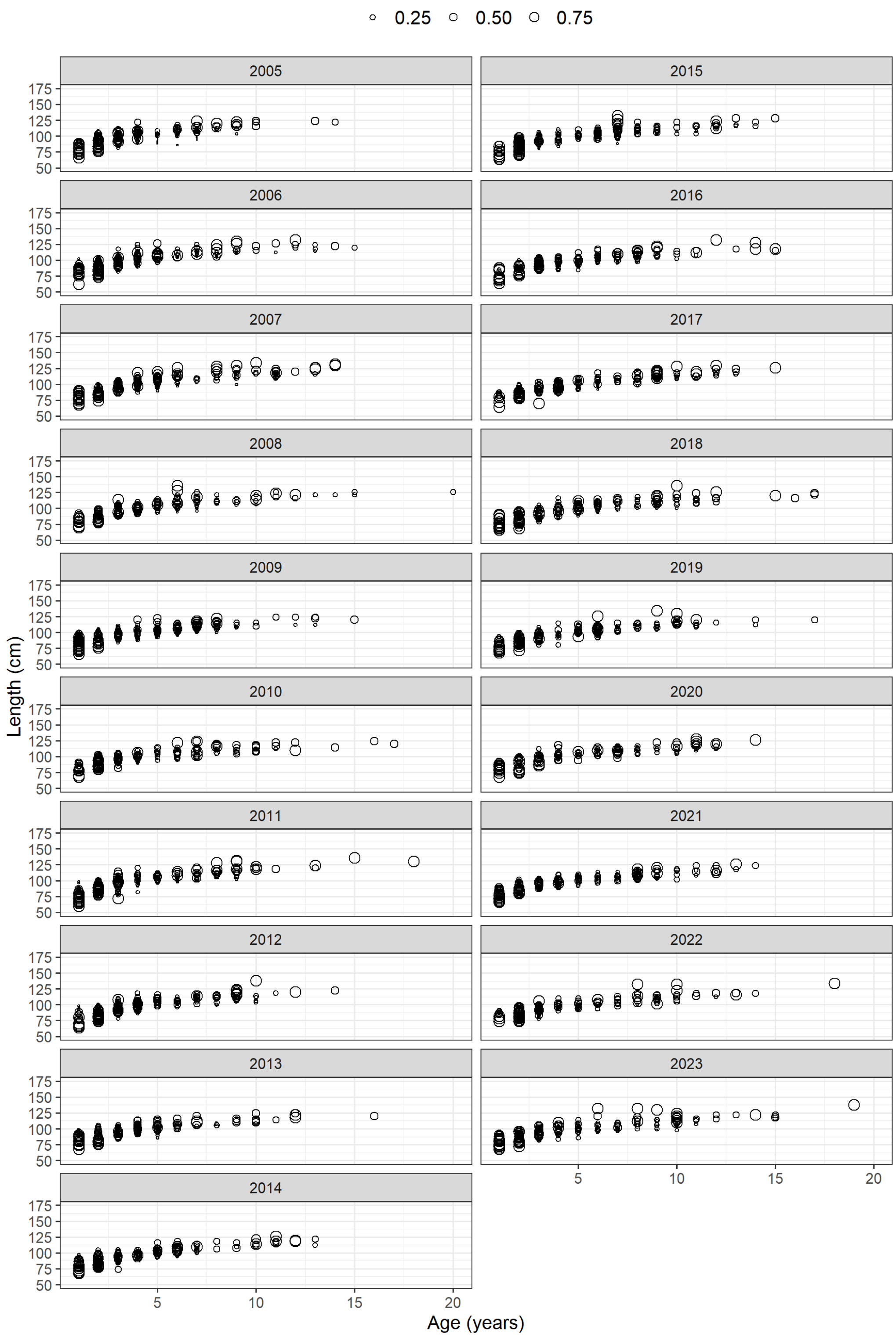

Figure C.11: Conditional age-at-length compositions for male Spanish mackerel in Fleet 6 (QldCommercialQ3)—circle size is proportional to relative sample size in each bin across rows (i.e. for a given length bin)

C.6 Biological data

C.6.1 Weight and length

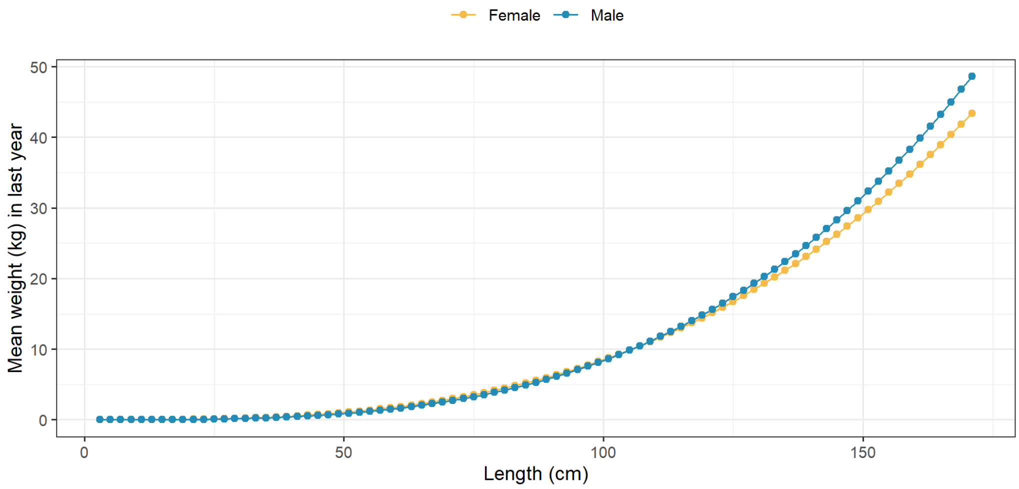

Figure C.12: Weight–length relationship for Spanish mackerel in the Australian east coast

C.6.2 Fecundity and maturity

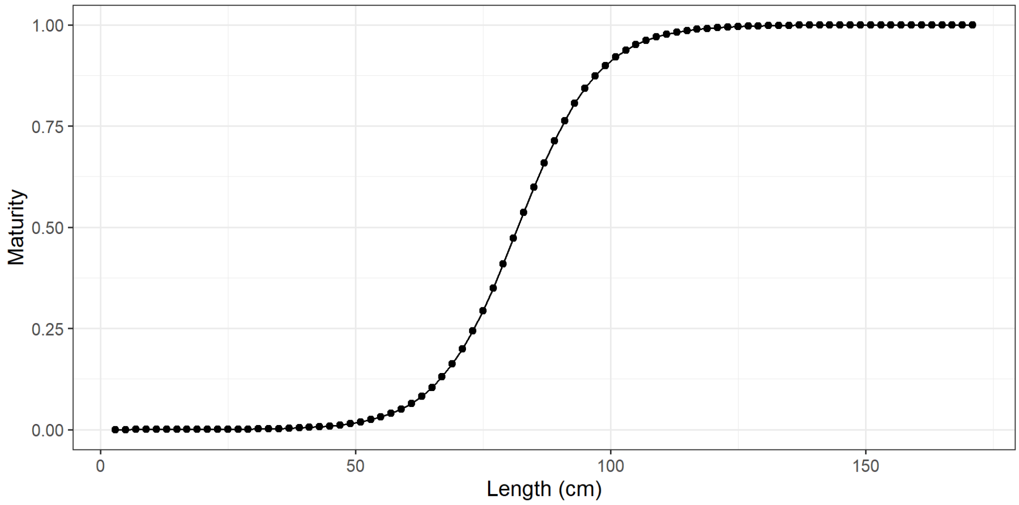

Figure C.13: Maturity at length for Spanish mackerel in the Australian east coast

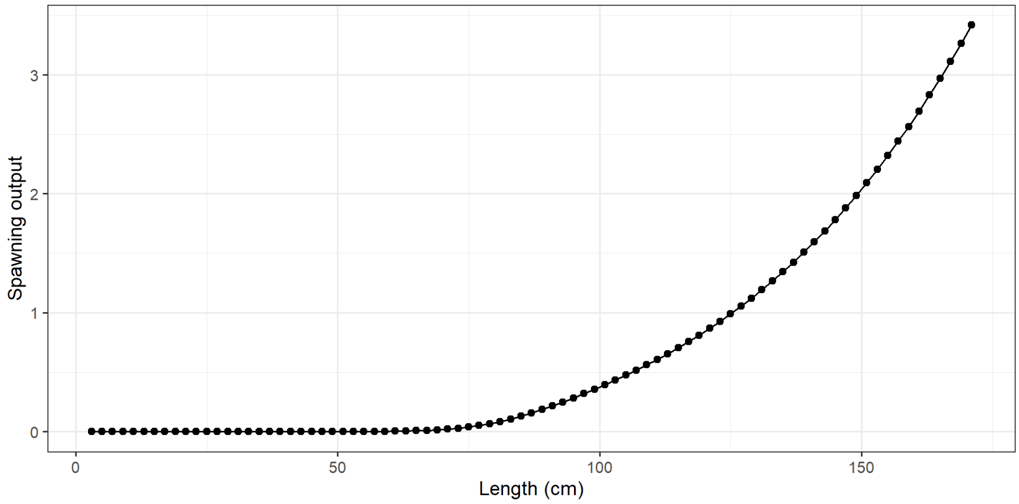

Figure C.14: Spawning output (maturity multiplied by fecundity) at length for Spanish mackerel in the Australian east coast

D Model outputs

D.1 Likelihood profile

Likelihood profile on R0, steepness and natural mortality was conducted on scenario 2 as reference.

Figure D.1: Likelihood profile for ln(R0)

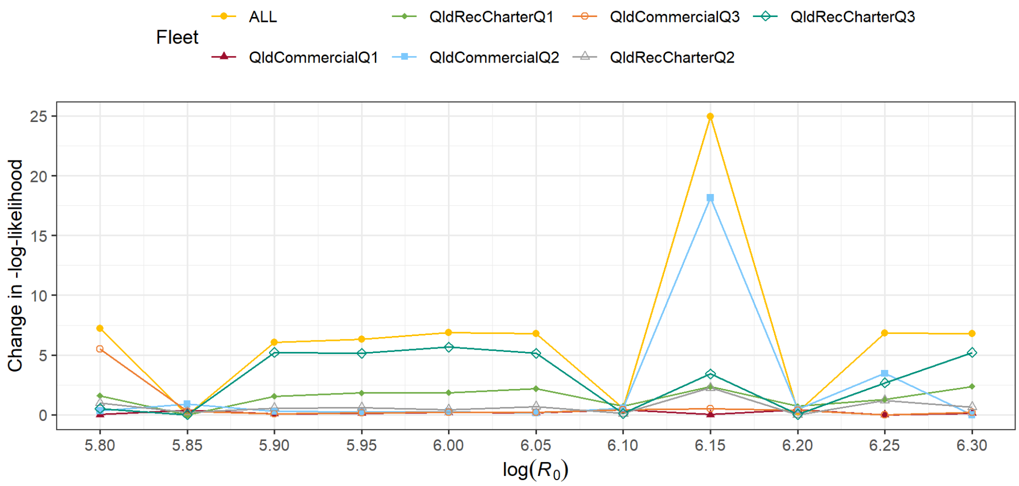

Figure D.2: Piner plot of length-composition likelihoods by fleet for ln(R0)

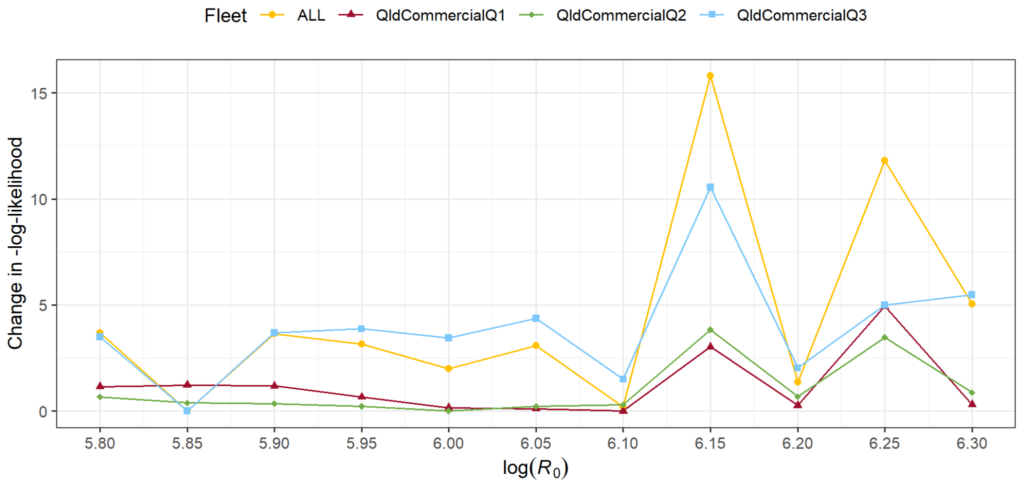

Figure D.3: Piner plot of age-composition likelihoods by fleet for ln(R0)

Figure D.4: Likelihood profile for natural mortality

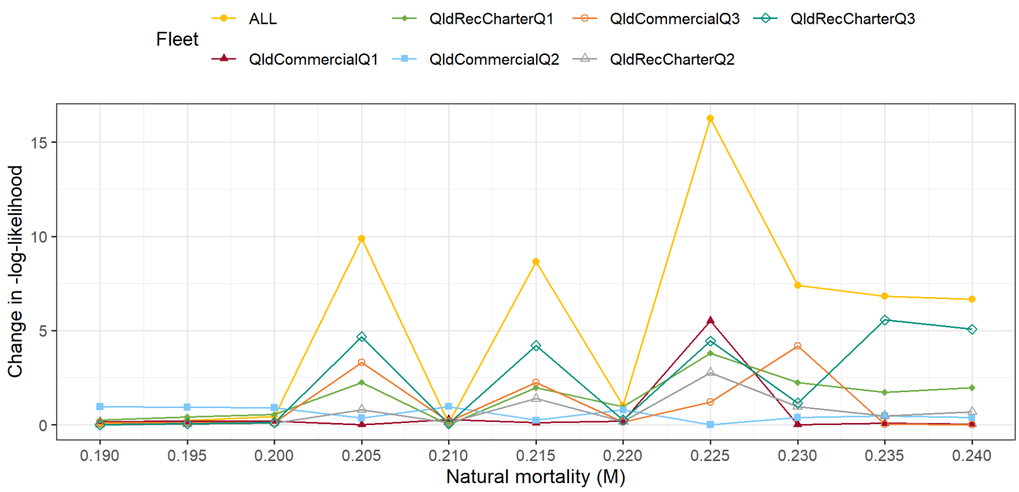

Figure D.5: Piner plot of length-composition likelihoods by fleet for natural mortality

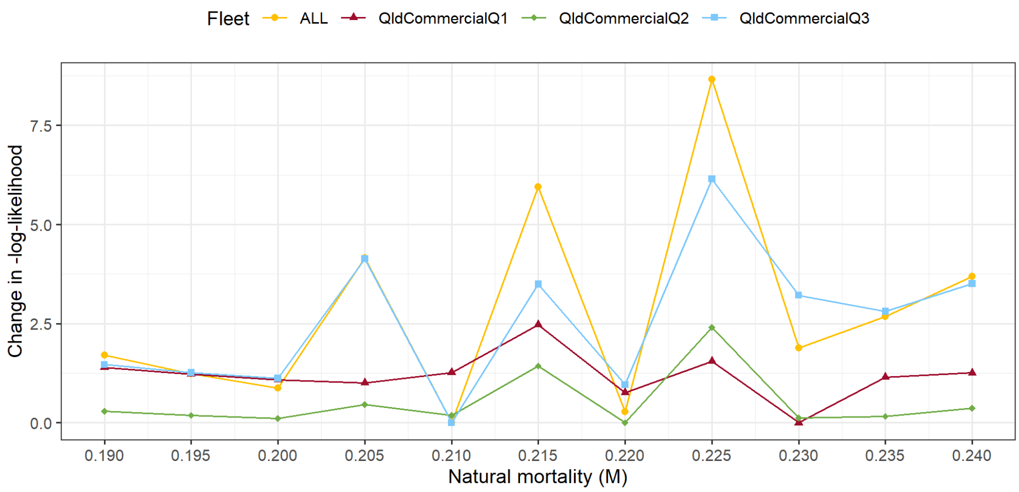

Figure D.6: Piner plot of age-composition likelihoods by fleet for natural mortality

D.2 Andre plots

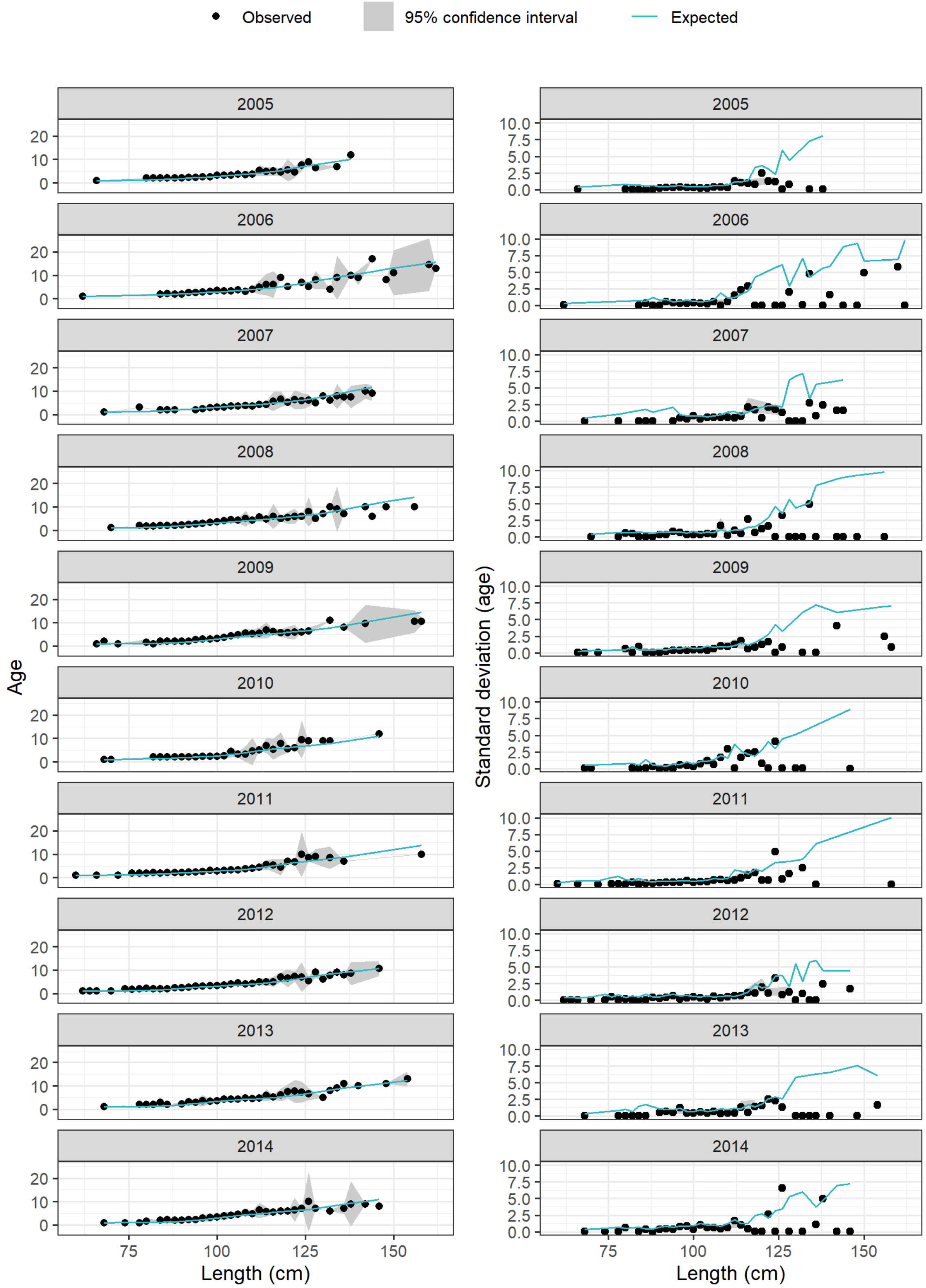

Figure D.7: Scenario 2: Mean age and standard deviation in female conditional age-at-length data for Fleet 1 between 2005 and 2014. Left plots are mean age at length by size-class (observed and expected) with confidence intervals obtained by adding the appropriate number of standard errors of mean to the data. Right plots in each pair are SE of mean age-at-length with confidence intervals based on the chi-square distribution.

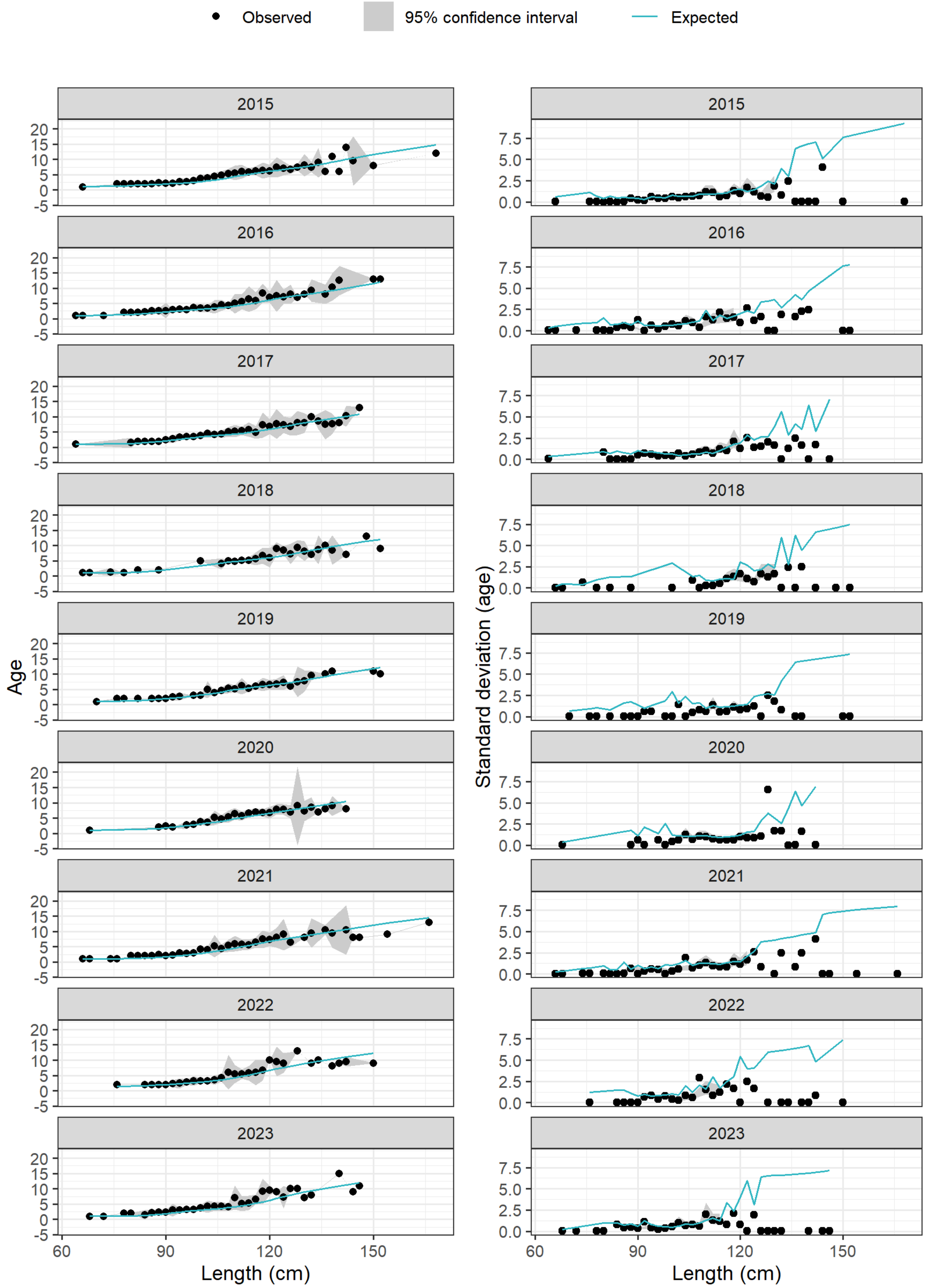

Figure D.8: Scenario 2: Mean age and standard deviation in female conditional age-at-length data for Fleet 1 between 2015 and 2023. Left plots are mean age at length by size-class (observed and expected) with confidence intervals obtained by adding the appropriate number of standard errors of mean to the data. Right plots in each pair are SE of mean age-at-length with confidence intervals based on the chi-square distribution.

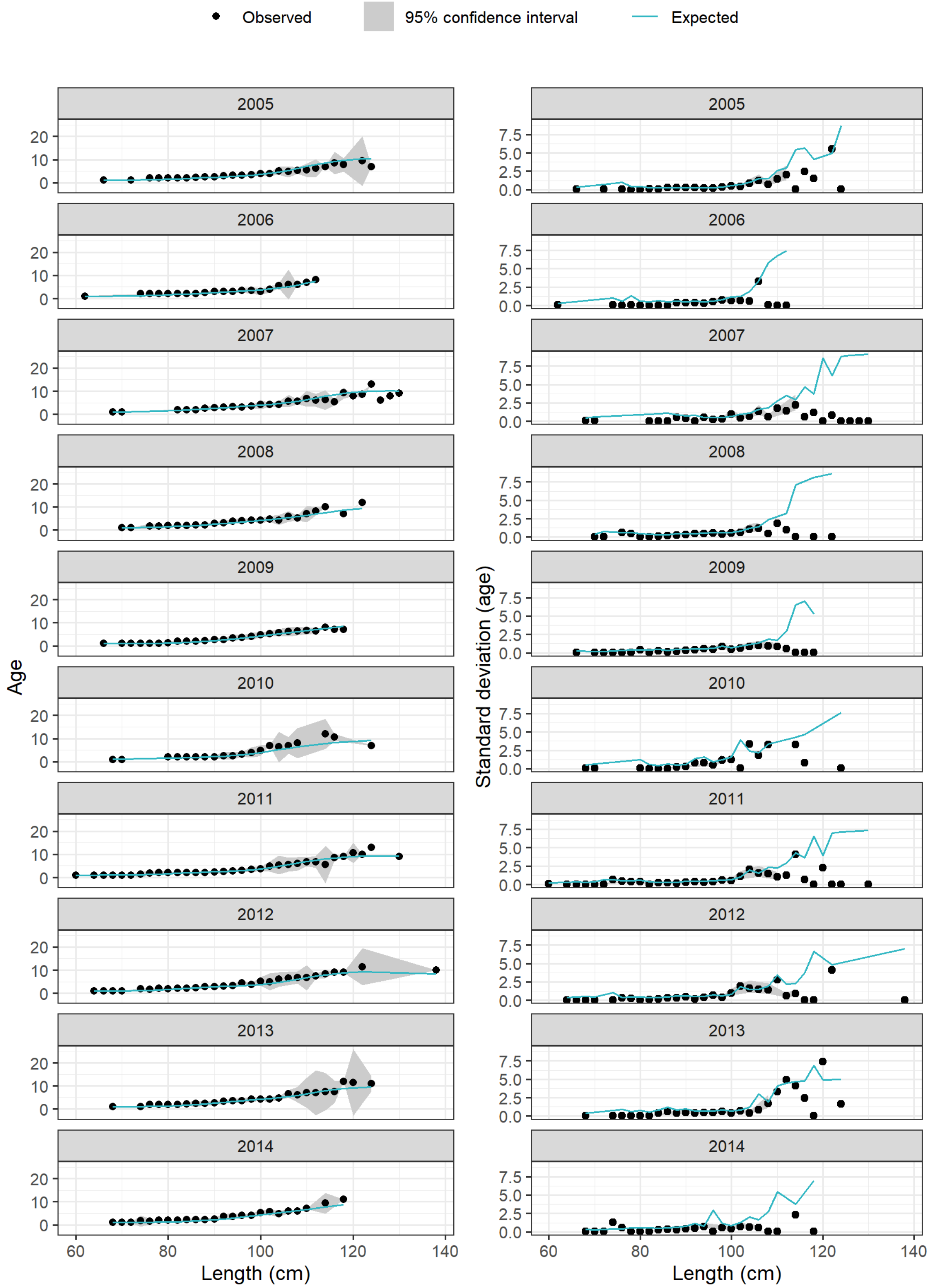

Figure D.9: Scenario 2: Mean age and standard deviation in male conditional age-at-length data for Fleet 1 between 2005 and 2014. Left plots are mean age at length by size-class (observed and expected) with confidence intervals obtained by adding the appropriate number of standard errors of mean to the data. Right plots in each pair are SE of mean age-at-length with confidence intervals based on the chi-square distribution.

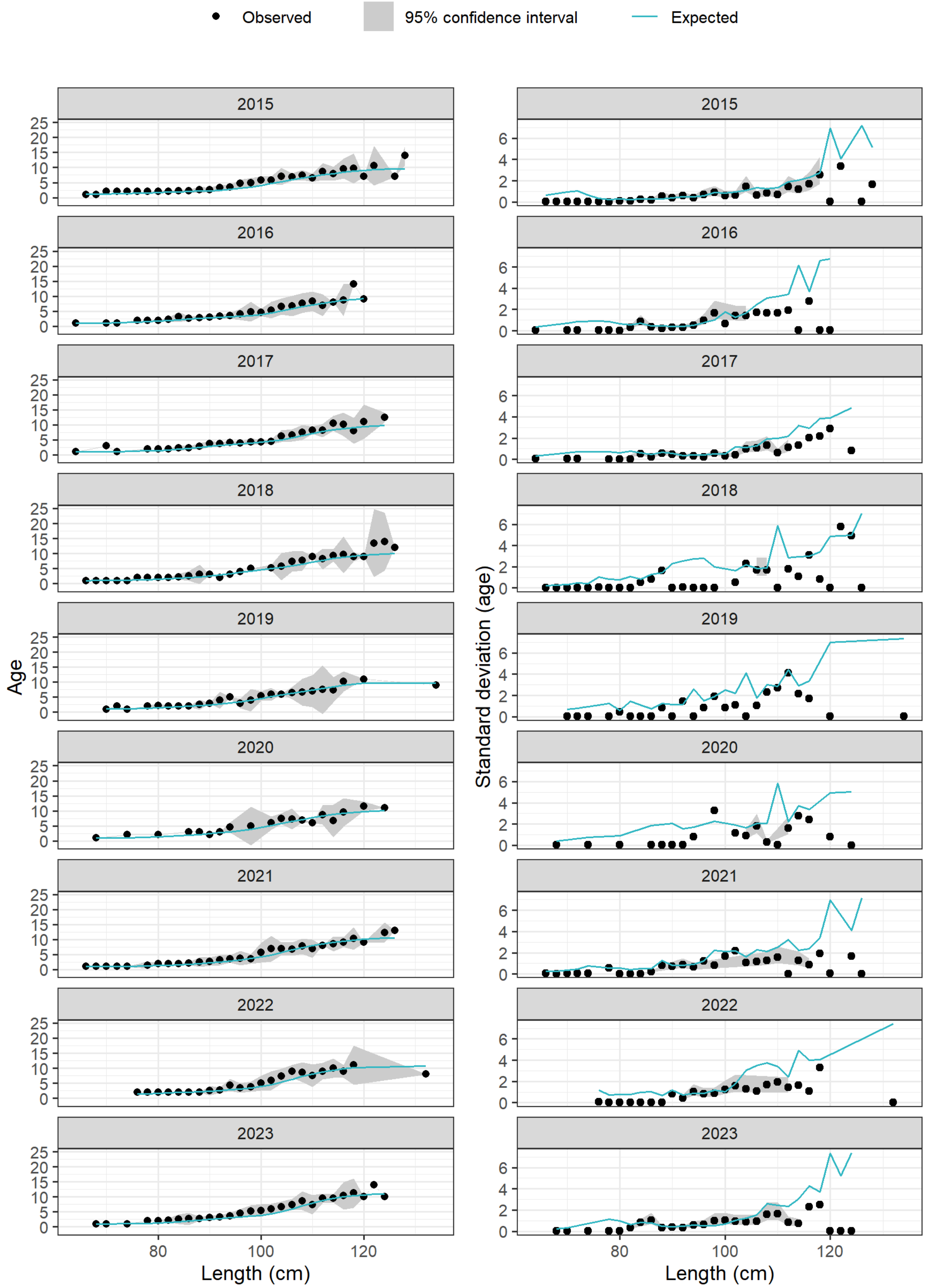

Figure D.10: Scenario 2: Mean age and standard deviation in male conditional age-at-length data for Fleet 1 between 2015 and 2023. Left plots are mean age at length by size-class (observed and expected) with confidence intervals obtained by adding the appropriate number of standard errors of mean to the data. Right plots in each pair are SE of mean age-at-length with confidence intervals based on the chi-square distribution.

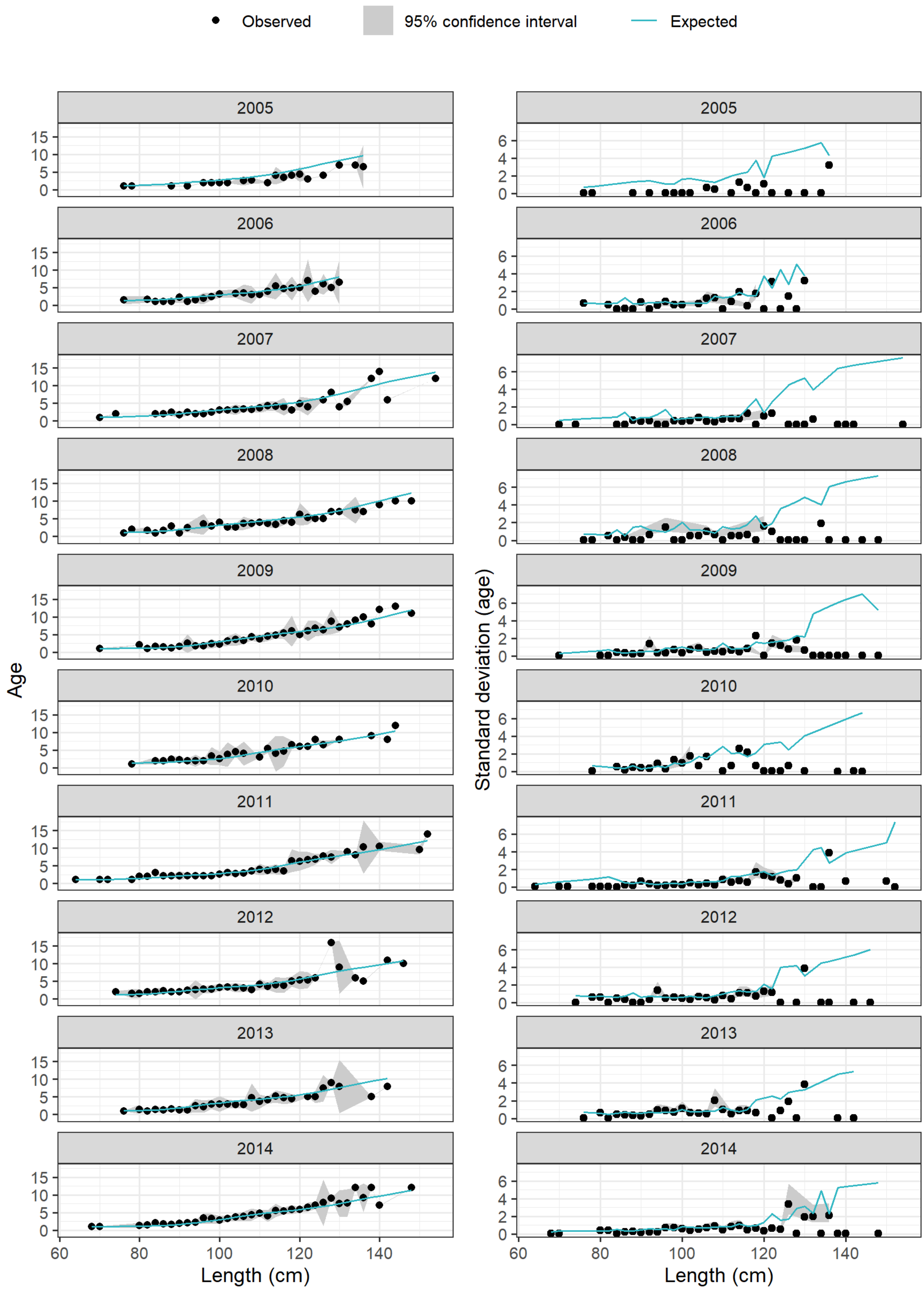

Figure D.11: Scenario 2: Mean age and standard deviation in female conditional age-at-length data for Fleet 5 between 2005 and 2014. Left plots are mean age at length by size-class (observed and expected) with confidence intervals obtained by adding the appropriate number of standard errors of mean to the data. Right plots in each pair are SE of mean age-at-length with confidence intervals based on the chi-square distribution.

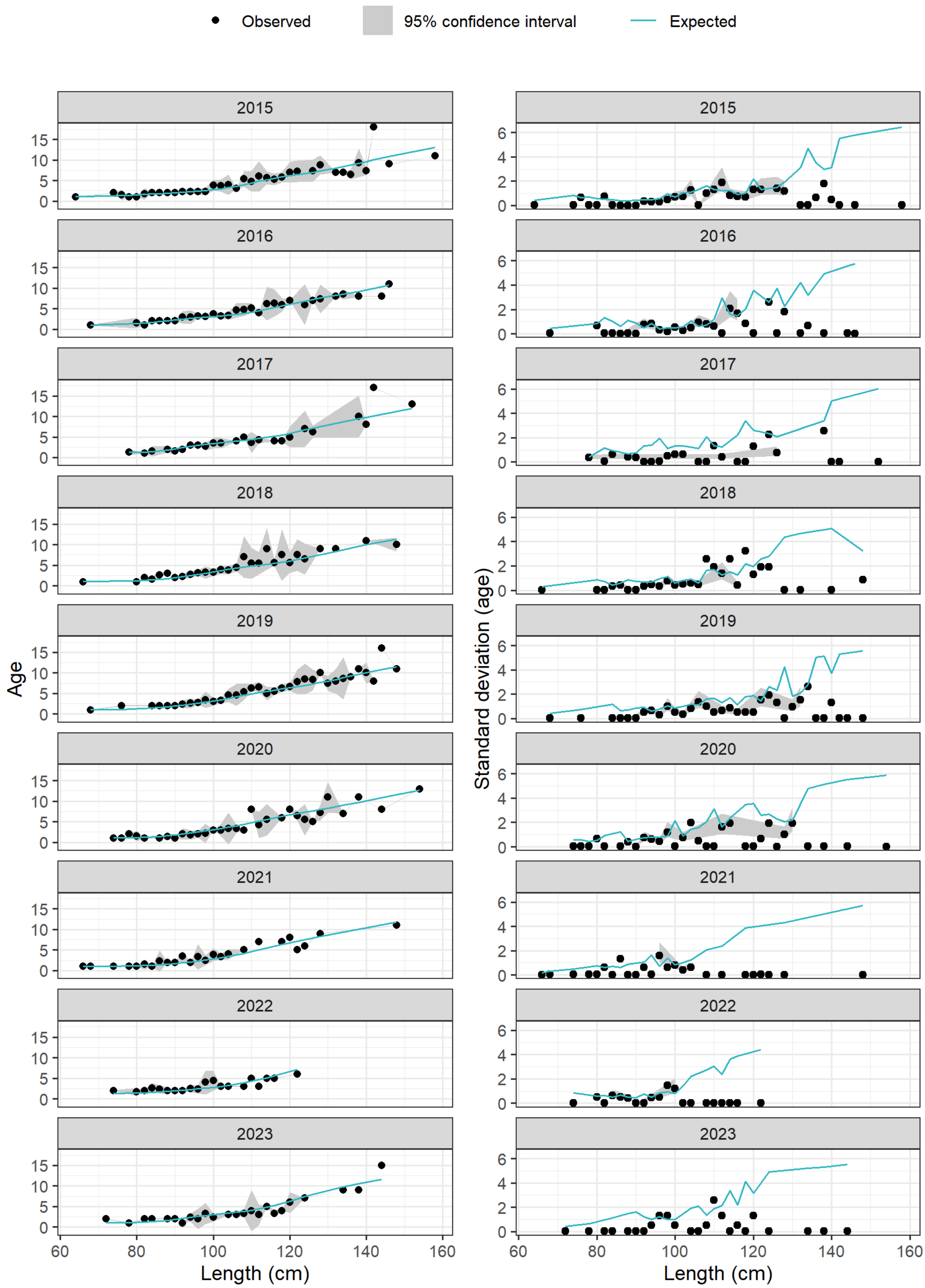

Figure D.12: Scenario 2: Mean age and standard deviation in female conditional age-at-length data for Fleet 5 between 2015 and 2023. Left plots are mean age at length by size-class (observed and expected) with confidence intervals obtained by adding the appropriate number of standard errors of mean to the data. Right plots in each pair are SE of mean age-at-length with confidence intervals based on the chi-square distribution.

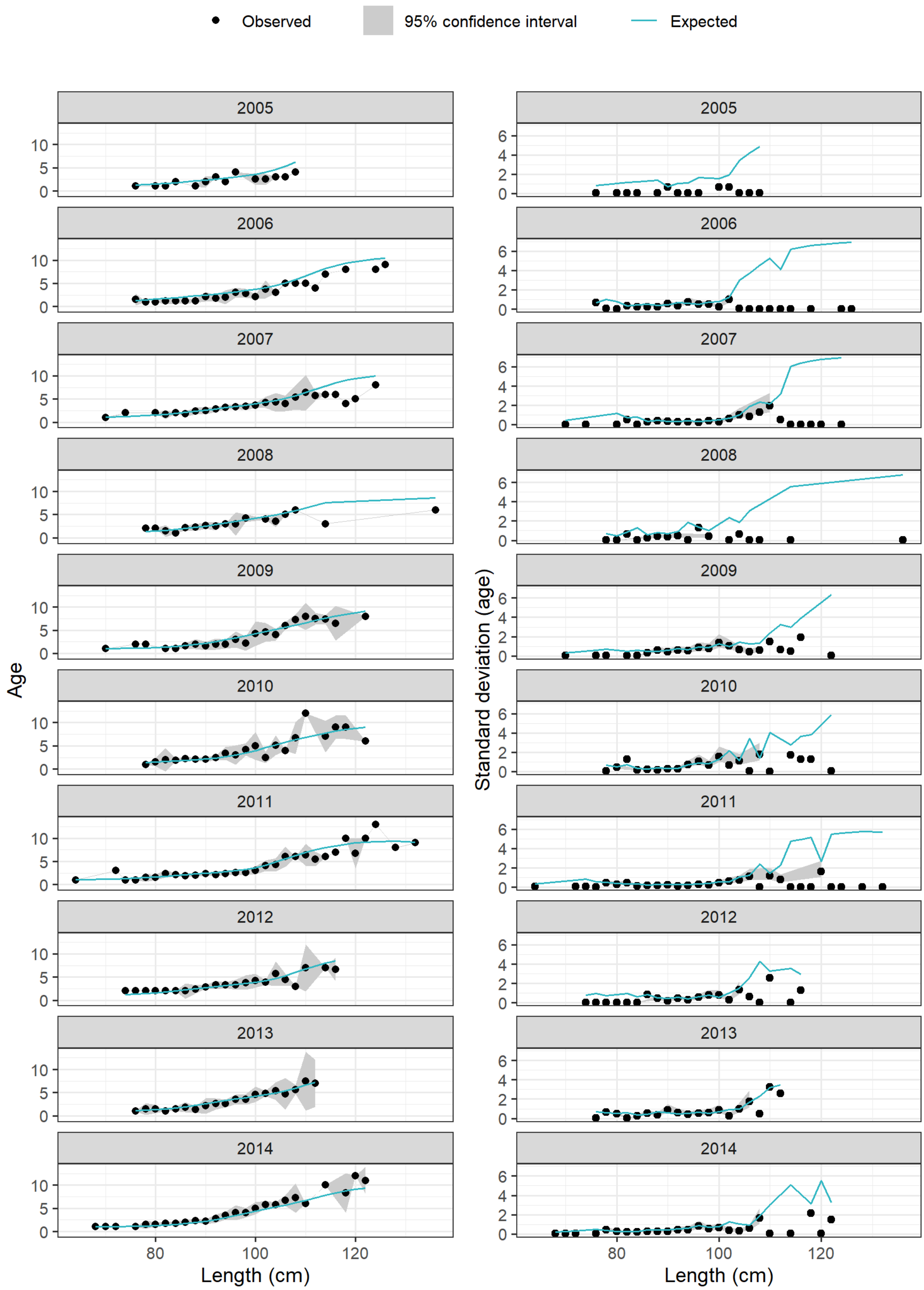

Figure D.13: Scenario 2: Mean age and standard deviation in male conditional age-at-length data for Fleet 5 between 2005 and 2014. Left plots are mean age at length by size-class (observed and expected) with confidence intervals obtained by adding the appropriate number of standard errors of mean to the data. Right plots in each pair are SE of mean age-at-length with confidence intervals based on the chi-square distribution.

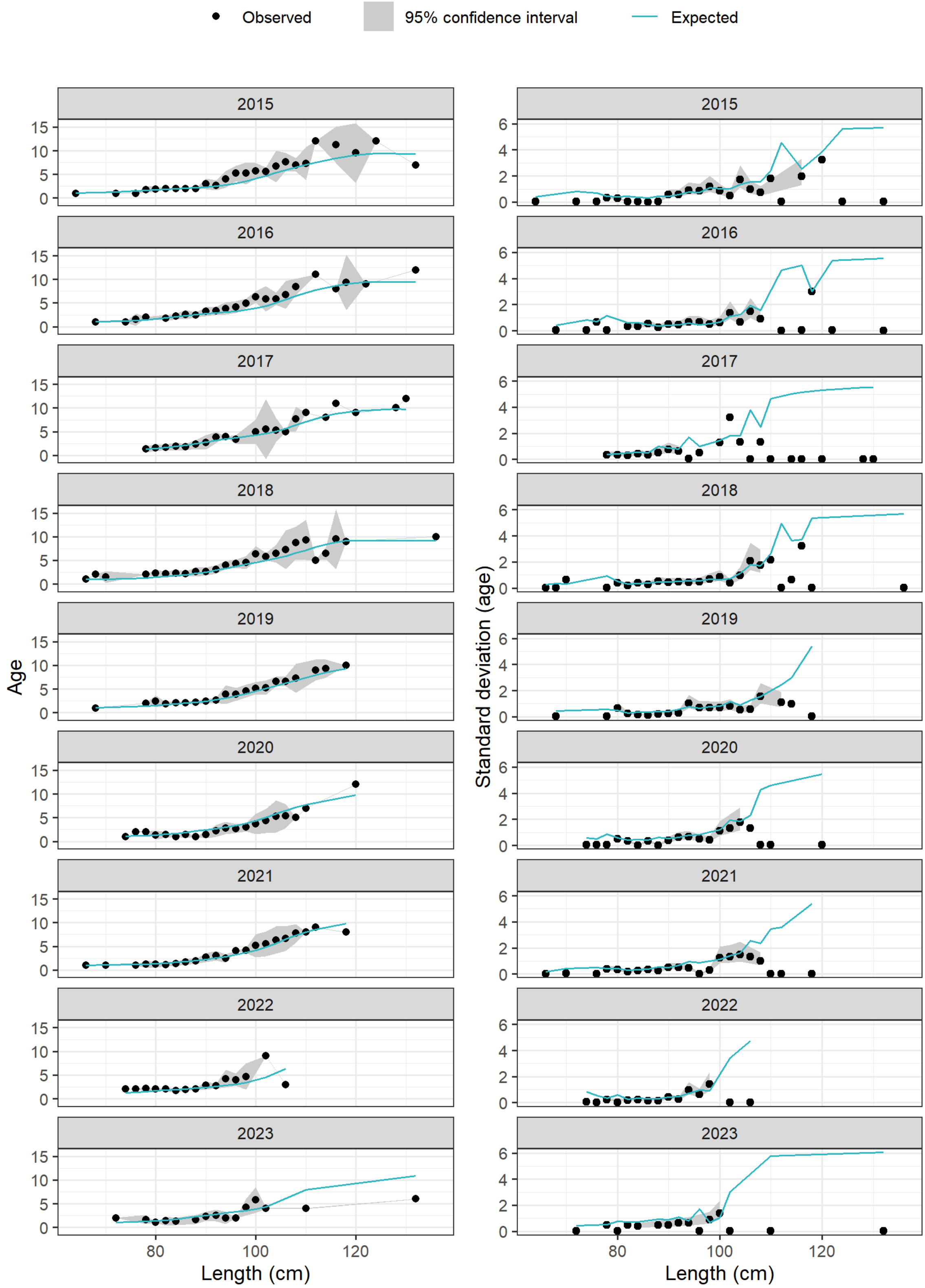

Figure D.14: Scenario 2: Mean age and standard deviation in male conditional age-at-length data for Fleet 5 between 2015 and 2023. Left plots are mean age at length by size-class (observed and expected) with confidence intervals obtained by adding the appropriate number of standard errors of mean to the data. Right plots in each pair are SE of mean age-at-length with confidence intervals based on the chi-square distribution.

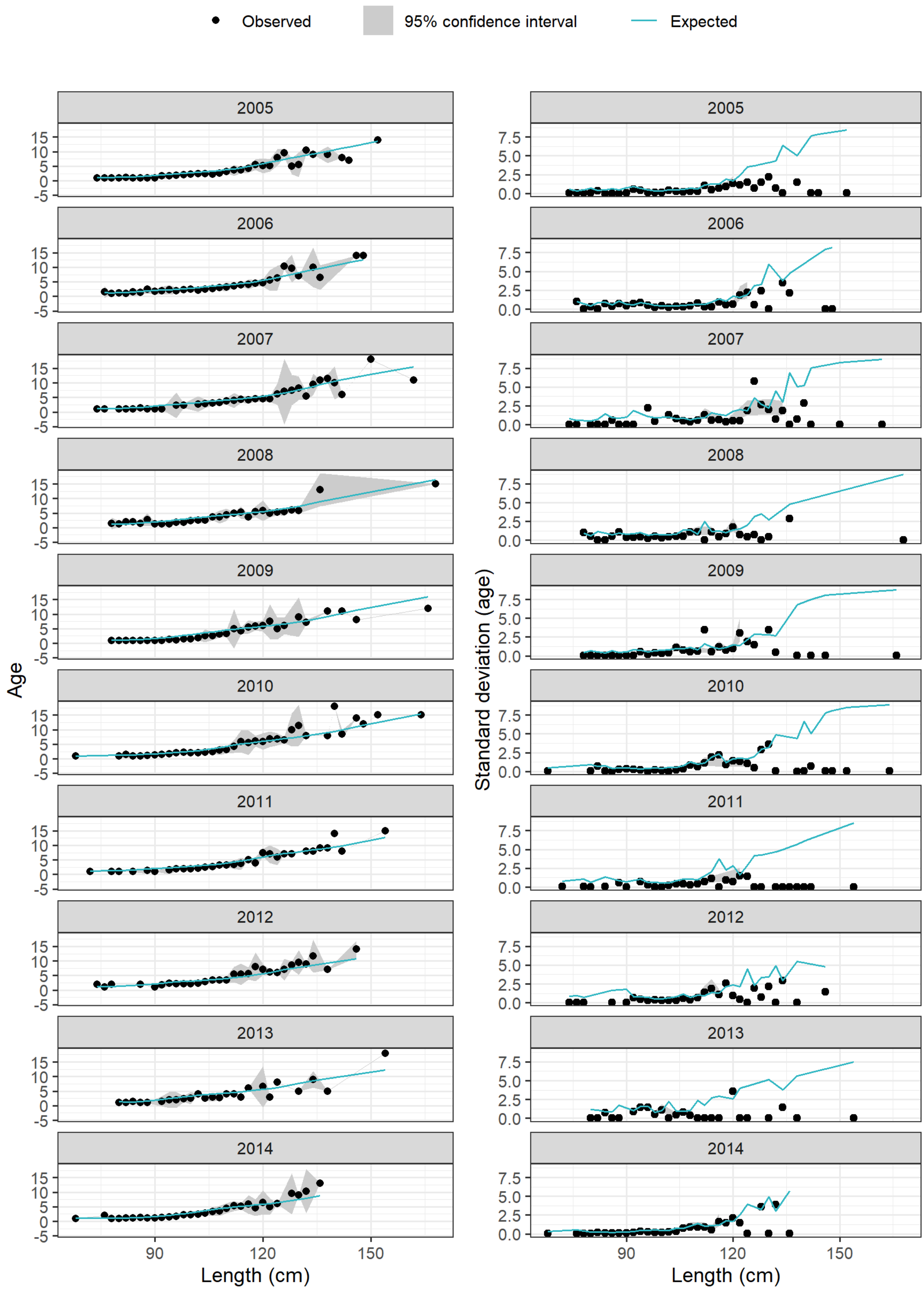

Figure D.15: Scenario 2: Mean age and standard deviation in female conditional age-at-length data for Fleet 6 between 2005 and 2014. Left plots are mean age at length by size-class (observed and expected) with confidence intervals obtained by adding the appropriate number of standard errors of mean to the data. Right plots in each pair are SE of mean age-at-length with confidence intervals based on the chi-square distribution.

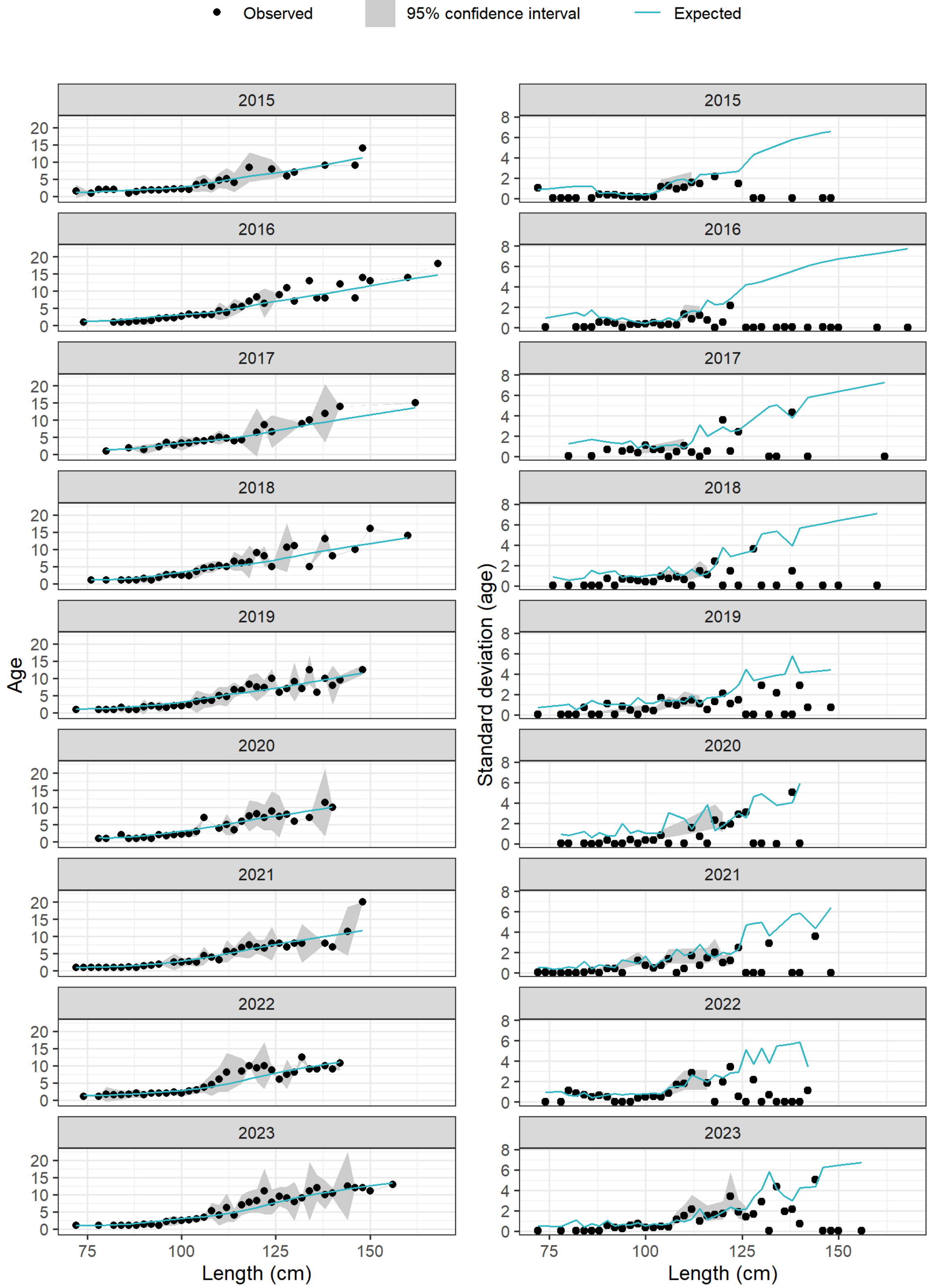

Figure D.16: Scenario 2: Mean age and standard deviation in female conditional age-at-length data for Fleet 6 between 2015 and 2023. Left plots are mean age at length by size-class (observed and expected) with confidence intervals obtained by adding the appropriate number of standard errors of mean to the data. Right plots in each pair are SE of mean age-at-length with confidence intervals based on the chi-square distribution.

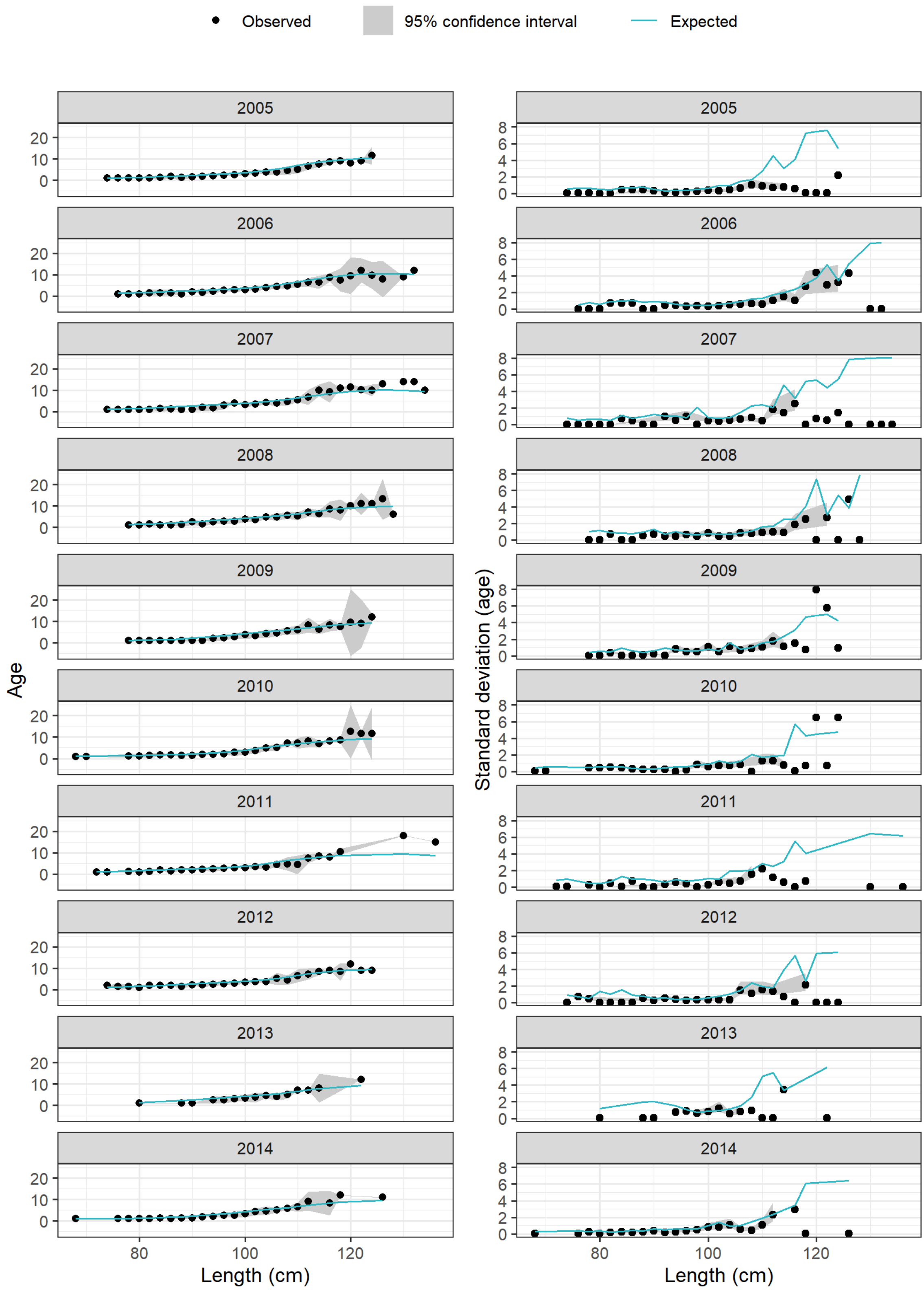

Figure D.17: Scenario 2: Mean age and standard deviation in male conditional age-at-length data for Fleet 6 between 2005 and 2014. Left plots are mean age at length by size-class (observed and expected) with confidence intervals obtained by adding the appropriate number of standard errors of mean to the data. Right plots in each pair are SE of mean age-at-length with confidence intervals based on the chi-square distribution.

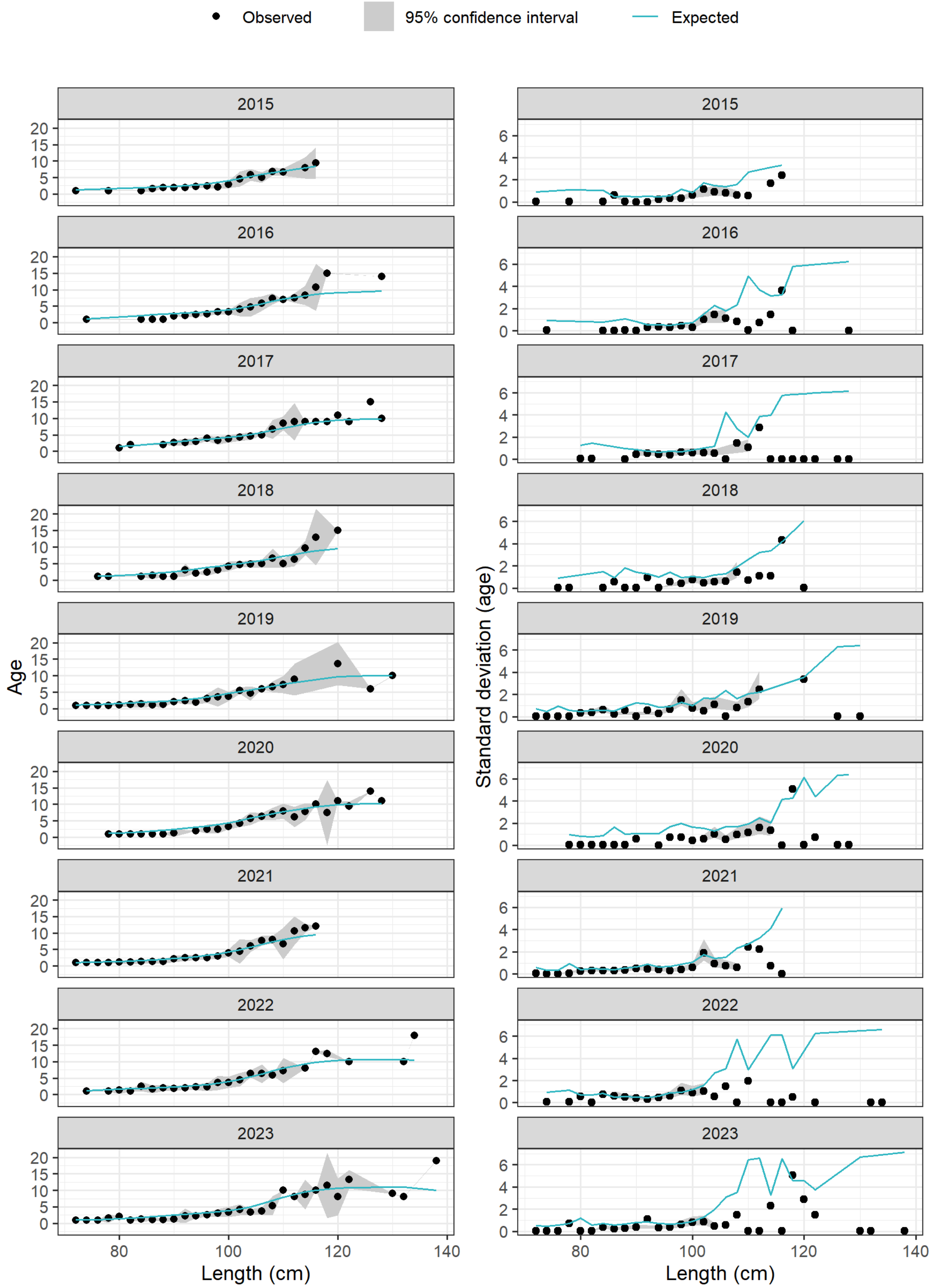

Figure D.18: Scenario 2: Mean age and standard deviation in male conditional age-at-length data for Fleet 6 between 2015 and 2023. Left plots are mean age at length by size-class (observed and expected) with confidence intervals obtained by adding the appropriate number of standard errors of mean to the data. Right plots in each pair are SE of mean age-at-length with confidence intervals based on the chi-square distribution.

D.3 Stock-recruit curve

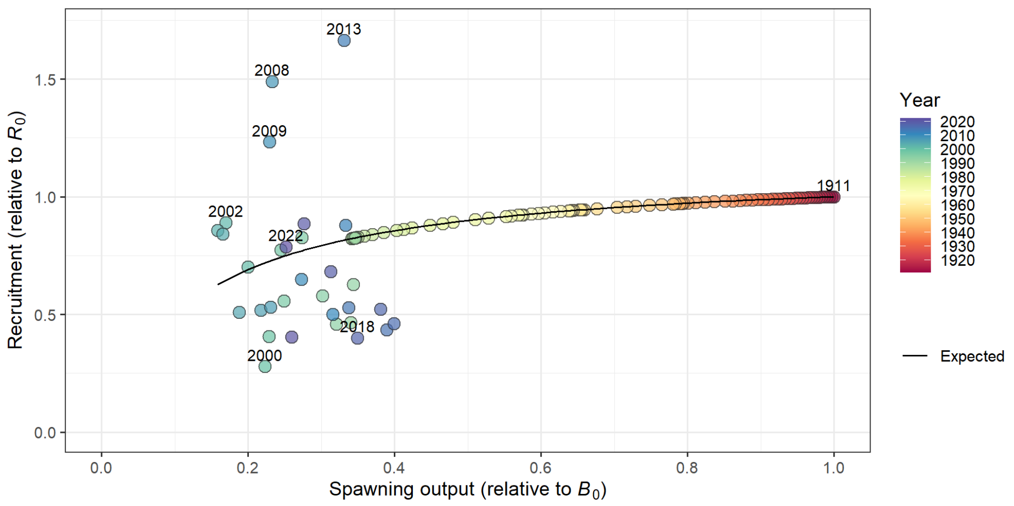

Figure D.19: Stock-recruit curve for Spanish mackerel in the Australian east coast based on the reference scenario 2—point colors indicate year, with warmer colors indicating earlier years and cooler colors in showing later years

D.4 Fishing mortality

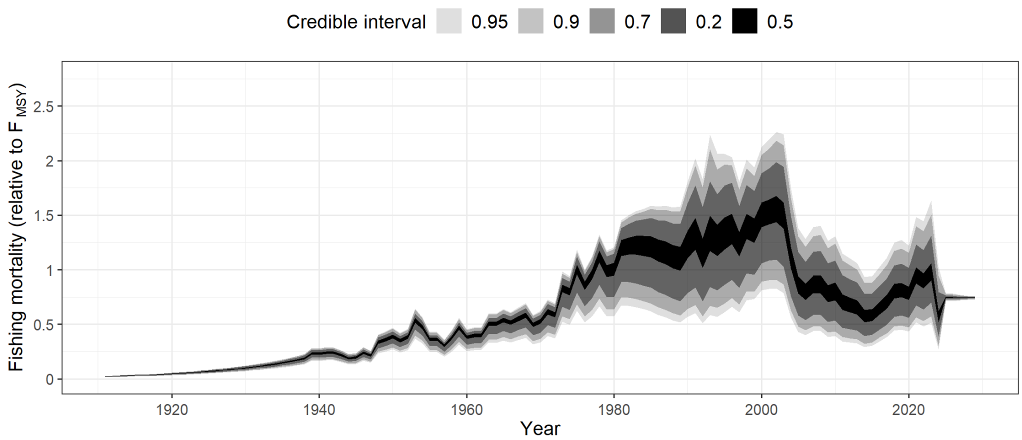

Figure D.20: Time series of fishing mortality ratio (F/F_{MSY}) from the ensemble model

D.5 Recruitment deviations

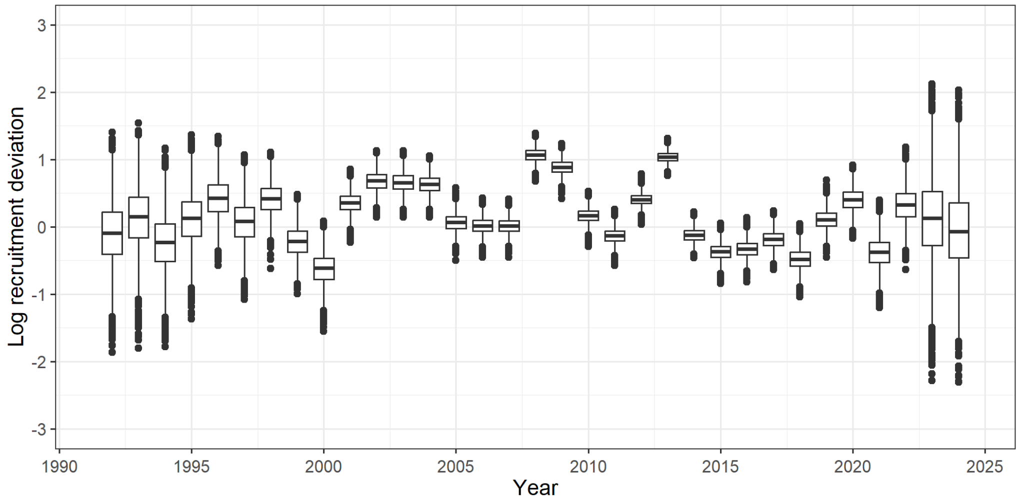

Figure D.21: Recruitment deviations from the ensemble model—whiskers represent 95% credible intervals, boxes represent 50% credible intervals, horizontal bars represent medians, and the points represent outliers

D.6 Sensitivity: parameter estimates and derived quantities

Figure D.22: Comparison of parameter estimates and derived quantities among the 6 scenarios included in the ensemble model

E Detailed model outputs

E.1 Scenario 1

Symbol	Value	Phase	Min	Max	Init	ParmStDev
Natural mortality	0.26	5	0.15	0.4	0.216	0.0204844
Length at minimum age (female)	75.29	3	65	90	75	0.962552
Length at maximum age (female)	138.86	3	130	160	140	1.52084
VonBert growth coefficient (female)	0.19	3	0.05	0.3	0.15	0.015019
SD of length at minimum age (female)	0.09	3	0.03	0.2	0.09	0.00450602
SD of length at maximum age (female)	0.07	3	0.03	0.2	0.07	0.00342233
Length at minimum age (male)	69.07	3	60	85	70	0.847748
Length at maximum age (male)	114	3	105	130	115	0.745012
VonBert growth coefficient (male)	0.33	3	0.15	0.4	0.3	0.0176862
SD of length at minimum age (male)	0.11	3	0.03	0.2	0.085	0.00418431
SD of length at maximum age (male)	0.04	3	0.01	0.15	0.04	0.00175962
Log of number of recruits when unfished	6.44	1	5	7	6.5	0.108525
Selectivity plateau start, Fleet 1	95.83	2	60	140	90	2.15626
Selectivity plateau width, Fleet 1	-12.1	2	-25	15	-2	143.27
Selectivity asc. width, Fleet 1	5.28	2	0	10	5	0.276461
Selectivity desc. width, Fleet 1	6.18	2	3	9	5	0.663967
Selectivity at max length, Fleet 1	0.17	2	0	1	0.2	0.175119
Selectivity plateau start, Fleet 2	101.22	2	60	140	90	6.77926
Selectivity plateau width, Fleet 2	5.37	2	-25	15	-2	24.2153
Selectivity asc. width, Fleet 2	6.85	2	0	10	5	0.514419
Selectivity desc. width, Fleet 2	5.99	2	3	9	5	67.1994
Selectivity at max length, Fleet 2	0.71	2	0.5	1	0.6	5.37718
Selectivity plateau start, Fleet 5	88.69	2	60	140	90	1.76837
Selectivity plateau width, Fleet 5	-12.35	2	-25	15	-2	141.186
Selectivity asc. width, Fleet 5	4.98	2	0	10	3	0.298546
Selectivity desc. width, Fleet 5	4.84	2	3	9	5	0.48925
Selectivity at max length, Fleet 5	0.24	2	0	1	0.2	0.0561615
Selectivity plateau start, Fleet 6	98.01	2	60	140	90	3.7124
Selectivity plateau width, Fleet 6	-11.59	2	-25	15	-2	148.104
Selectivity asc. width, Fleet 6	6.19	2	0	10	3	0.359462
Selectivity desc. width, Fleet 6	6.19	2	3	9	5	1.06195
Selectivity at max length, Fleet 6	0.36	2	0	1	0.2	0.256208
Selectivity plateau start, Fleet 7	93.24	2	60	140	90	5.46011
Selectivity plateau width, Fleet 7	-3.03	2	-25	15	-2	2.06291
Selectivity asc. width, Fleet 7	6.21	2	0	10	3	0.536328
Selectivity desc. width, Fleet 7	3.01	2	3	9	5	0.377722
Selectivity at max length, Fleet 7	0.85	2	0	1	0.6	0.134098
Selectivity plateau start, Fleet 8	97.88	2	60	140	90	3.8745
Selectivity plateau width, Fleet 8	5.44	2	-25	15	-2	18.9069
Selectivity asc. width, Fleet 8	6.49	2	0	10	3	0.367324
Selectivity desc. width, Fleet 8	6.02	2	3	9	5	67.4923
Selectivity at max length, Fleet 8	0.32	2	0	1	0.6	9.1318

Table E.1: Scenario 1: Summary of MLE parameter estimates. Fleet definitions are listed in Table 2.2.

Symbol	MCMC median	MCMC 2.5%	MCMC 97.5%
Natural mortality	0.25	0.22	0.3
Length at minimum age (female)	75.59	73.39	77.55
Length at maximum age (female)	138.8	136.16	142.55
VonBert growth coefficient (female)	0.19	0.15	0.22
SD of length at minimum age (female)	0.09	0.08	0.1
SD of length at maximum age (female)	0.07	0.06	0.08
Length at minimum age (male)	69.38	67.91	70.94
Length at maximum age (male)	114.34	113.06	115.84
VonBert growth coefficient (male)	0.33	0.29	0.36
SD of length at minimum age (male)	0.11	0.1	0.12
SD of length at maximum age (male)	0.04	0.03	0.04
Log of number of recruits when unfished	6.28	6.13	6.61
Selectivity plateau start, Fleet 1	96.53	91.87	101.34
Selectivity plateau width, Fleet 1	-14.52	-24.41	-2.92
Selectivity asc. width, Fleet 1	5.39	4.79	5.98
Selectivity desc. width, Fleet 1	5.71	3.95	7.01
Selectivity at max length, Fleet 1	0.27	0.03	0.56
Selectivity plateau start, Fleet 2	106.61	90.67	137.1
Selectivity plateau width, Fleet 2	2.43	-23.57	14.34
Selectivity asc. width, Fleet 2	7.34	6.1	9.17
Selectivity desc. width, Fleet 2	6.17	3.18	8.82
Selectivity at max length, Fleet 2	0.81	0.51	0.99
Selectivity plateau start, Fleet 5	89.14	85.57	93.16
Selectivity plateau width, Fleet 5	-14.12	-24.29	-3.58
Selectivity asc. width, Fleet 5	5.12	4.53	5.69
Selectivity desc. width, Fleet 5	4.71	3.43	5.63
Selectivity at max length, Fleet 5	0.24	0.15	0.38
Selectivity plateau start, Fleet 6	97.22	89.86	105.62
Selectivity plateau width, Fleet 6	-13.15	-24.41	-0.34
Selectivity asc. width, Fleet 6	6.19	5.45	7.07
Selectivity desc. width, Fleet 6	5.84	3.21	8.33
Selectivity at max length, Fleet 6	0.45	0.06	0.85
Selectivity plateau start, Fleet 7	91.85	83.67	102.05
Selectivity plateau width, Fleet 7	-16.37	-24.11	1.58
Selectivity asc. width, Fleet 7	6.16	5.25	7.42
Selectivity desc. width, Fleet 7	5.02	3.13	8.81
Selectivity at max length, Fleet 7	0.81	0.39	0.99
Selectivity plateau start, Fleet 8	98.37	92.41	105.97
Selectivity plateau width, Fleet 8	-12.99	-24.39	8.36
Selectivity asc. width, Fleet 8	6.43	5.92	7.26
Selectivity desc. width, Fleet 8	4	3.04	8.2
Selectivity at max length, Fleet 8	0.6	0.22	0.91

Table E.2: Scenario 1: Summary of MCMC parameter estimates. Fleet definitions are listed in Table 2.2.

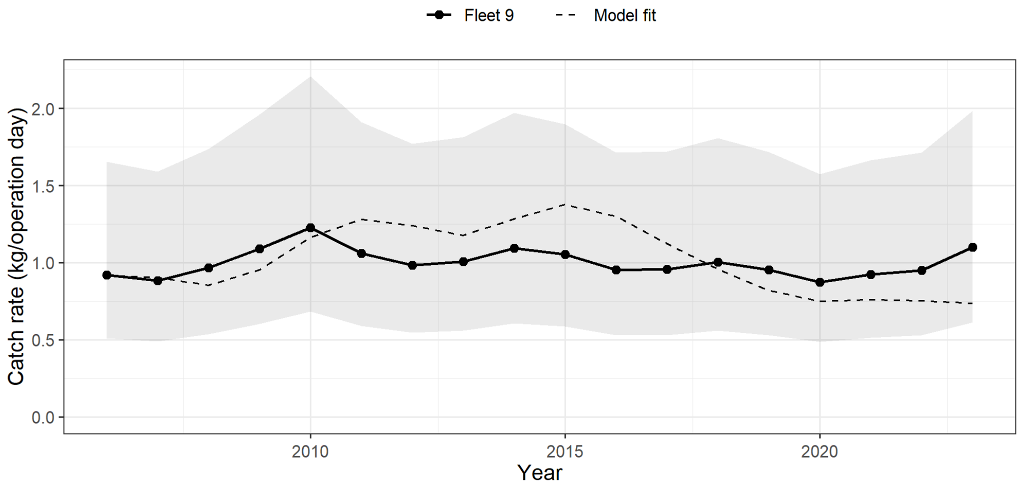

Figure E.1: Scenario 1: Model predictions (dotted line) to standardised catch rates for Australian east coast Spanish mackerel, based on maximum likelihood estimation—grey shade represent the model input and associated uncertainty

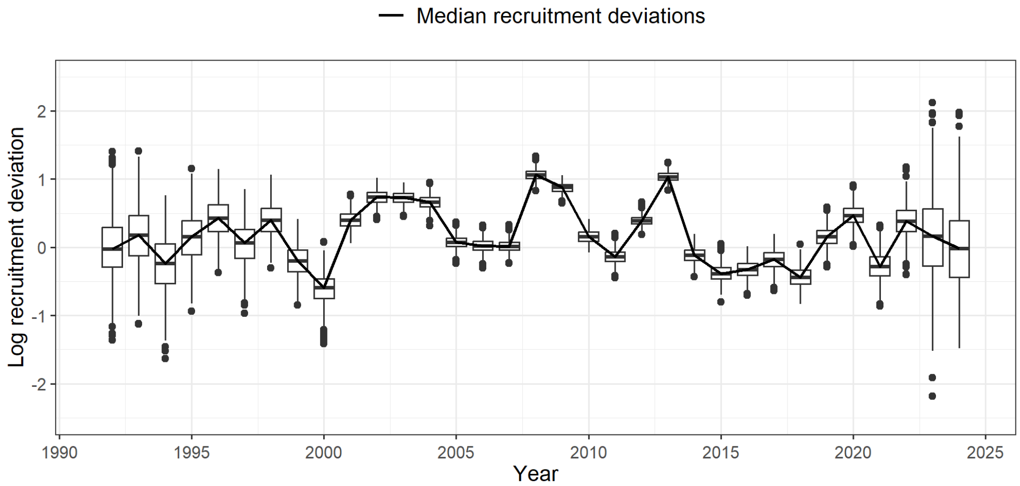

Figure E.2: Scenario 1: Recruitment deviations—whiskers represent 95% credible intervals, boxes represent 50% credible intervals, horizontal bars represent medians, and the points represent outliers

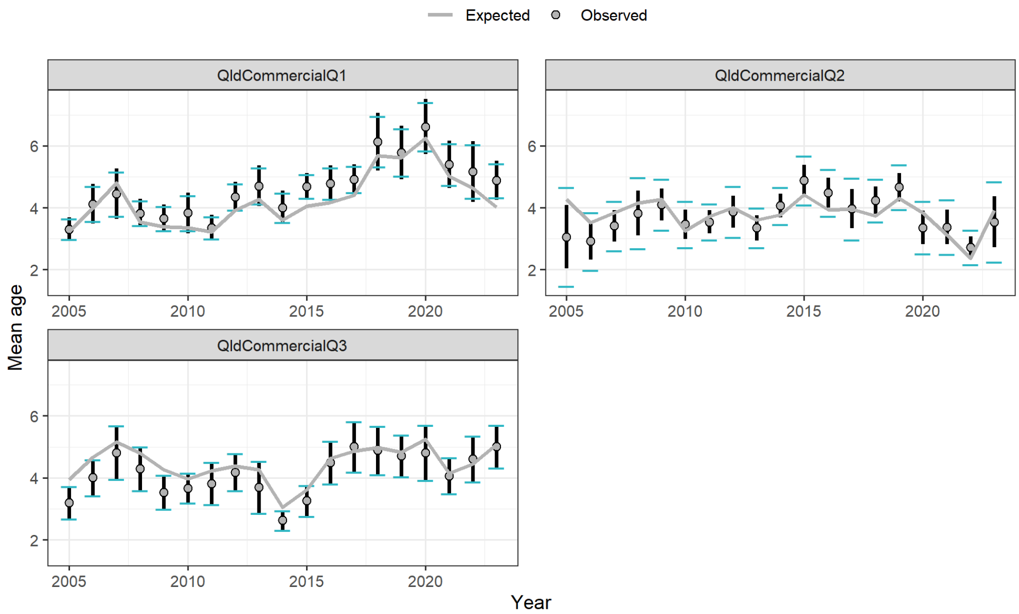

Figure E.3: Scenario 1: Mean age from conditional data (aggregated across length bins) with 95% confidence intervals based on current samples sizes: thinner intervals (with capped ends) show result of further adjusting sample sizes based on suggested multiplier (with 95% interval) for conditional age-at-length data

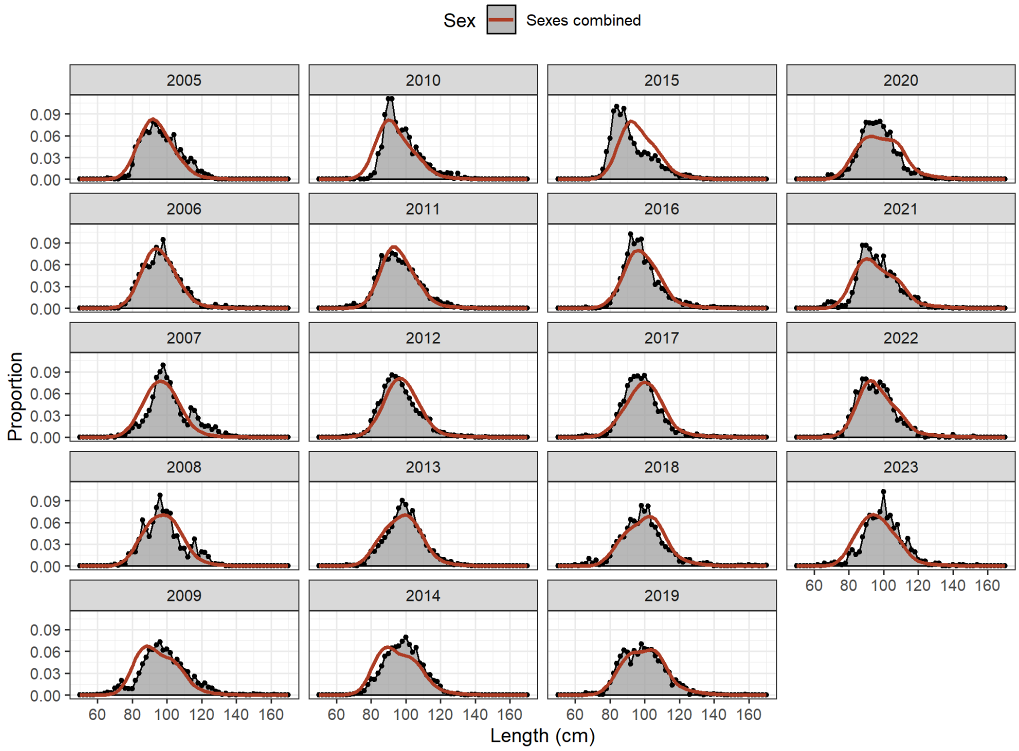

Figure E.4: Scenario 1: Fits to length structures for Fleet 1, based on maximum likelihood estimation—the grey area and black line represent data inputs and the red and blue line represents the model fits for female and male, respectively

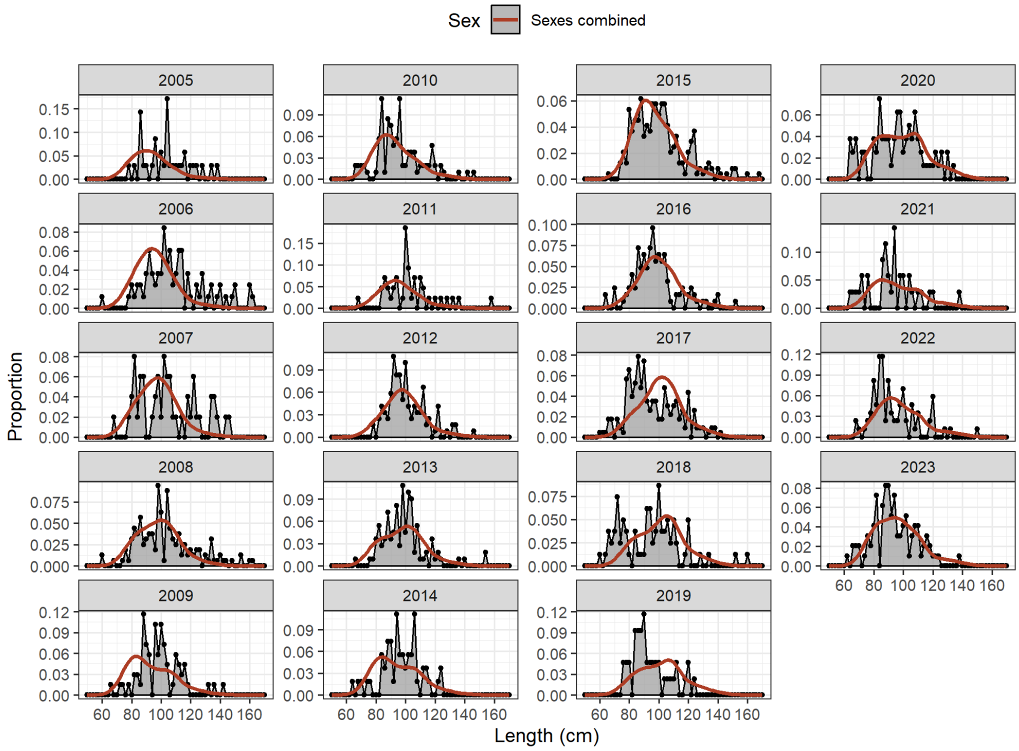

Figure E.5: Scenario 1: Fits to length structures for Fleet 2, based on maximum likelihood estimation—the grey area and black line represent data inputs and the red and blue line represents the model fits for female and male, respectively

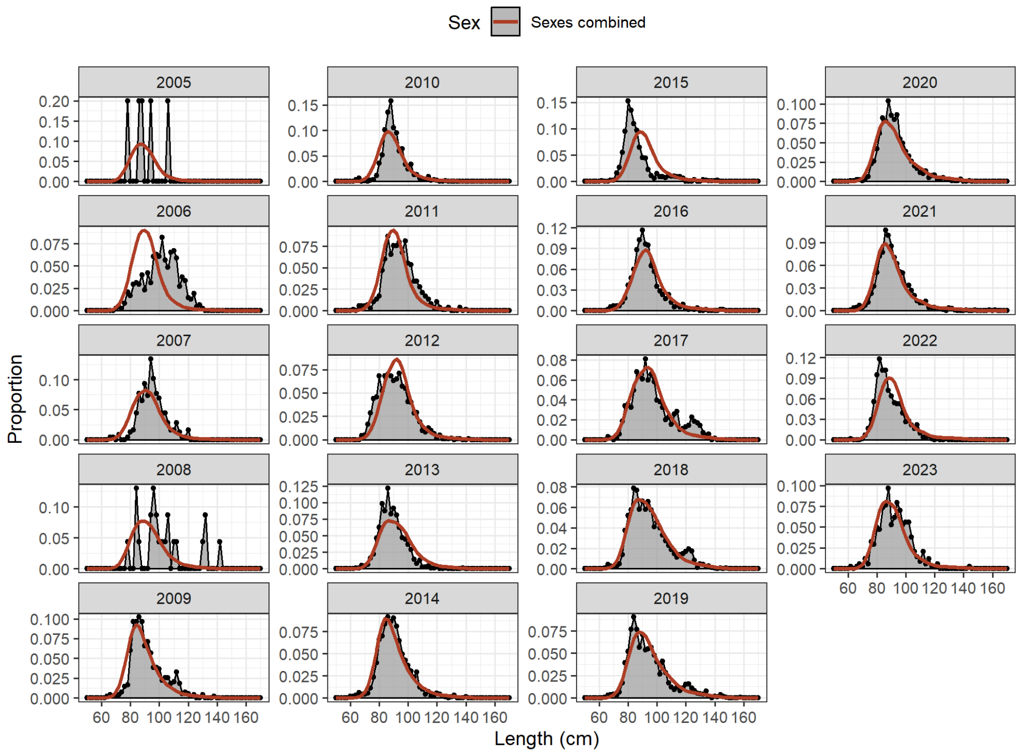

Figure E.6: Scenario 1: Fits to length structures for Fleet 5, based on maximum likelihood estimation—the grey area and black line represent data inputs and the red and blue line represents the model fits for female and male, respectively

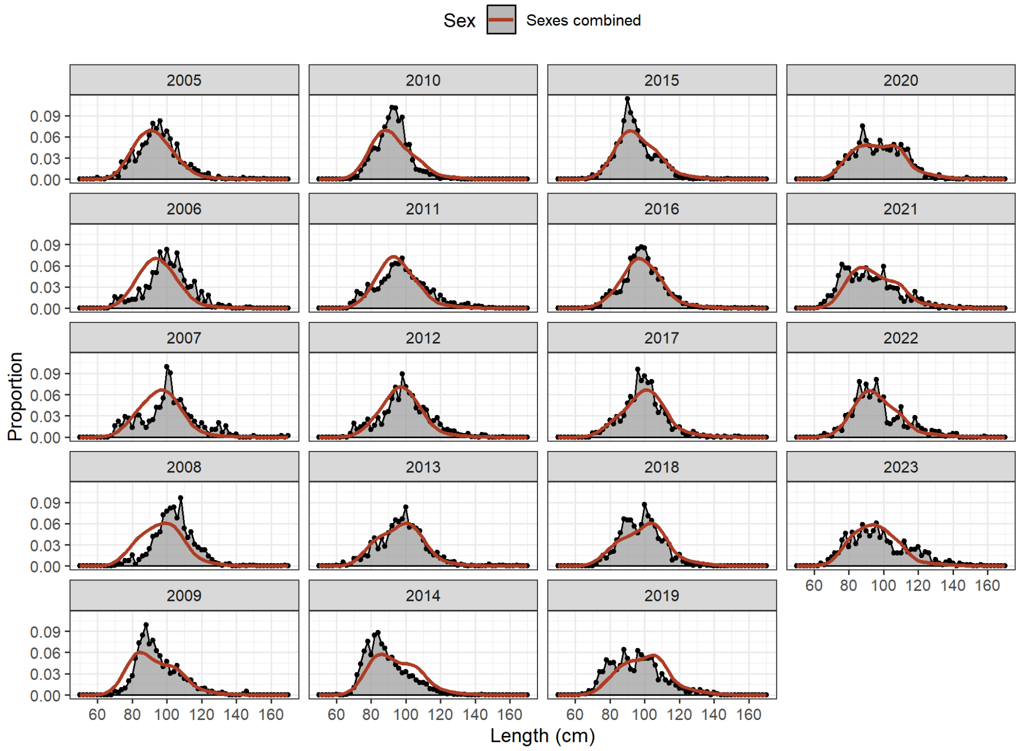

Figure E.7: Scenario 1: Fits to length structures for Fleet 6, based on maximum likelihood estimation—the grey area and black line represent data inputs and the red and blue line represents the model fits for female and male, respectively

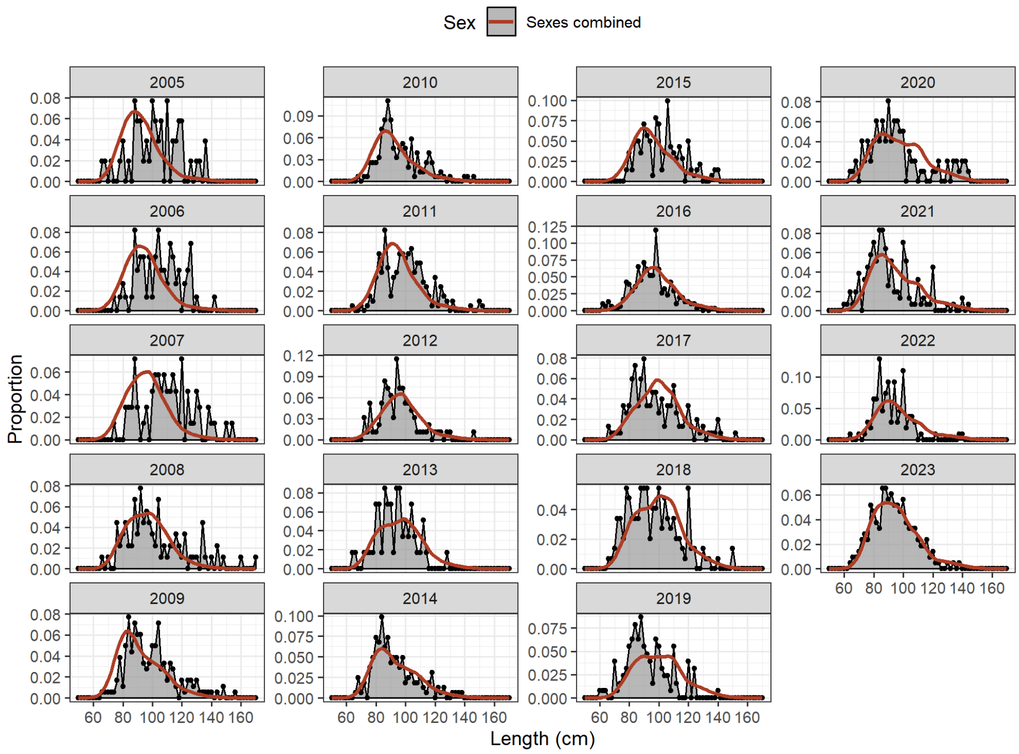

Figure E.8: Scenario 1: Fits to length structures for Fleet 7, based on maximum likelihood estimation—the grey area and black line represent data inputs and the red and blue line represents the model fits for female and male, respectively

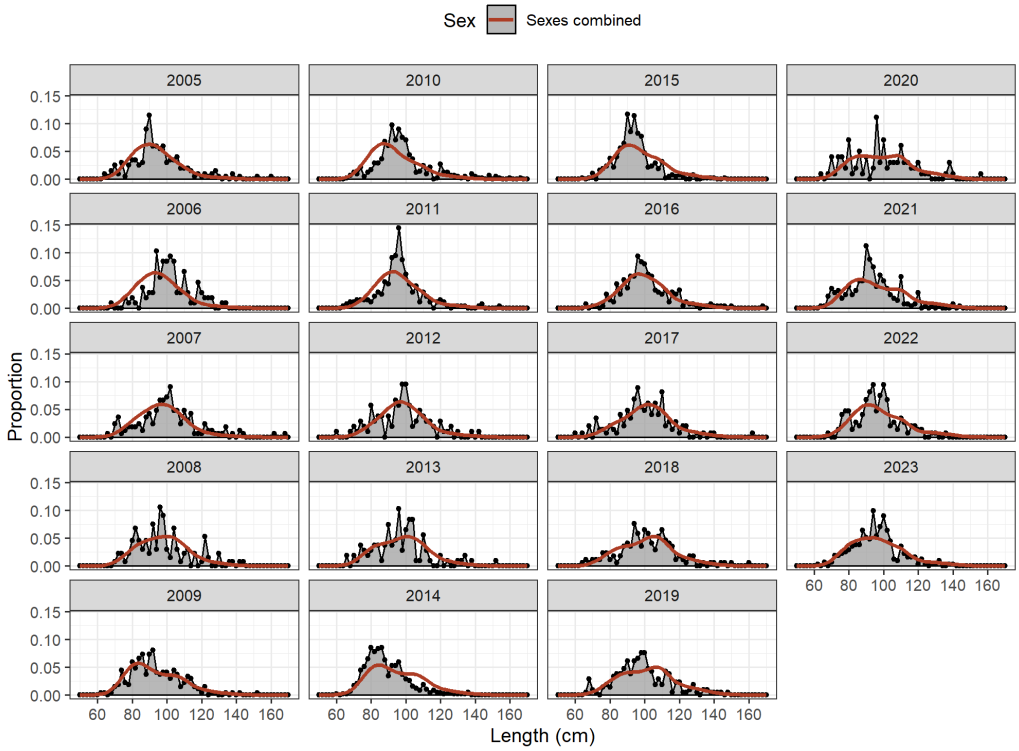

Figure E.9: Scenario 1: Fits to length structures for Fleet 8, based on maximum likelihood estimation—the grey area and black line represent data inputs and the red and blue line represents the model fits for female and male, respectively

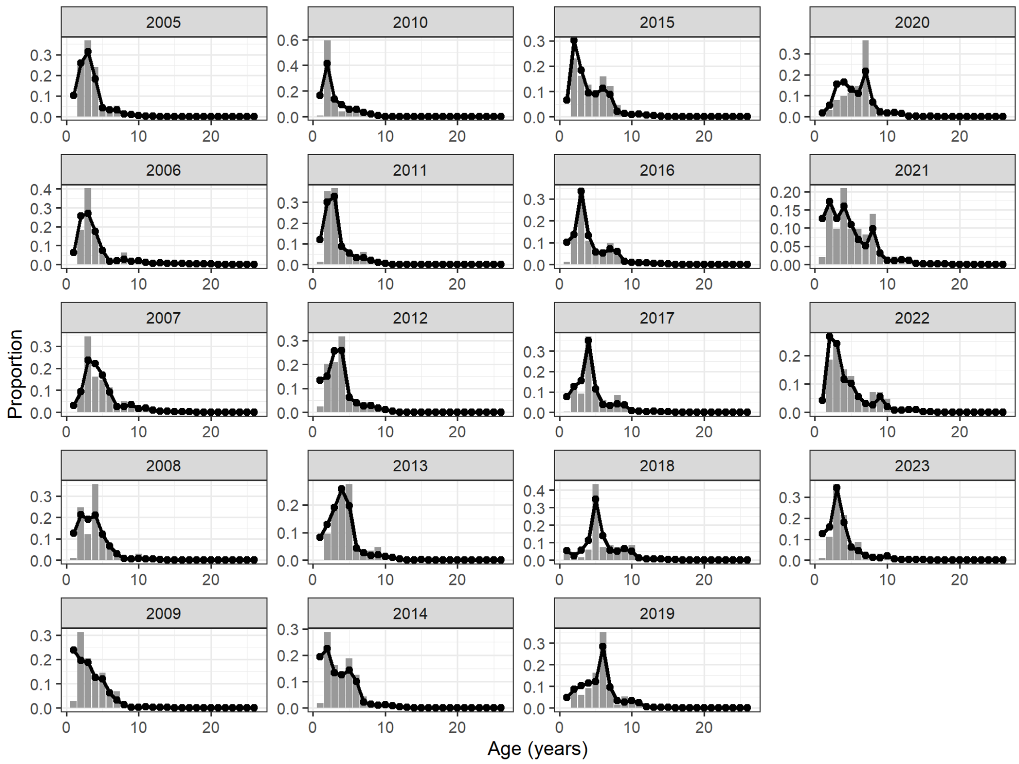

Figure E.10: Scenario 1: Fits to annual age compositions of female Spanish mackerel for Fleet 1

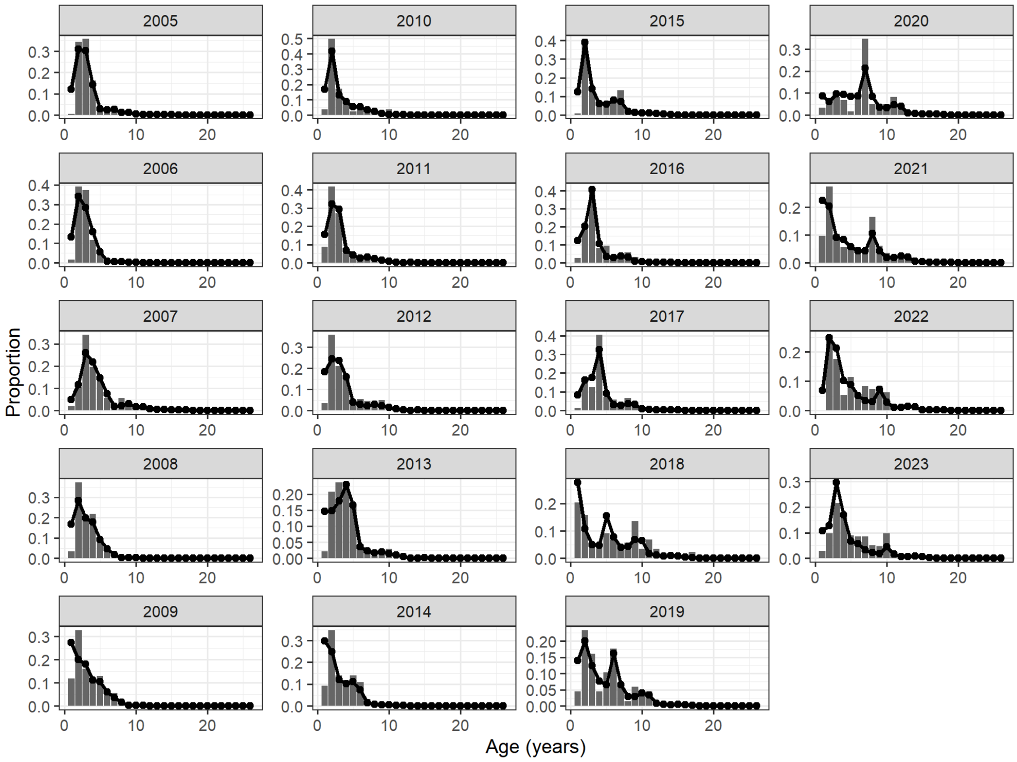

Figure E.11: Scenario 1: Fits to annual age compositions of male Spanish mackerel for Fleet 1

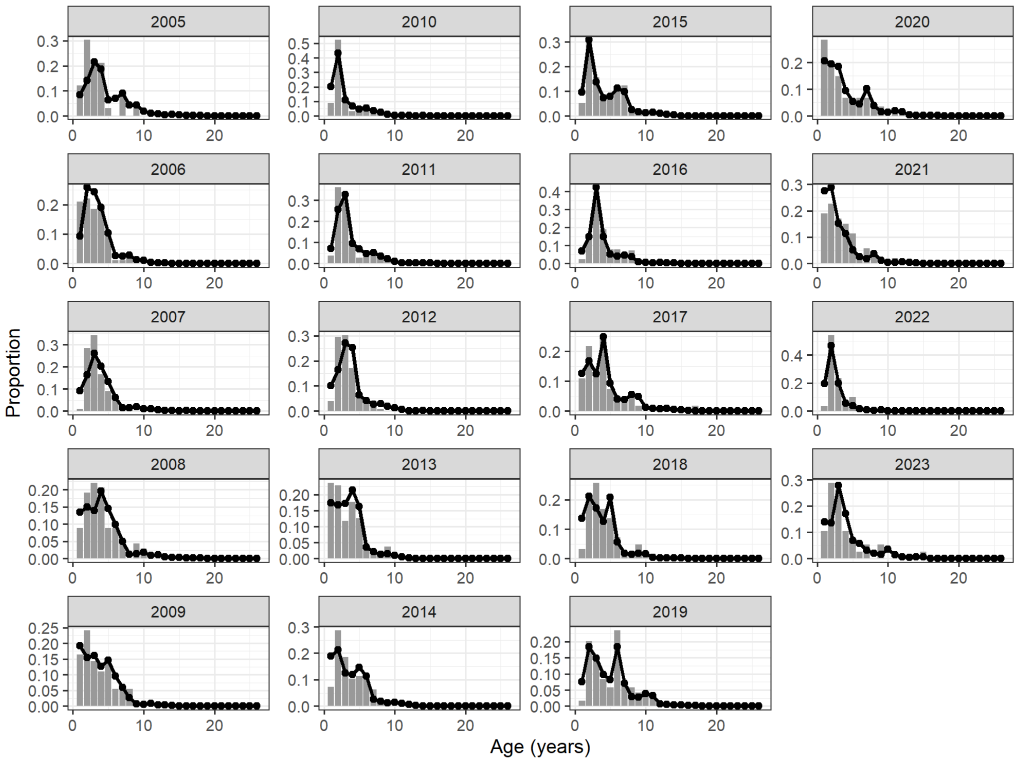

Figure E.12: Scenario 1: Fits to annual age compositions of female Spanish mackerel for Fleet 5

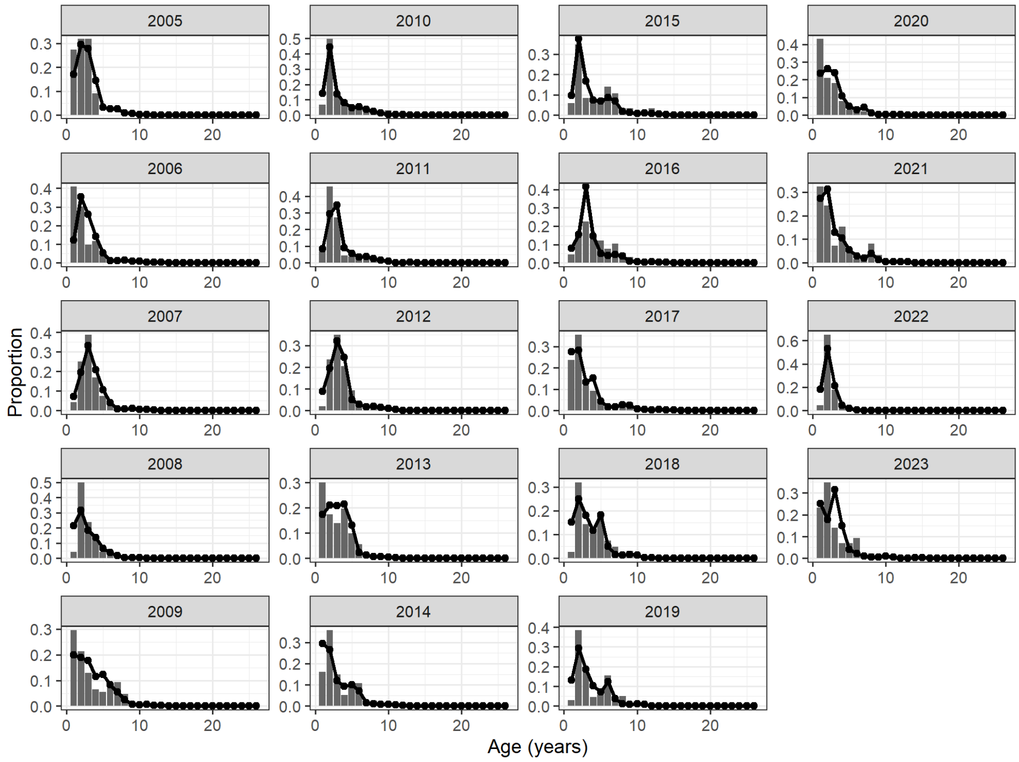

Figure E.13: Scenario 1: Fits to annual age compositions of male Spanish mackerel for Fleet 5

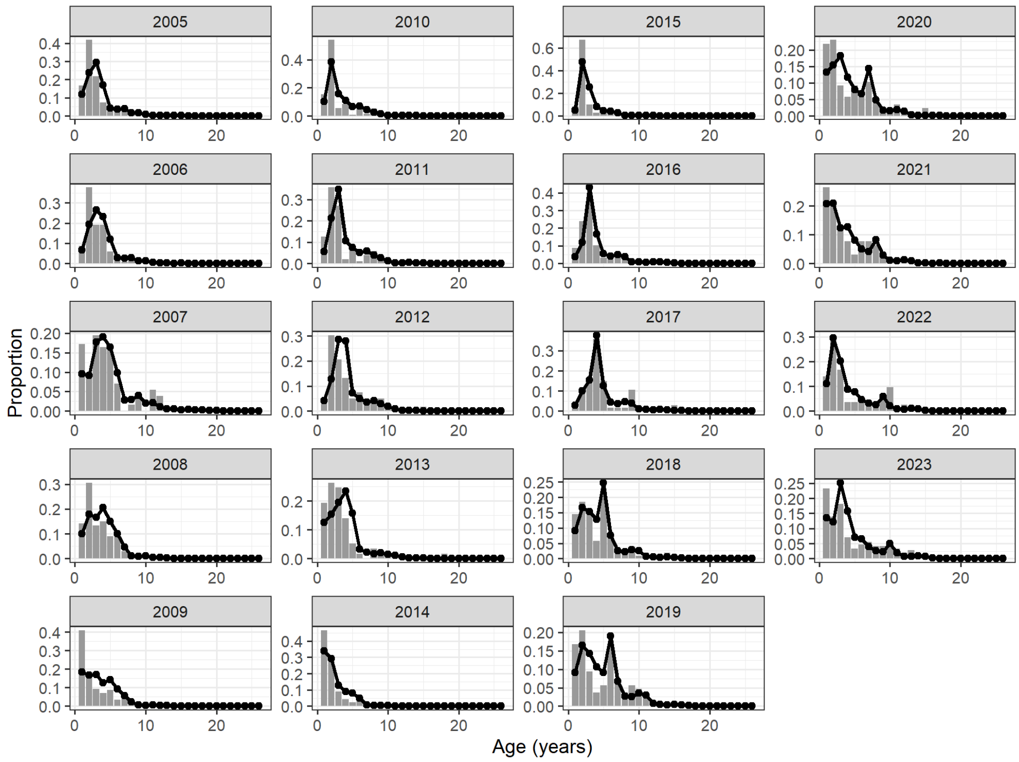

Figure E.14: Scenario 1: Fits to annual age compositions of female Spanish mackerel for Fleet 6

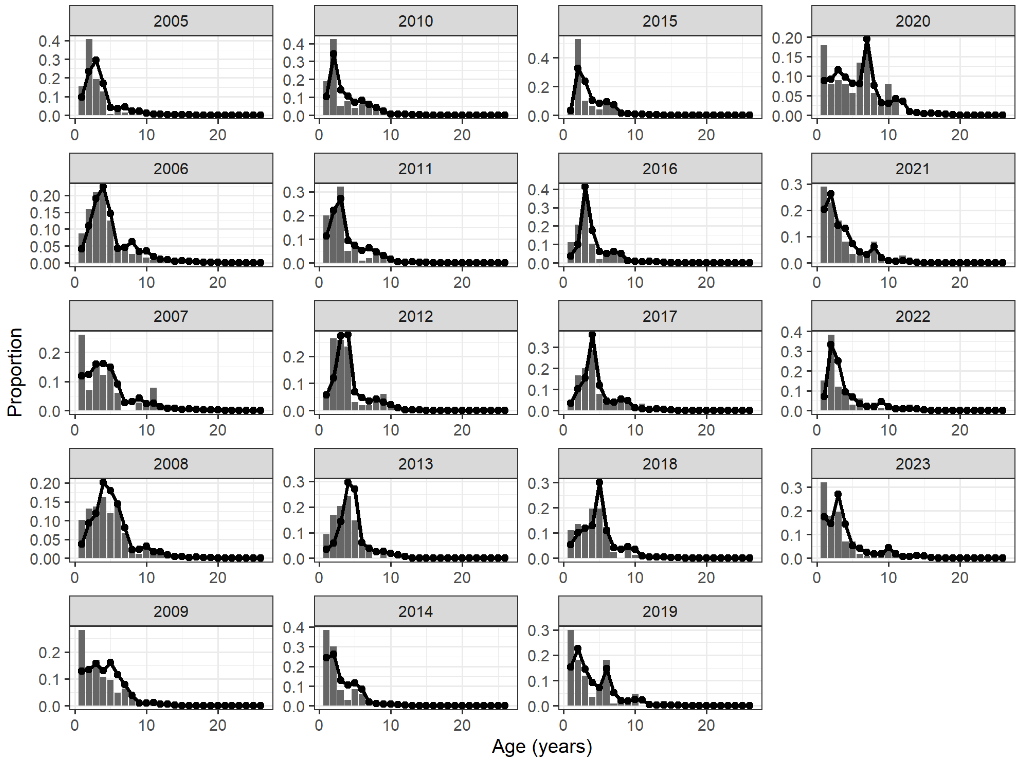

Figure E.15: Scenario 1: Fits to annual age compositions of male Spanish mackerel for Fleet 6

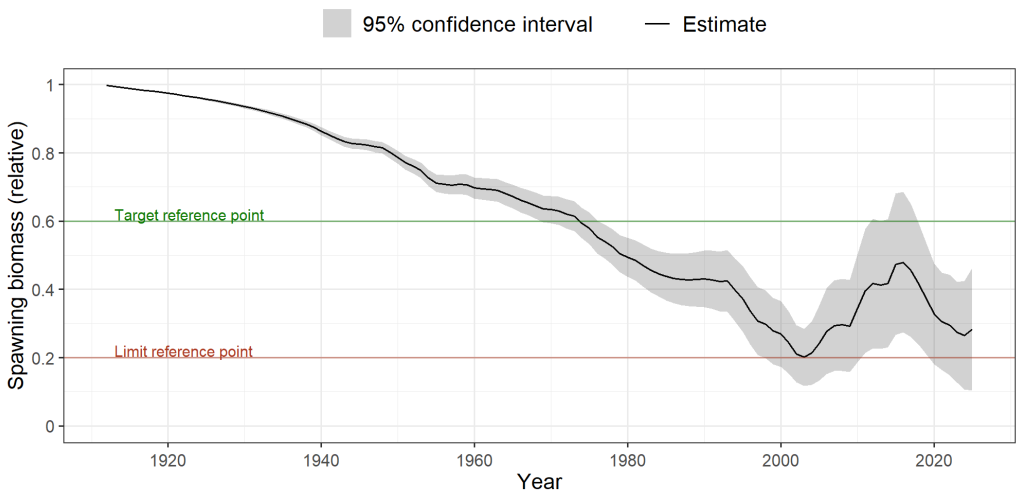

Figure E.16: Scenario 1: Predicted spawning biomass trajectory relative to unfished for Australian east coast Spanish mackerel, based on maximum likelihood estimation

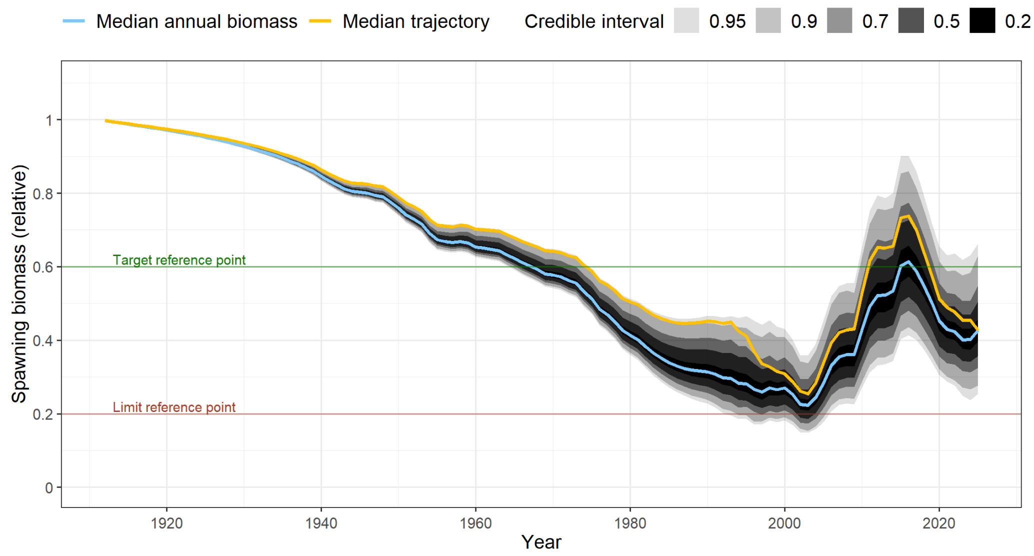

Figure E.17: Scenario 1: Predicted spawning biomass trajectory relative to unfished for Australian east coast Spanish mackerel, based on MCMC

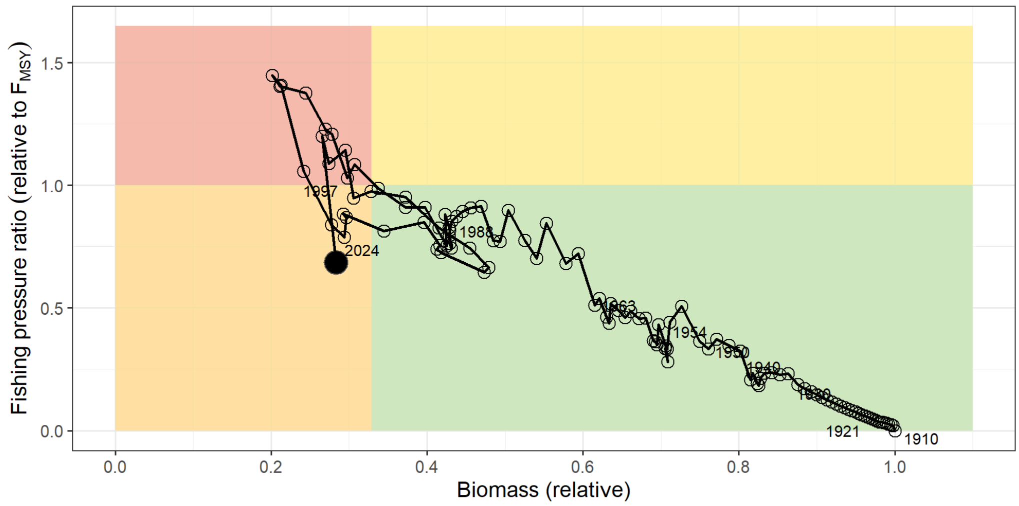

Figure E.18: Scenario 1: Stock status indicator trajectory for Australian east coast Spanish mackerel, based on maximum likelihood estimation

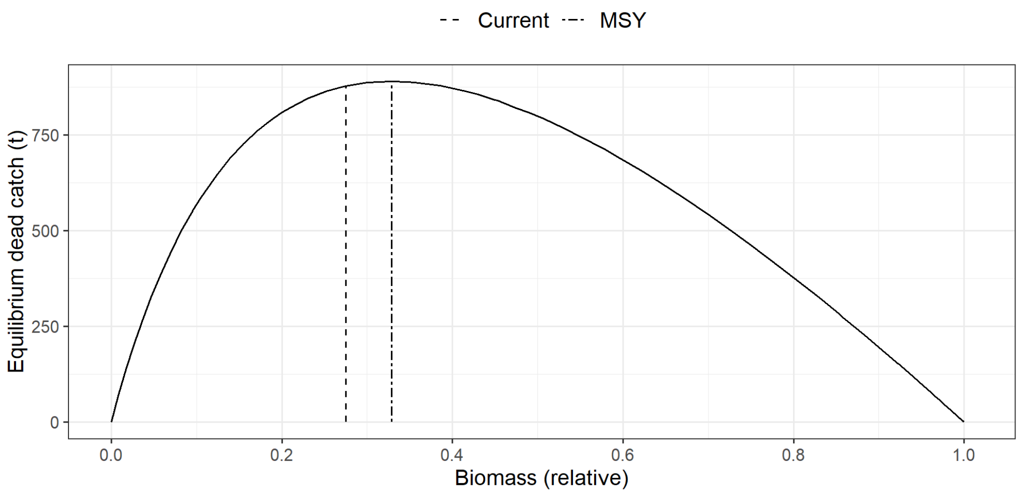

Figure E.19: Scenario 1: Equilibrium dead catch curve for Australian east coast Spanish mackerel, based on maximum likelihood estimation

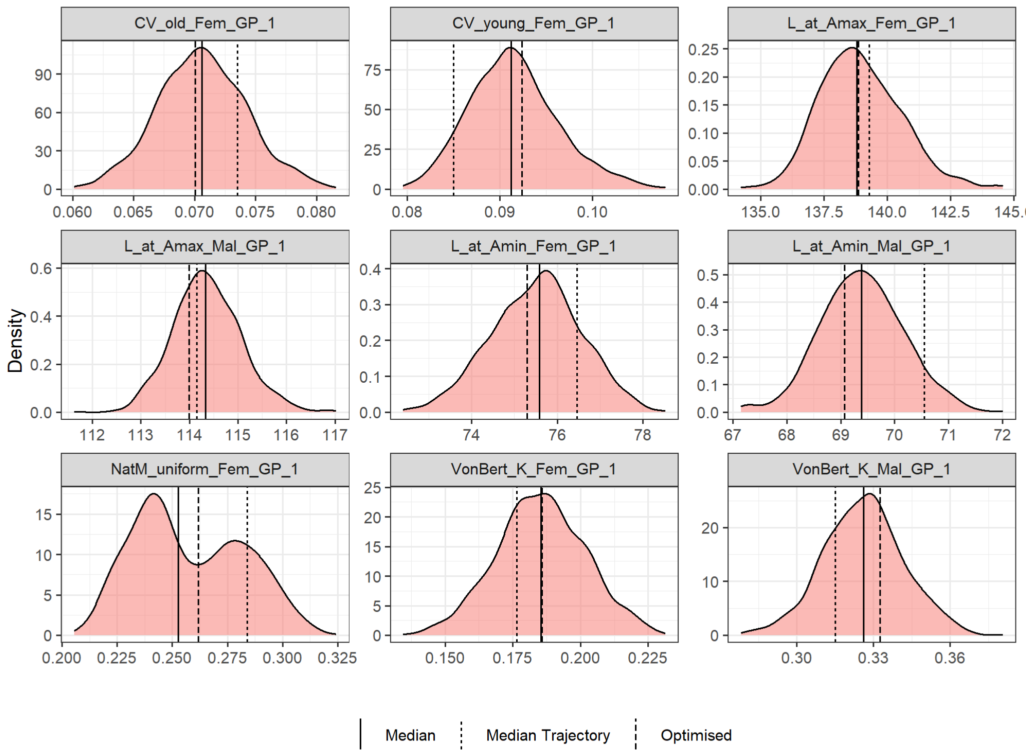

Figure E.20: Scenario 1: Posterior density of MCMC iterations. "Median" line shows median parameter value for MCMC iterations "Optimised" shows the parameter value found from maximum likelihood estimates.

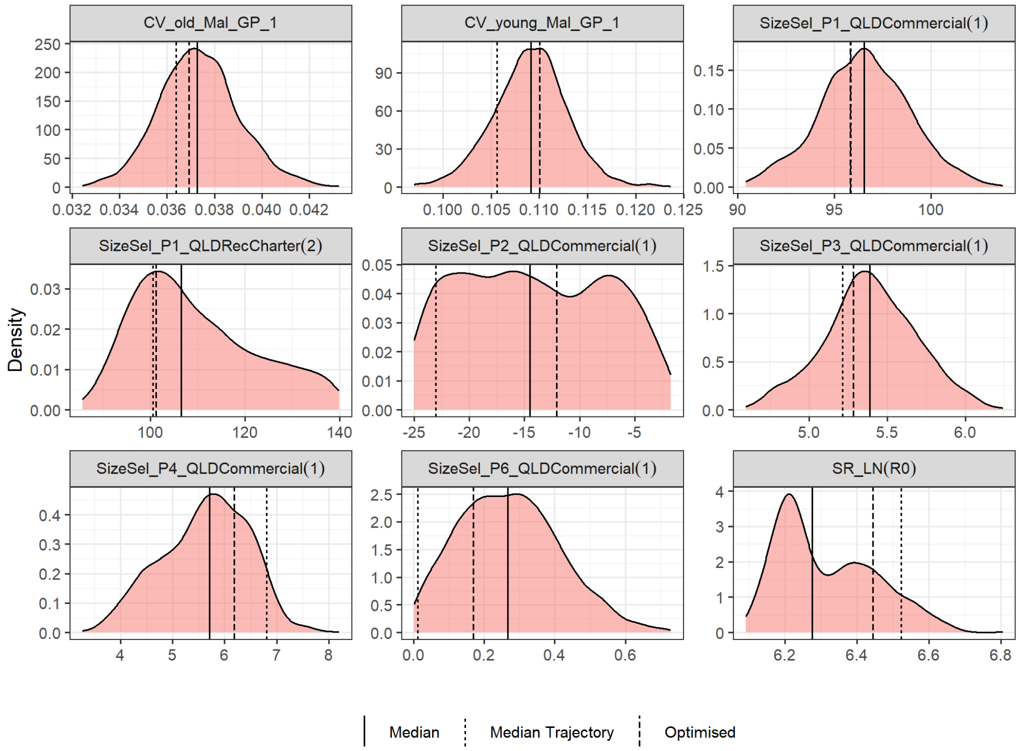

Figure E.21: Scenario 1: Posterior density of MCMC iterations. "Median" line shows median parameter value for MCMC iterations "Optimised" shows the parameter value found from maximum likelihood estimates.

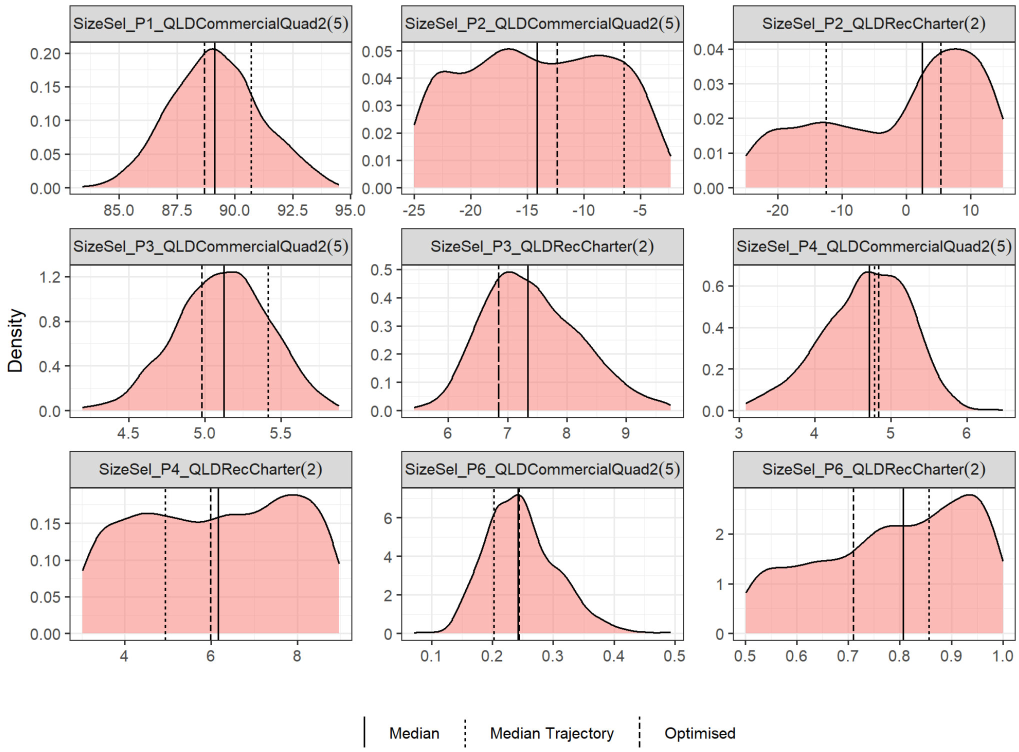

Figure E.22: Scenario 1: Posterior density of MCMC iterations. "Median" line shows median parameter value for MCMC iterations "Optimised" shows the parameter value found from maximum likelihood estimates.

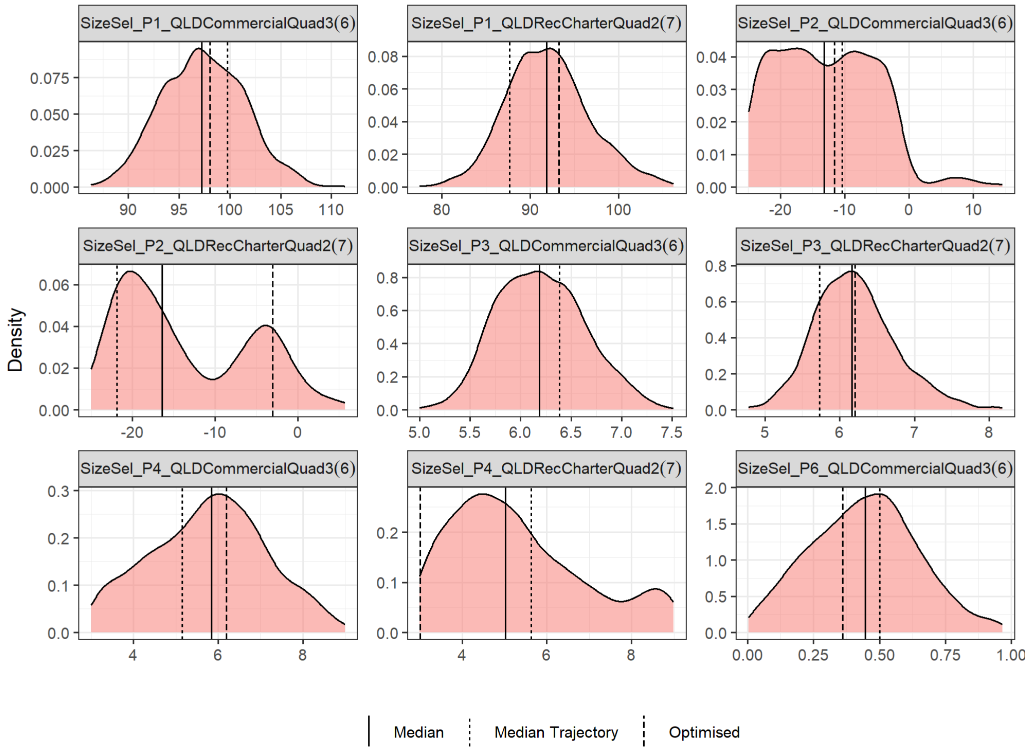

Figure E.23: Scenario 1: Posterior density of MCMC iterations. "Median" line shows median parameter value for MCMC iterations "Optimised" shows the parameter value found from maximum likelihood estimates.

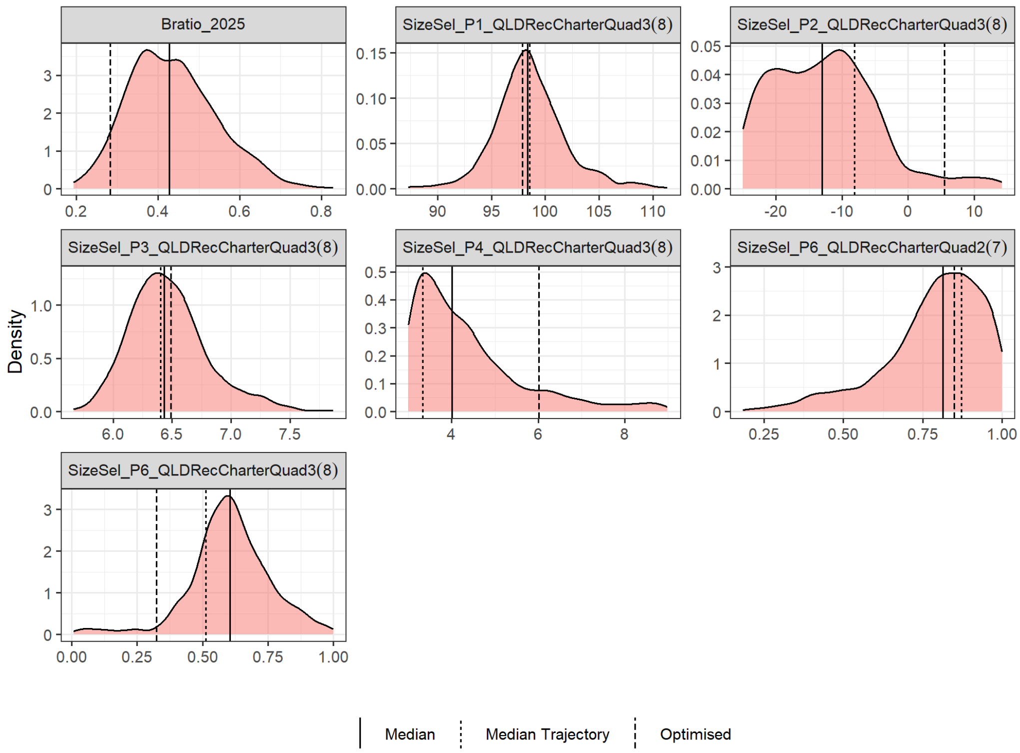

Figure E.24: Scenario 1: Posterior density of MCMC iterations. "Median" line shows median parameter value for MCMC iterations "Optimised" shows the parameter value found from maximum likelihood estimates.

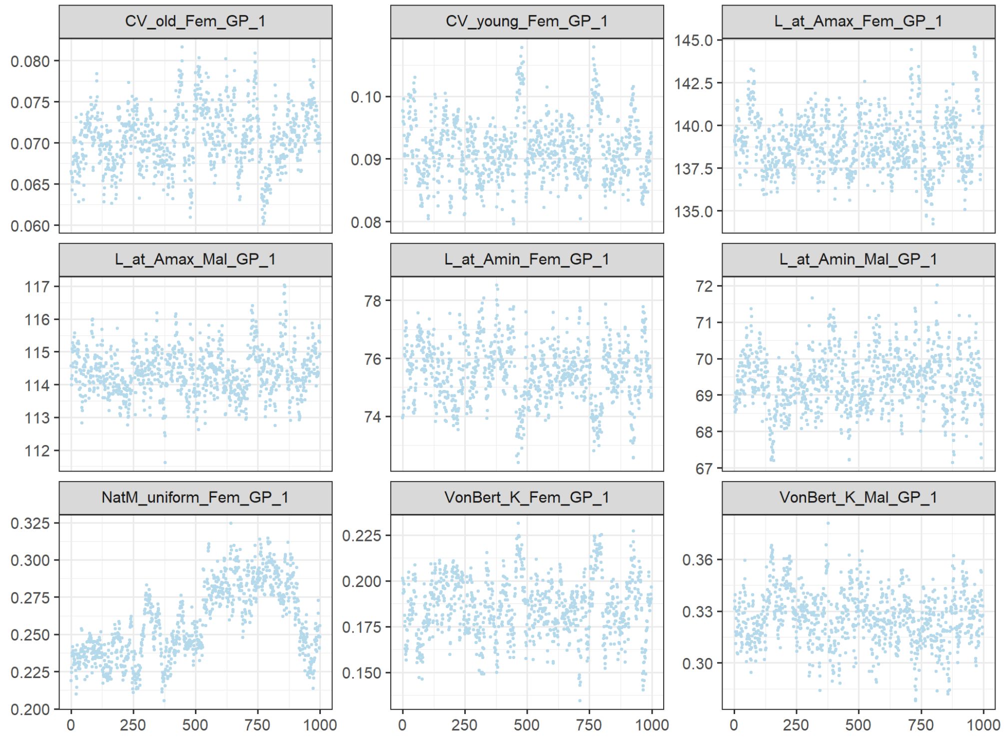

Figure E.25: Scenario 1: Trace plot of MCMC iterations

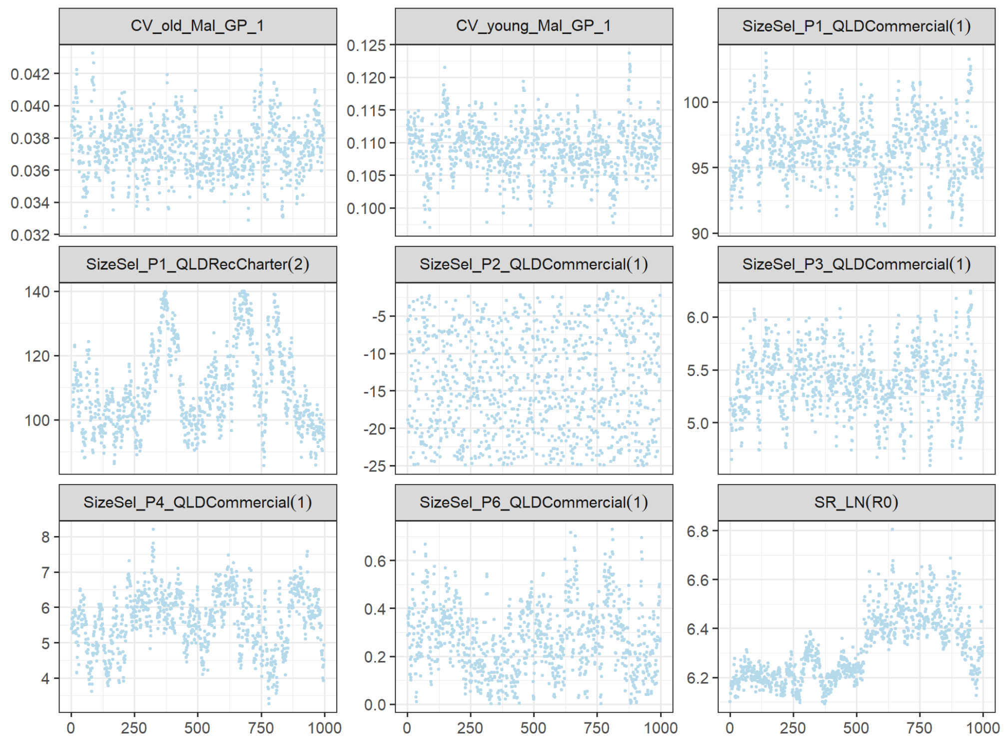

Figure E.26: Scenario 1: Trace plot of MCMC iterations

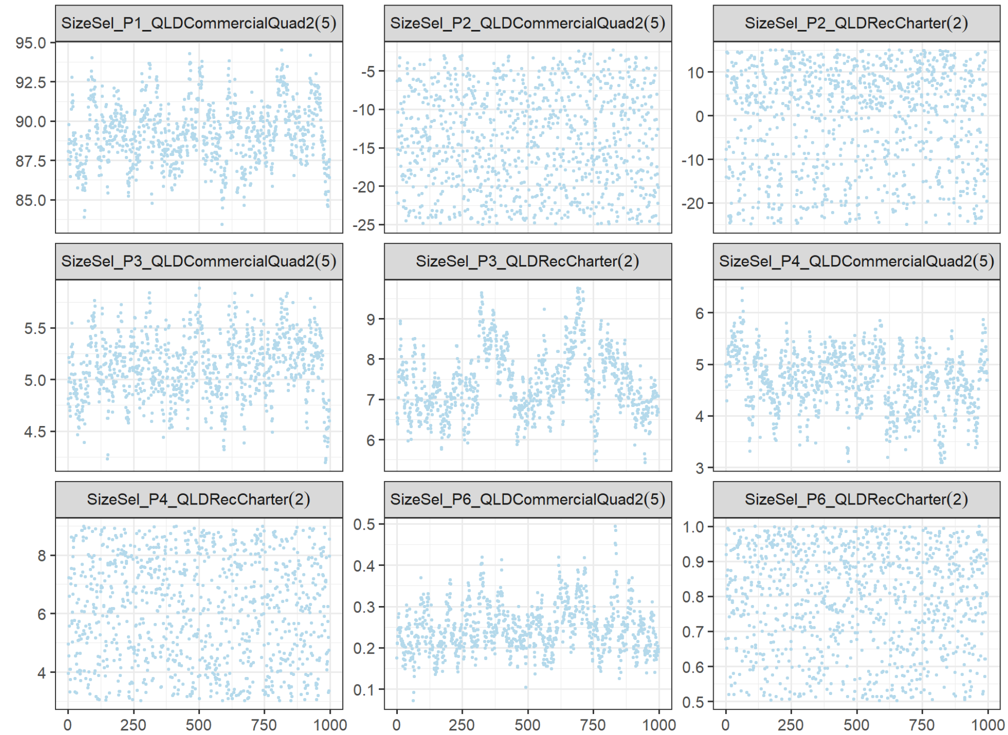

Figure E.27: Scenario 1: Trace plot of MCMC iterations

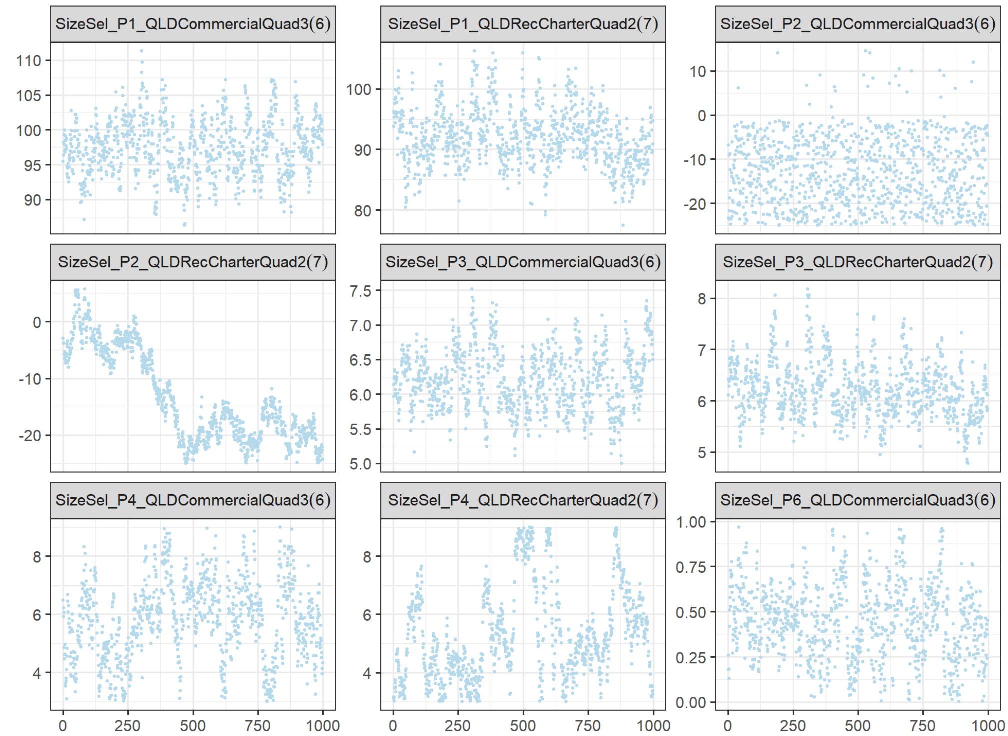

Figure E.28: Scenario 1: Trace plot of MCMC iterations

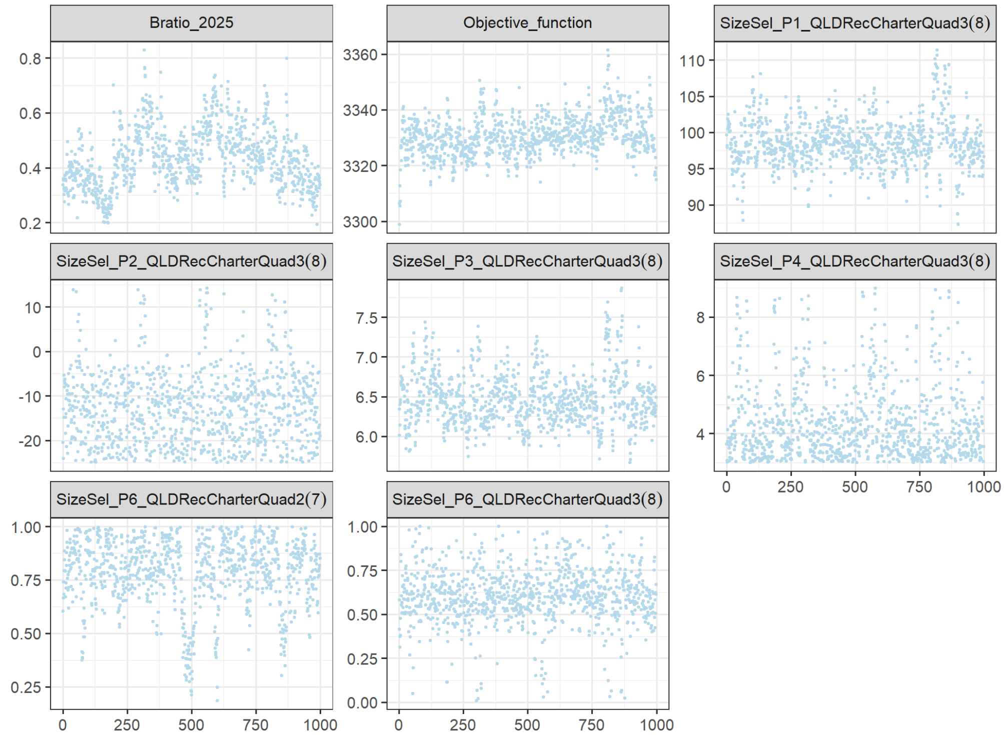

Figure E.29: Scenario 1: Trace plot of MCMC iterations

E.2 Scenario 2

Symbol	Value	Phase	Min	Max	Init	ParmStDev
Natural mortality	0.23	5	0.15	0.4	0.216	0.0221016
Length at minimum age (female)	75.57	3	65	90	75	0.933925
Length at maximum age (female)	138.55	3	130	160	140	1.49386
VonBert growth coefficient (female)	0.18	3	0.05	0.3	0.15	0.0146228
SD of length at minimum age (female)	0.09	3	0.03	0.2	0.09	0.00439556
SD of length at maximum age (female)	0.07	3	0.03	0.2	0.07	0.00346451
Length at minimum age (male)	69.39	3	60	85	70	0.824127
Length at maximum age (male)	113.72	3	105	130	115	0.71614
VonBert growth coefficient (male)	0.33	3	0.15	0.4	0.3	0.0173607
SD of length at minimum age (male)	0.11	3	0.03	0.2	0.085	0.00395282
SD of length at maximum age (male)	0.04	3	0.01	0.15	0.04	0.00170605
Log of number of recruits when unfished	6.07	1	5	7	6.5	0.103758
Selectivity plateau start, Fleet 1	96.32	2	60	140	90	2.21371
Selectivity plateau width, Fleet 1	-11.97	2	-25	15	-2	146.26
Selectivity asc. width, Fleet 1	5.33	2	0	10	5	0.277738
Selectivity desc. width, Fleet 1	6.24	2	3	9	5	0.66863
Selectivity at max length, Fleet 1	0.17	2	0	1	0.2	0.186771
Selectivity plateau start, Fleet 2	104.19	2	60	140	90	8.35783
Selectivity plateau width, Fleet 2	5.32	2	-25	15	-2	24.8516
Selectivity asc. width, Fleet 2	7	2	0	10	5	0.568187
Selectivity desc. width, Fleet 2	5.99	2	3	9	5	67.1679
Selectivity at max length, Fleet 2	0.73	2	0.5	1	0.6	5.53085
Selectivity plateau start, Fleet 5	88.85	2	60	140	90	1.82941
Selectivity plateau width, Fleet 5	-12.24	2	-25	15	-2	141.966
Selectivity asc. width, Fleet 5	5.01	2	0	10	3	0.304655
Selectivity desc. width, Fleet 5	4.79	2	3	9	5	0.527327
Selectivity at max length, Fleet 5	0.27	2	0	1	0.2	0.0594884
Selectivity plateau start, Fleet 6	96.92	2	60	140	90	4.8635
Selectivity plateau width, Fleet 6	4.67	2	-25	15	-2	88.5465
Selectivity asc. width, Fleet 6	6.19	2	0	10	3	0.461323
Selectivity desc. width, Fleet 6	5.99	2	3	9	5	67.0559
Selectivity at max length, Fleet 6	0.95	2	0	1	0.2	1.62739
Selectivity plateau start, Fleet 7	92.57	2	60	140	90	4.57355
Selectivity plateau width, Fleet 7	2	2	-25	15	-2	32.7988
Selectivity asc. width, Fleet 7	6.21	2	0	10	3	0.502788
Selectivity desc. width, Fleet 7	5.98	2	3	9	5	67.3785
Selectivity at max length, Fleet 7	0.99	2	0	1	0.6	0.254526
Selectivity plateau start, Fleet 8	99.04	2	60	140	90	3.74548
Selectivity plateau width, Fleet 8	5.43	2	-25	15	-2	19.5508
Selectivity asc. width, Fleet 8	6.54	2	0	10	3	0.349016
Selectivity desc. width, Fleet 8	6.02	2	3	9	5	67.502
Selectivity at max length, Fleet 8	0.38	2	0	1	0.6	10.1189

Table E.3: Scenario 2: Summary of MLE parameter estimates. Fleet definitions are listed in Table 2.2.

Symbol	MCMC median	MCMC 2.5%	MCMC 97.5%
Natural mortality	0.19	0.17	0.22
Length at minimum age (female)	75.15	73.52	76.83
Length at maximum age (female)	138.76	136.04	141.88
VonBert growth coefficient (female)	0.19	0.16	0.22
SD of length at minimum age (female)	0.09	0.08	0.1
SD of length at maximum age (female)	0.07	0.07	0.08
Length at minimum age (male)	69.62	68.02	71.17
Length at maximum age (male)	114.39	112.88	115.93
VonBert growth coefficient (male)	0.32	0.29	0.36
SD of length at minimum age (male)	0.11	0.1	0.12
SD of length at maximum age (male)	0.04	0.03	0.04
Log of number of recruits when unfished	5.79	5.7	5.9
Selectivity plateau start, Fleet 1	97.29	93.01	102.54
Selectivity plateau width, Fleet 1	-13.67	-24.47	-3.25
Selectivity asc. width, Fleet 1	5.5	4.95	6.02
Selectivity desc. width, Fleet 1	5.63	4.05	6.82
Selectivity at max length, Fleet 1	0.23	0.03	0.49
Selectivity plateau start, Fleet 2	104	91.11	134.97
Selectivity plateau width, Fleet 2	1.8	-23.59	14.51
Selectivity asc. width, Fleet 2	7.17	6.22	8.6
Selectivity desc. width, Fleet 2	6.15	3.13	8.88
Selectivity at max length, Fleet 2	0.81	0.53	0.99
Selectivity plateau start, Fleet 5	89.74	85.91	93.48
Selectivity plateau width, Fleet 5	-14.07	-24.46	-3.65
Selectivity asc. width, Fleet 5	5.18	4.58	5.81
Selectivity desc. width, Fleet 5	4.56	3.49	5.63
Selectivity at max length, Fleet 5	0.24	0.14	0.34
Selectivity plateau start, Fleet 6	97.45	89.84	105.97
Selectivity plateau width, Fleet 6	-12.81	-24.49	1.01
Selectivity asc. width, Fleet 6	6.19	5.52	6.97
Selectivity desc. width, Fleet 6	6.21	3.31	8.29
Selectivity at max length, Fleet 6	0.37	0.03	0.84
Selectivity plateau start, Fleet 7	91.19	81.95	102.12
Selectivity plateau width, Fleet 7	0.85	-23.3	14.23
Selectivity asc. width, Fleet 7	6.22	5.3	7.37
Selectivity desc. width, Fleet 7	5.83	3.15	8.89
Selectivity at max length, Fleet 7	0.68	0.09	0.99
Selectivity plateau start, Fleet 8	98.97	92.27	105.12
Selectivity plateau width, Fleet 8	-13.8	-24.55	4.16
Selectivity asc. width, Fleet 8	6.42	5.93	7.08
Selectivity desc. width, Fleet 8	3.83	3.04	7.54
Selectivity at max length, Fleet 8	0.59	0.32	0.86

Table E.4: Scenario 2: Summary of MCMC parameter estimates. Fleet definitions are listed in Table 2.2.

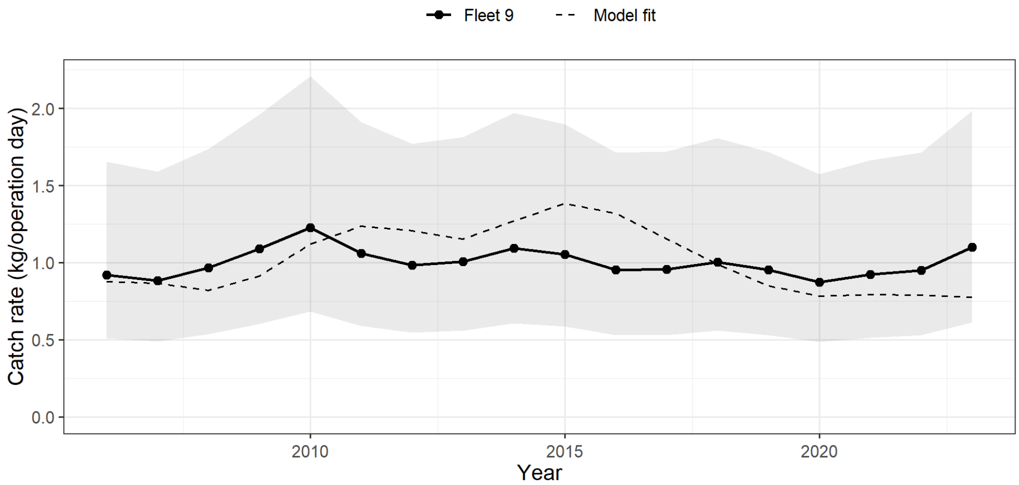

Figure E.30: Scenario 2: Model predictions (dotted line) to standardised catch rates for Australian east coast Spanish mackerel, based on maximum likelihood estimation—grey shade represent the model input and associated uncertainty

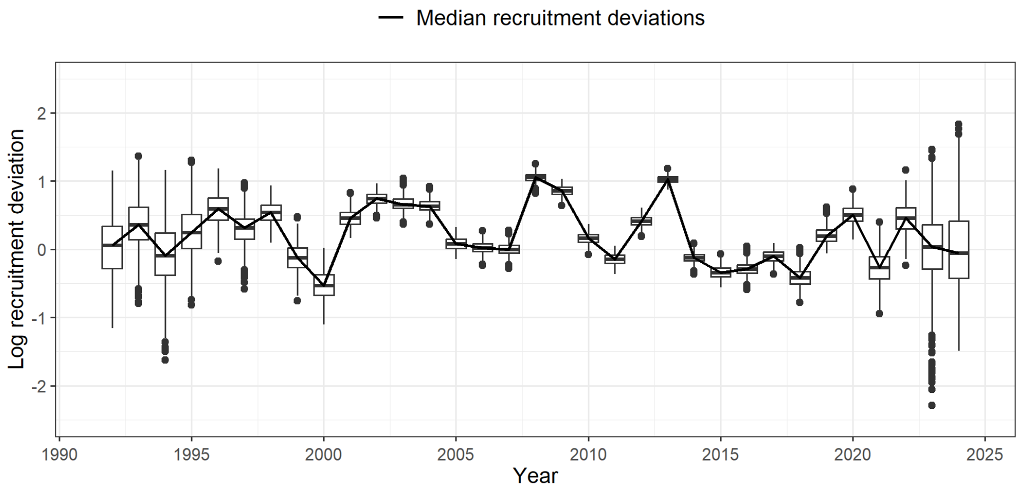

Figure E.31: Scenario 2: Recruitment deviations—whiskers represent 95% credible intervals, boxes represent 50% credible intervals, horizontal bars represent medians, and the points represent outliers

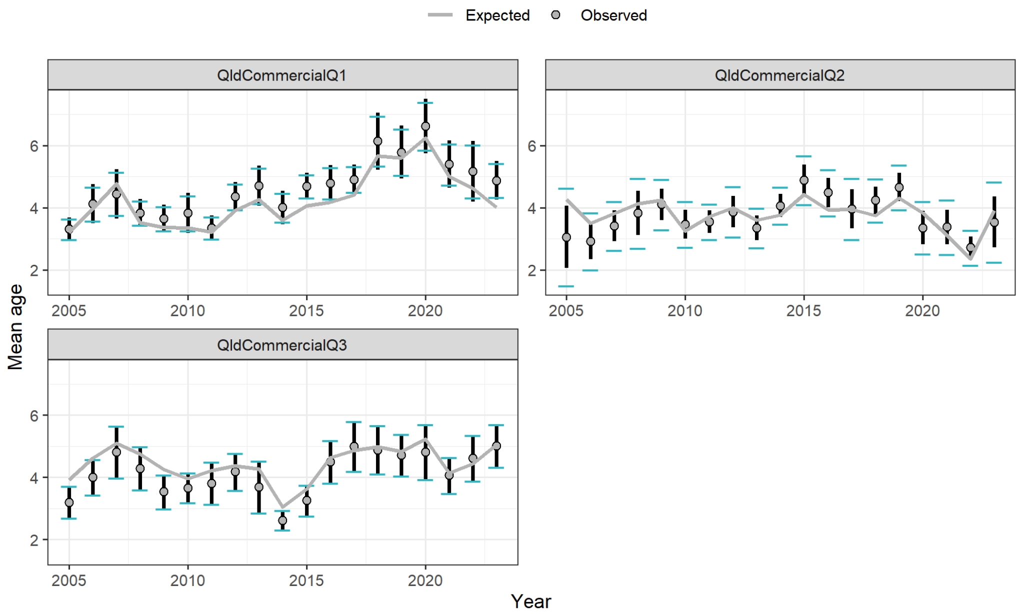

Figure E.32: Scenario 2: Mean age from conditional data (aggregated across length bins) with 95% confidence intervals based on current samples sizes: thinner intervals (with capped ends) show result of further adjusting sample sizes based on suggested multiplier (with 95% interval) for conditional age-at-length data

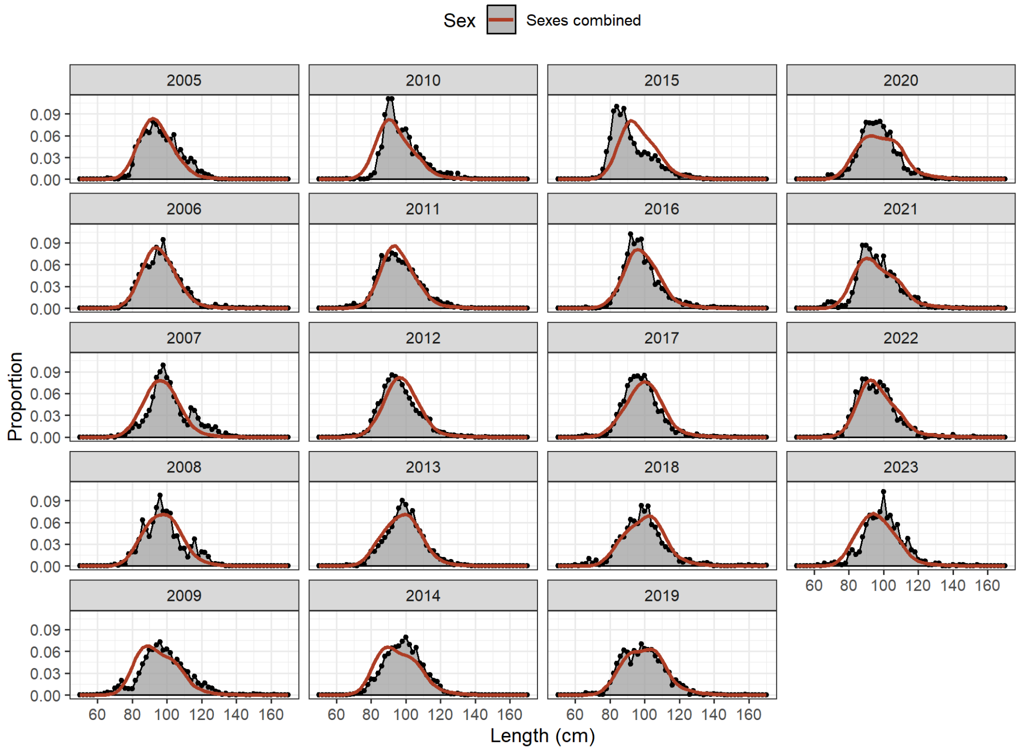

Figure E.33: Scenario 2: Fits to length structures for Fleet 1, based on maximum likelihood estimation—the grey area and black line represent data inputs and the red and blue line represents the model fits for female and male, respectively

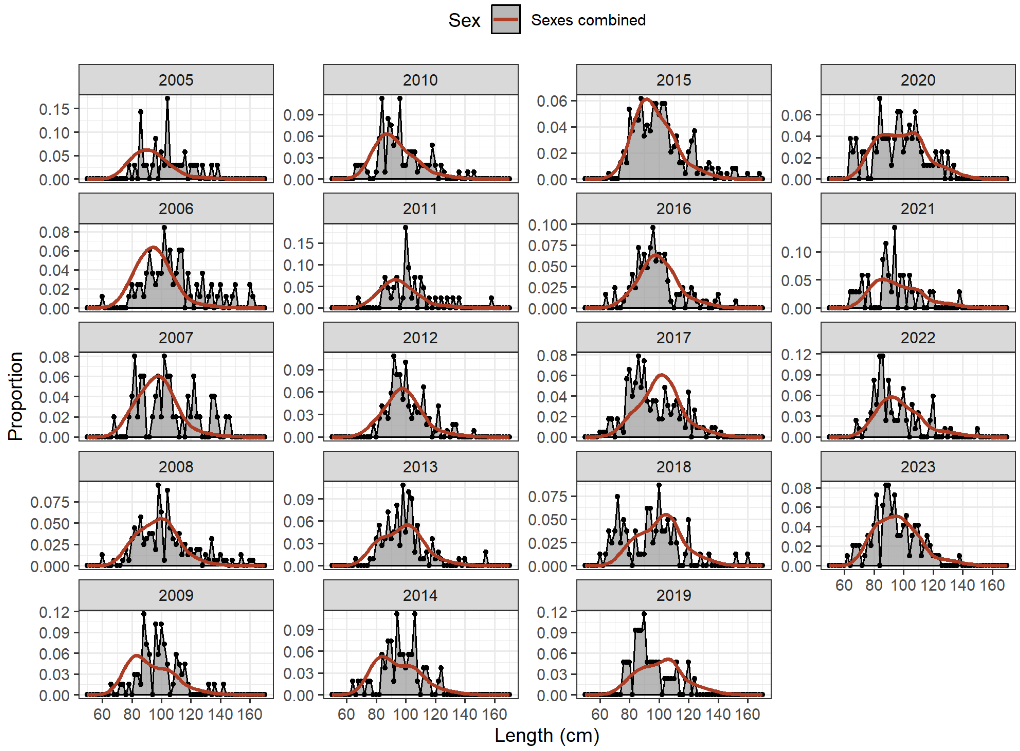

Figure E.34: Scenario 2: Fits to length structures for Fleet 2, based on maximum likelihood estimation—the grey area and black line represent data inputs and the red and blue line represents the model fits for female and male, respectively

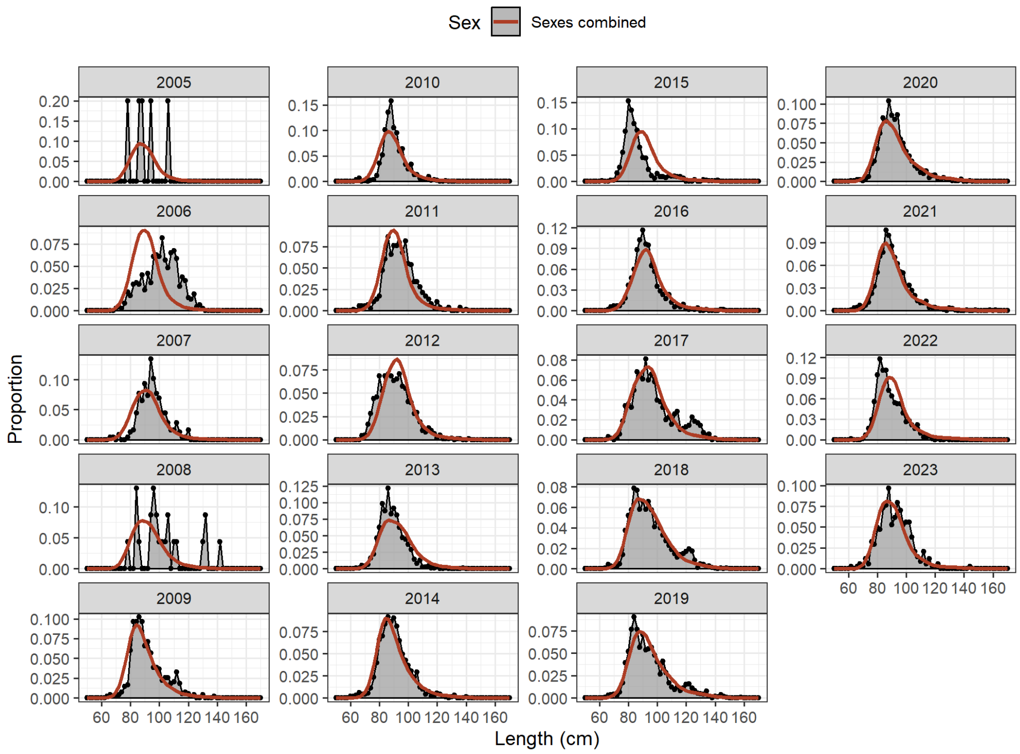

Figure E.35: Scenario 2: Fits to length structures for Fleet 5, based on maximum likelihood estimation—the grey area and black line represent data inputs and the red and blue line represents the model fits for female and male, respectively

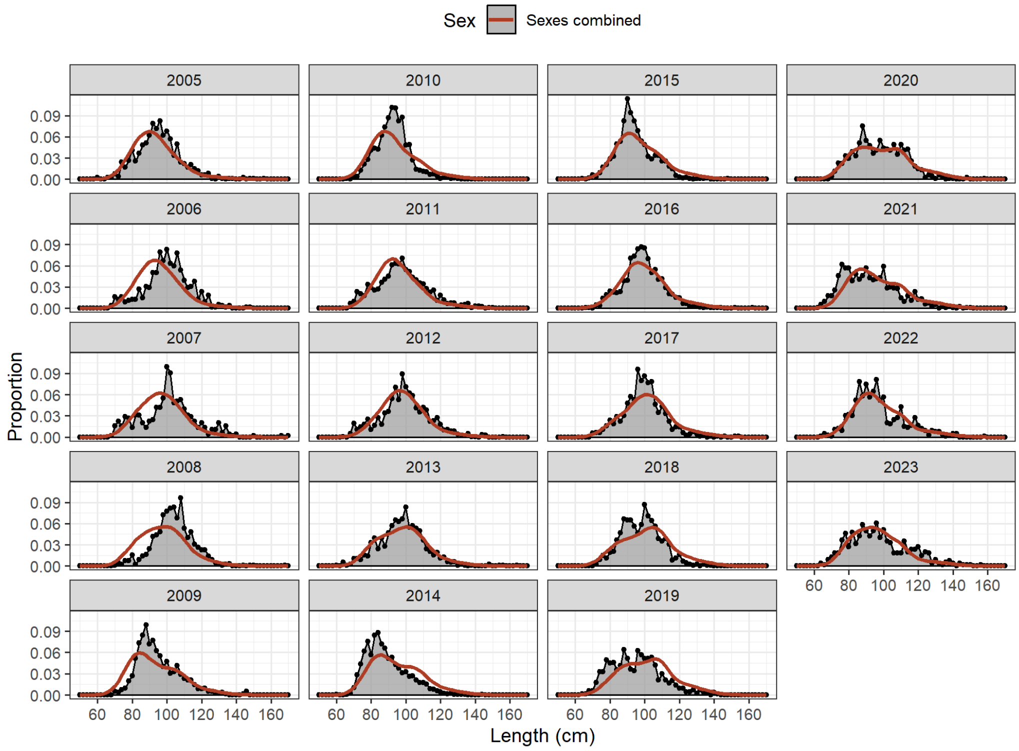

Figure E.36: Scenario 2: Fits to length structures for Fleet 6, based on maximum likelihood estimation—the grey area and black line represent data inputs and the red and blue line represents the model fits for female and male, respectively

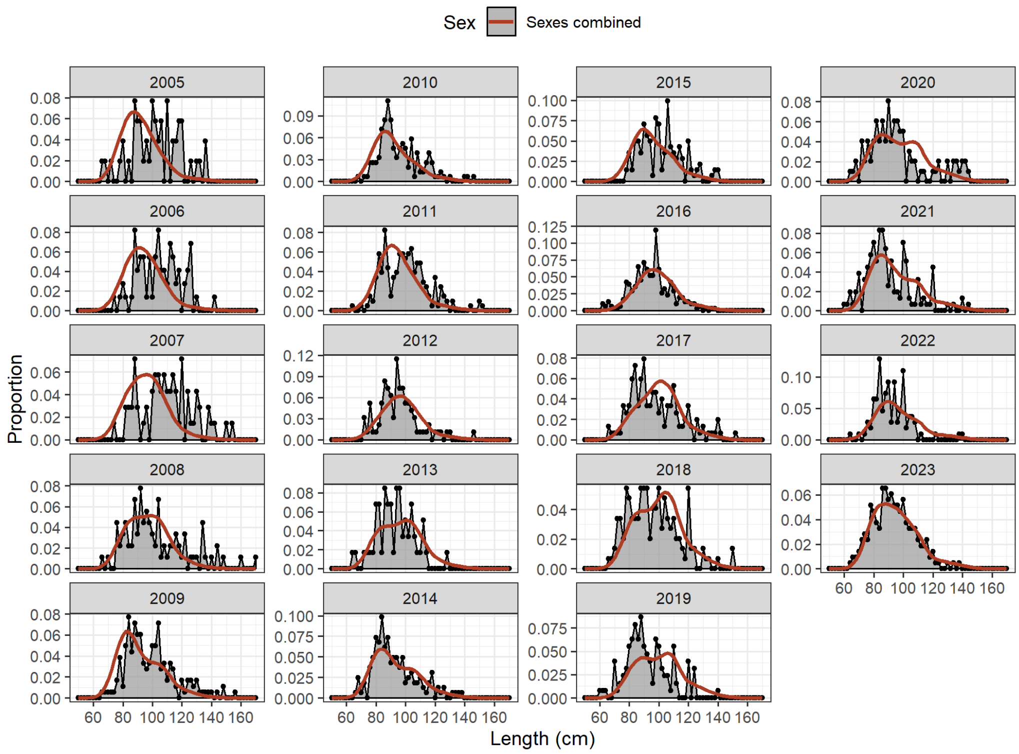

Figure E.37: Scenario 2: Fits to length structures for Fleet 7, based on maximum likelihood estimation—the grey area and black line represent data inputs and the red and blue line represents the model fits for female and male, respectively

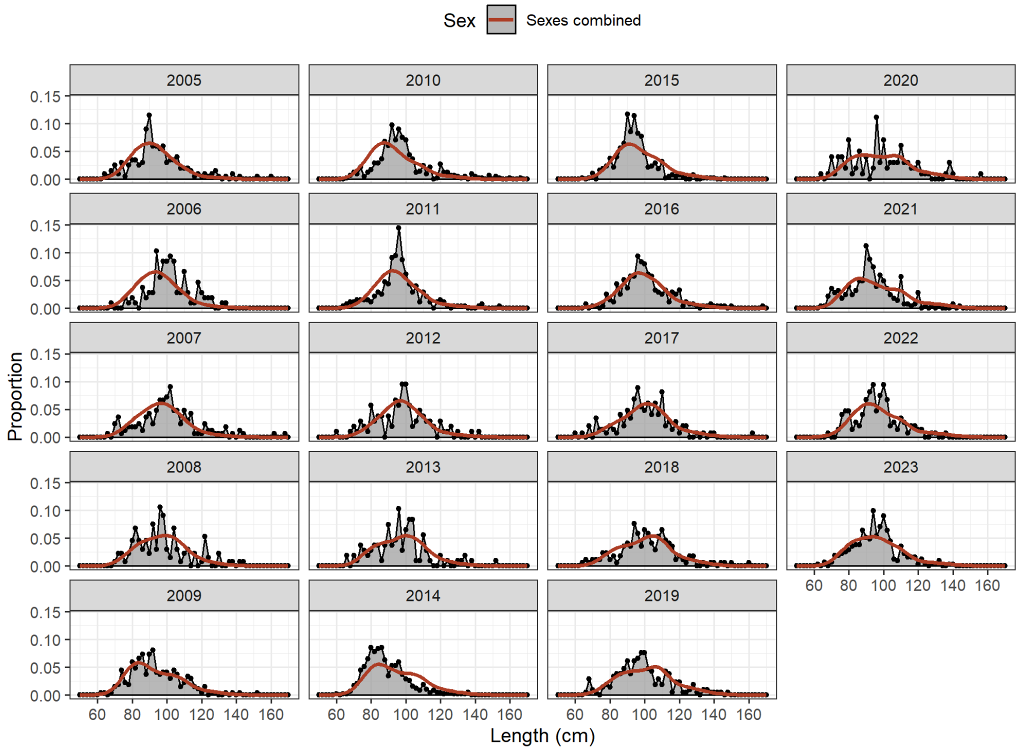

Figure E.38: Scenario 2: Fits to length structures for Fleet 8, based on maximum likelihood estimation—the grey area and black line represent data inputs and the red and blue line represents the model fits for female and male, respectively

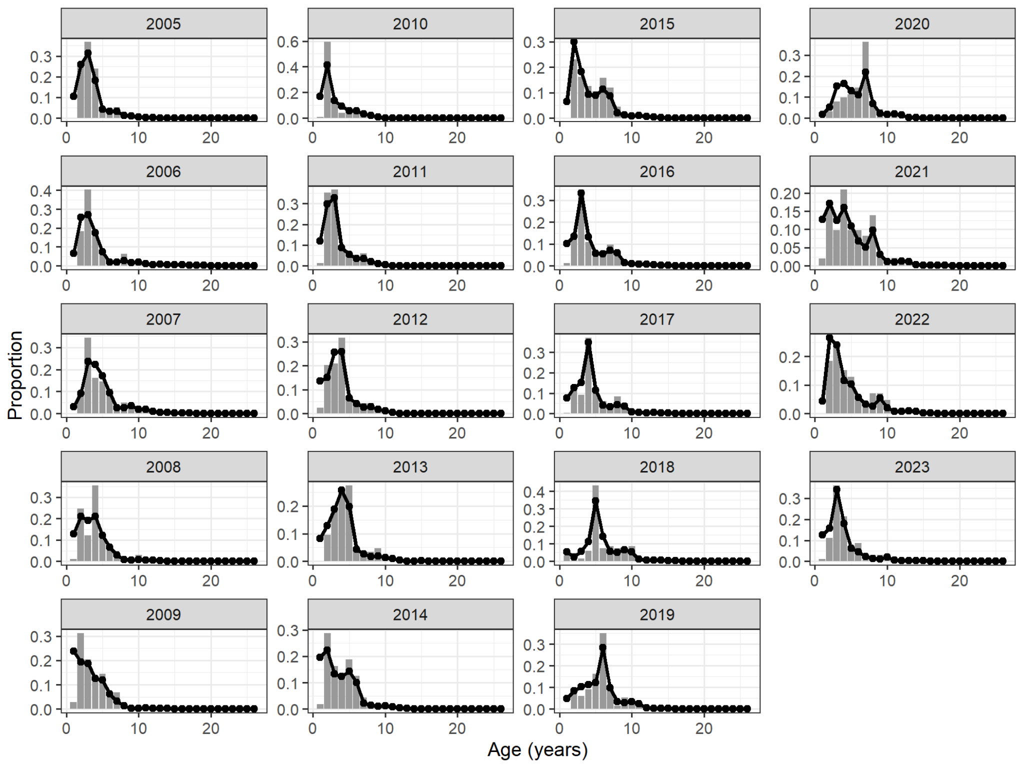

Figure E.39: Scenario 2: Fits to annual age compositions of female Spanish mackerel for Fleet 1

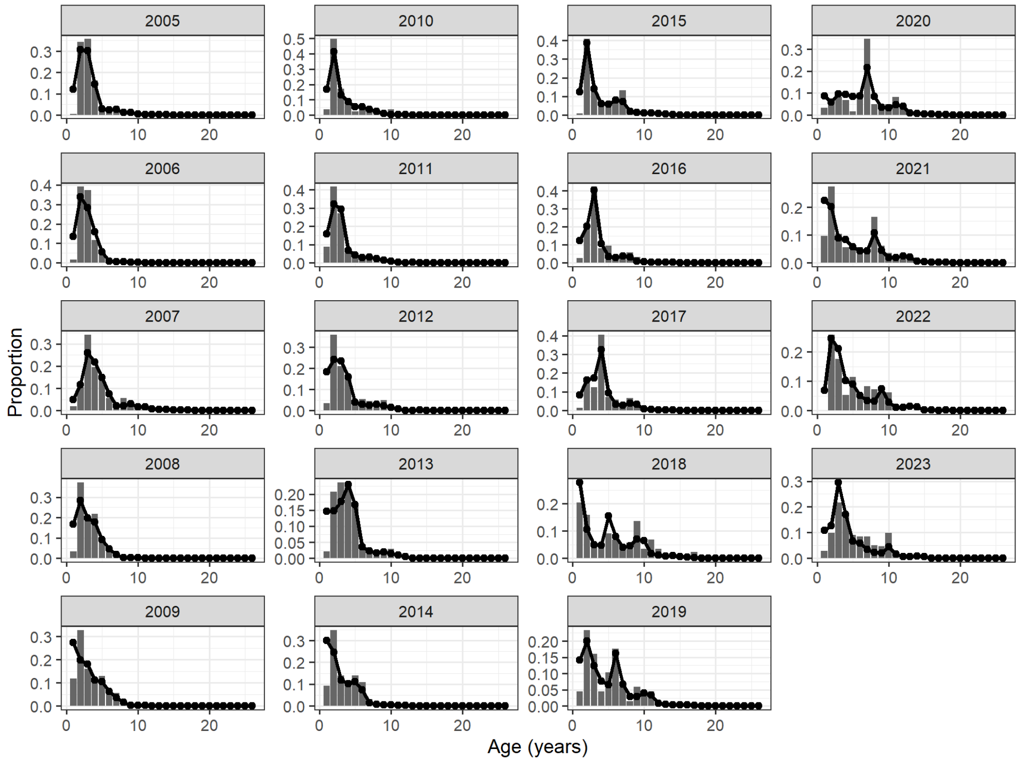

Figure E.40: Scenario 2: Fits to annual age compositions of male Spanish mackerel for Fleet 1

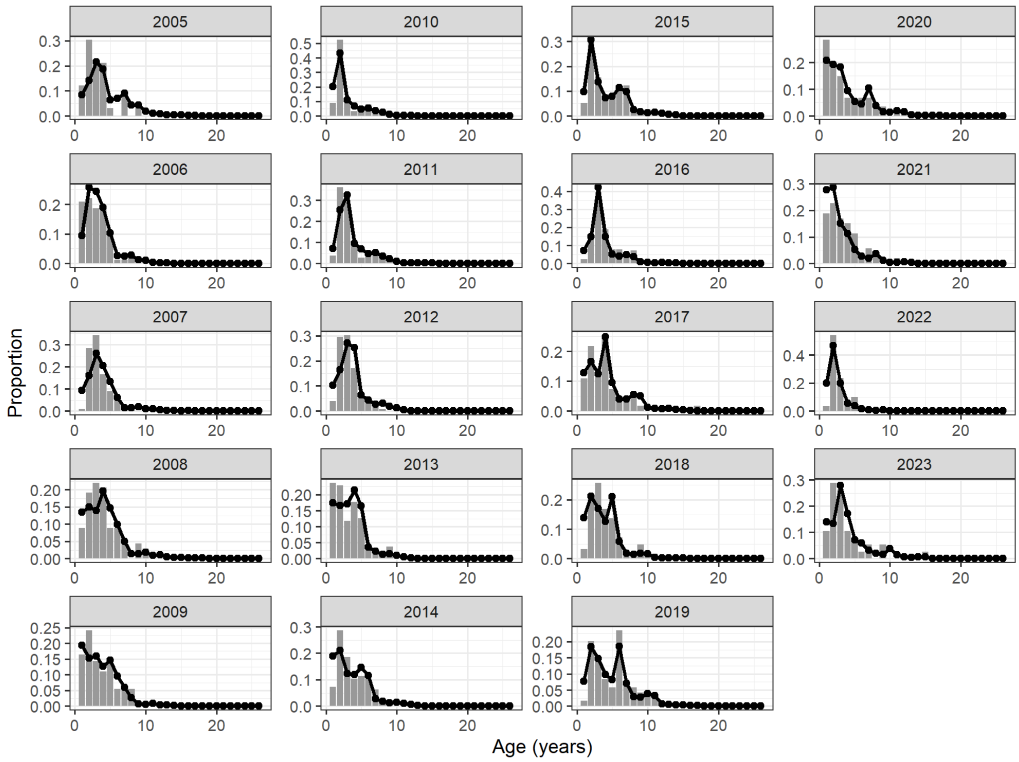

Figure E.41: Scenario 2: Fits to annual age compositions of female Spanish mackerel for Fleet 5

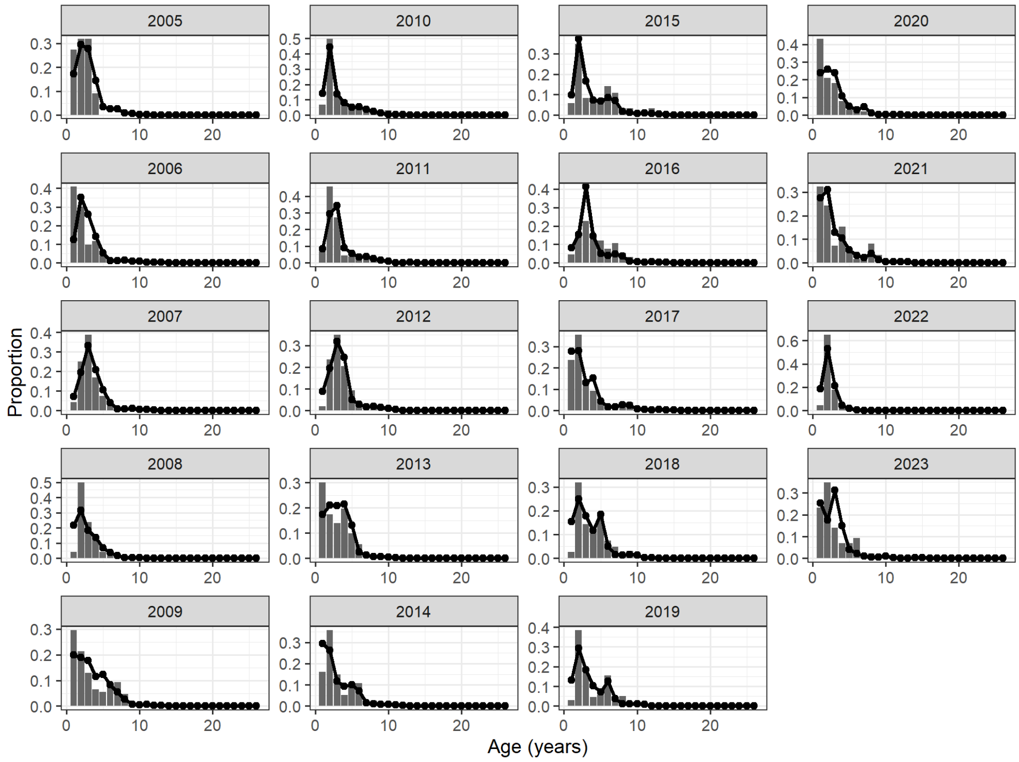

Figure E.42: Scenario 2: Fits to annual age compositions of male Spanish mackerel for Fleet 5

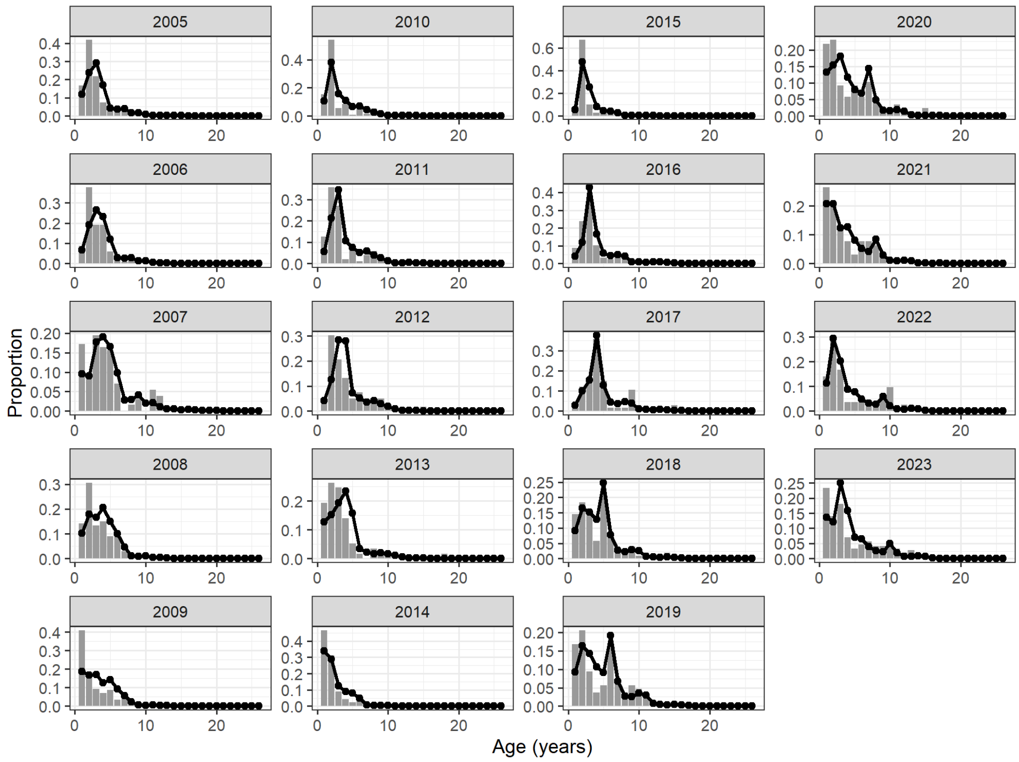

Figure E.43: Scenario 2: Fits to annual age compositions of female Spanish mackerel for Fleet 6

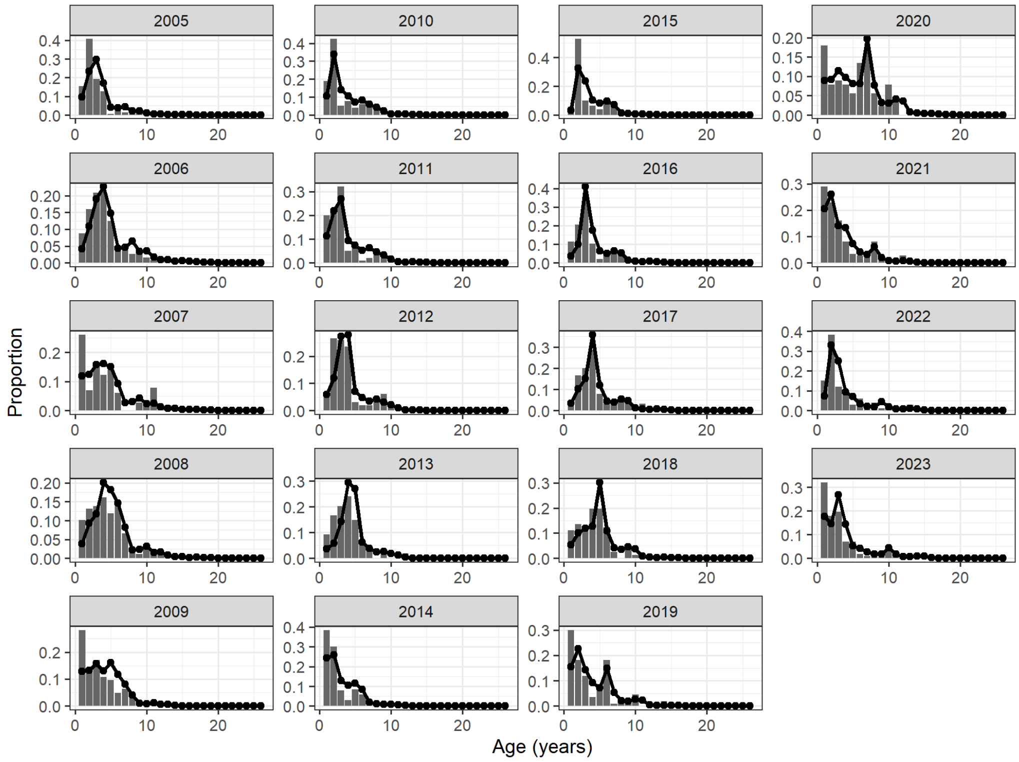

Figure E.44: Scenario 2: Fits to annual age compositions of male Spanish mackerel for Fleet 6

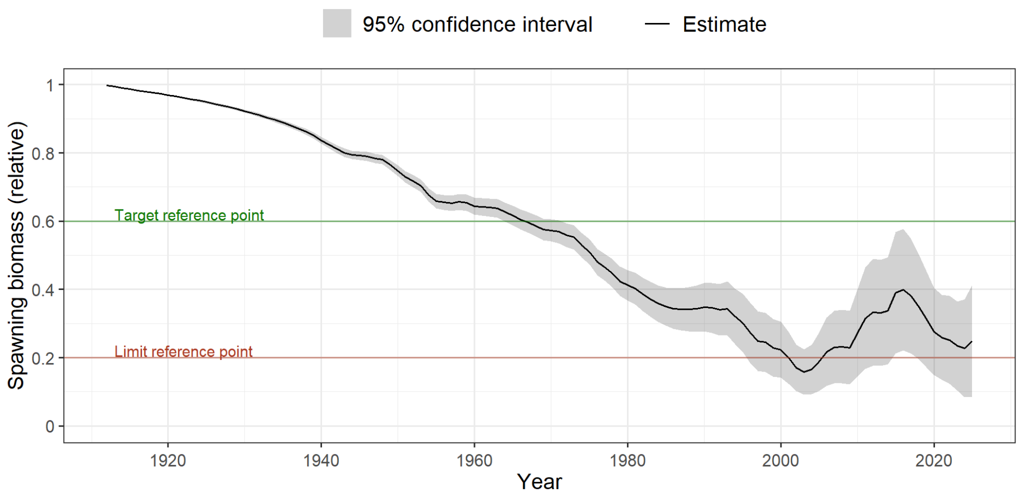

Figure E.45: Scenario 2: Predicted spawning biomass trajectory relative to unfished for Australian east coast Spanish mackerel, based on maximum likelihood estimation

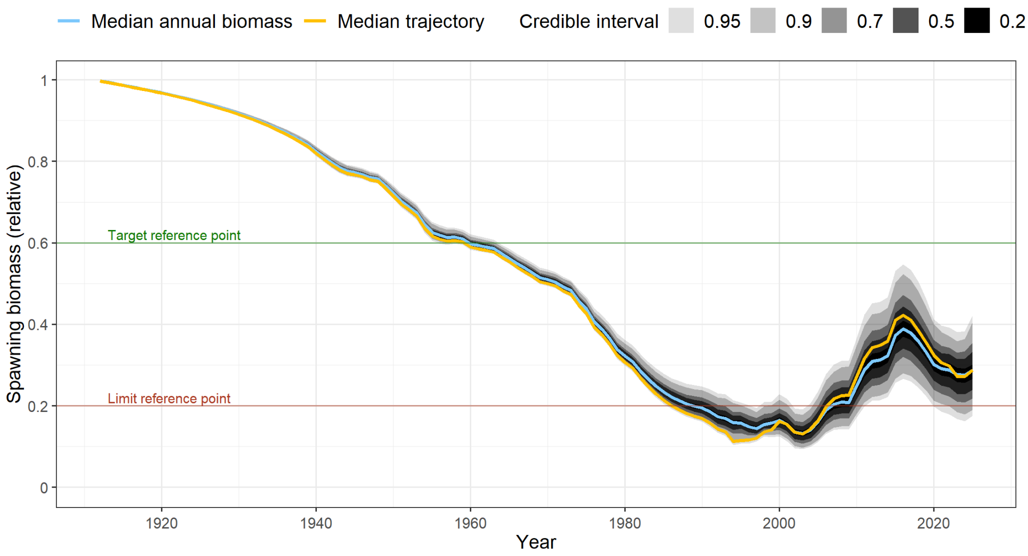

Figure E.46: Scenario 2: Predicted spawning biomass trajectory relative to unfished for Australian east coast Spanish mackerel, based on MCMC

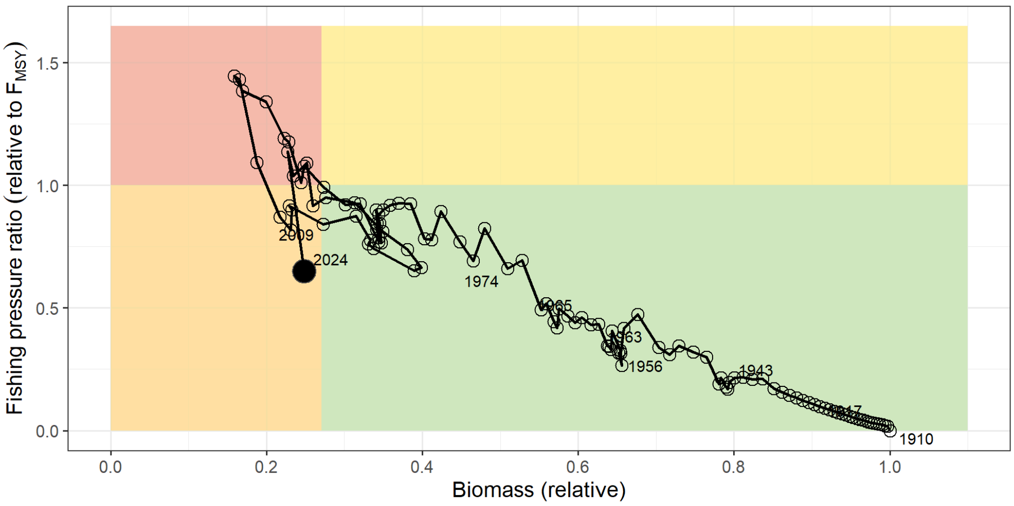

Figure E.47: Scenario 2: Stock status indicator trajectory for Australian east coast Spanish mackerel, based on maximum likelihood estimation

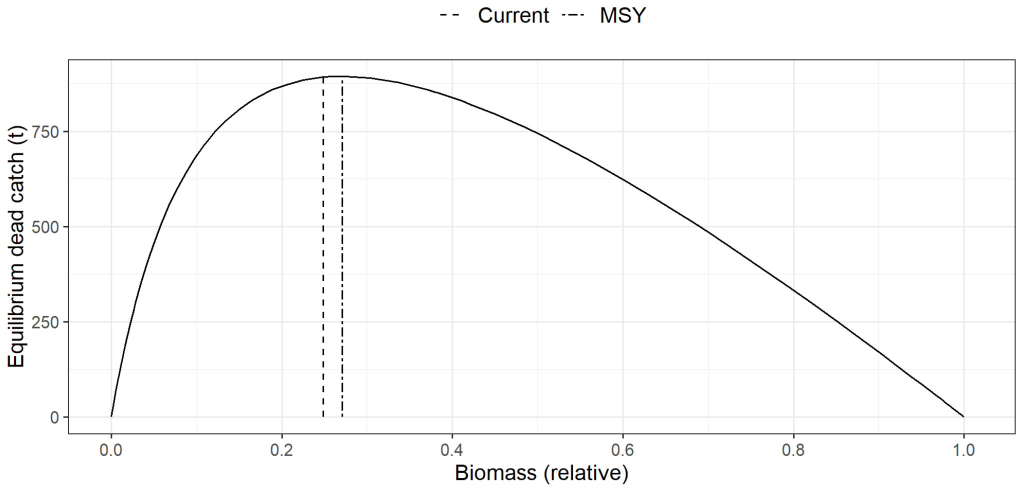

Figure E.48: Scenario 2: Equilibrium dead catch curve for Australian east coast Spanish mackerel, based on maximum likelihood estimation

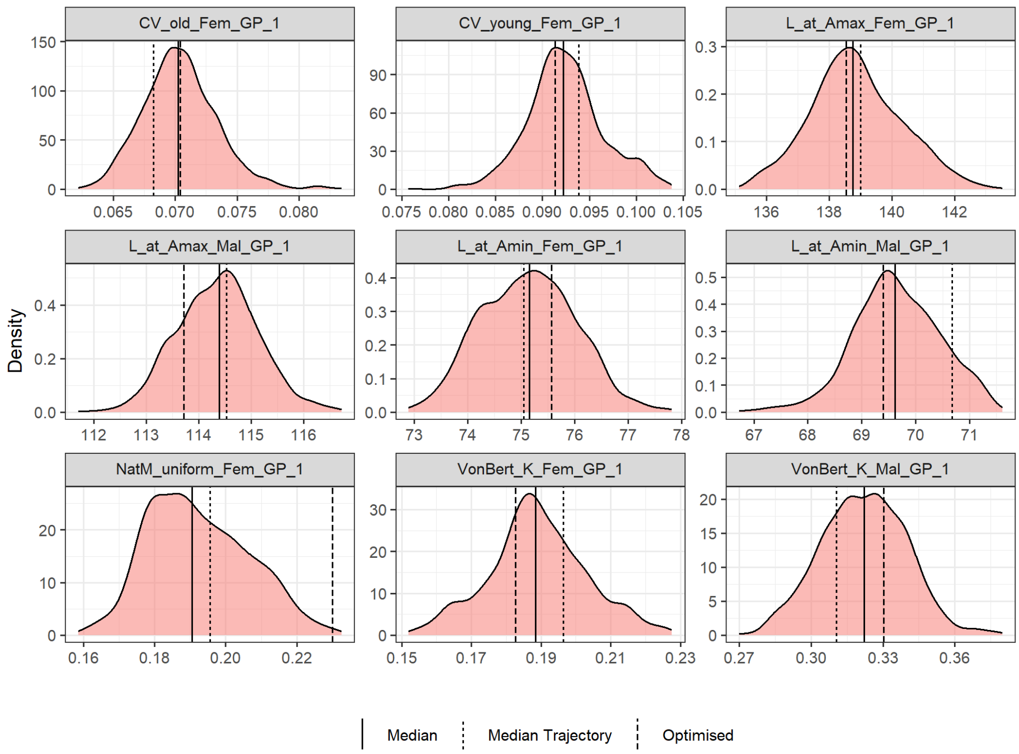

Figure E.49: Scenario 2: Posterior density of MCMC iterations. "Median" line shows median parameter value for MCMC iterations "Optimised" shows the parameter value found from maximum likelihood estimates.

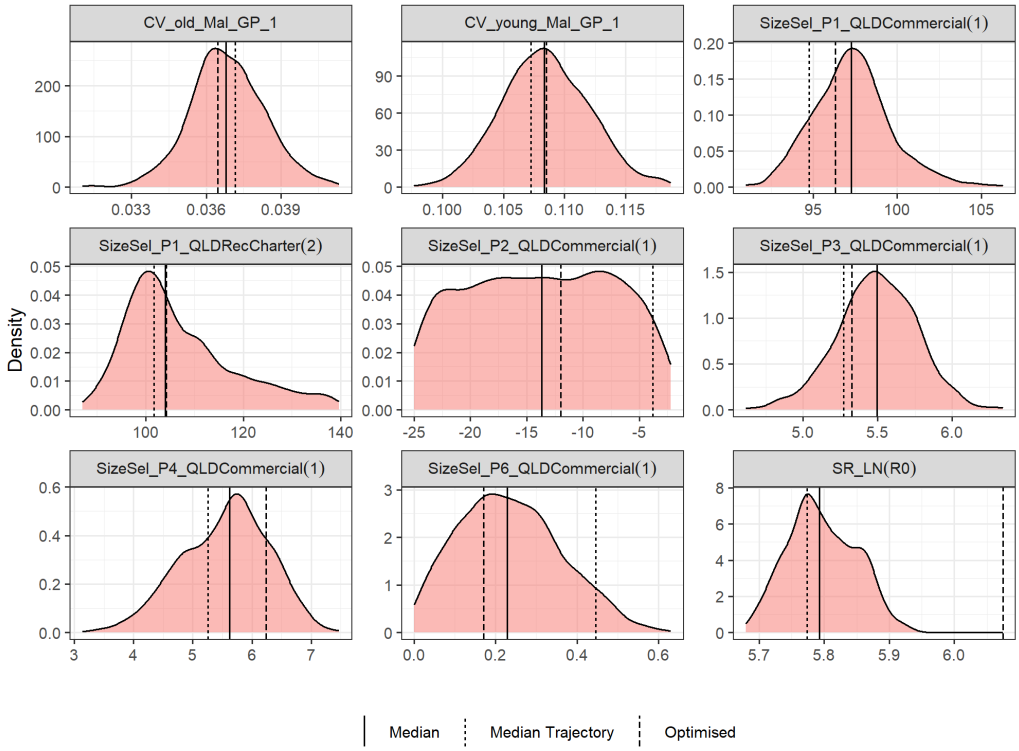

Figure E.50: Scenario 2: Posterior density of MCMC iterations. "Median" line shows median parameter value for MCMC iterations "Optimised" shows the parameter value found from maximum likelihood estimates.

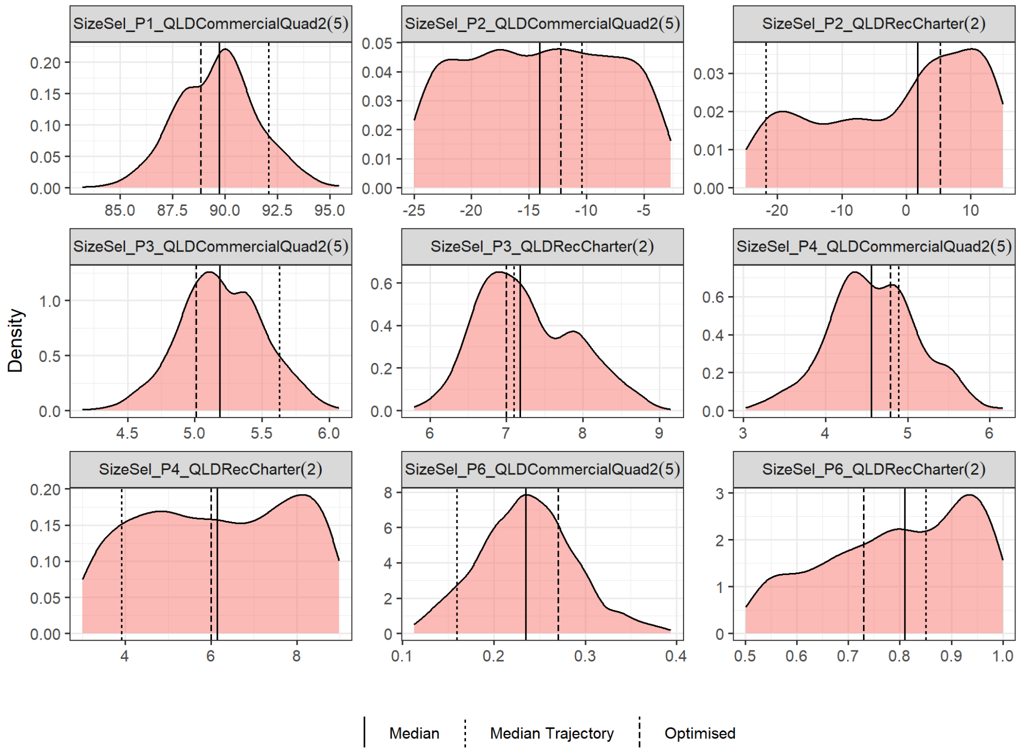

Figure E.51: Scenario 2: Posterior density of MCMC iterations. "Median" line shows median parameter value for MCMC iterations "Optimised" shows the parameter value found from maximum likelihood estimates.

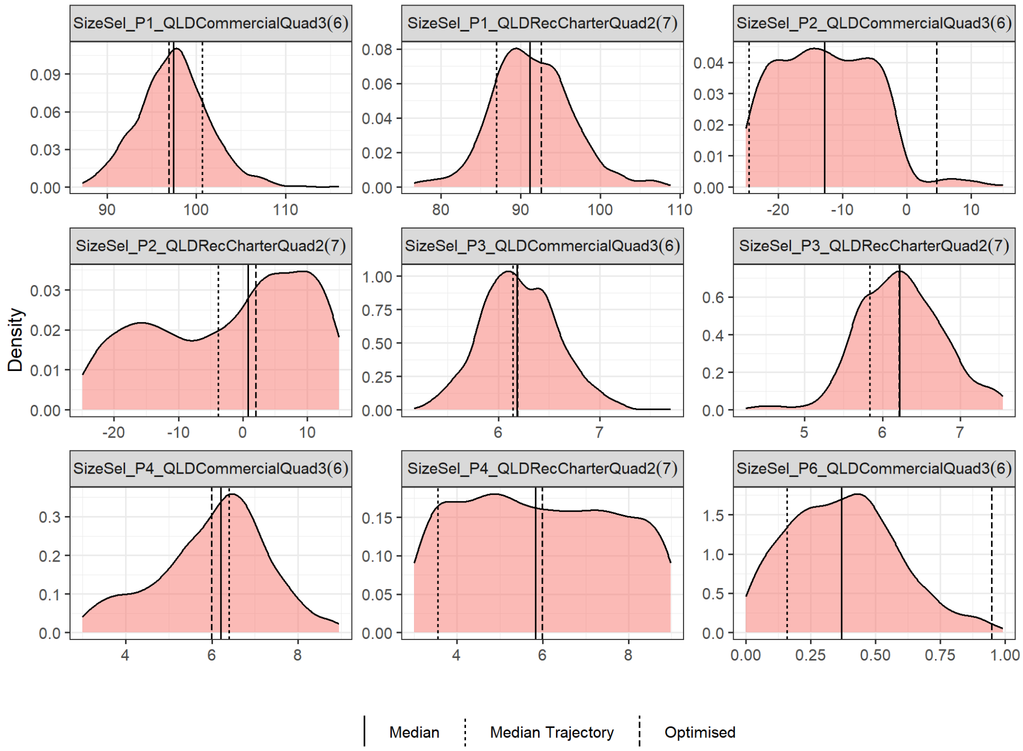

Figure E.52: Scenario 2: Posterior density of MCMC iterations. "Median" line shows median parameter value for MCMC iterations "Optimised" shows the parameter value found from maximum likelihood estimates.

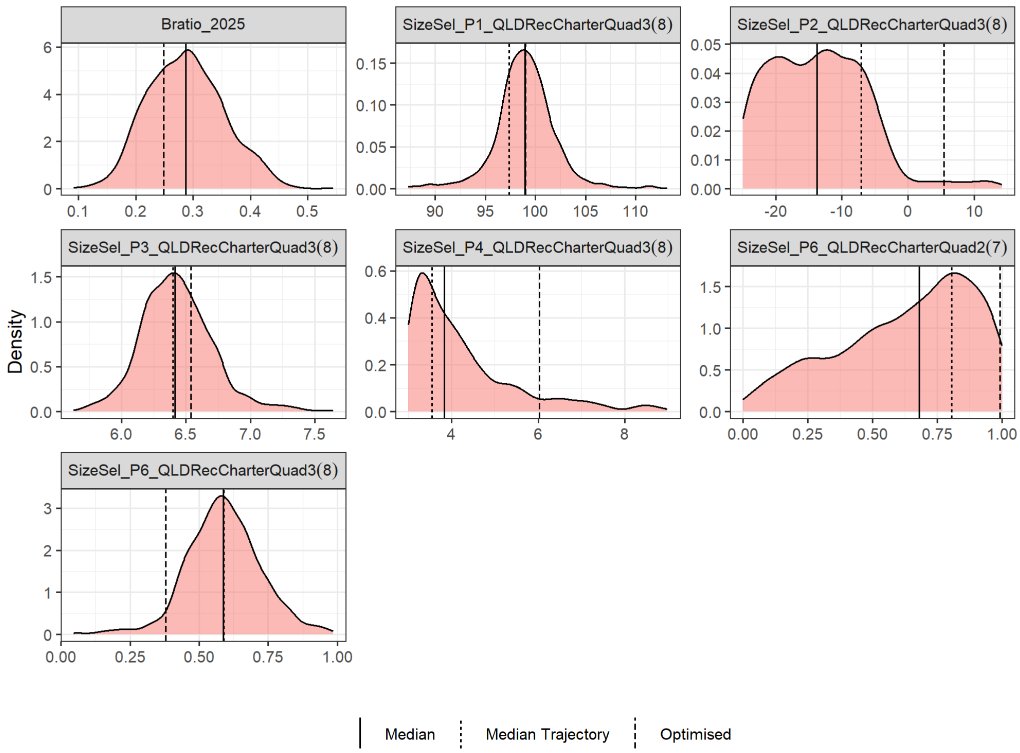

Figure E.53: Scenario 2: Posterior density of MCMC iterations. "Median" line shows median parameter value for MCMC iterations "Optimised" shows the parameter value found from maximum likelihood estimates.

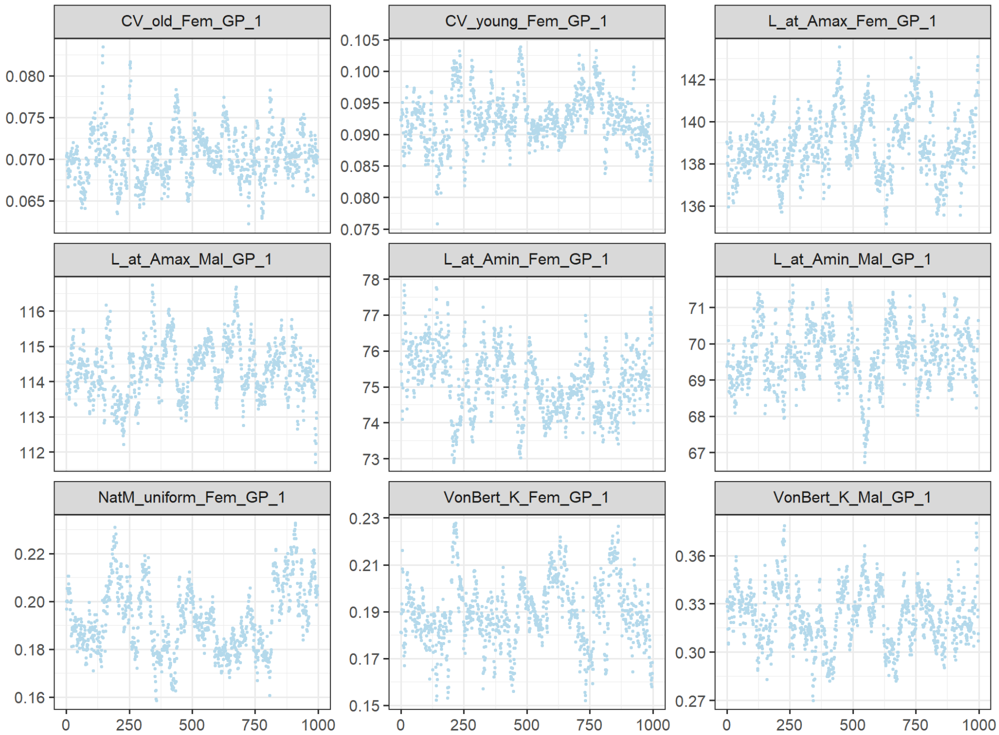

Figure E.54: Scenario 2: Trace plot of MCMC iterations

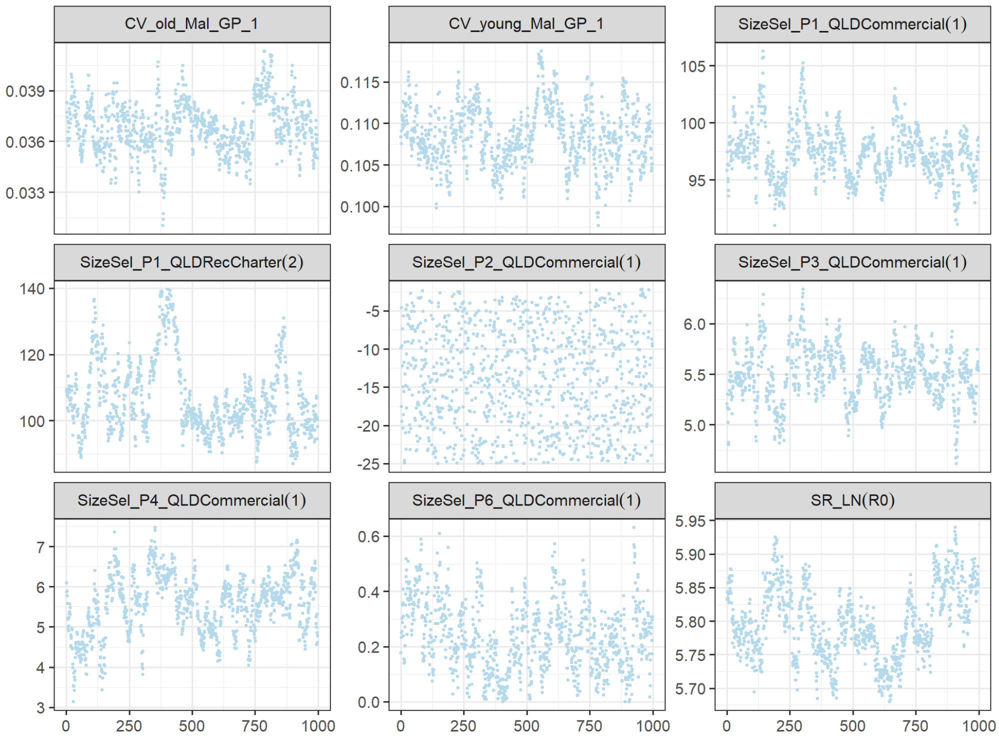

Figure E.55: Scenario 2: Trace plot of MCMC iterations

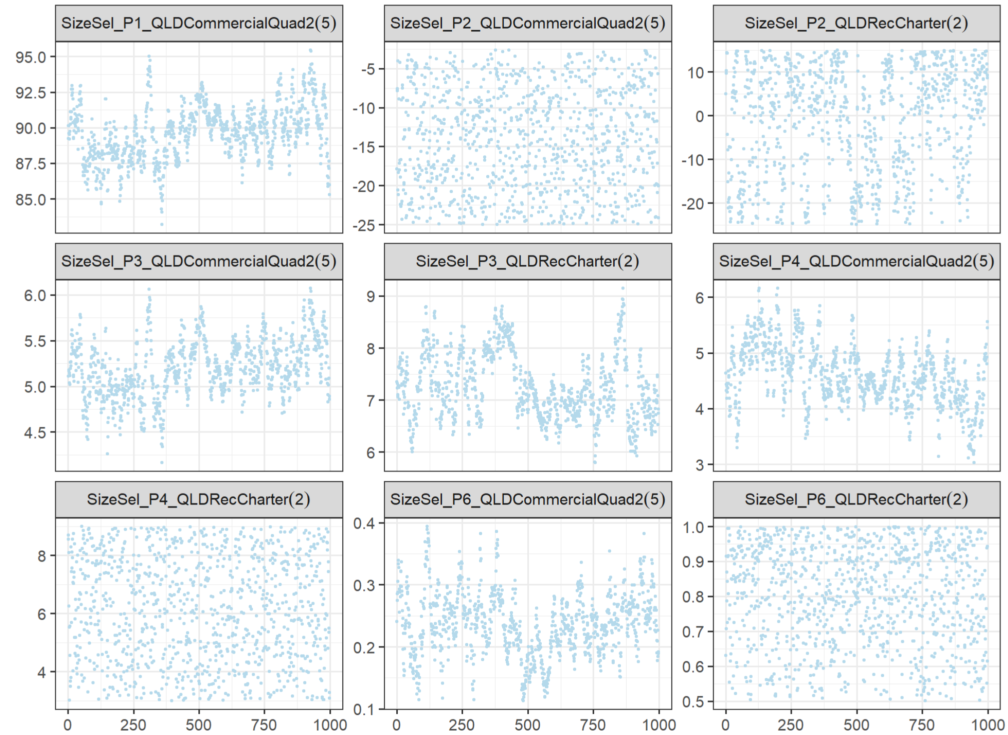

Figure E.56: Scenario 2: Trace plot of MCMC iterations

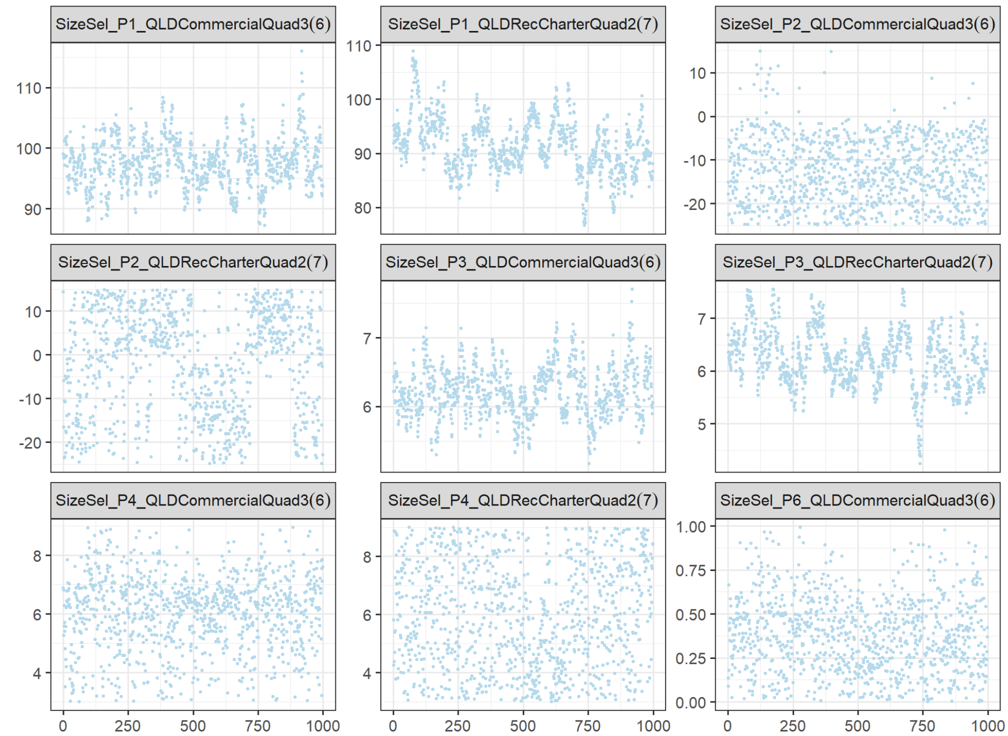

Figure E.57: Scenario 2: Trace plot of MCMC iterations

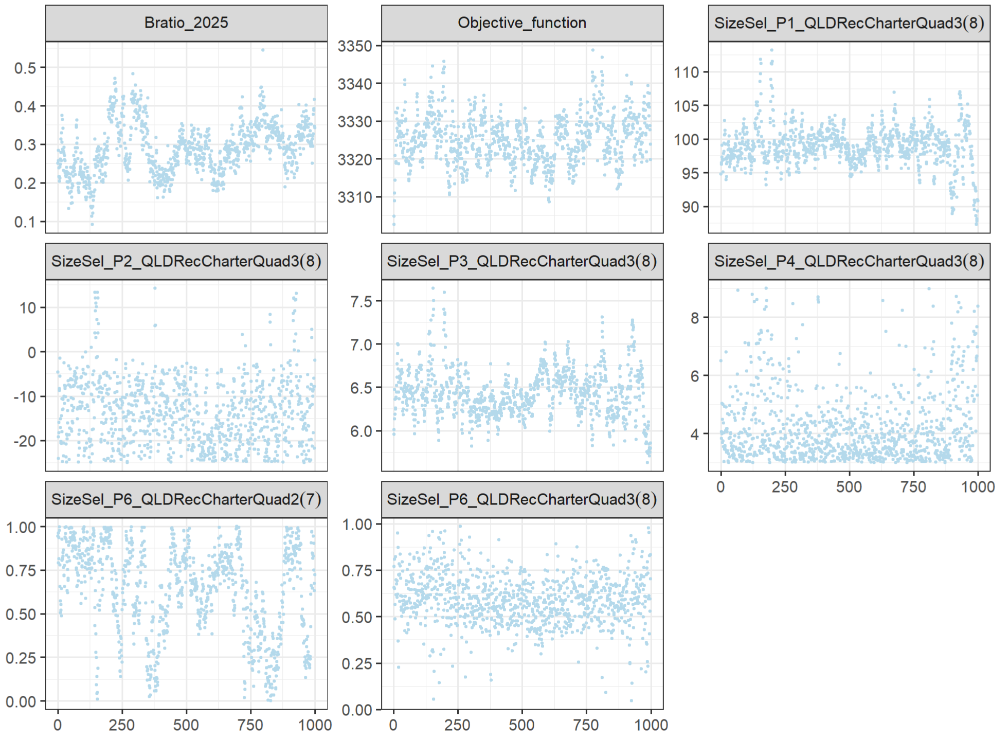

Figure E.58: Scenario 2: Trace plot of MCMC iterations

E.3 Scenario 3

Symbol	Value	Phase	Min	Max	Init	ParmStDev
Natural mortality	0.19	5	0.15	0.4	0.216	0.0194633
Length at minimum age (female)	74.44	3	65	90	75	0.997217
Length at maximum age (female)	138.86	3	130	160	140	1.50867
VonBert growth coefficient (female)	0.2	3	0.05	0.3	0.15	0.0153732
SD of length at minimum age (female)	0.1	3	0.03	0.2	0.09	0.00472112
SD of length at maximum age (female)	0.07	3	0.03	0.2	0.07	0.00323044
Length at minimum age (male)	68.81	3	60	85	70	0.870133
Length at maximum age (male)	114.25	3	105	130	115	0.750045
VonBert growth coefficient (male)	0.33	3	0.15	0.4	0.3	0.0176665
SD of length at minimum age (male)	0.11	3	0.03	0.2	0.085	0.00438798
SD of length at maximum age (male)	0.04	3	0.01	0.15	0.04	0.00177585
Log of number of recruits when unfished	5.77	1	5	7	6.5	0.0969631
Selectivity plateau start, Fleet 1	95.3	2	60	140	90	2.03613
Selectivity plateau width, Fleet 1	-12.34	2	-25	15	-2	145.195
Selectivity asc. width, Fleet 1	5.22	2	0	10	5	0.269918
Selectivity desc. width, Fleet 1	6.07	2	3	9	5	0.582593
Selectivity at max length, Fleet 1	0.15	2	0	1	0.2	0.138083
Selectivity plateau start, Fleet 2	97.79	2	60	140	90	6.05118
Selectivity plateau width, Fleet 2	5.42	2	-25	15	-2	24.7268
Selectivity asc. width, Fleet 2	6.64	2	0	10	5	0.517286
Selectivity desc. width, Fleet 2	6	2	3	9	5	67.1821
Selectivity at max length, Fleet 2	0.73	2	0.5	1	0.6	5.53277
Selectivity plateau start, Fleet 5	88.5	2	60	140	90	1.68765
Selectivity plateau width, Fleet 5	-12.52	2	-25	15	-2	139.418
Selectivity asc. width, Fleet 5	4.93	2	0	10	3	0.289189
Selectivity desc. width, Fleet 5	4.92	2	3	9	5	0.444315
Selectivity at max length, Fleet 5	0.2	2	0	1	0.2	0.0495519
Selectivity plateau start, Fleet 6	96.99	2	60	140	90	3.37528
Selectivity plateau width, Fleet 6	-11.81	2	-25	15	-2	148.345
Selectivity asc. width, Fleet 6	6.09	2	0	10	3	0.343671
Selectivity desc. width, Fleet 6	6.15	2	3	9	5	0.849691
Selectivity at max length, Fleet 6	0.29	2	0	1	0.2	0.199087
Selectivity plateau start, Fleet 7	92.85	2	60	140	90	4.57144
Selectivity plateau width, Fleet 7	-2.85	2	-25	15	-2	1.40533
Selectivity asc. width, Fleet 7	6.12	2	0	10	3	0.469165
Selectivity desc. width, Fleet 7	3.01	2	3	9	5	0.439131
Selectivity at max length, Fleet 7	0.76	2	0	1	0.6	0.118669
Selectivity plateau start, Fleet 8	98.7	2	60	140	90	1.42085
Selectivity plateau width, Fleet 8	-13.01	2	-25	15	-2	140.065
Selectivity asc. width, Fleet 8	6.28	2	0	10	3	0.211322
Selectivity desc. width, Fleet 8	3	2	3	9	5	0.046026
Selectivity at max length, Fleet 8	0.54	2	0	1	0.6	0.0890943

Table E.5: Scenario 3: Summary of MLE parameter estimates. Fleet definitions are listed in Table 2.2.

Symbol	MCMC median	MCMC 2.5%	MCMC 97.5%
Natural mortality	0.21	0.17	0.28
Length at minimum age (female)	76.16	74.31	78.07
Length at maximum age (female)	139.42	136.58	142.72
VonBert growth coefficient (female)	0.18	0.15	0.2
SD of length at minimum age (female)	0.09	0.08	0.1
SD of length at maximum age (female)	0.07	0.07	0.08
Length at minimum age (male)	69.98	68.32	71.62
Length at maximum age (male)	114.18	112.61	115.81
VonBert growth coefficient (male)	0.32	0.29	0.36
SD of length at minimum age (male)	0.11	0.1	0.11
SD of length at maximum age (male)	0.04	0.03	0.04
Log of number of recruits when unfished	5.83	5.58	6.34
Selectivity plateau start, Fleet 1	96.74	92.43	101.63
Selectivity plateau width, Fleet 1	-14.08	-24.51	-2.34
Selectivity asc. width, Fleet 1	5.43	4.84	5.98
Selectivity desc. width, Fleet 1	5.96	3.72	7.11
Selectivity at max length, Fleet 1	0.24	0.02	0.56
Selectivity plateau start, Fleet 2	128.08	122.2	139.13
Selectivity plateau width, Fleet 2	1.41	-22.9	14.17
Selectivity asc. width, Fleet 2	8.36	7.81	9.5
Selectivity desc. width, Fleet 2	6.29	3.13	8.89
Selectivity at max length, Fleet 2	0.79	0.52	0.99
Selectivity plateau start, Fleet 5	88.91	85.35	93.2
Selectivity plateau width, Fleet 5	-14.13	-24.17	-3.25
Selectivity asc. width, Fleet 5	5.12	4.5	5.83
Selectivity desc. width, Fleet 5	4.78	3.25	5.77
Selectivity at max length, Fleet 5	0.26	0.15	0.41
Selectivity plateau start, Fleet 6	98.72	90.18	110.71
Selectivity plateau width, Fleet 6	-11.92	-24.34	9.59
Selectivity asc. width, Fleet 6	6.37	5.51	7.32
Selectivity desc. width, Fleet 6	6.04	3.22	8.3
Selectivity at max length, Fleet 6	0.38	0.04	0.83
Selectivity plateau start, Fleet 7	91.11	60.89	110.84
Selectivity plateau width, Fleet 7	-19.32	-24.73	7.85
Selectivity asc. width, Fleet 7	6.18	4.01	7.57
Selectivity desc. width, Fleet 7	6.28	3.11	8.89
Selectivity at max length, Fleet 7	0.86	0.51	0.99
Selectivity plateau start, Fleet 8	99.7	93.12	109.86
Selectivity plateau width, Fleet 8	-12.4	-24.31	13.56
Selectivity asc. width, Fleet 8	6.62	5.96	7.77
Selectivity desc. width, Fleet 8	4.45	3.05	8.57
Selectivity at max length, Fleet 8	0.61	0.08	0.93

Table E.6: Scenario 3: Summary of MCMC parameter estimates. Fleet definitions are listed in Table 2.2.

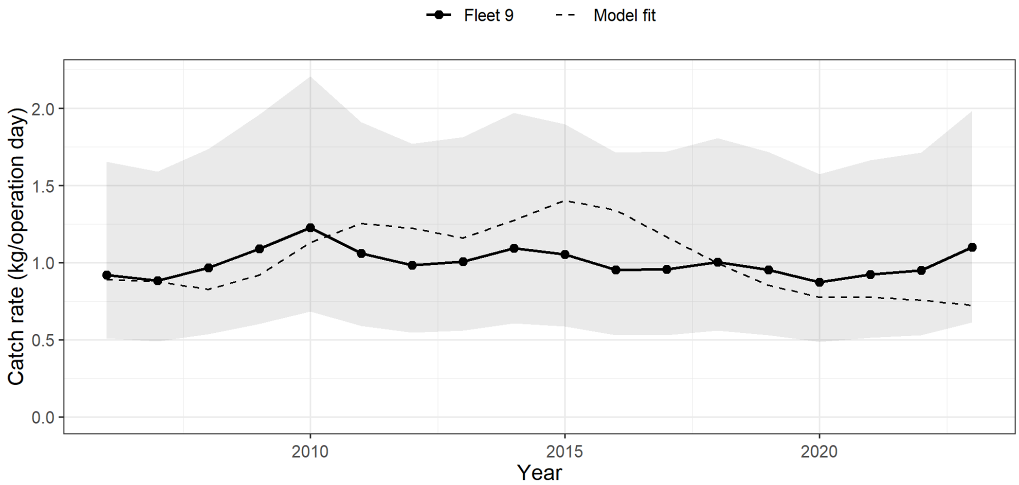

Figure E.59: Scenario 3: Model predictions (dotted line) to standardised catch rates for Australian east coast Spanish mackerel, based on maximum likelihood estimation—grey shade represent the model input and associated uncertainty

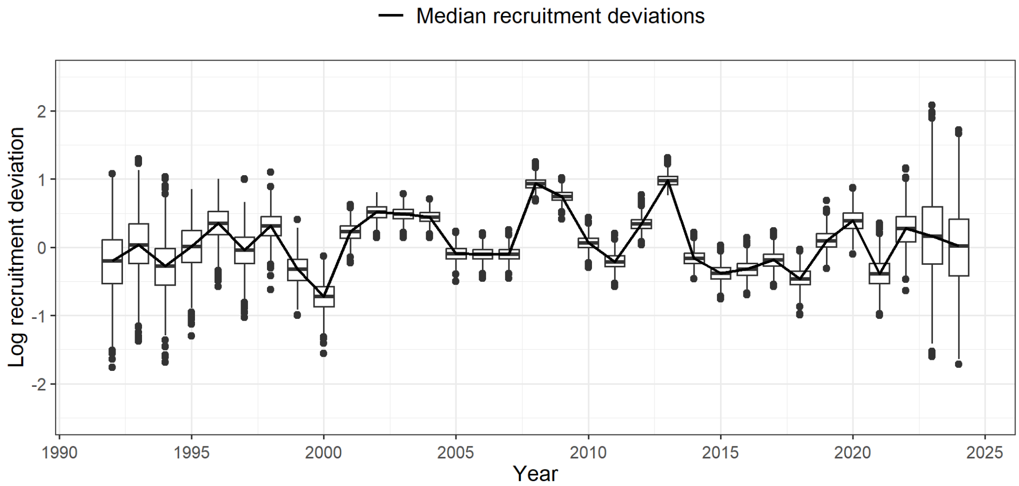

Figure E.60: Scenario 3: Recruitment deviations—whiskers represent 95% credible intervals, boxes represent 50% credible intervals, horizontal bars represent medians, and the points represent outliers

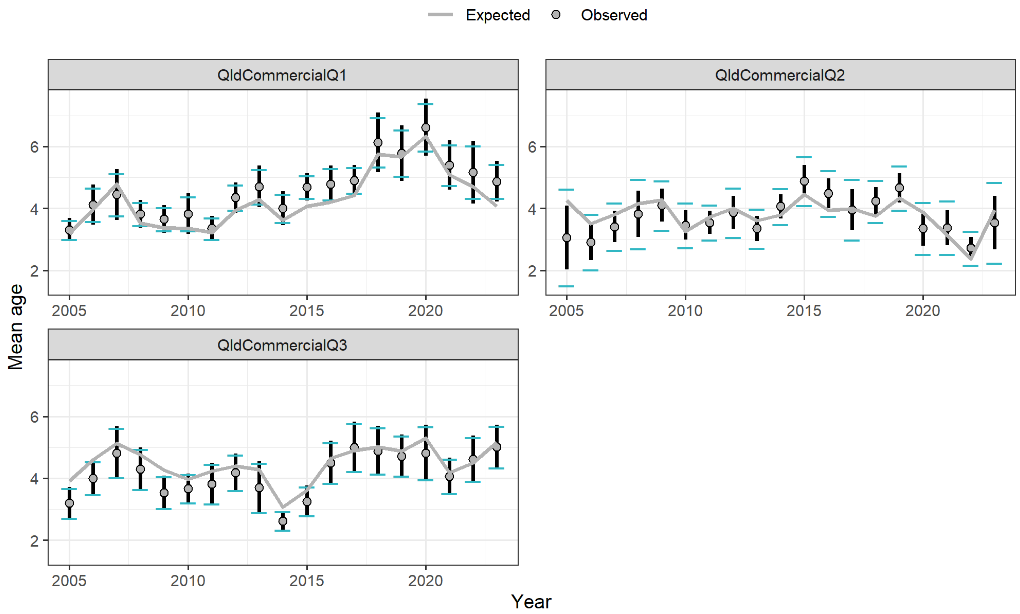

Figure E.61: Scenario 3: Mean age from conditional data (aggregated across length bins) with 95% confidence intervals based on current samples sizes: thinner intervals (with capped ends) show result of further adjusting sample sizes based on suggested multiplier (with 95% interval) for conditional age-at-length data

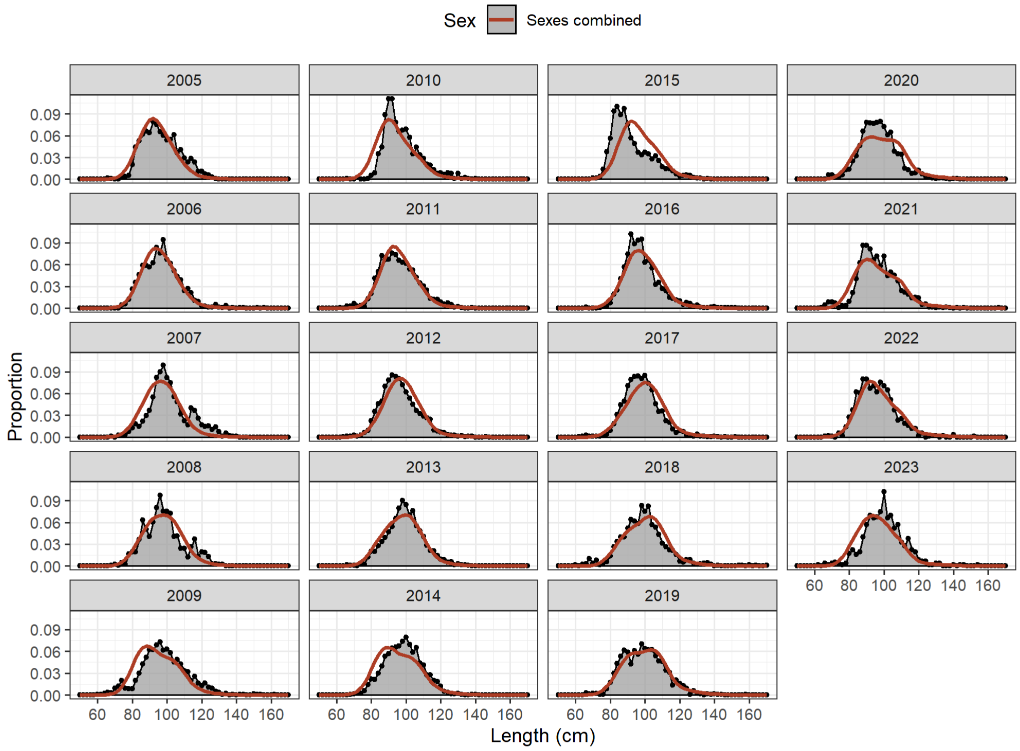

Figure E.62: Scenario 3: Fits to length structures for Fleet 1, based on maximum likelihood estimation—the grey area and black line represent data inputs and the red and blue line represents the model fits for female and male, respectively

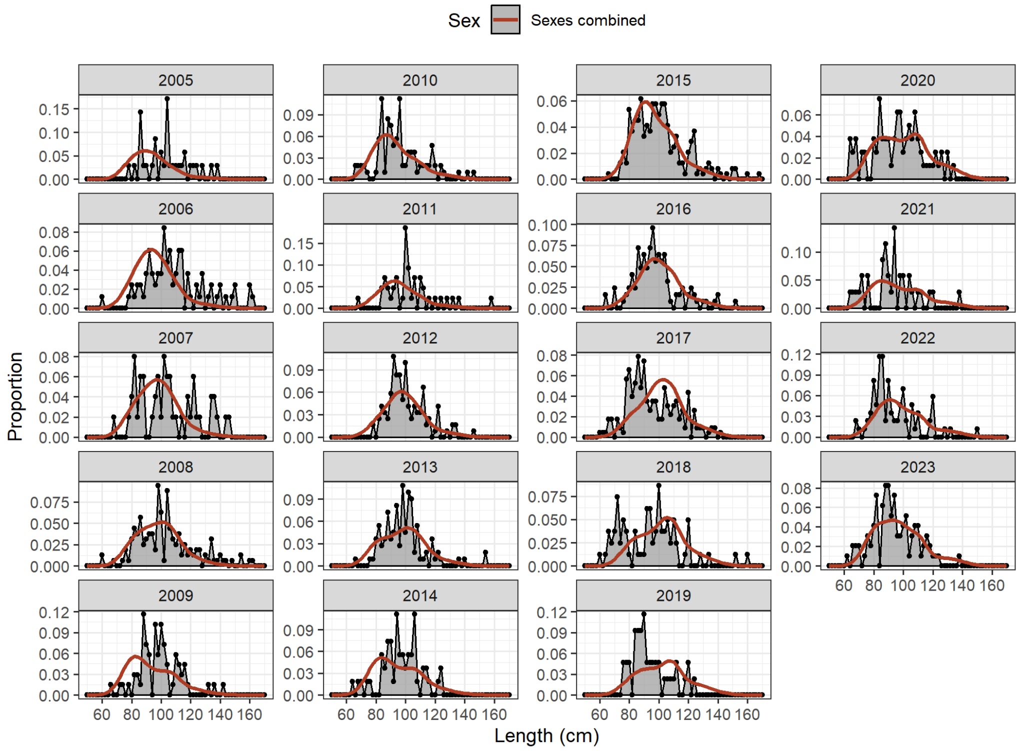

Figure E.63: Scenario 3: Fits to length structures for Fleet 2, based on maximum likelihood estimation—the grey area and black line represent data inputs and the red and blue line represents the model fits for female and male, respectively

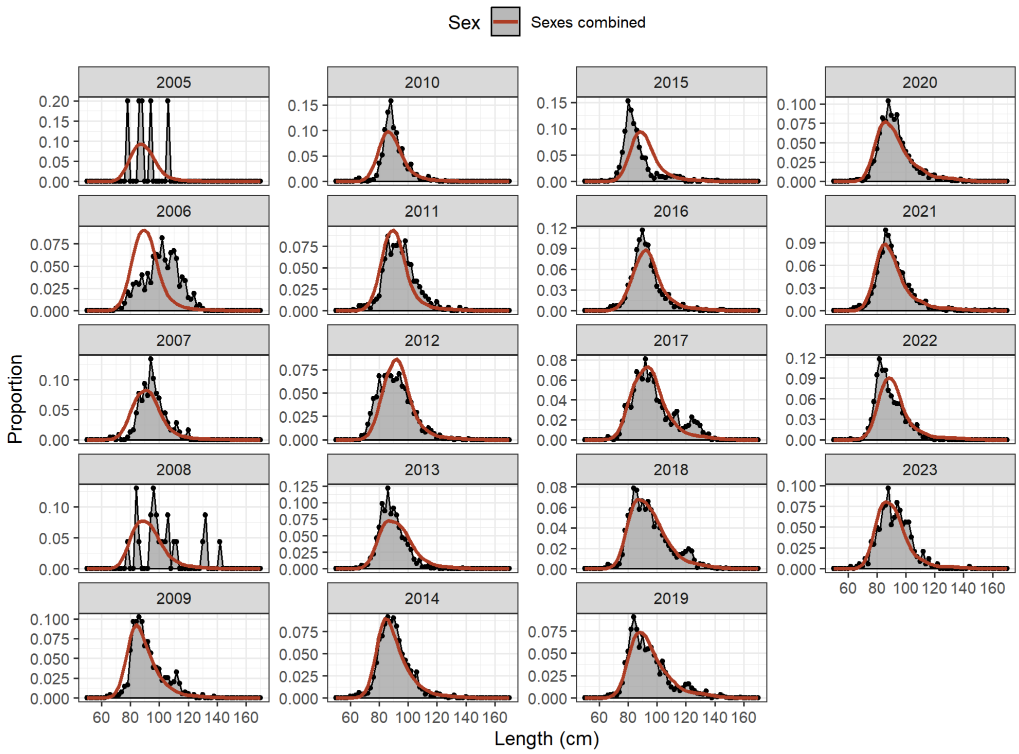

Figure E.64: Scenario 3: Fits to length structures for Fleet 5, based on maximum likelihood estimation—the grey area and black line represent data inputs and the red and blue line represents the model fits for female and male, respectively

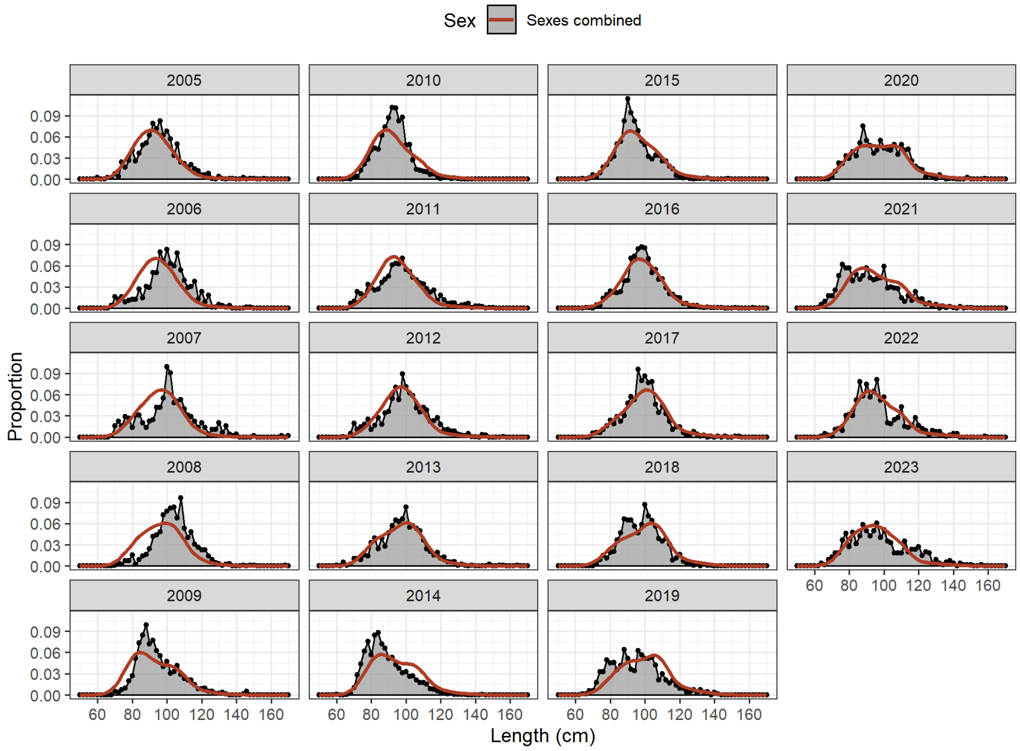

Figure E.65: Scenario 3: Fits to length structures for Fleet 6, based on maximum likelihood estimation—the grey area and black line represent data inputs and the red and blue line represents the model fits for female and male, respectively

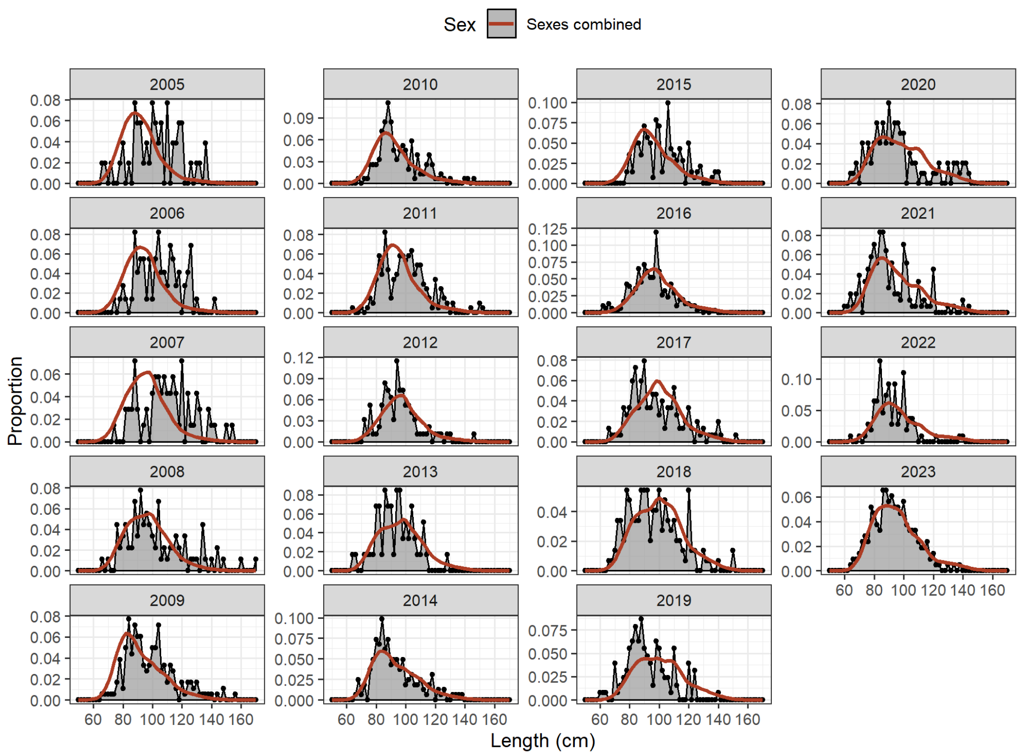

Figure E.66: Scenario 3: Fits to length structures for Fleet 7, based on maximum likelihood estimation—the grey area and black line represent data inputs and the red and blue line represents the model fits for female and male, respectively

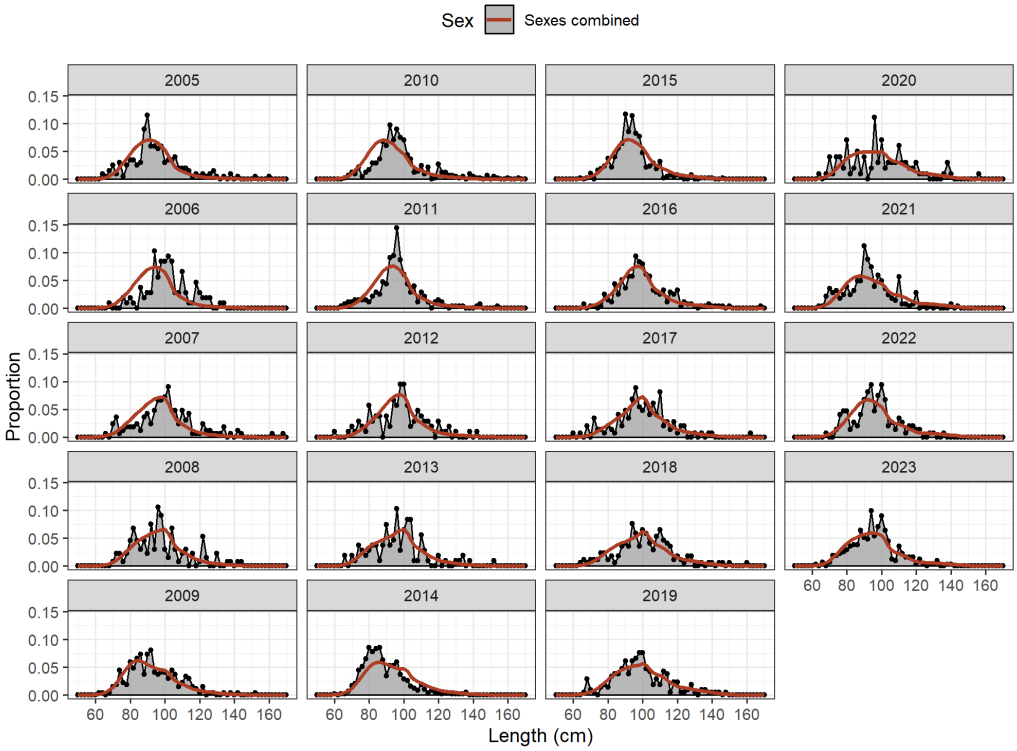

Figure E.67: Scenario 3: Fits to length structures for Fleet 8, based on maximum likelihood estimation—the grey area and black line represent data inputs and the red and blue line represents the model fits for female and male, respectively

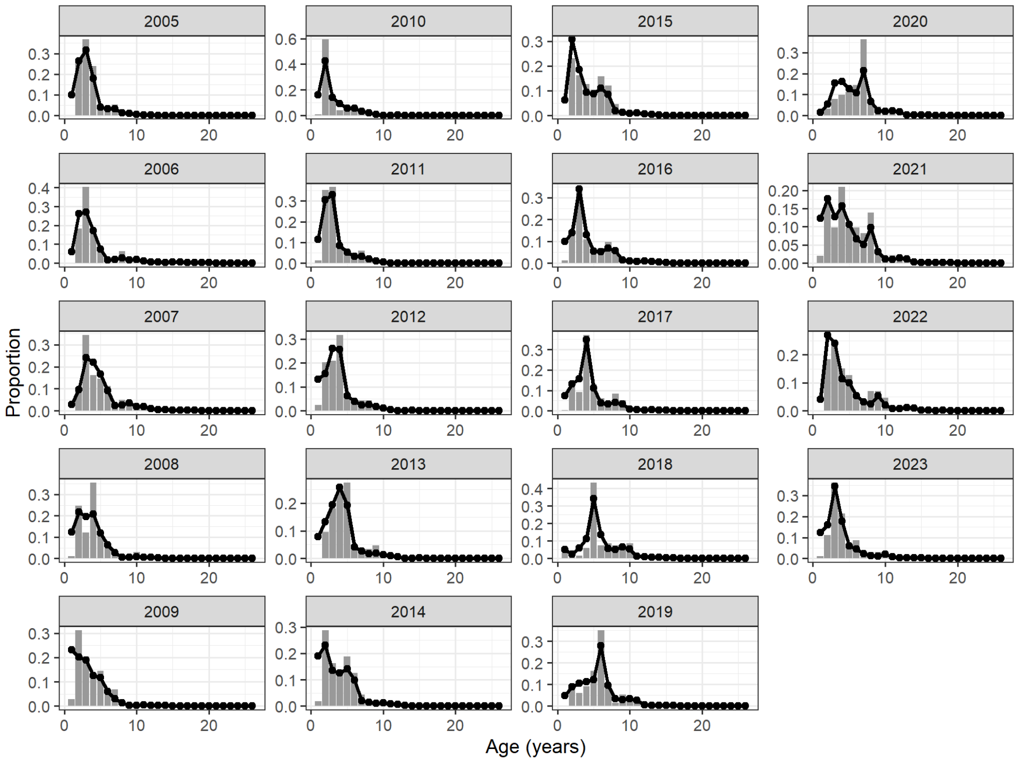

Figure E.68: Scenario 3: Fits to annual age compositions of female Spanish mackerel for Fleet 1

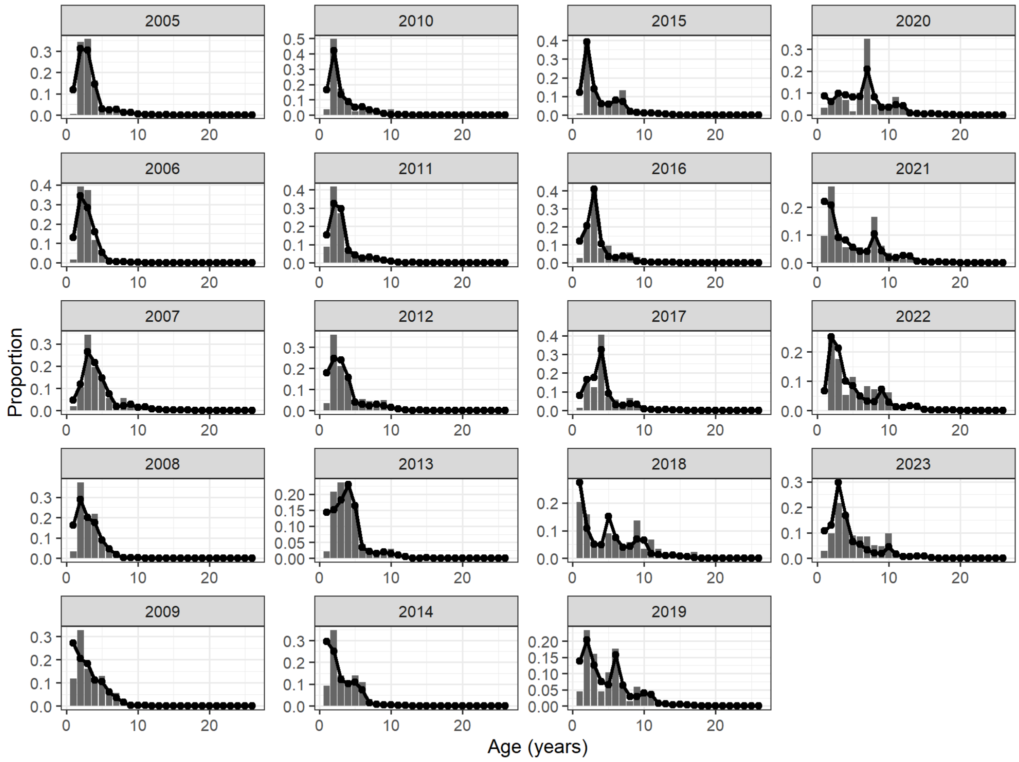

Figure E.69: Scenario 3: Fits to annual age compositions of male Spanish mackerel for Fleet 1

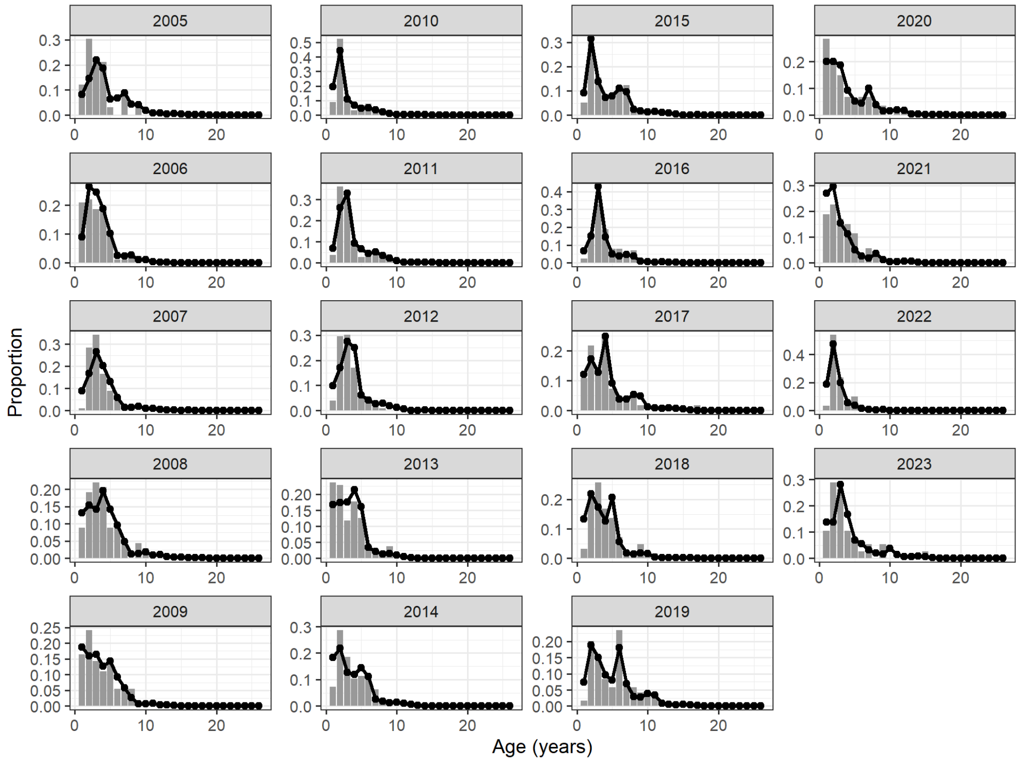

Figure E.70: Scenario 3: Fits to annual age compositions of female Spanish mackerel for Fleet 5

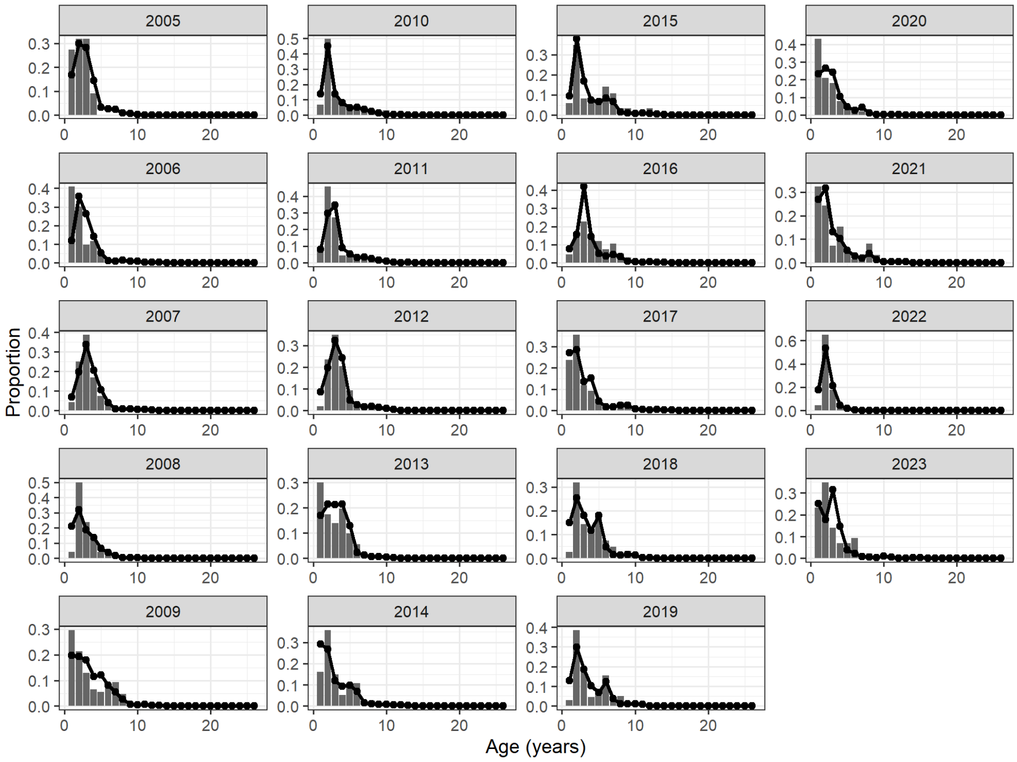

Figure E.71: Scenario 3: Fits to annual age compositions of male Spanish mackerel for Fleet 5

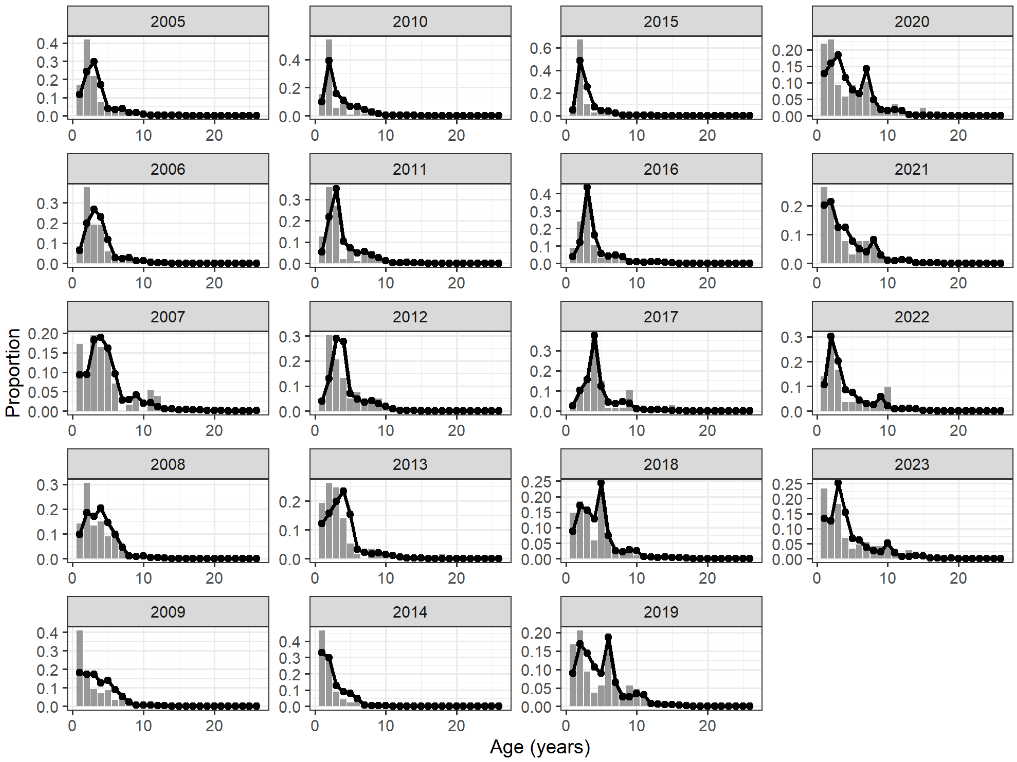

Figure E.72: Scenario 3: Fits to annual age compositions of female Spanish mackerel for Fleet 6

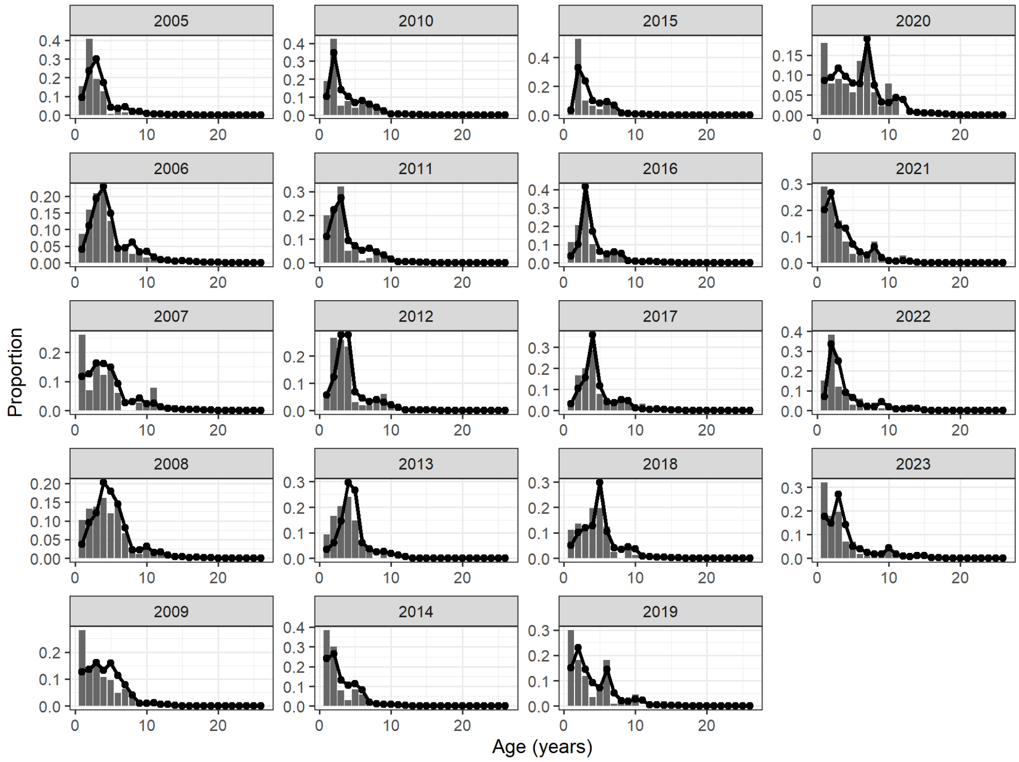

Figure E.73: Scenario 3: Fits to annual age compositions of male Spanish mackerel for Fleet 6

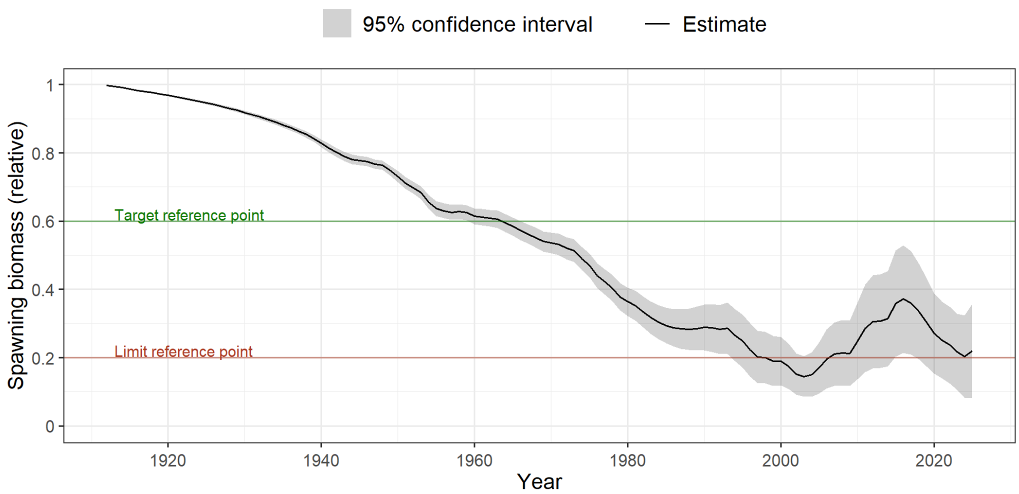

Figure E.74: Scenario 3: Predicted spawning biomass trajectory relative to unfished for Australian east coast Spanish mackerel, based on maximum likelihood estimation

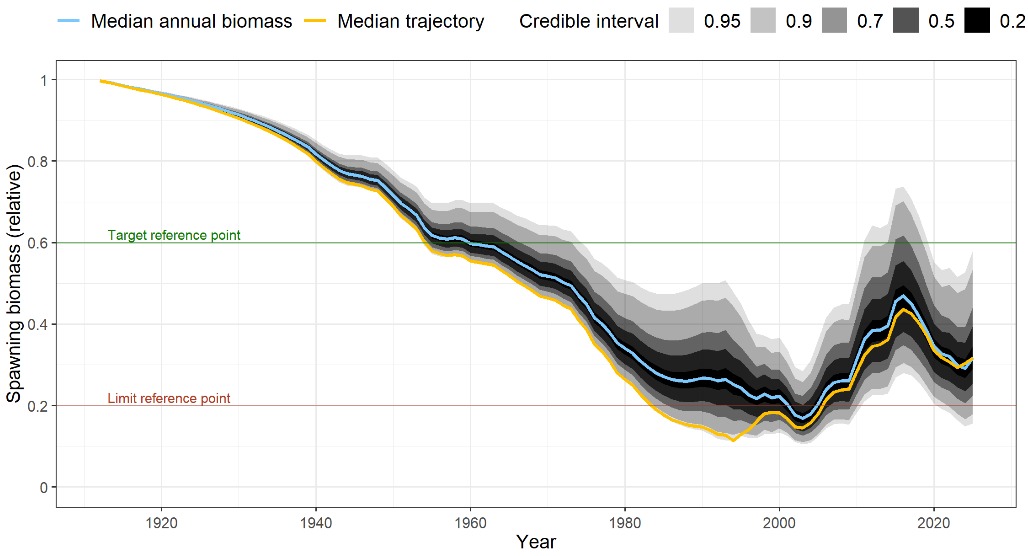

Figure E.75: Scenario 3: Predicted spawning biomass trajectory relative to unfished for Australian east coast Spanish mackerel, based on MCMC

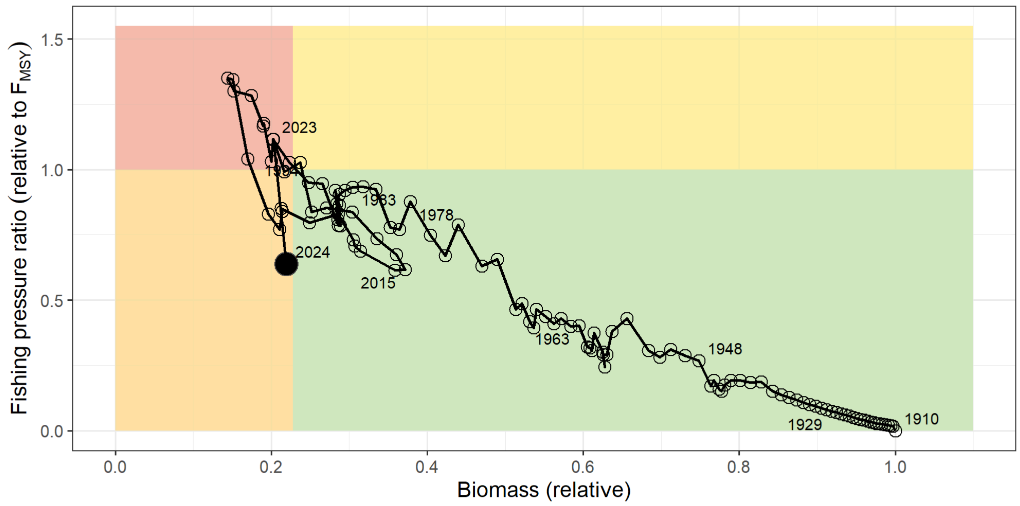

Figure E.76: Scenario 3: Stock status indicator trajectory for Australian east coast Spanish mackerel, based on maximum likelihood estimation

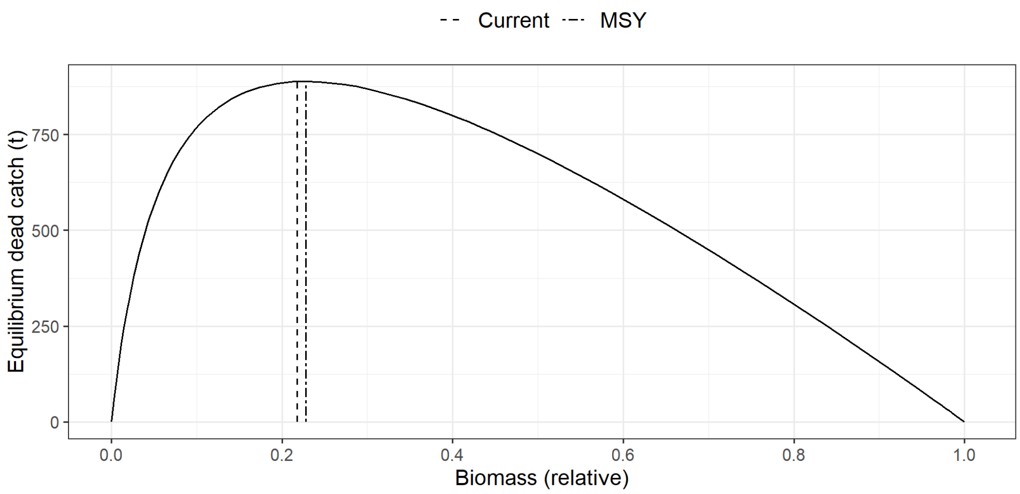

Figure E.77: Scenario 3: Equilibrium dead catch curve for Australian east coast Spanish mackerel, based on maximum likelihood estimation

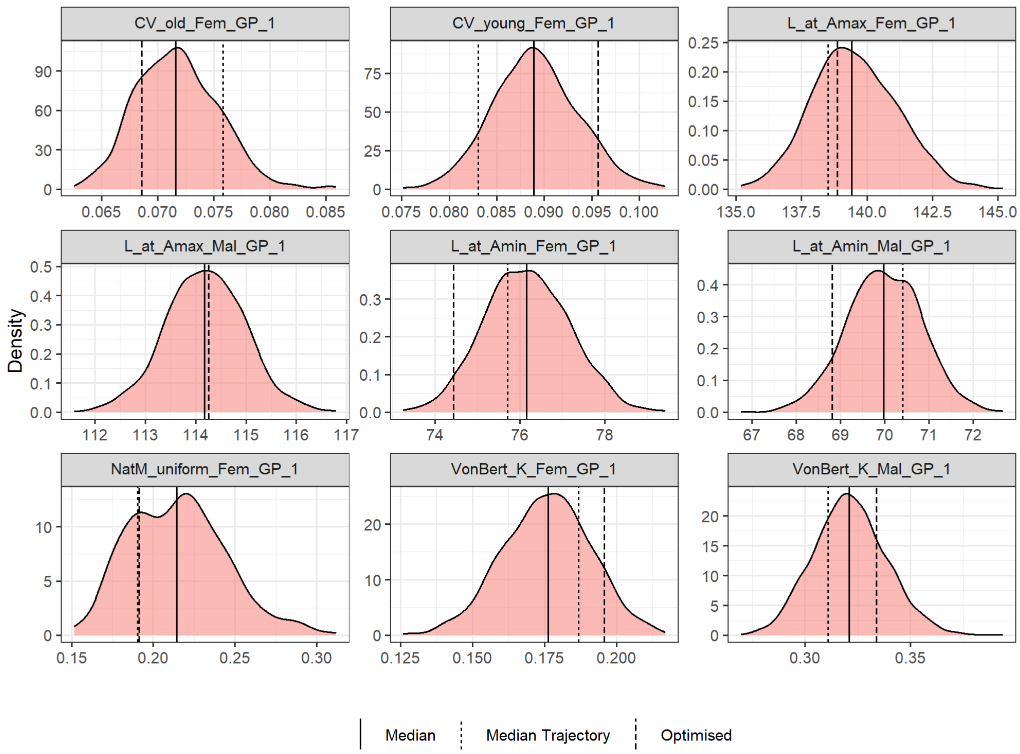

Figure E.78: Scenario 3: Posterior density of MCMC iterations. "Median" line shows median parameter value for MCMC iterations "Optimised" shows the parameter value found from maximum likelihood estimates.

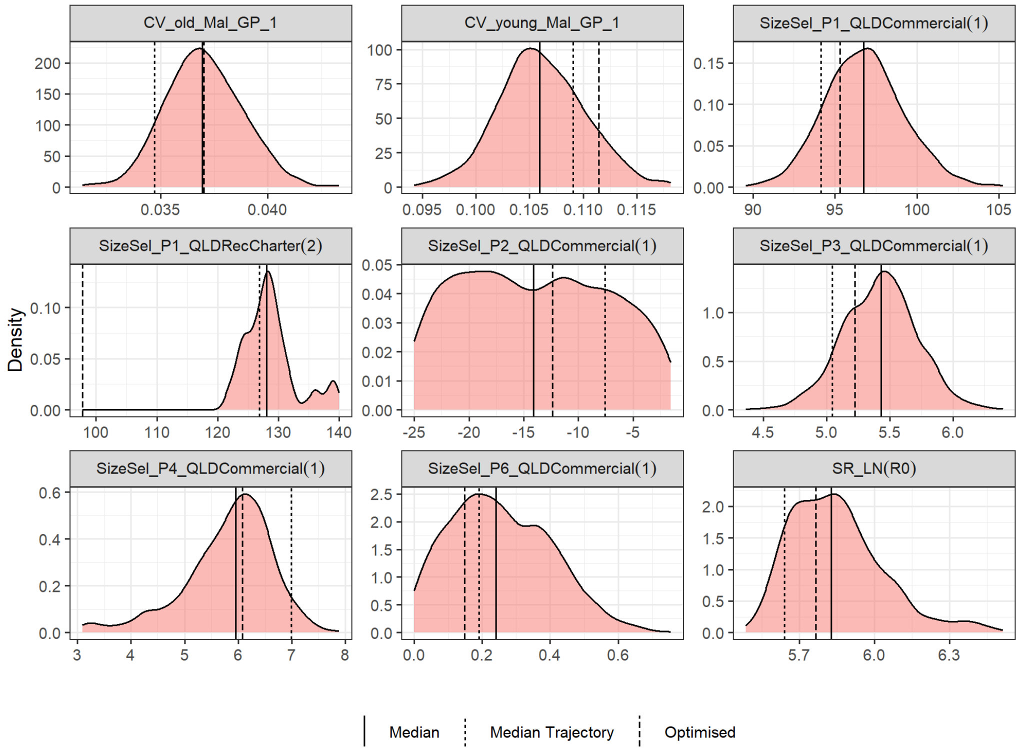

Figure E.79: Scenario 3: Posterior density of MCMC iterations. "Median" line shows median parameter value for MCMC iterations "Optimised" shows the parameter value found from maximum likelihood estimates.

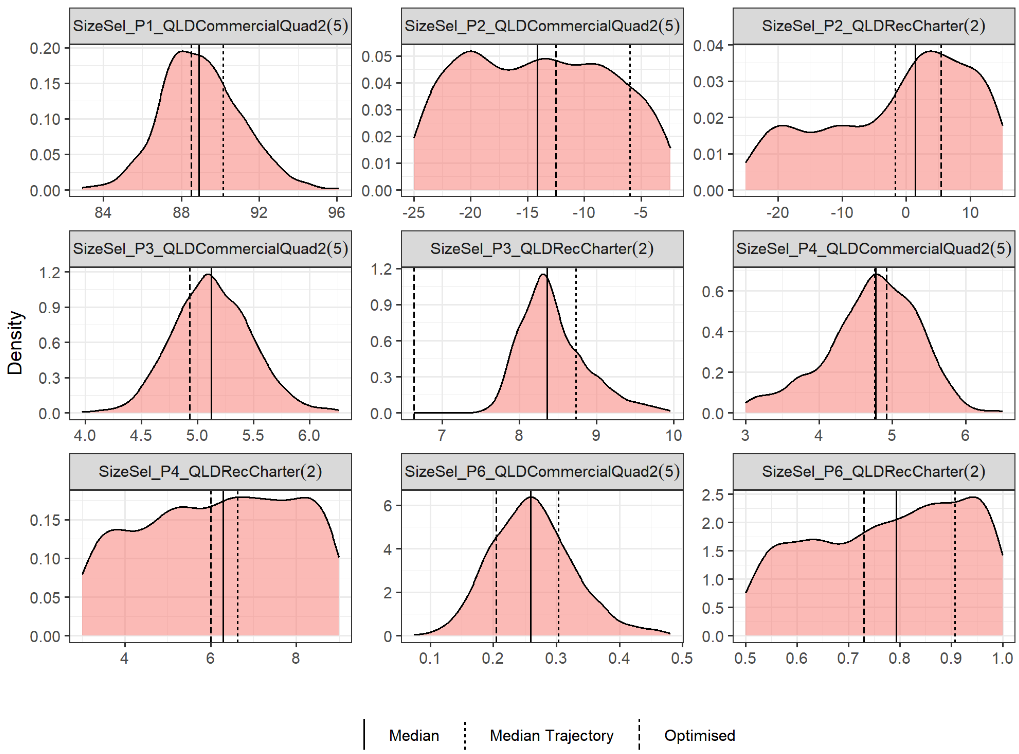

Figure E.80: Scenario 3: Posterior density of MCMC iterations. "Median" line shows median parameter value for MCMC iterations "Optimised" shows the parameter value found from maximum likelihood estimates.

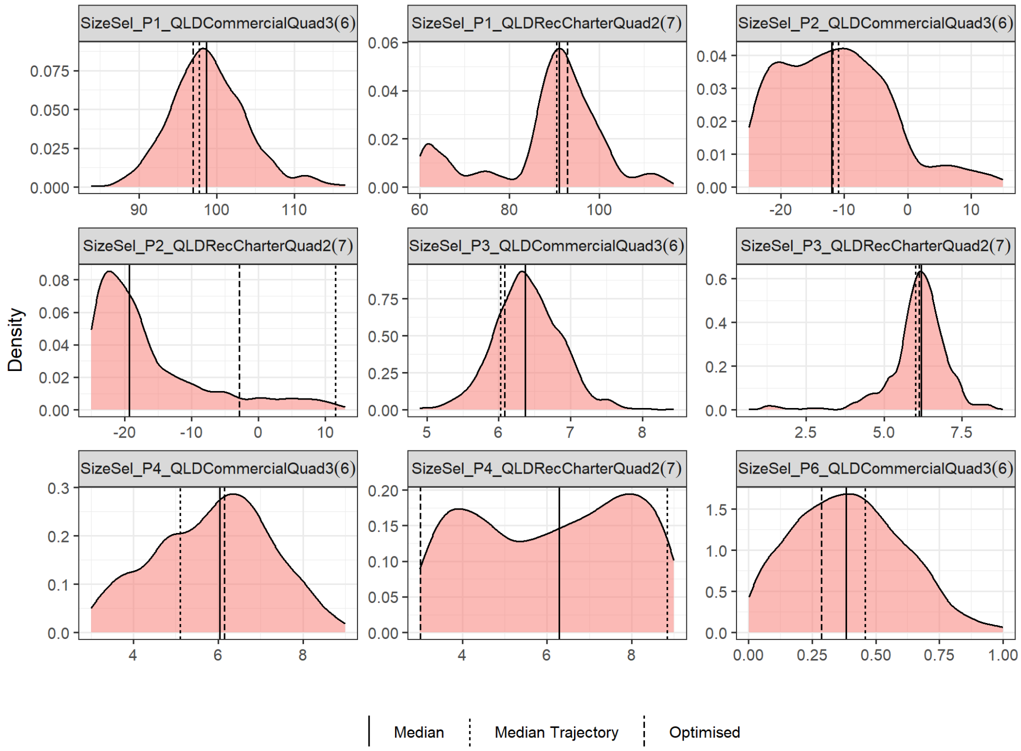

Figure E.81: Scenario 3: Posterior density of MCMC iterations. "Median" line shows median parameter value for MCMC iterations "Optimised" shows the parameter value found from maximum likelihood estimates.

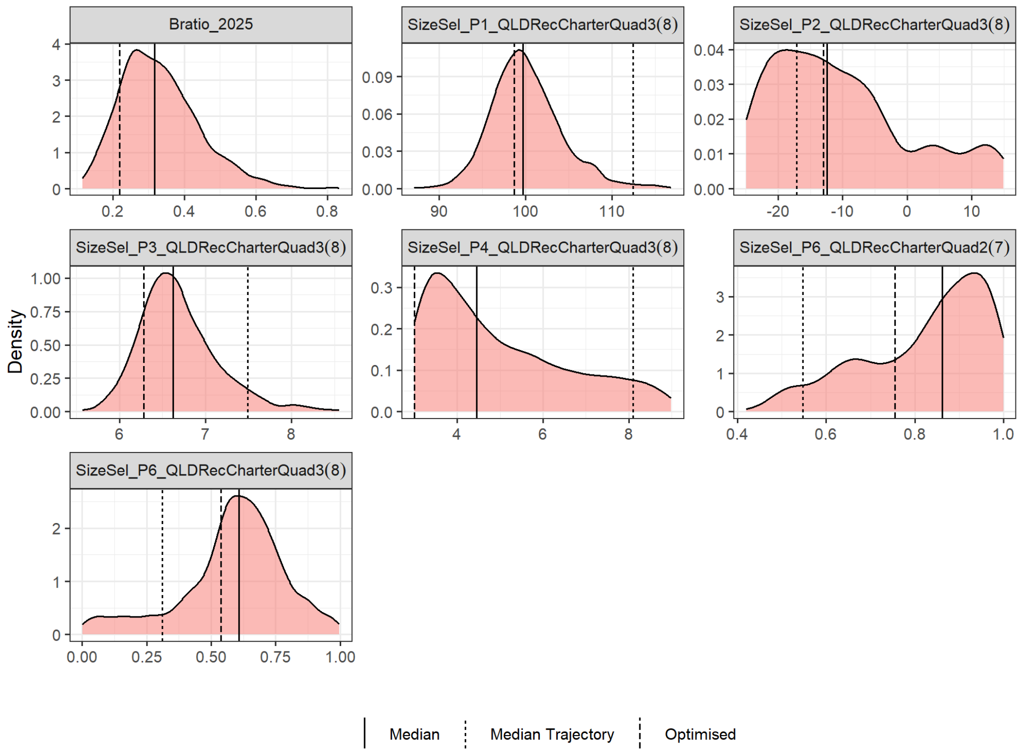

Figure E.82: Scenario 3: Posterior density of MCMC iterations. "Median" line shows median parameter value for MCMC iterations "Optimised" shows the parameter value found from maximum likelihood estimates.

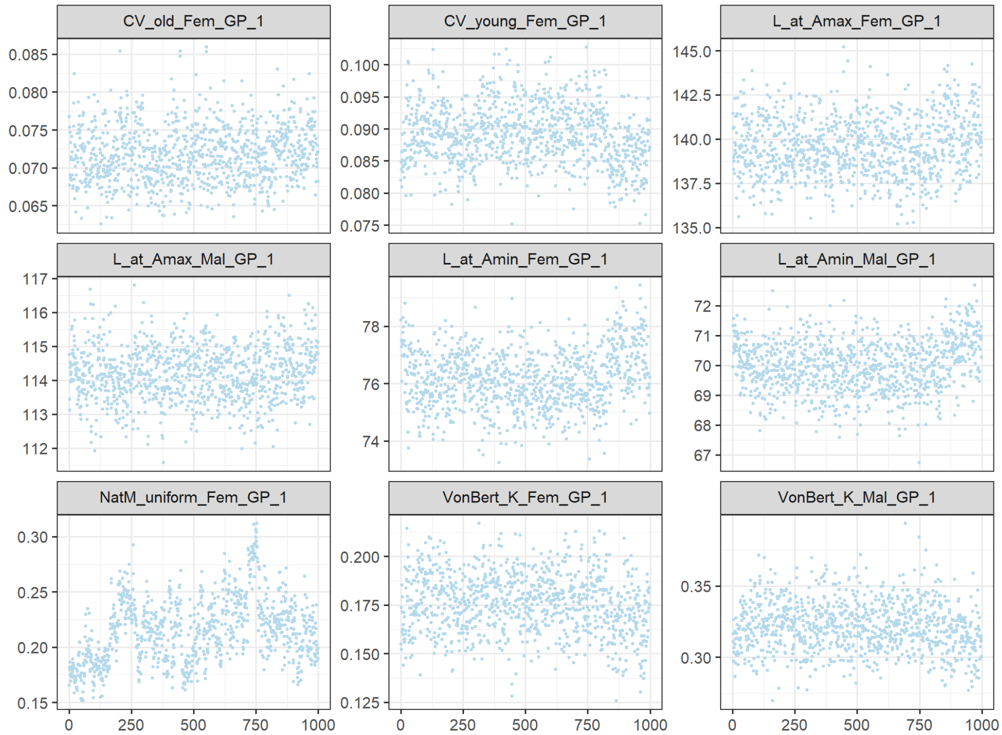

Figure E.83: Scenario 3: Trace plot of MCMC iterations

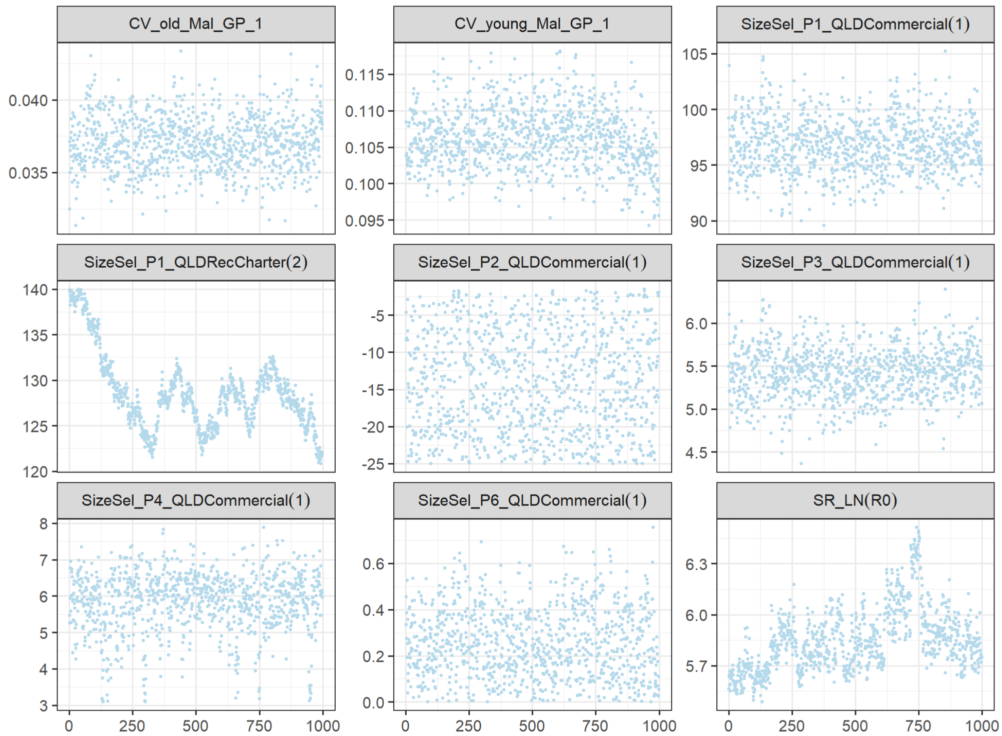

Figure E.84: Scenario 3: Trace plot of MCMC iterations

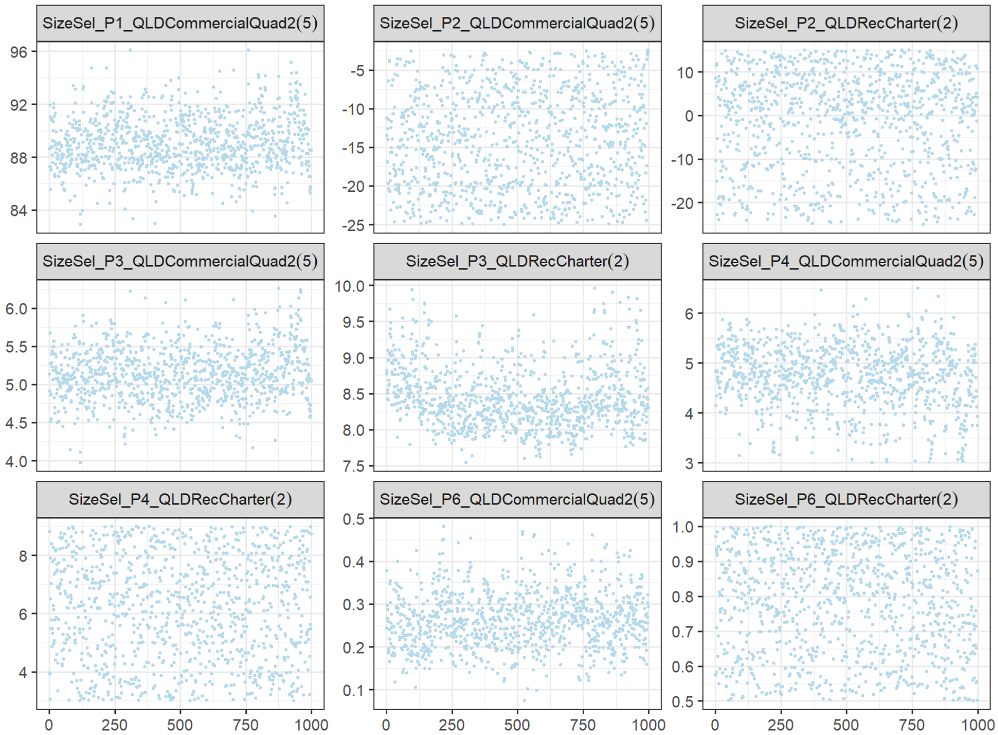

Figure E.85: Scenario 3: Trace plot of MCMC iterations

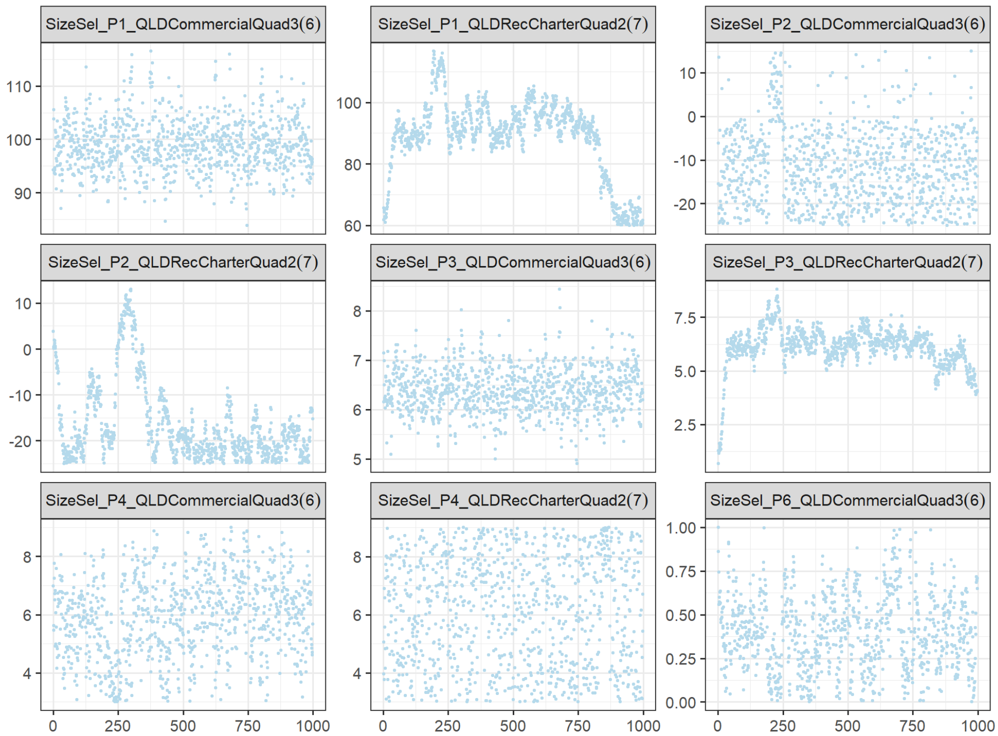

Figure E.86: Scenario 3: Trace plot of MCMC iterations

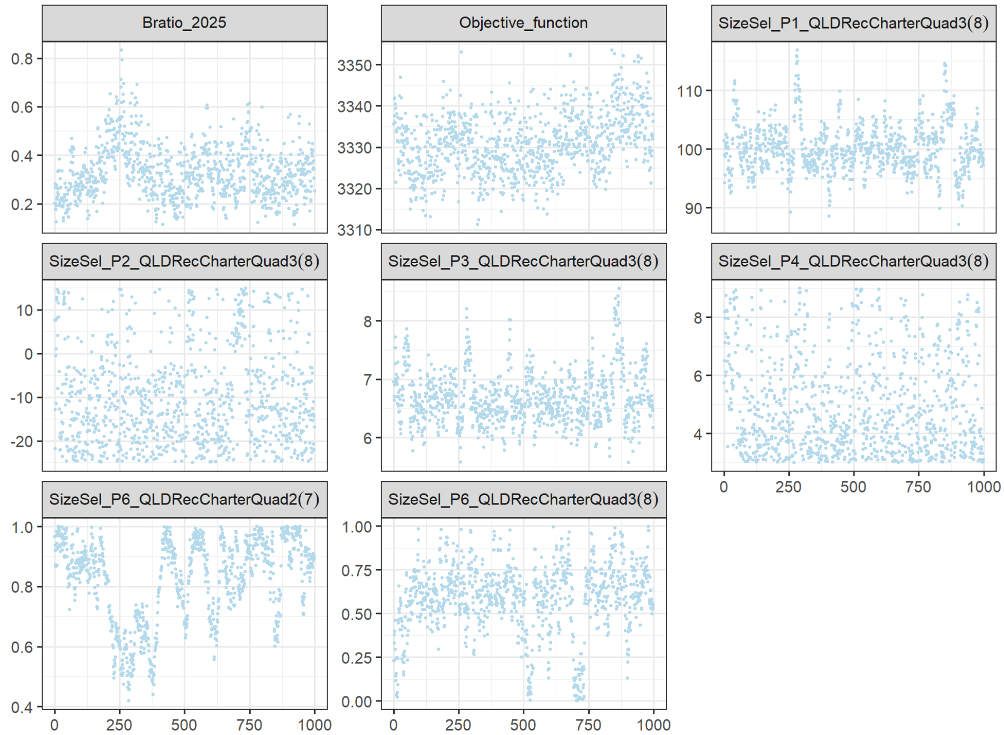

Figure E.87: Scenario 3: Trace plot of MCMC iterations

E.4 Scenario 4

Symbol	Value	Phase	Min	Max	Init	ParmStDev
Natural mortality	0.27	5	0.15	0.4	0.216	0.0207119
Length at minimum age (female)	74.67	3	65	90	75	0.997827
Length at maximum age (female)	135.81	3	130	160	140	1.61841
VonBert growth coefficient (female)	0.21	3	0.05	0.3	0.15	0.017097
SD of length at minimum age (female)	0.09	3	0.03	0.2	0.09	0.00474527
SD of length at maximum age (female)	0.07	3	0.03	0.2	0.07	0.0033879
Length at minimum age (male)	69.51	3	60	85	70	0.843672
Length at maximum age (male)	113.76	3	105	130	115	0.712146
VonBert growth coefficient (male)	0.33	3	0.15	0.4	0.3	0.0174488
SD of length at minimum age (male)	0.11	3	0.03	0.2	0.085	0.00406097
SD of length at maximum age (male)	0.04	3	0.01	0.15	0.04	0.00168049
Log of number of recruits when unfished	6.48	1	5	7	6.5	0.108916
Selectivity plateau start, Fleet 1	95.94	2	60	140	90	3.07764
Selectivity plateau width, Fleet 1	-11.43	2	-25	15	-2	152.62
Selectivity asc. width, Fleet 1	5.28	2	0	10	5	0.388449
Selectivity desc. width, Fleet 1	5.75	2	3	9	5	1.28368
Selectivity at max length, Fleet 1	0.32	2	0	1	0.2	0.262143
Selectivity plateau start, Fleet 2	100.89	2	60	140	90	9.3336
Selectivity plateau width, Fleet 2	5.32	2	-25	15	-2	33.2684
Selectivity asc. width, Fleet 2	6.75	2	0	10	5	0.703385
Selectivity desc. width, Fleet 2	5.95	2	3	9	5	67.1139
Selectivity at max length, Fleet 2	0.75	2	0.5	1	0.6	5.59294
Selectivity plateau start, Fleet 5	88.82	2	60	140	90	2.47071
Selectivity plateau width, Fleet 5	-11.74	2	-25	15	-2	148.171
Selectivity asc. width, Fleet 5	4.98	2	0	10	3	0.416031
Selectivity desc. width, Fleet 5	4.74	2	3	9	5	0.688678
Selectivity at max length, Fleet 5	0.25	2	0	1	0.2	0.0748012
Selectivity plateau start, Fleet 6	95.91	2	60	140	90	6.11858
Selectivity plateau width, Fleet 6	4.65	2	-25	15	-2	89.8266
Selectivity asc. width, Fleet 6	6.1	2	0	10	3	0.609815
Selectivity desc. width, Fleet 6	5.98	2	3	9	5	67.0545
Selectivity at max length, Fleet 6	0.89	2	0	1	0.2	3.25946
Selectivity plateau start, Fleet 7	91.65	2	60	140	90	5.61399
Selectivity plateau width, Fleet 7	2.06	2	-25	15	-2	26.5712
Selectivity asc. width, Fleet 7	6.09	2	0	10	3	0.642709
Selectivity desc. width, Fleet 7	5.93	2	3	9	5	67.0758
Selectivity at max length, Fleet 7	0.98	2	0	1	0.6	0.61009
Selectivity plateau start, Fleet 8	98.09	2	60	140	90	5.31029
Selectivity plateau width, Fleet 8	5.4	2	-25	15	-2	28.2424
Selectivity asc. width, Fleet 8	6.45	2	0	10	3	0.494431
Selectivity desc. width, Fleet 8	6.05	2	3	9	5	67.225
Selectivity at max length, Fleet 8	0.51	2	0	1	0.6	11.1644

Table E.7: Scenario 4: Summary of MLE parameter estimates. Fleet definitions are listed in Table 2.2.

Symbol	MCMC median	MCMC 2.5%	MCMC 97.5%
Natural mortality	0.27	0.22	0.32
Length at minimum age (female)	75.33	73.36	77.16
Length at maximum age (female)	136.68	133.3	139.97
VonBert growth coefficient (female)	0.2	0.17	0.23
SD of length at minimum age (female)	0.09	0.08	0.1
SD of length at maximum age (female)	0.07	0.06	0.07
Length at minimum age (male)	69.94	68.25	71.43
Length at maximum age (male)	113.96	112.64	115.42
VonBert growth coefficient (male)	0.32	0.29	0.36
SD of length at minimum age (male)	0.11	0.1	0.11
SD of length at maximum age (male)	0.04	0.03	0.04
Log of number of recruits when unfished	6.36	6.15	6.7
Selectivity plateau start, Fleet 1	96.99	90.84	104.97
Selectivity plateau width, Fleet 1	-13.94	-24.49	-1.68
Selectivity asc. width, Fleet 1	5.47	4.67	6.27
Selectivity desc. width, Fleet 1	5.5	3.25	8.31
Selectivity at max length, Fleet 1	0.35	0.02	0.74
Selectivity plateau start, Fleet 2	107.62	87.2	137.64
Selectivity plateau width, Fleet 2	0.19	-23.67	14.21
Selectivity asc. width, Fleet 2	7.4	5.64	9.14
Selectivity desc. width, Fleet 2	6.22	3.16	8.82
Selectivity at max length, Fleet 2	0.79	0.52	0.99
Selectivity plateau start, Fleet 5	89.12	83.42	94.71
Selectivity plateau width, Fleet 5	-14.31	-24.25	-2.94
Selectivity asc. width, Fleet 5	5.14	4.29	6.06
Selectivity desc. width, Fleet 5	4.64	3.16	6.01
Selectivity at max length, Fleet 5	0.25	0.11	0.44
Selectivity plateau start, Fleet 6	96.88	84.35	112.69
Selectivity plateau width, Fleet 6	-9.84	-24.5	13.33
Selectivity asc. width, Fleet 6	6.27	4.81	8.09
Selectivity desc. width, Fleet 6	6.25	3.2	8.8
Selectivity at max length, Fleet 6	0.51	0.04	0.96
Selectivity plateau start, Fleet 7	95.35	75.57	122.5
Selectivity plateau width, Fleet 7	2.35	-23.58	14.22
Selectivity asc. width, Fleet 7	6.66	4.65	9.02
Selectivity desc. width, Fleet 7	6.47	3.14	8.89
Selectivity at max length, Fleet 7	0.65	0.04	0.98
Selectivity plateau start, Fleet 8	98.31	85.11	117.69
Selectivity plateau width, Fleet 8	-7.53	-24.17	13.86
Selectivity asc. width, Fleet 8	6.51	5.54	8.36
Selectivity desc. width, Fleet 8	5.53	3.09	8.77
Selectivity at max length, Fleet 8	0.61	0.08	0.98

Table E.8: Scenario 4: Summary of MCMC parameter estimates. Fleet definitions are listed in Table 2.2.

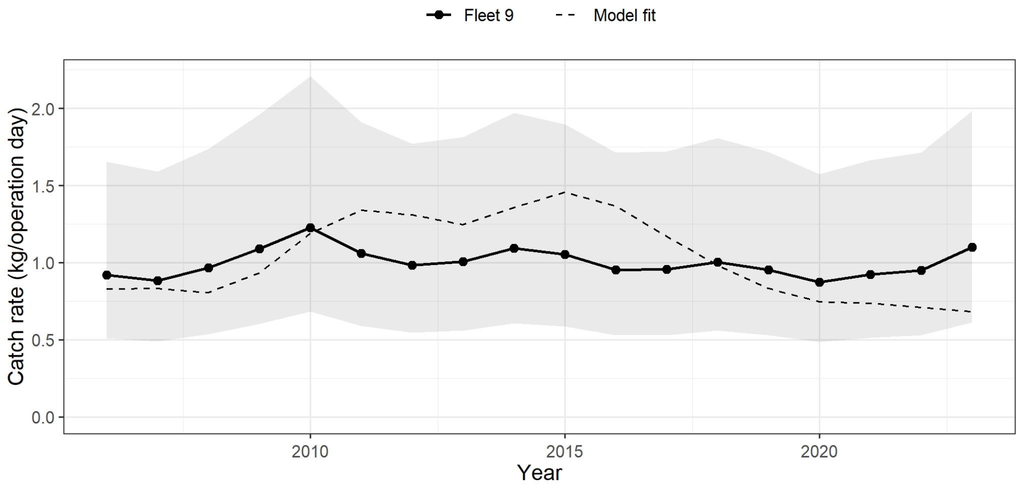

Figure E.88: Scenario 4: Model predictions (dotted line) to standardised catch rates for Australian east coast Spanish mackerel, based on maximum likelihood estimation—grey shade represent the model input and associated uncertainty

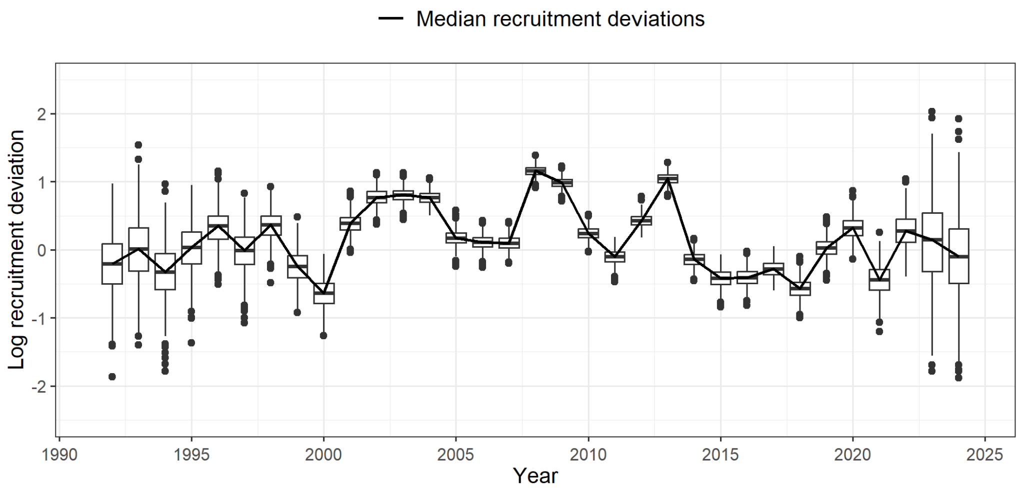

Figure E.89: Scenario 4: Recruitment deviations—whiskers represent 95% credible intervals, boxes represent 50% credible intervals, horizontal bars represent medians, and the points represent outliers

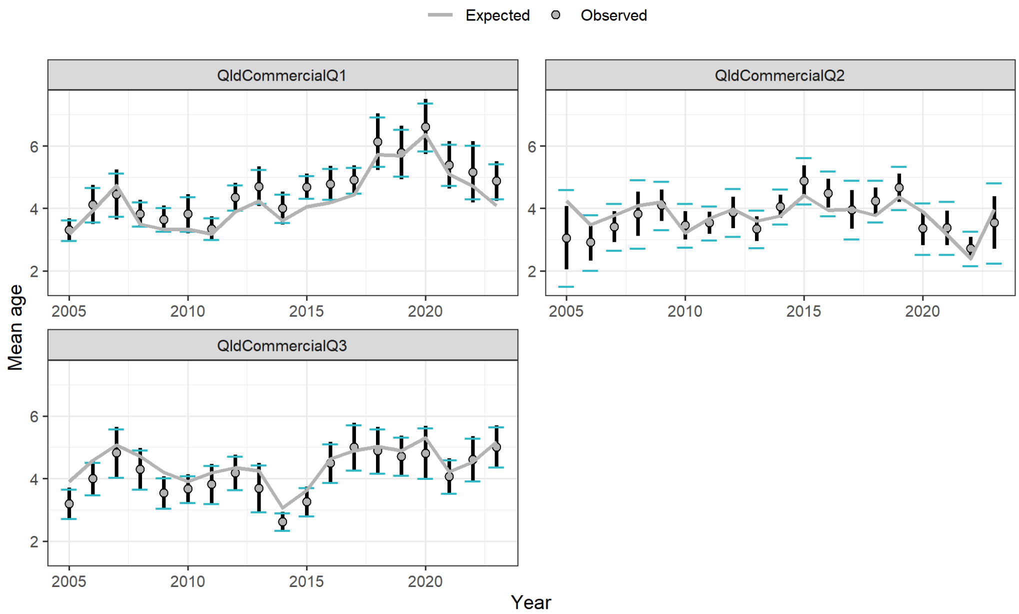

Figure E.90: Scenario 4: Mean age from conditional data (aggregated across length bins) with 95% confidence intervals based on current samples sizes: thinner intervals (with capped ends) show result of further adjusting sample sizes based on suggested multiplier (with 95% interval) for conditional age-at-length data

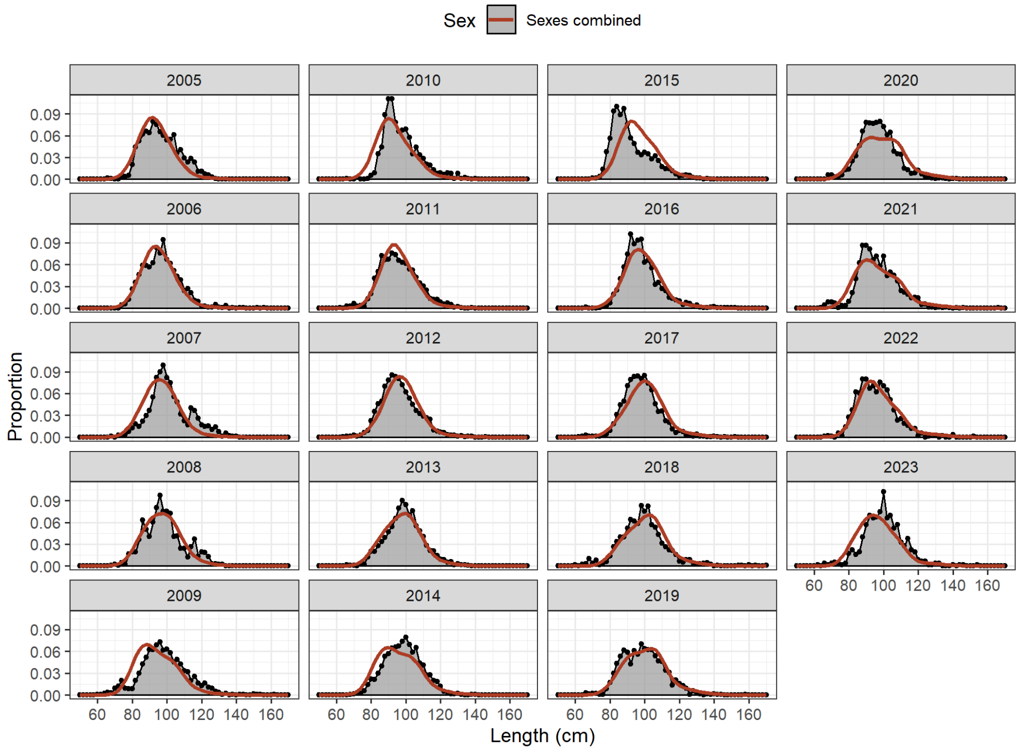

Figure E.91: Scenario 4: Fits to length structures for Fleet 1, based on maximum likelihood estimation—the grey area and black line represent data inputs and the red and blue line represents the model fits for female and male, respectively

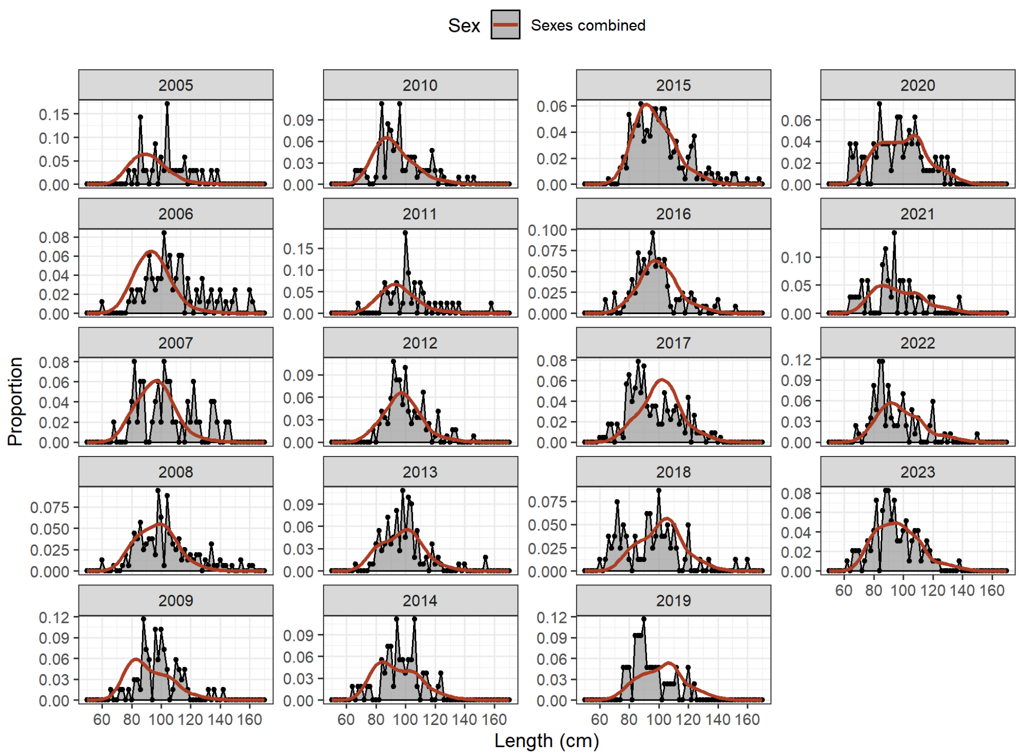

Figure E.92: Scenario 4: Fits to length structures for Fleet 2, based on maximum likelihood estimation—the grey area and black line represent data inputs and the red and blue line represents the model fits for female and male, respectively

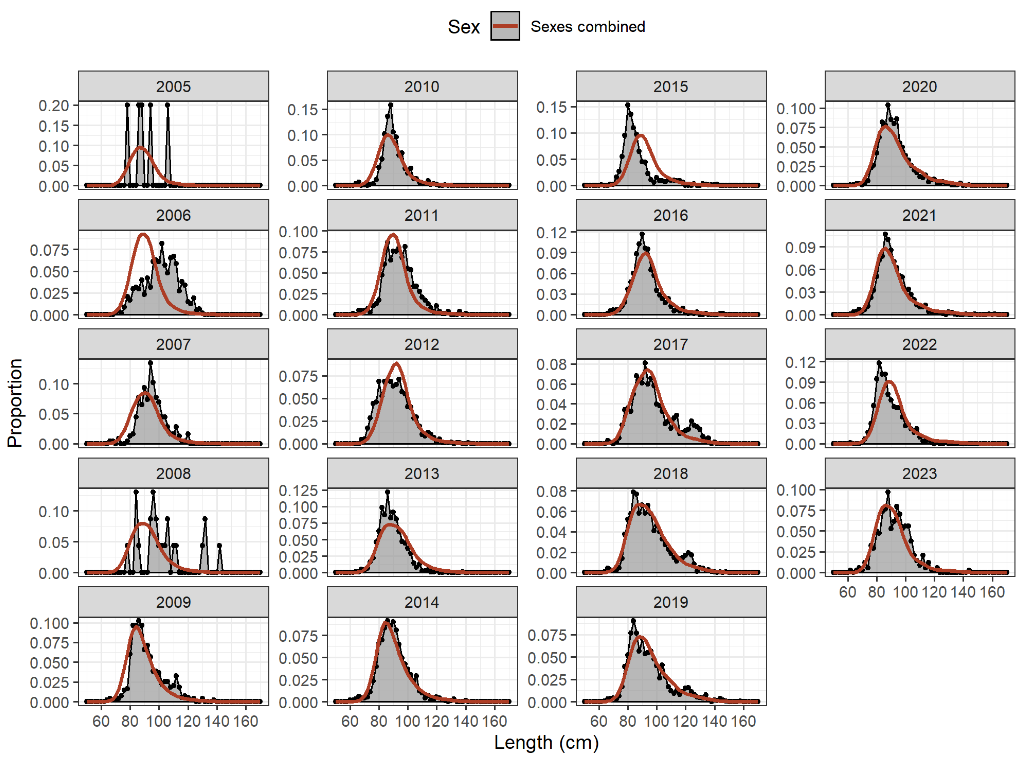

Figure E.93: Scenario 4: Fits to length structures for Fleet 5, based on maximum likelihood estimation—the grey area and black line represent data inputs and the red and blue line represents the model fits for female and male, respectively

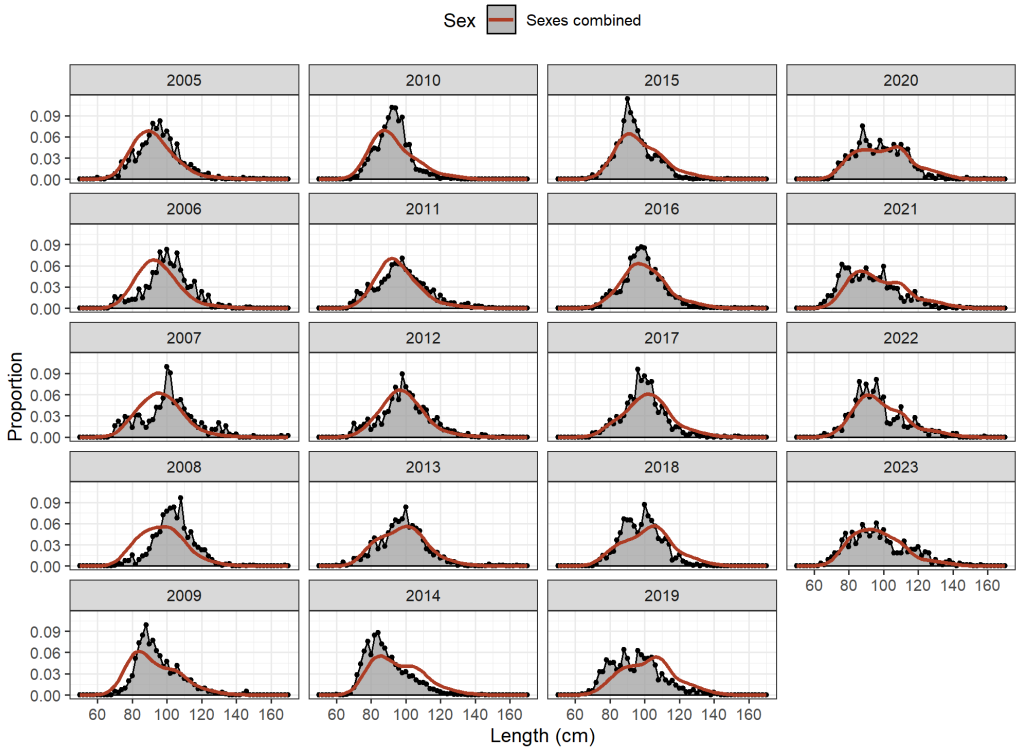

Figure E.94: Scenario 4: Fits to length structures for Fleet 6, based on maximum likelihood estimation—the grey area and black line represent data inputs and the red and blue line represents the model fits for female and male, respectively

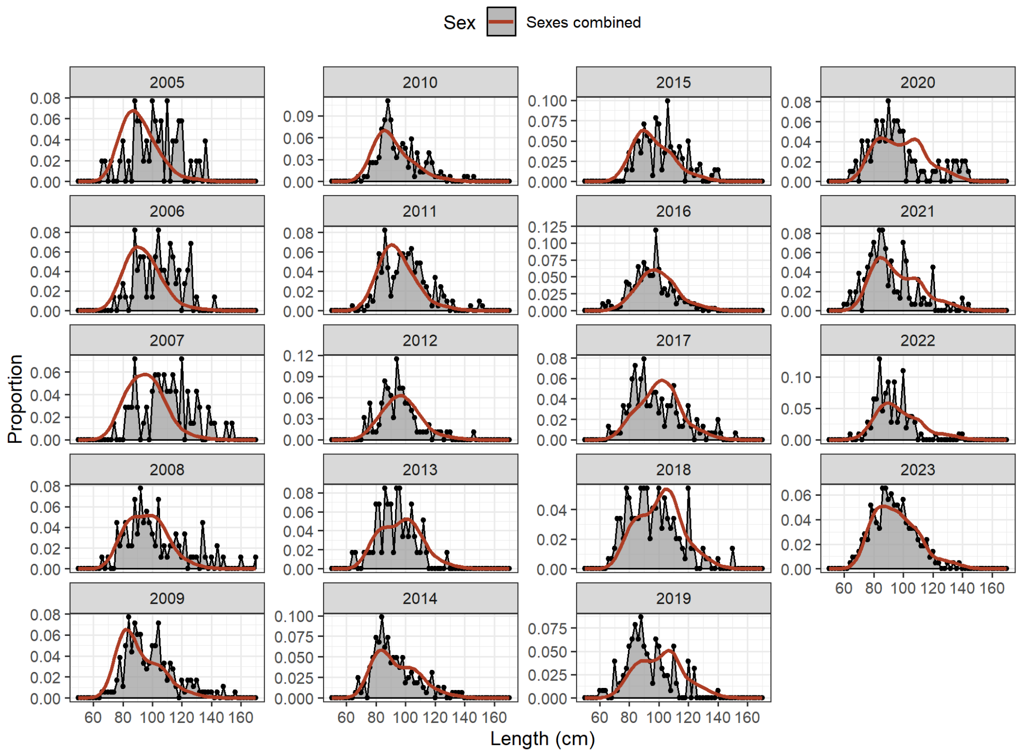

Figure E.95: Scenario 4: Fits to length structures for Fleet 7, based on maximum likelihood estimation—the grey area and black line represent data inputs and the red and blue line represents the model fits for female and male, respectively

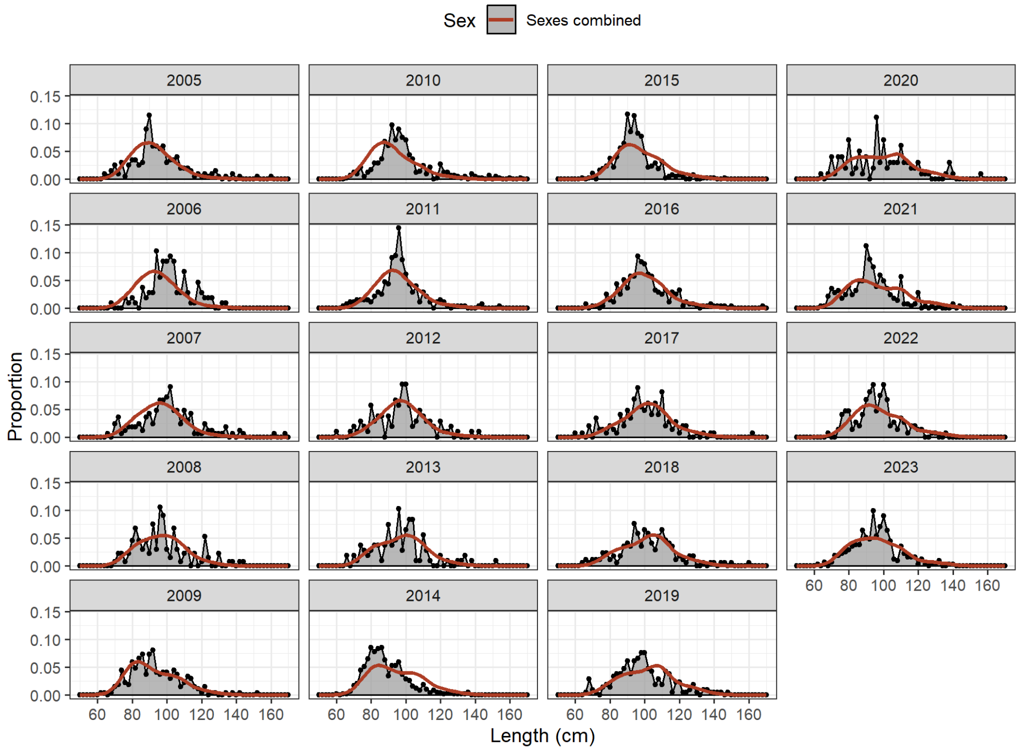

Figure E.96: Scenario 4: Fits to length structures for Fleet 8, based on maximum likelihood estimation—the grey area and black line represent data inputs and the red and blue line represents the model fits for female and male, respectively

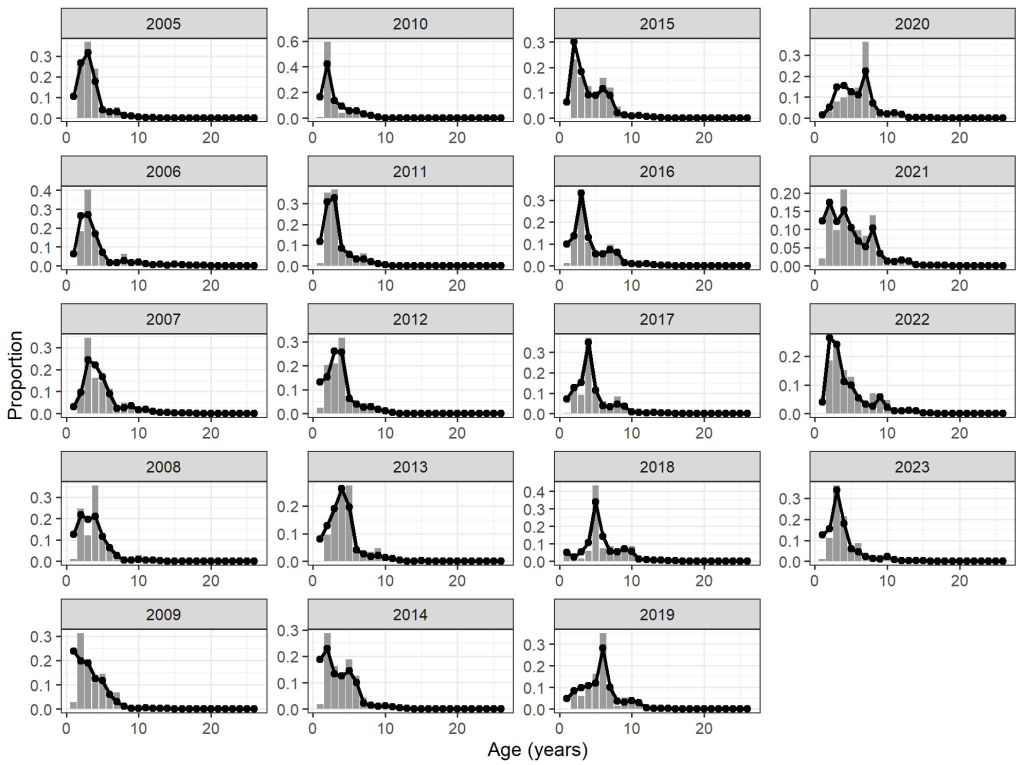

Figure E.97: Scenario 4: Fits to annual age compositions of female Spanish mackerel for Fleet 1

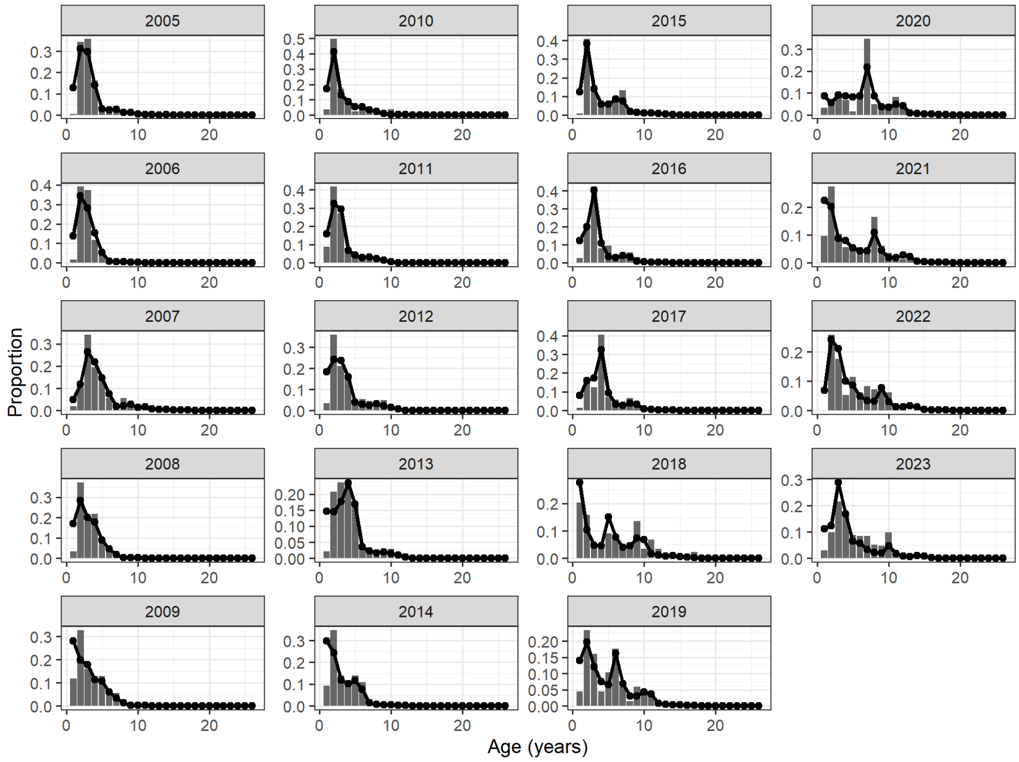

Figure E.98: Scenario 4: Fits to annual age compositions of male Spanish mackerel for Fleet 1

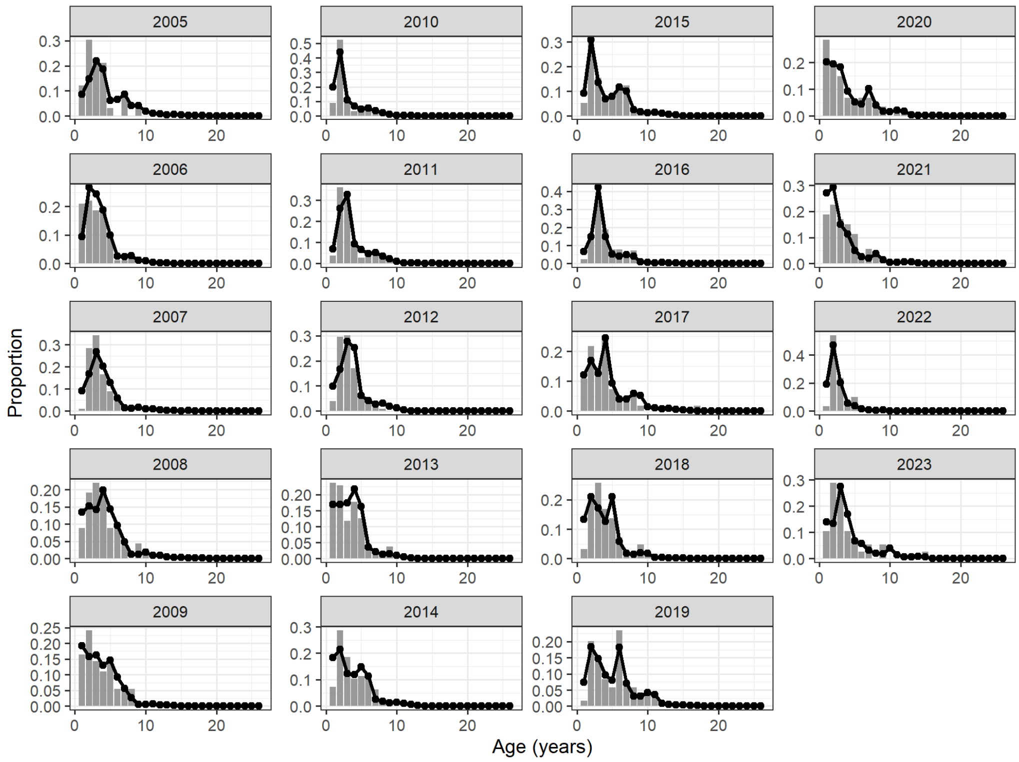

Figure E.99: Scenario 4: Fits to annual age compositions of female Spanish mackerel for Fleet 5

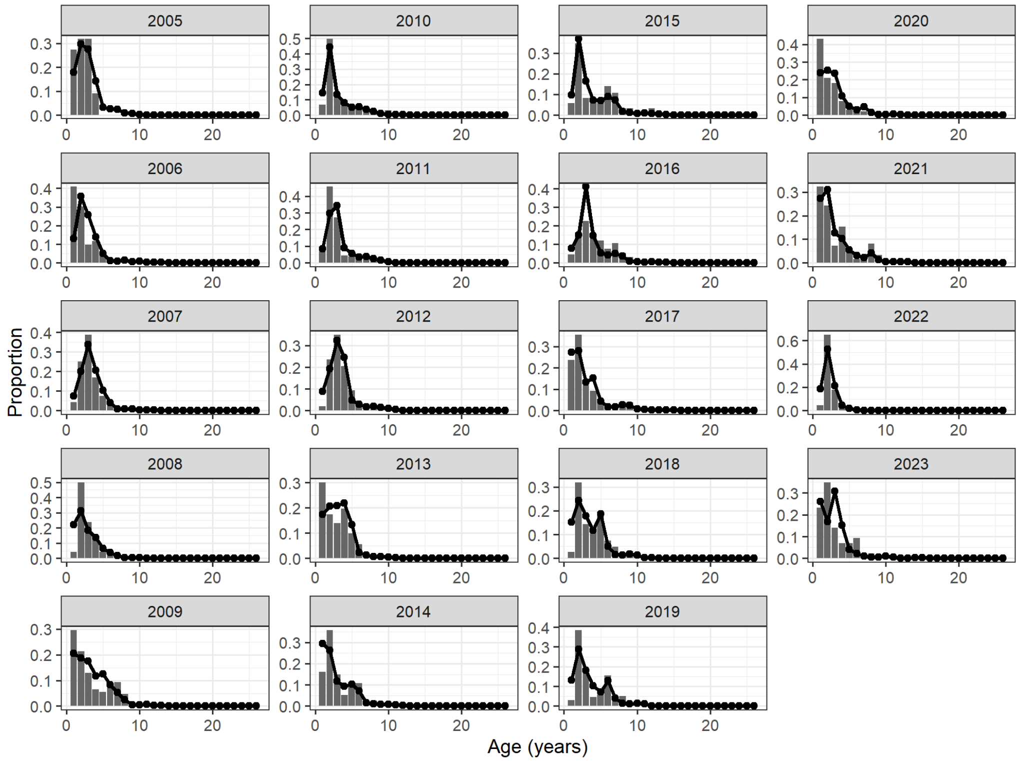

Figure E.100: Scenario 4: Fits to annual age compositions of male Spanish mackerel for Fleet 5

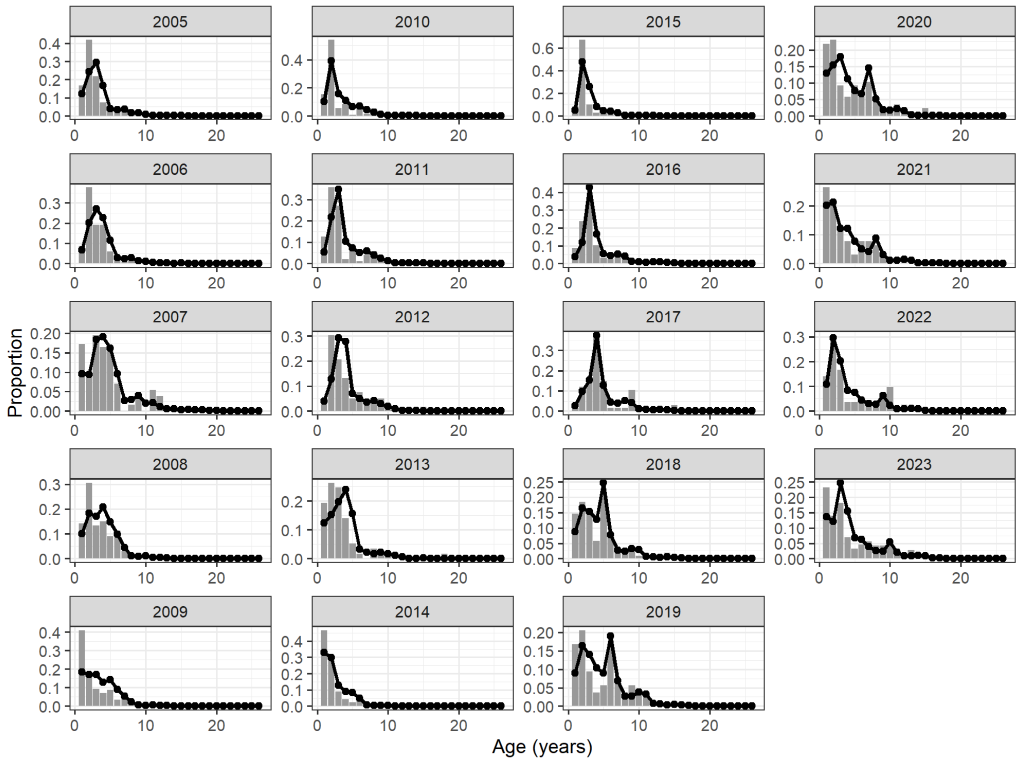

Figure E.101: Scenario 4: Fits to annual age compositions of female Spanish mackerel for Fleet 6

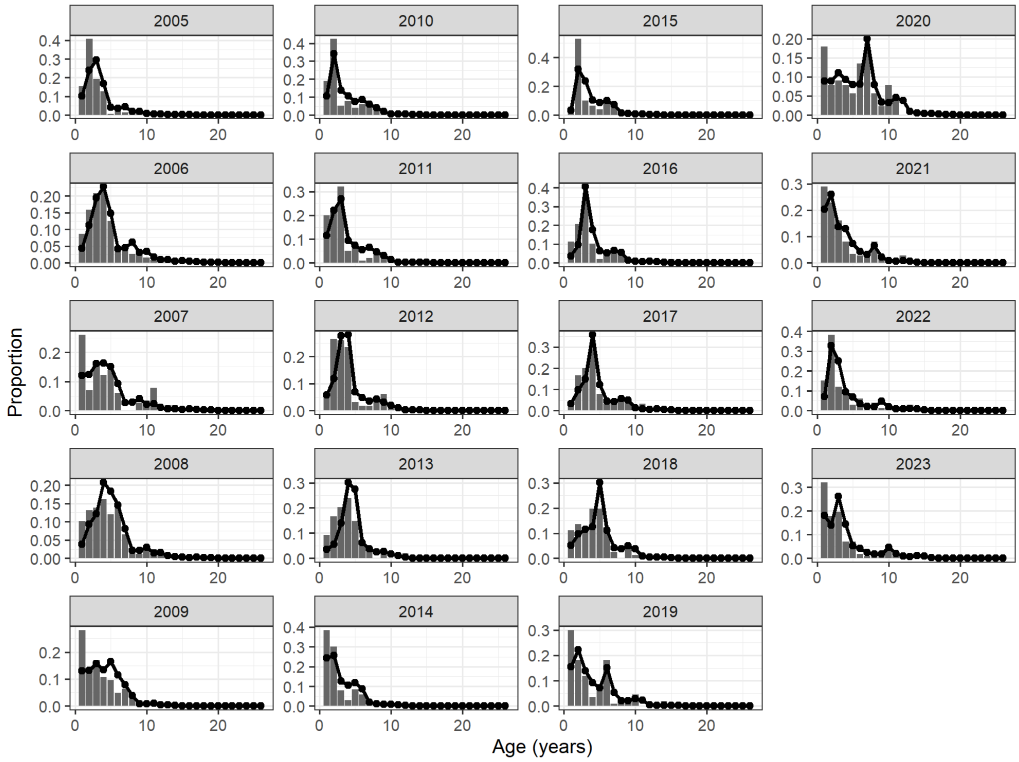

Figure E.102: Scenario 4: Fits to annual age compositions of male Spanish mackerel for Fleet 6

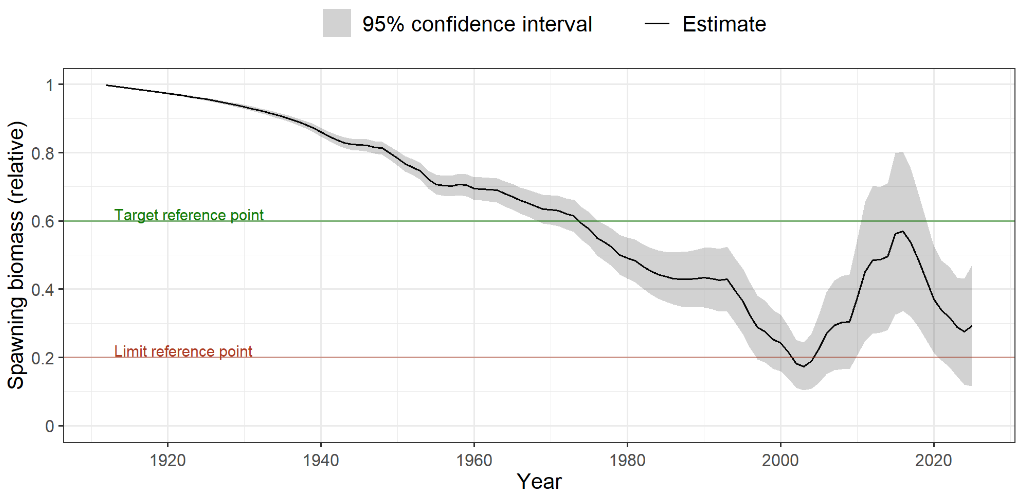

Figure E.103: Scenario 4: Predicted spawning biomass trajectory relative to unfished for Australian east coast Spanish mackerel, based on maximum likelihood estimation

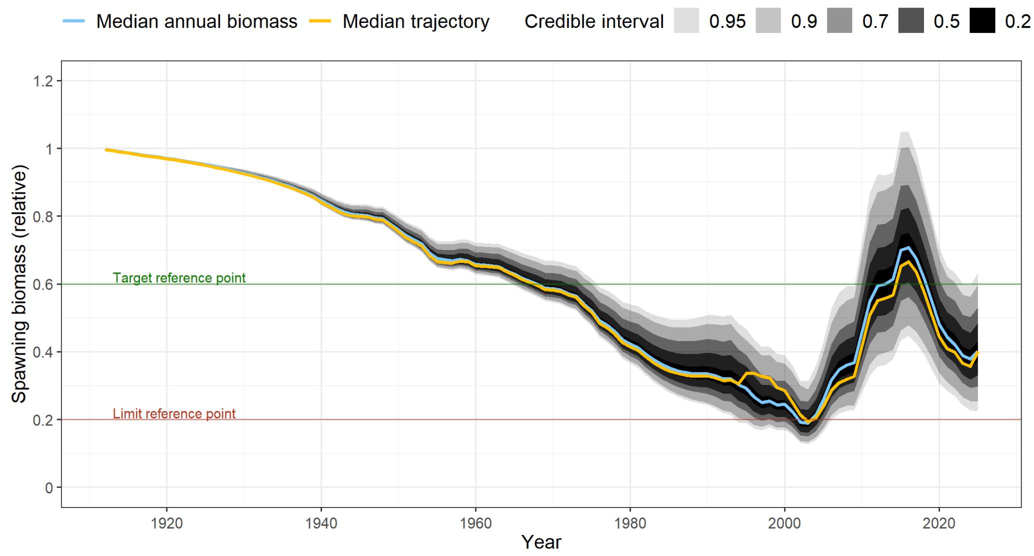

Figure E.104: Scenario 4: Predicted spawning biomass trajectory relative to unfished for Australian east coast Spanish mackerel, based on MCMC

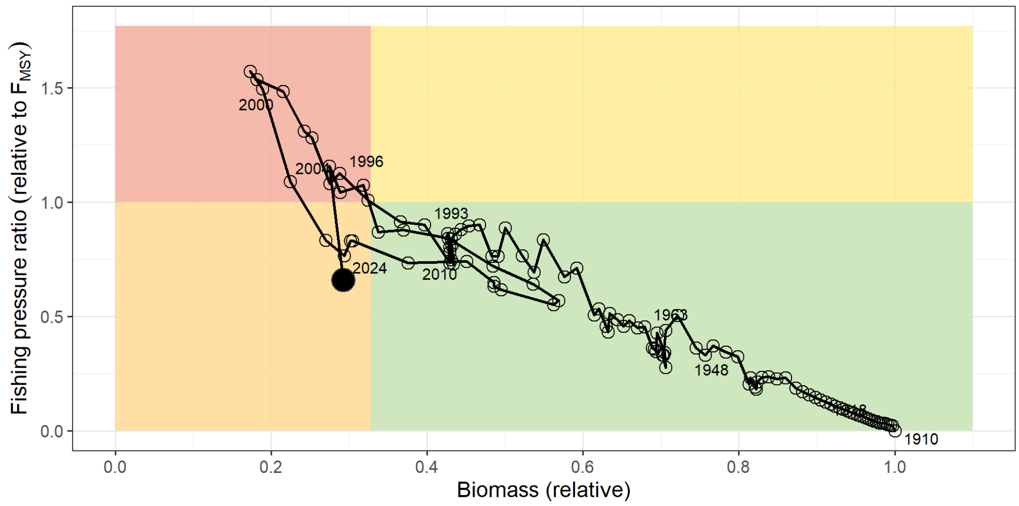

Figure E.105: Scenario 4: Stock status indicator trajectory for Australian east coast Spanish mackerel, based on maximum likelihood estimation

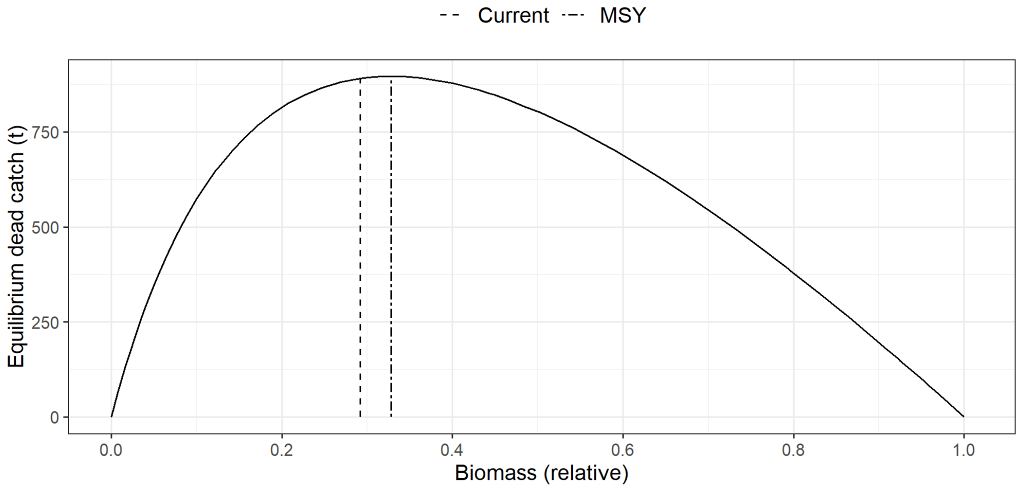

Figure E.106: Scenario 4: Equilibrium dead catch curve for Australian east coast Spanish mackerel, based on maximum likelihood estimation

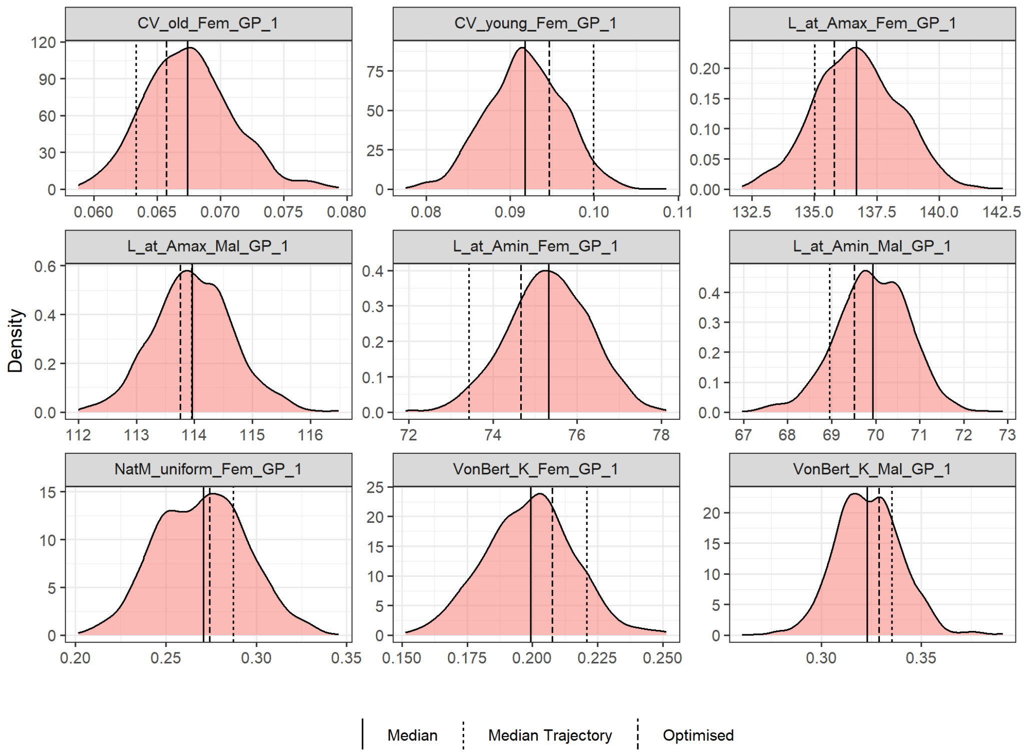

Figure E.107: Scenario 4: Posterior density of MCMC iterations. "Median" line shows median parameter value for MCMC iterations "Optimised" shows the parameter value found from maximum likelihood estimates.

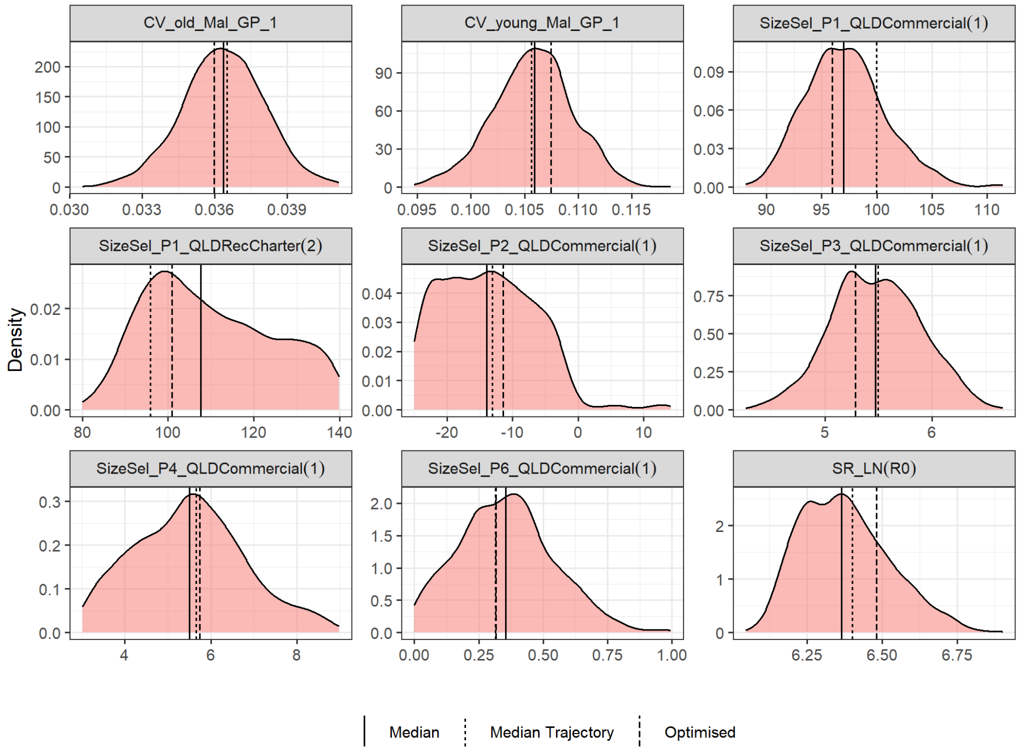

Figure E.108: Scenario 4: Posterior density of MCMC iterations. "Median" line shows median parameter value for MCMC iterations "Optimised" shows the parameter value found from maximum likelihood estimates.

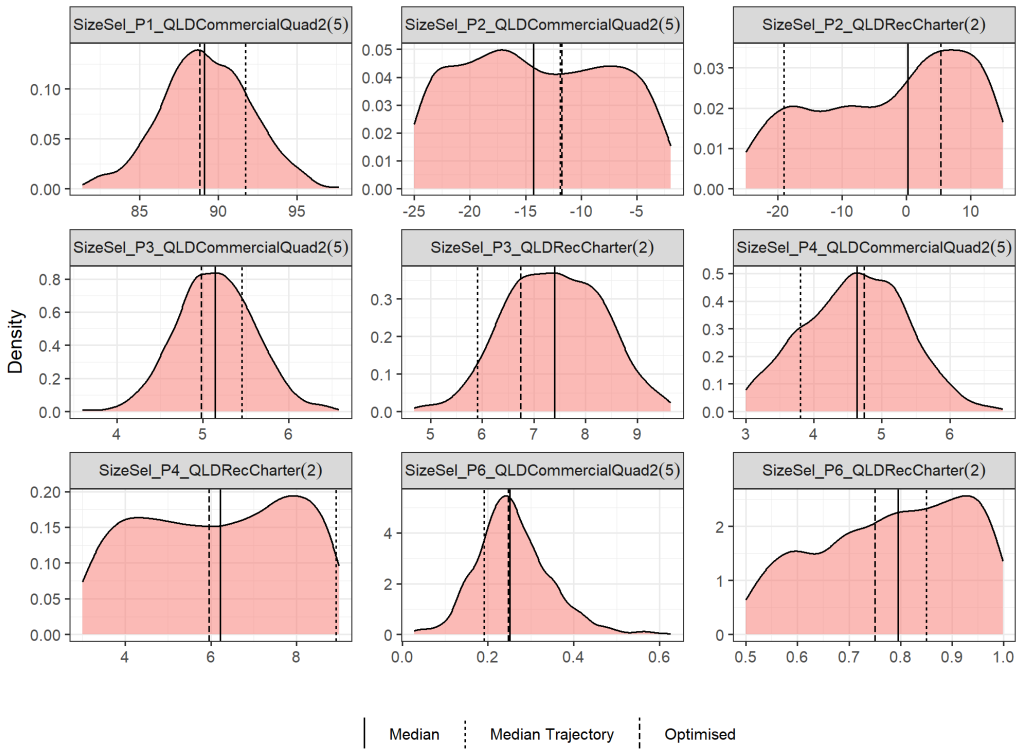

Figure E.109: Scenario 4: Posterior density of MCMC iterations. "Median" line shows median parameter value for MCMC iterations "Optimised" shows the parameter value found from maximum likelihood estimates.

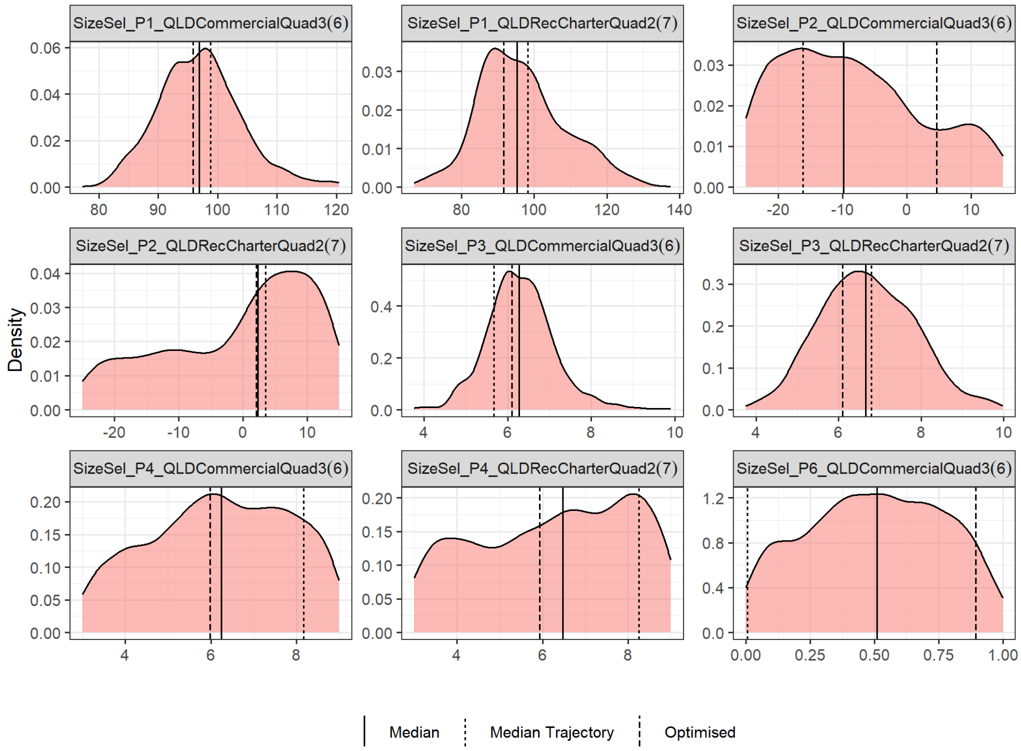

Figure E.110: Scenario 4: Posterior density of MCMC iterations. "Median" line shows median parameter value for MCMC iterations "Optimised" shows the parameter value found from maximum likelihood estimates.

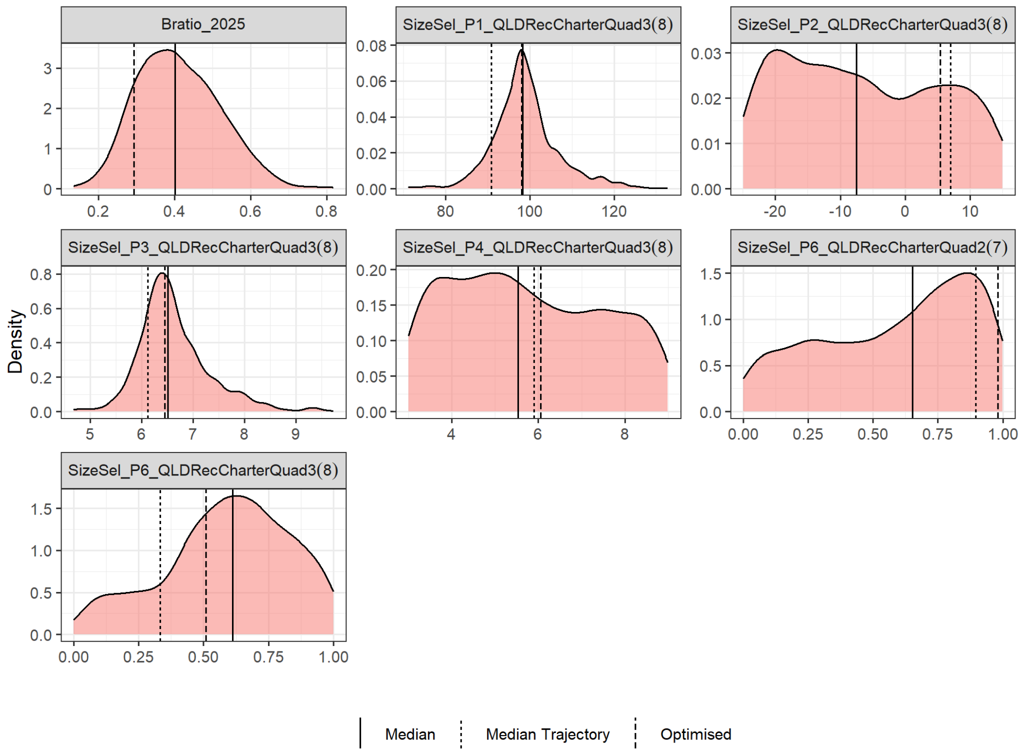

Figure E.111: Scenario 4: Posterior density of MCMC iterations. "Median" line shows median parameter value for MCMC iterations "Optimised" shows the parameter value found from maximum likelihood estimates.

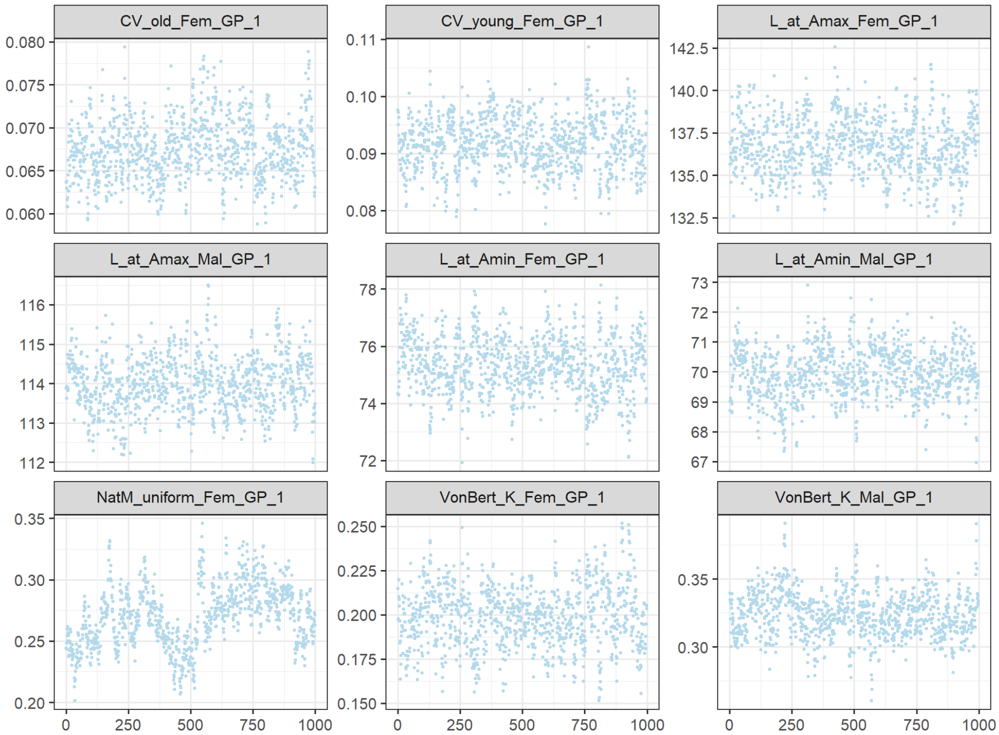

Figure E.112: Scenario 4: Trace plot of MCMC iterations

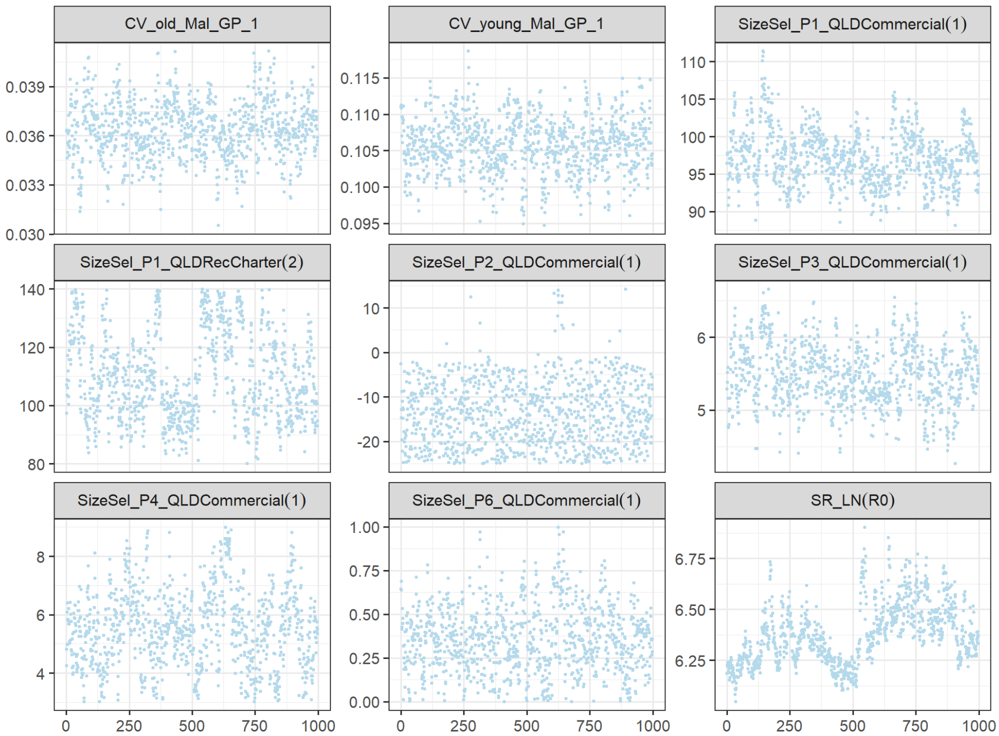

Figure E.113: Scenario 4: Trace plot of MCMC iterations

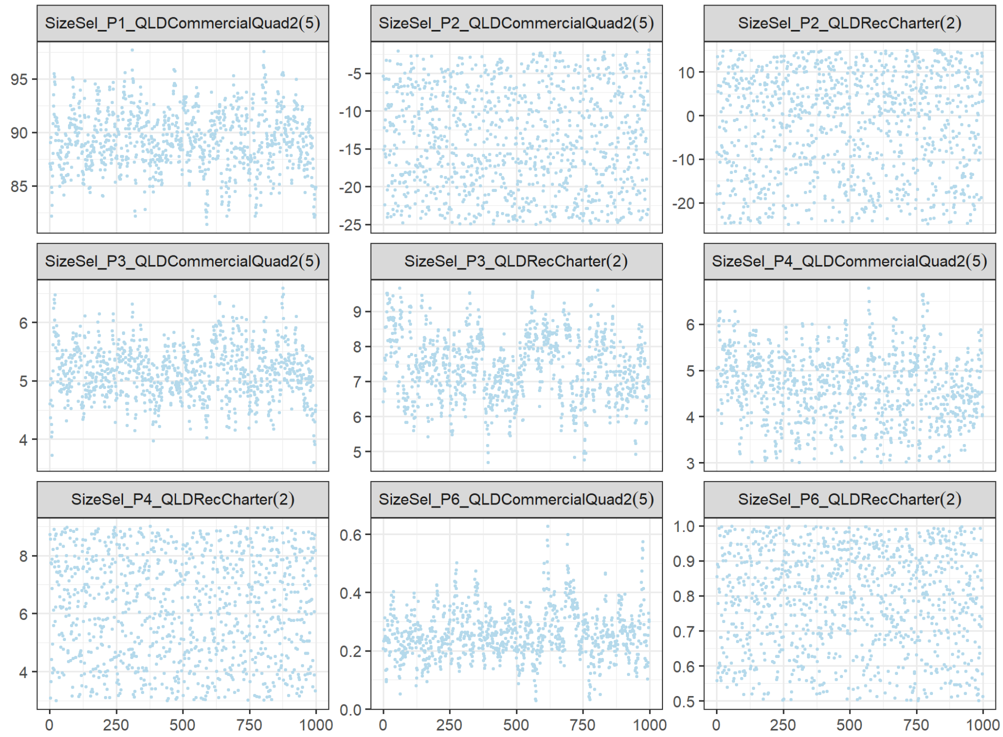

Figure E.114: Scenario 4: Trace plot of MCMC iterations

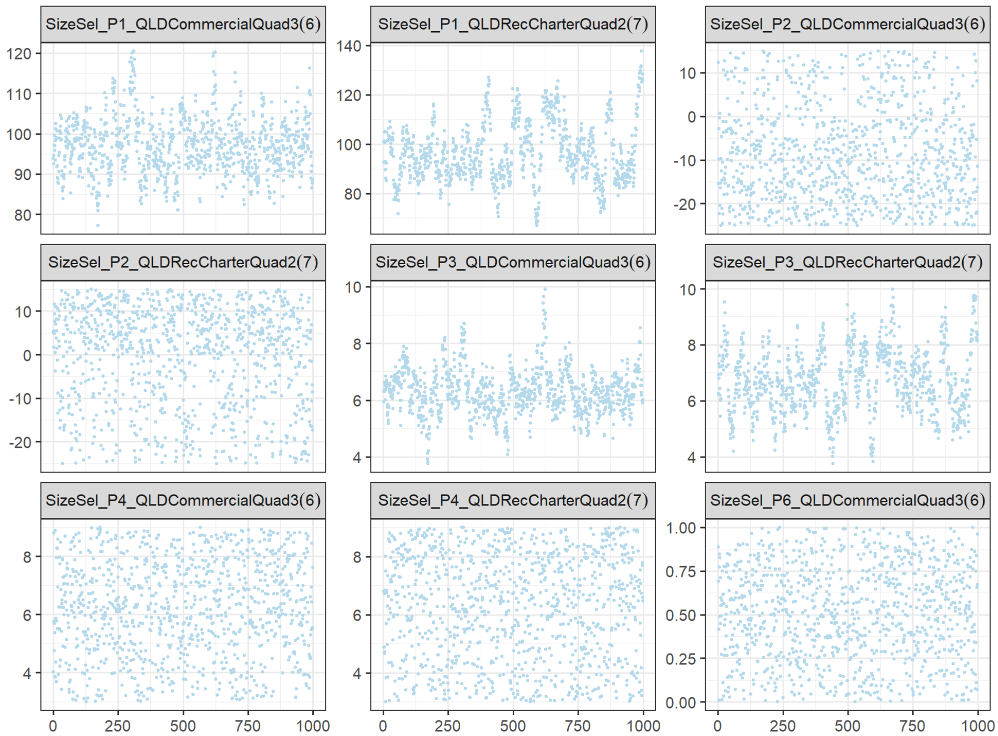

Figure E.115: Scenario 4: Trace plot of MCMC iterations

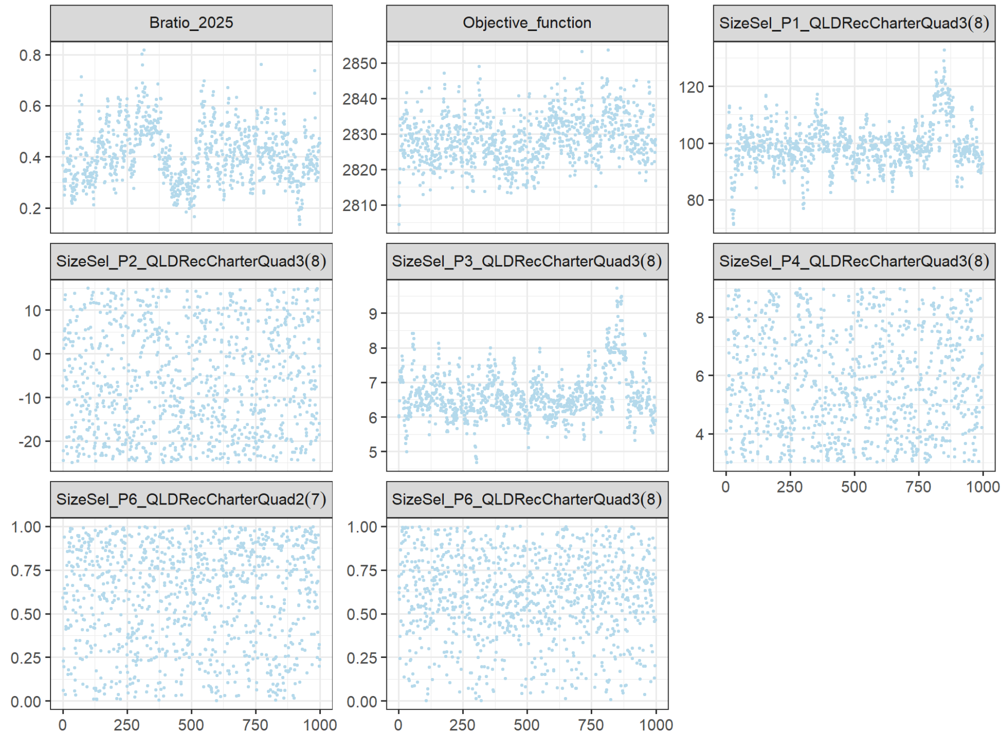

Figure E.116: Scenario 4: Trace plot of MCMC iterations

E.5 Scenario 5

Symbol	Value	Phase	Min	Max	Init	ParmStDev
Natural mortality	0.23	5	0.15	0.4	0.216	0.0197322
Length at minimum age (female)	74.27	3	65	90	75	1.01449
Length at maximum age (female)	135.89	3	130	160	140	1.6186
VonBert growth coefficient (female)	0.21	3	0.05	0.3	0.15	0.0172588
SD of length at minimum age (female)	0.1	3	0.03	0.2	0.09	0.00485808
SD of length at maximum age (female)	0.07	3	0.03	0.2	0.07	0.00331217
Length at minimum age (male)	69.42	3	60	85	70	0.852083
Length at maximum age (male)	113.88	3	105	130	115	0.714533
VonBert growth coefficient (male)	0.33	3	0.15	0.4	0.3	0.0174351
SD of length at minimum age (male)	0.11	3	0.03	0.2	0.085	0.00414276
SD of length at maximum age (male)	0.04	3	0.01	0.15	0.04	0.00168436
Log of number of recruits when unfished	6.06	1	5	7	6.5	0.0946789
Selectivity plateau start, Fleet 1	95.62	2	60	140	90	2.96214
Selectivity plateau width, Fleet 1	-11.53	2	-25	15	-2	150.05
Selectivity asc. width, Fleet 1	5.25	2	0	10	5	0.382358
Selectivity desc. width, Fleet 1	5.69	2	3	9	5	1.13621
Selectivity at max length, Fleet 1	0.29	2	0	1	0.2	0.221922
Selectivity plateau start, Fleet 2	98.94	2	60	140	90	8.51051
Selectivity plateau width, Fleet 2	5.35	2	-25	15	-2	33.2255
Selectivity asc. width, Fleet 2	6.63	2	0	10	5	0.690955
Selectivity desc. width, Fleet 2	6	2	3	9	5	67.137
Selectivity at max length, Fleet 2	0.75	2	0.5	1	0.6	5.59195
Selectivity plateau start, Fleet 5	88.74	2	60	140	90	2.408
Selectivity plateau width, Fleet 5	-11.83	2	-25	15	-2	147.955
Selectivity asc. width, Fleet 5	4.96	2	0	10	3	0.408781
Selectivity desc. width, Fleet 5	4.77	2	3	9	5	0.652725
Selectivity at max length, Fleet 5	0.23	2	0	1	0.2	0.069509
Selectivity plateau start, Fleet 6	95.03	2	60	140	90	5.6987
Selectivity plateau width, Fleet 6	4.67	2	-25	15	-2	89.1121
Selectivity asc. width, Fleet 6	6.03	2	0	10	3	0.593665
Selectivity desc. width, Fleet 6	6	2	3	9	5	67.0577
Selectivity at max length, Fleet 6	0.89	2	0	1	0.2	3.30799
Selectivity plateau start, Fleet 7	91.06	2	60	140	90	5.13093
Selectivity plateau width, Fleet 7	2.07	2	-25	15	-2	26.5047
Selectivity asc. width, Fleet 7	6.04	2	0	10	3	0.613339
Selectivity desc. width, Fleet 7	6	2	3	9	5	67.0918
Selectivity at max length, Fleet 7	0.98	2	0	1	0.6	0.609947
Selectivity plateau start, Fleet 8	98.61	2	60	140	90	2.08035
Selectivity plateau width, Fleet 8	-12.39	2	-25	15	-2	140.329
Selectivity asc. width, Fleet 8	6.26	2	0	10	3	0.294261
Selectivity desc. width, Fleet 8	3	2	3	9	5	0.0799885
Selectivity at max length, Fleet 8	0.58	2	0	1	0.6	0.129281

Table E.9: Scenario 5: Summary of MLE parameter estimates. Fleet definitions are listed in Table 2.2.

Symbol	MCMC median	MCMC 2.5%	MCMC 97.5%
Natural mortality	0.22	0.18	0.29
Length at minimum age (female)	75.07	73.16	77.04
Length at maximum age (female)	136.78	133.86	140.44
VonBert growth coefficient (female)	0.2	0.17	0.23
SD of length at minimum age (female)	0.09	0.08	0.1
SD of length at maximum age (female)	0.07	0.06	0.07
Length at minimum age (male)	70.09	68.35	71.59
Length at maximum age (male)	114.16	112.68	115.92
VonBert growth coefficient (male)	0.32	0.28	0.36
SD of length at minimum age (male)	0.11	0.1	0.11
SD of length at maximum age (male)	0.04	0.03	0.04
Log of number of recruits when unfished	5.95	5.73	6.31
Selectivity plateau start, Fleet 1	96.25	90.57	103.45
Selectivity plateau width, Fleet 1	-13.73	-24.64	-2.29
Selectivity asc. width, Fleet 1	5.39	4.59	6.18
Selectivity desc. width, Fleet 1	5.37	3.31	7.31
Selectivity at max length, Fleet 1	0.33	0.04	0.69
Selectivity plateau start, Fleet 2	102.82	85.7	136.99
Selectivity plateau width, Fleet 2	1.77	-24.05	14.19
Selectivity asc. width, Fleet 2	7.11	5.46	9.14
Selectivity desc. width, Fleet 2	6.04	3.15	8.82
Selectivity at max length, Fleet 2	0.8	0.52	0.99
Selectivity plateau start, Fleet 5	89.47	83.73	94.25
Selectivity plateau width, Fleet 5	-13.36	-24.45	-3.12
Selectivity asc. width, Fleet 5	5.16	4.27	5.99
Selectivity desc. width, Fleet 5	4.65	3.11	6.01
Selectivity at max length, Fleet 5	0.24	0.11	0.42
Selectivity plateau start, Fleet 6	97.67	84.97	115.33
Selectivity plateau width, Fleet 6	-9.88	-23.83	12.18
Selectivity asc. width, Fleet 6	6.3	4.87	8.3
Selectivity desc. width, Fleet 6	5.97	3.19	8.77
Selectivity at max length, Fleet 6	0.48	0.04	0.95
Selectivity plateau start, Fleet 7	96	76.23	138.85
Selectivity plateau width, Fleet 7	-0.77	-23.83	14.02
Selectivity asc. width, Fleet 7	6.79	4.3	9.57
Selectivity desc. width, Fleet 7	6.19	3.18	8.85
Selectivity at max length, Fleet 7	0.65	0.03	0.98
Selectivity plateau start, Fleet 8	99.42	91.79	122.03
Selectivity plateau width, Fleet 8	-11.38	-24.23	13.6
Selectivity asc. width, Fleet 8	6.54	5.68	9.12
Selectivity desc. width, Fleet 8	4.17	3.09	5.02
Selectivity at max length, Fleet 8	0.61	0.15	0.96

Table E.10: Scenario 5: Summary of MCMC parameter estimates. Fleet definitions are listed in Table 2.2.

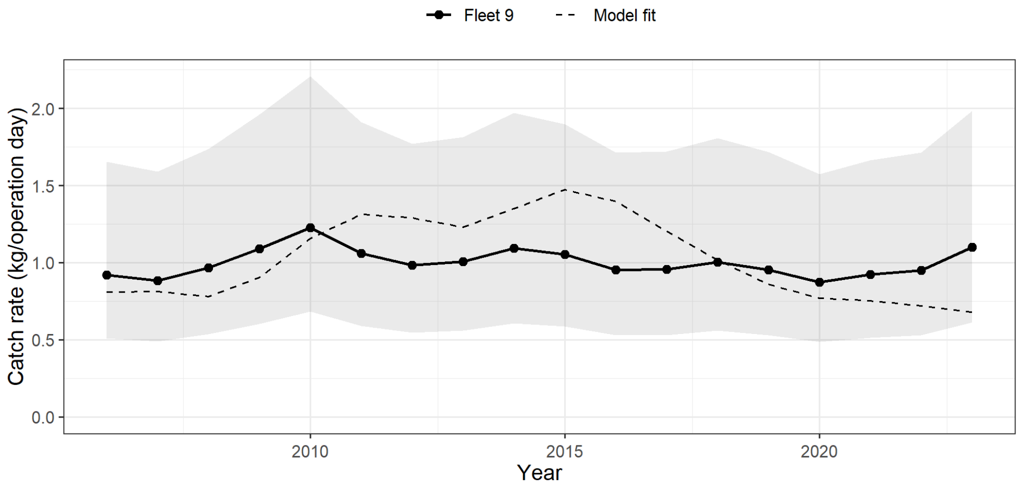

Figure E.117: Scenario 5: Model predictions (dotted line) to standardised catch rates for Australian east coast Spanish mackerel, based on maximum likelihood estimation—grey shade represent the model input and associated uncertainty

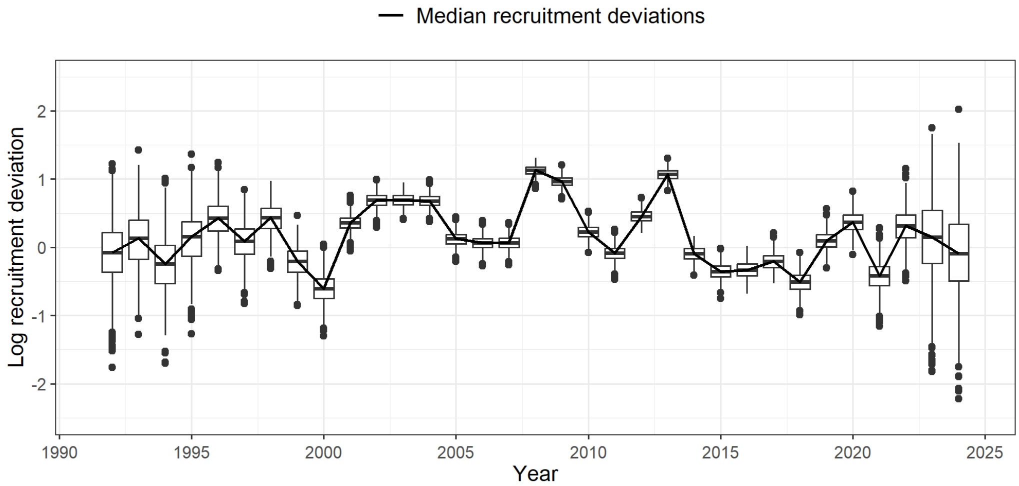

Figure E.118: Scenario 5: Recruitment deviations—whiskers represent 95% credible intervals, boxes represent 50% credible intervals, horizontal bars represent medians, and the points represent outliers

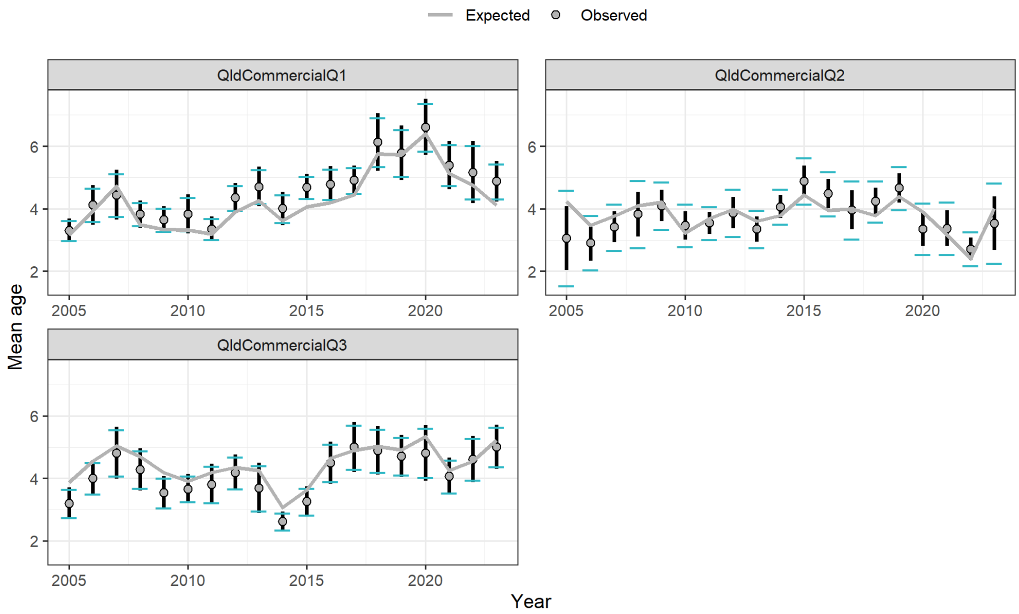

Figure E.119: Scenario 5: Mean age from conditional data (aggregated across length bins) with 95% confidence intervals based on current samples sizes: thinner intervals (with capped ends) show result of further adjusting sample sizes based on suggested multiplier (with 95% interval) for conditional age-at-length data

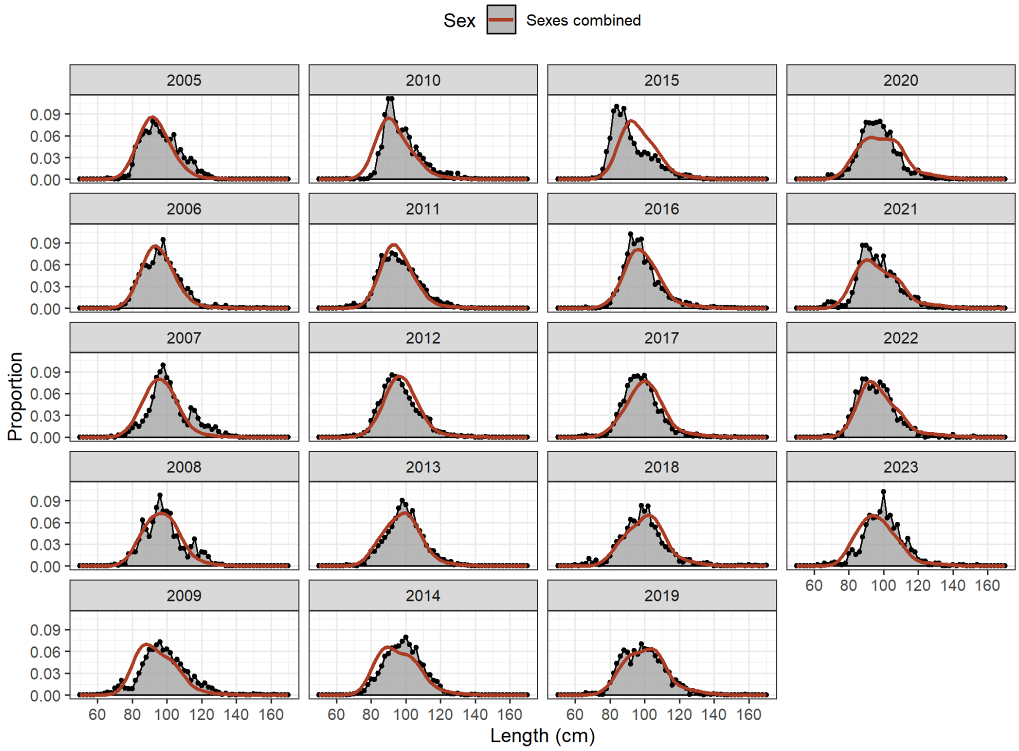

Figure E.120: Scenario 5: Fits to length structures for Fleet 1, based on maximum likelihood estimation—the grey area and black line represent data inputs and the red and blue line represents the model fits for female and male, respectively

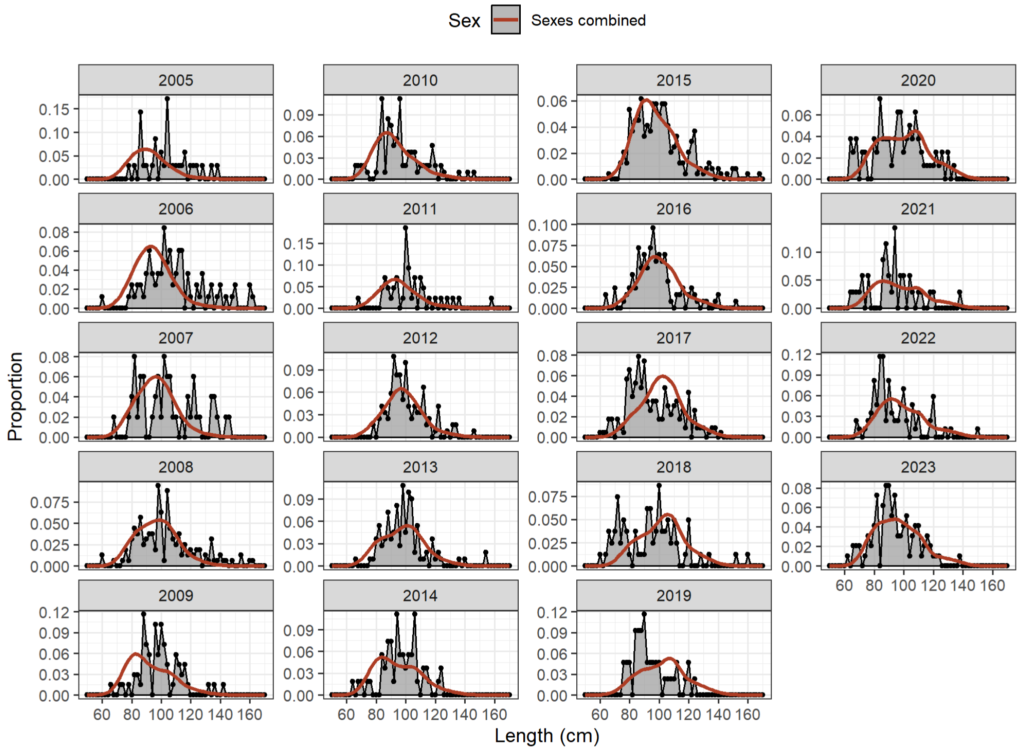

Figure E.121: Scenario 5: Fits to length structures for Fleet 2, based on maximum likelihood estimation—the grey area and black line represent data inputs and the red and blue line represents the model fits for female and male, respectively

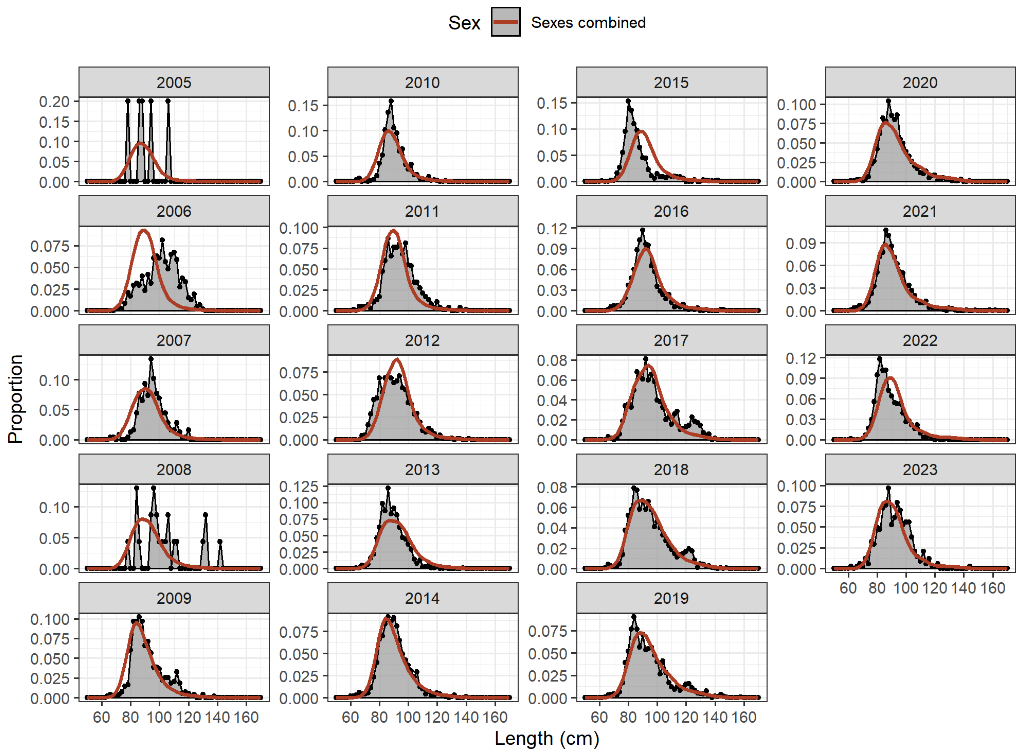

Figure E.122: Scenario 5: Fits to length structures for Fleet 5, based on maximum likelihood estimation—the grey area and black line represent data inputs and the red and blue line represents the model fits for female and male, respectively

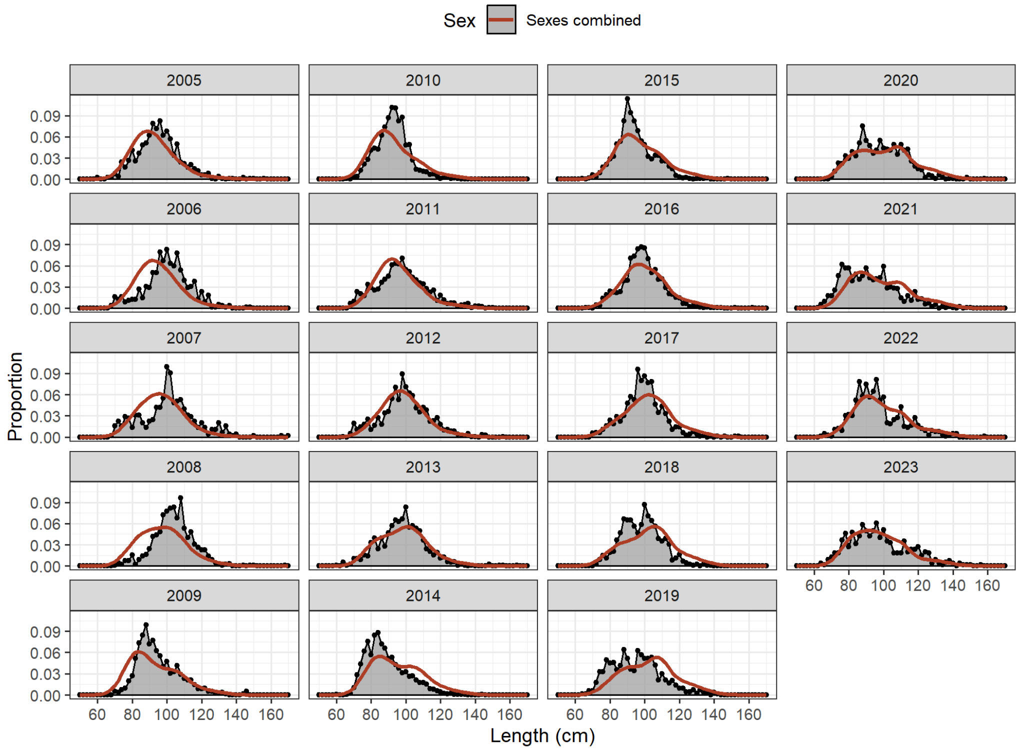

Figure E.123: Scenario 5: Fits to length structures for Fleet 6, based on maximum likelihood estimation—the grey area and black line represent data inputs and the red and blue line represents the model fits for female and male, respectively

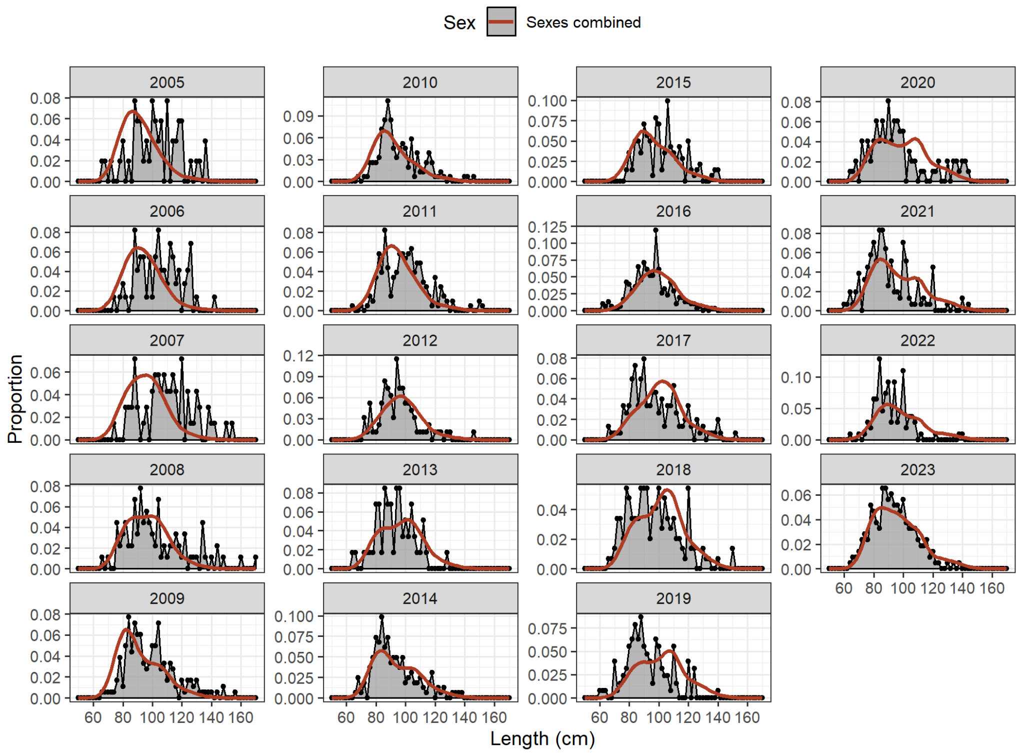

Figure E.124: Scenario 5: Fits to length structures for Fleet 7, based on maximum likelihood estimation—the grey area and black line represent data inputs and the red and blue line represents the model fits for female and male, respectively

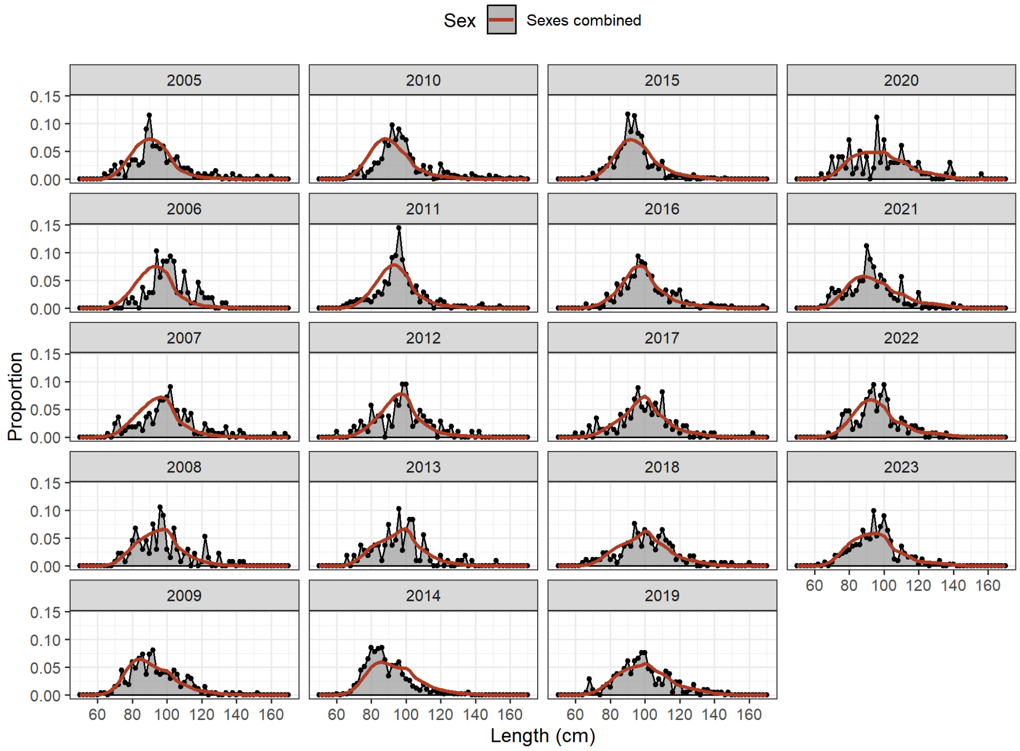

Figure E.125: Scenario 5: Fits to length structures for Fleet 8, based on maximum likelihood estimation—the grey area and black line represent data inputs and the red and blue line represents the model fits for female and male, respectively

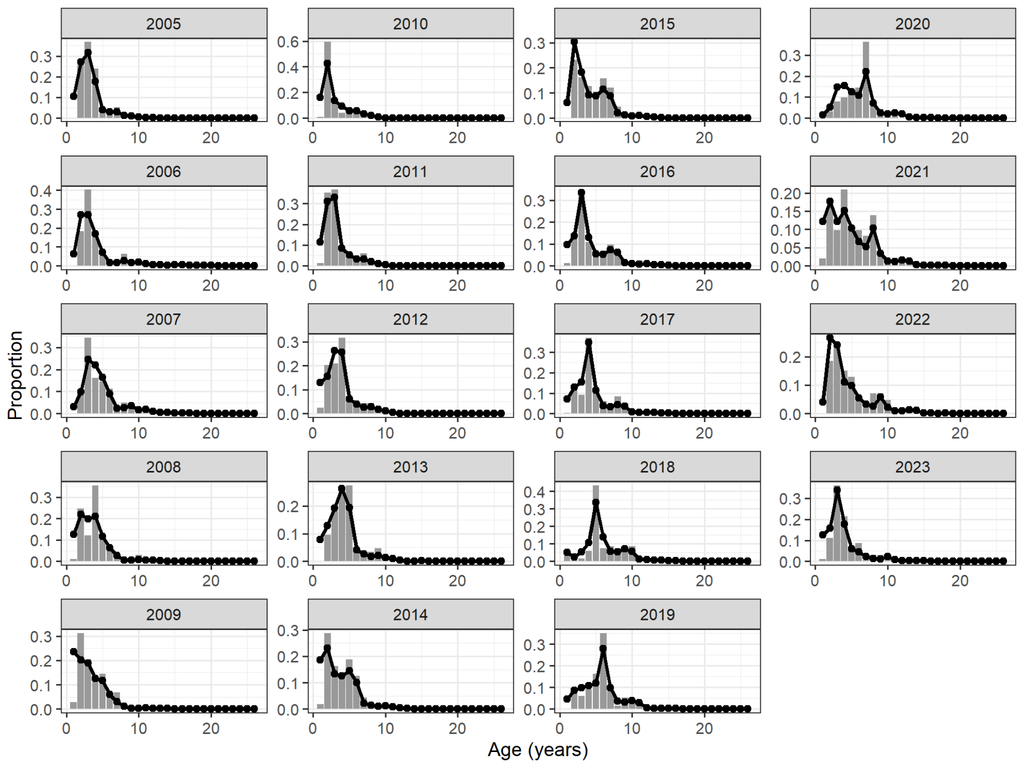

Figure E.126: Scenario 5: Fits to annual age compositions of female Spanish mackerel for Fleet 1

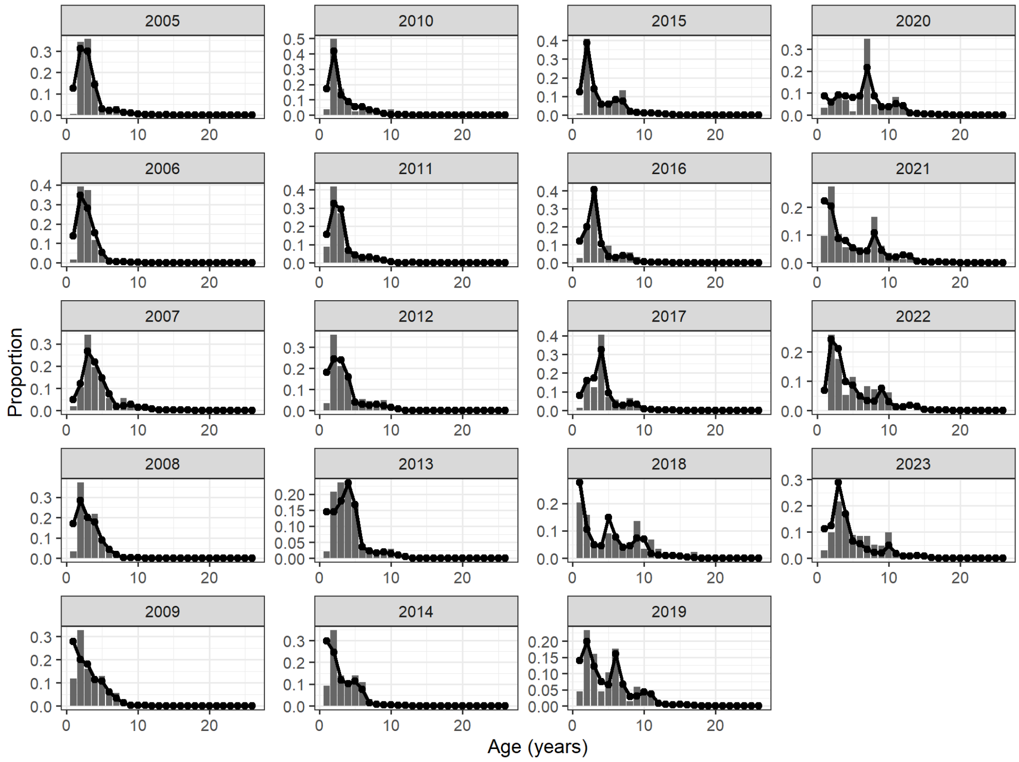

Figure E.127: Scenario 5: Fits to annual age compositions of male Spanish mackerel for Fleet 1

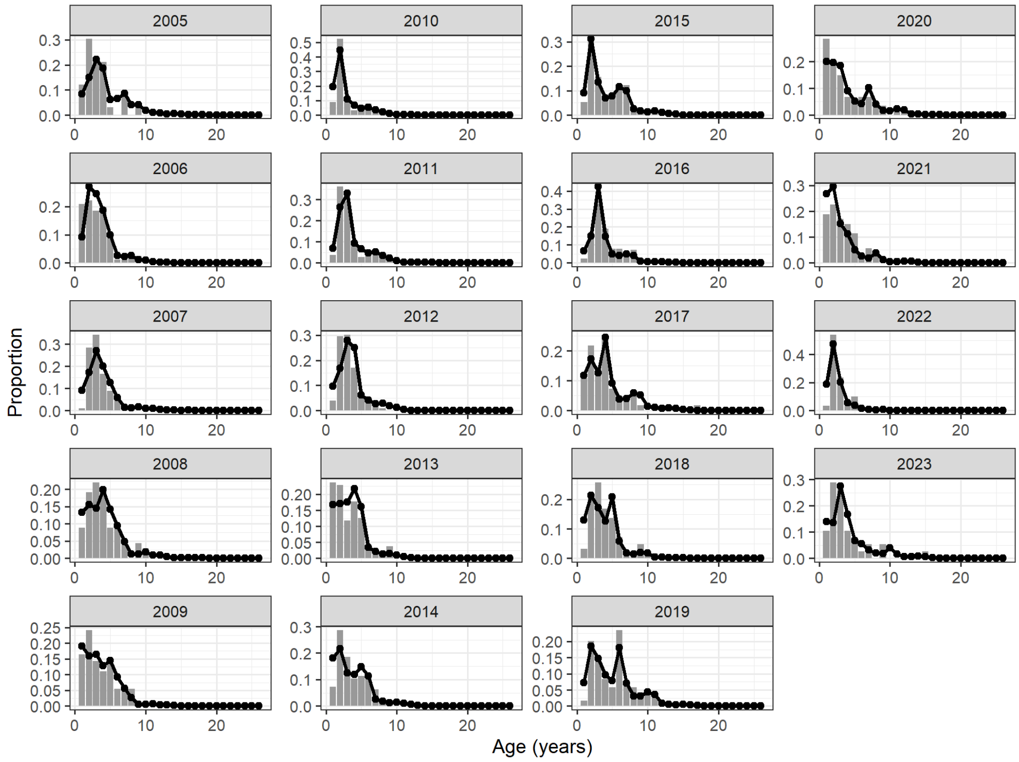

Figure E.128: Scenario 5: Fits to annual age compositions of female Spanish mackerel for Fleet 5

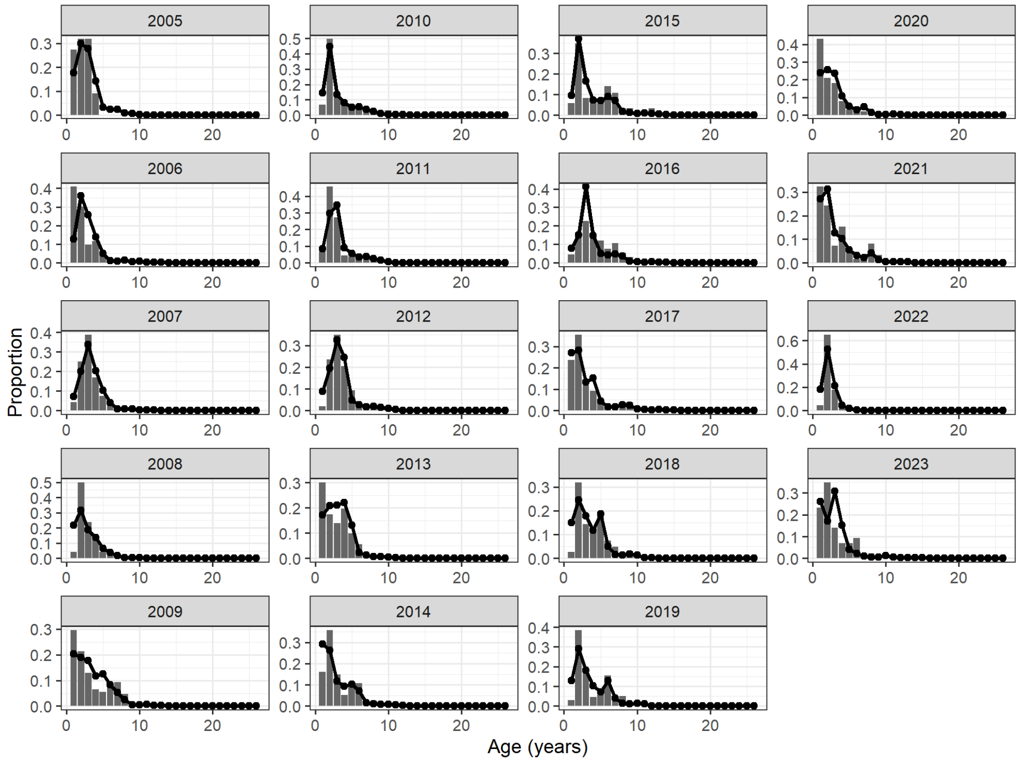

Figure E.129: Scenario 5: Fits to annual age compositions of male Spanish mackerel for Fleet 5

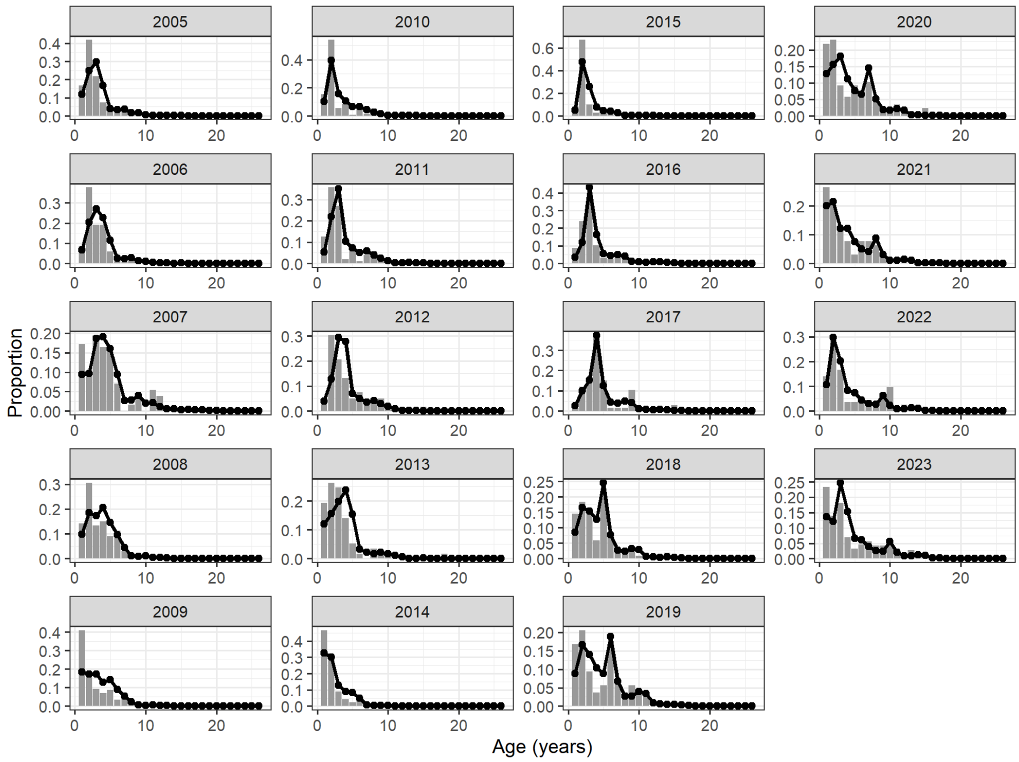

Figure E.130: Scenario 5: Fits to annual age compositions of female Spanish mackerel for Fleet 6

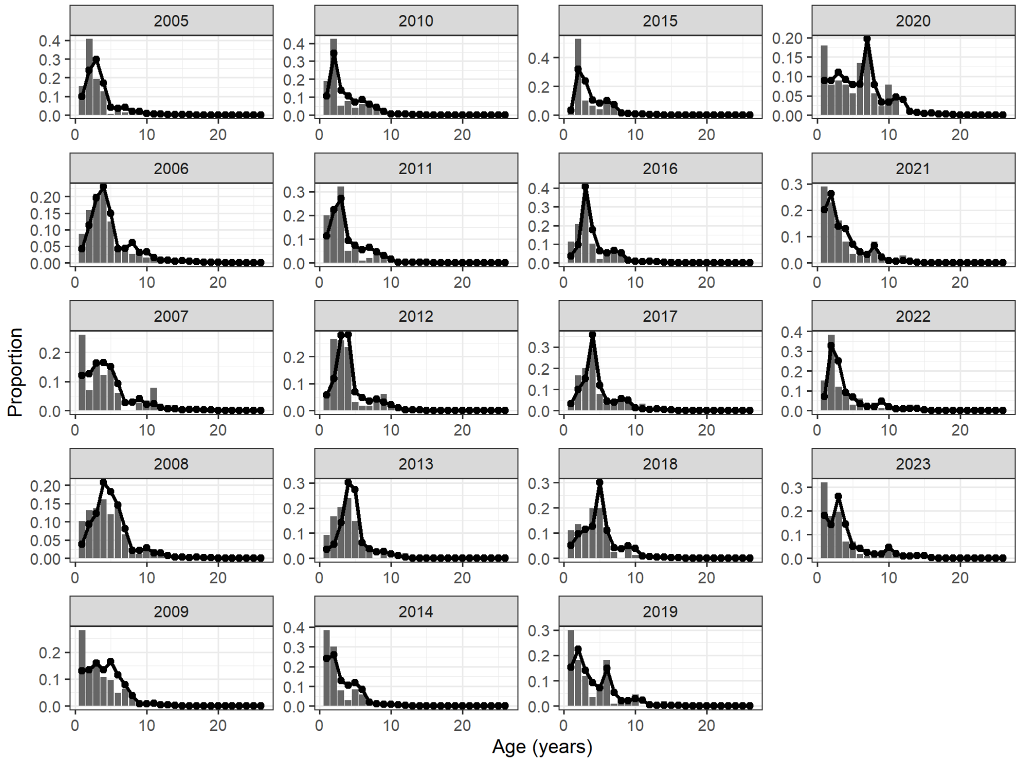

Figure E.131: Scenario 5: Fits to annual age compositions of male Spanish mackerel for Fleet 6

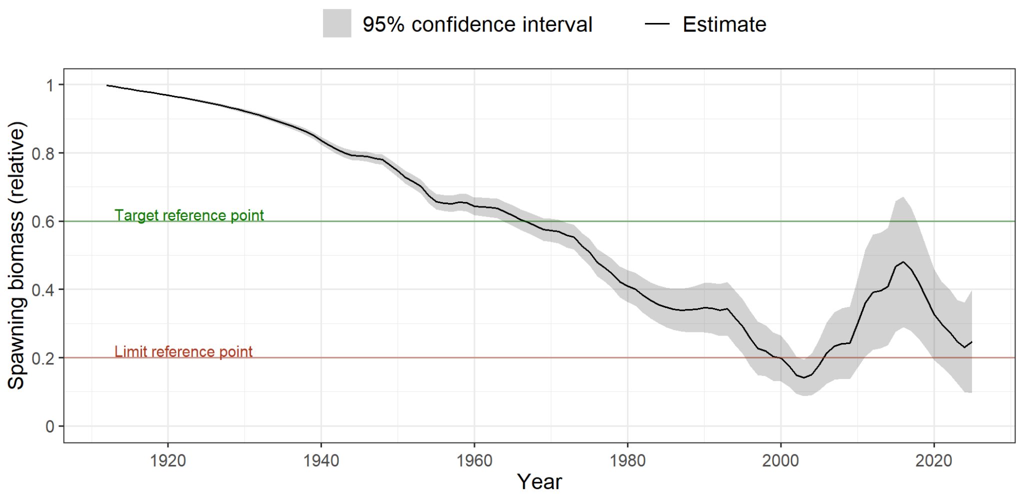

Figure E.132: Scenario 5: Predicted spawning biomass trajectory relative to unfished for Australian east coast Spanish mackerel, based on maximum likelihood estimation

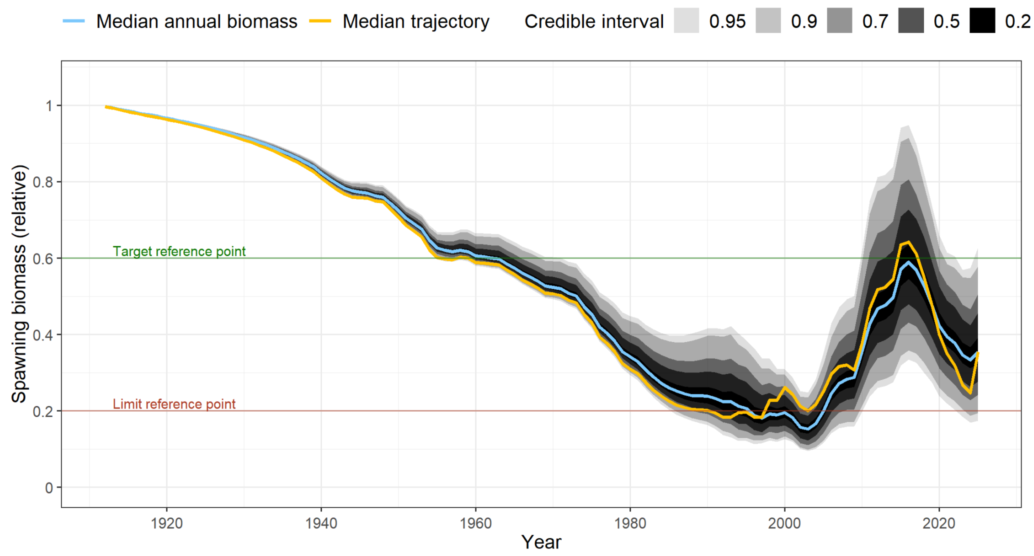

Figure E.133: Scenario 5: Predicted spawning biomass trajectory relative to unfished for Australian east coast Spanish mackerel, based on MCMC

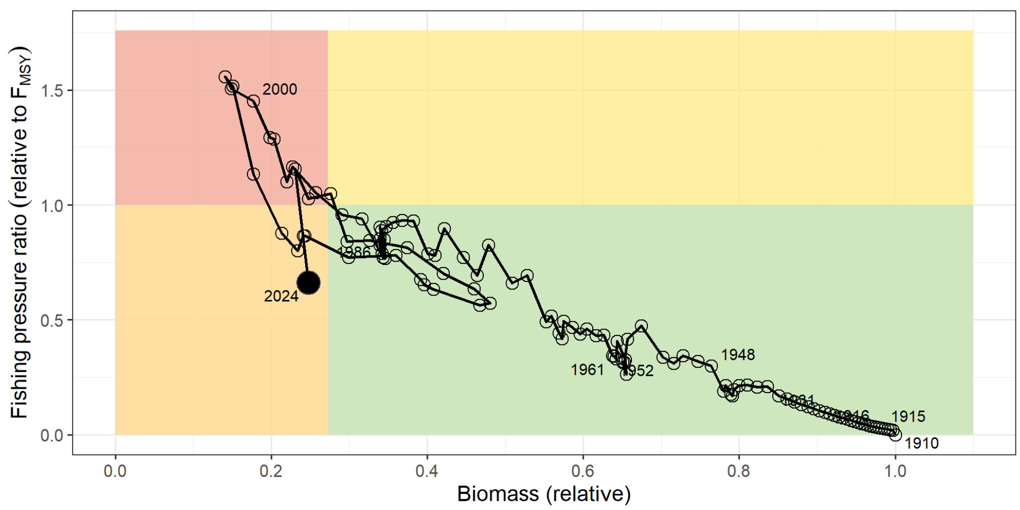

Figure E.134: Scenario 5: Stock status indicator trajectory for Australian east coast Spanish mackerel, based on maximum likelihood estimation

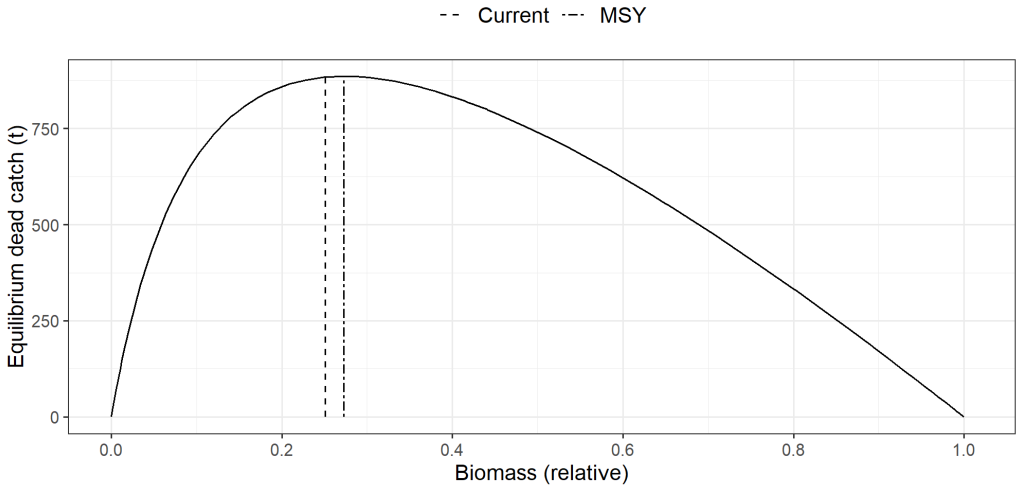

Figure E.135: Scenario 5: Equilibrium dead catch curve for Australian east coast Spanish mackerel, based on maximum likelihood estimation

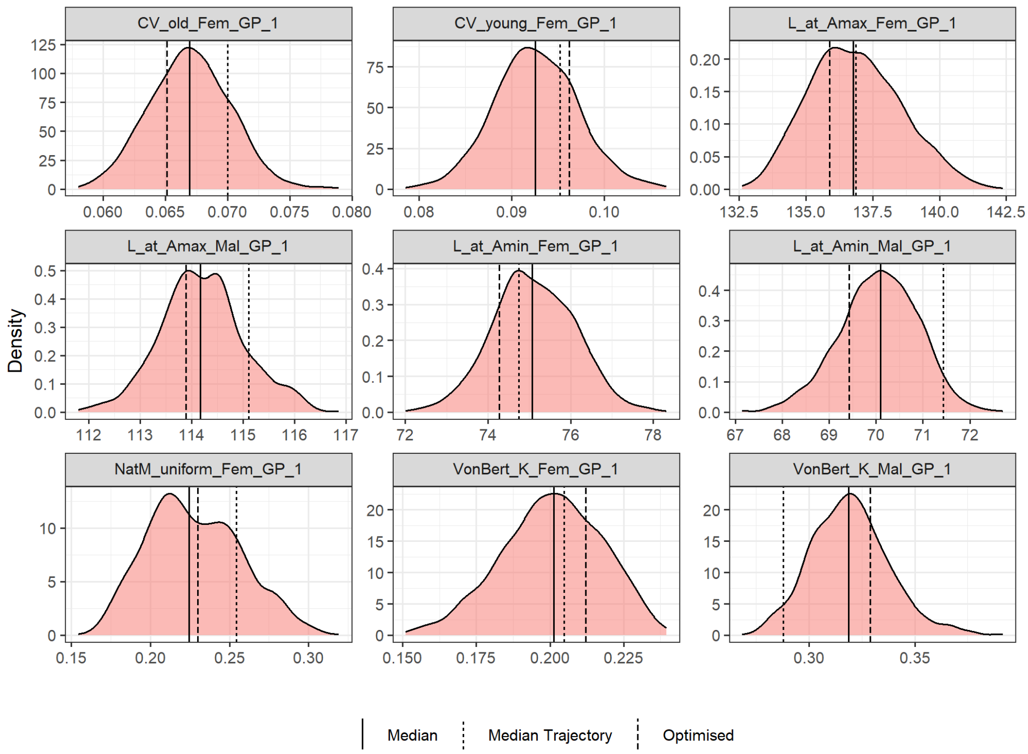

Figure E.136: Scenario 5: Posterior density of MCMC iterations. "Median" line shows median parameter value for MCMC iterations "Optimised" shows the parameter value found from maximum likelihood estimates.

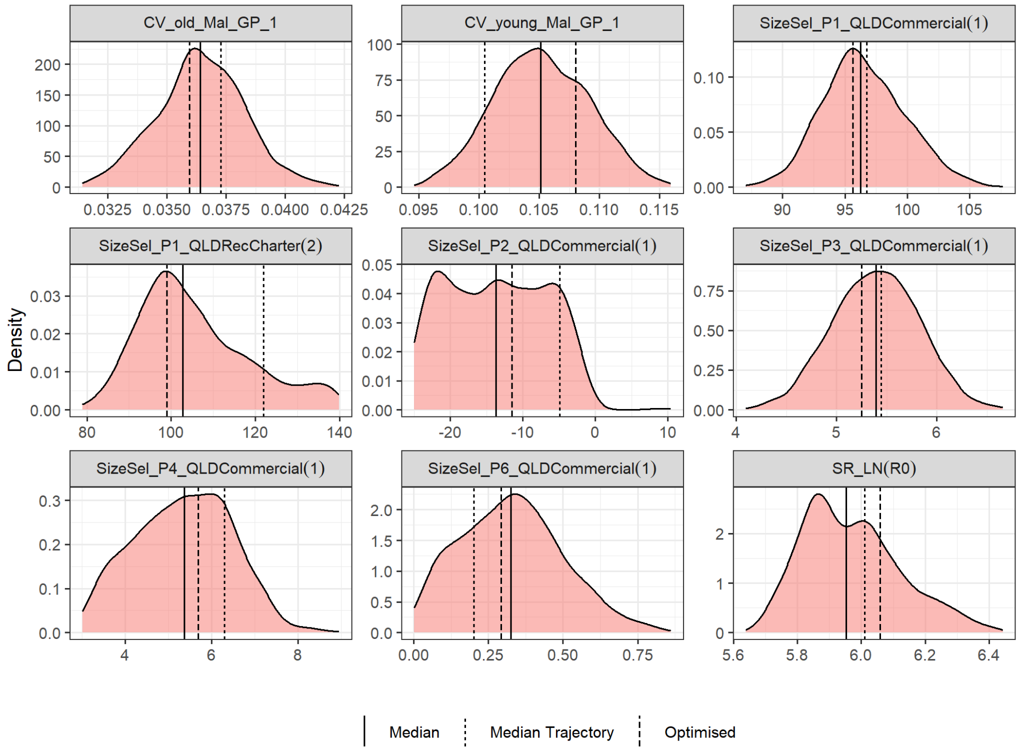

Figure E.137: Scenario 5: Posterior density of MCMC iterations. "Median" line shows median parameter value for MCMC iterations "Optimised" shows the parameter value found from maximum likelihood estimates.

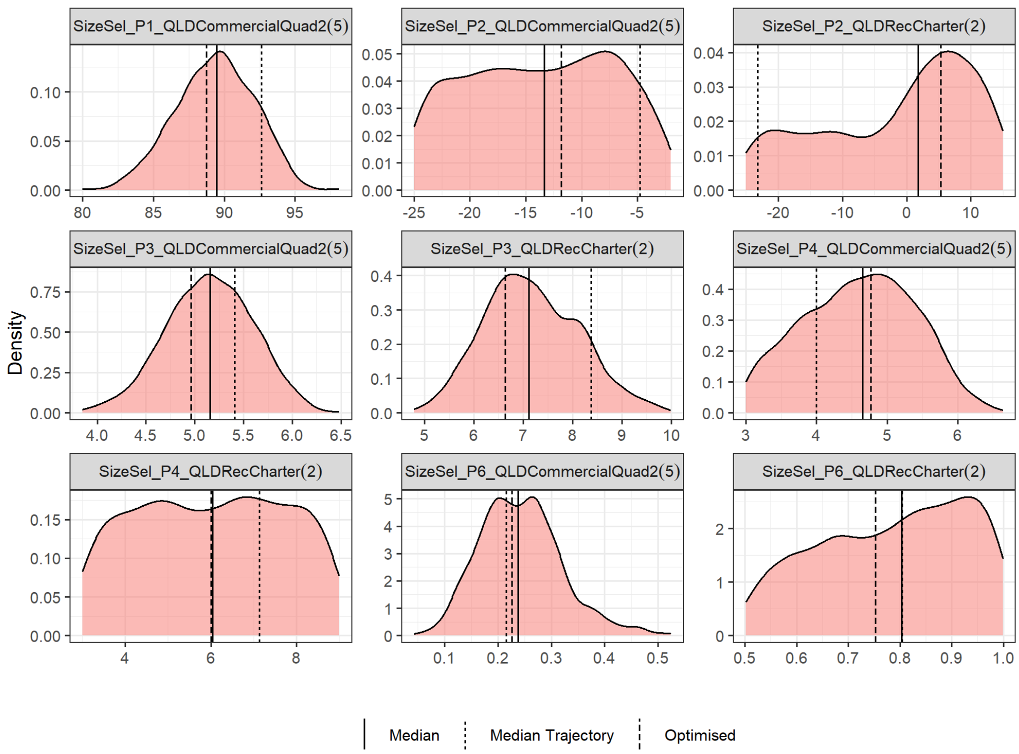

Figure E.138: Scenario 5: Posterior density of MCMC iterations. "Median" line shows median parameter value for MCMC iterations "Optimised" shows the parameter value found from maximum likelihood estimates.

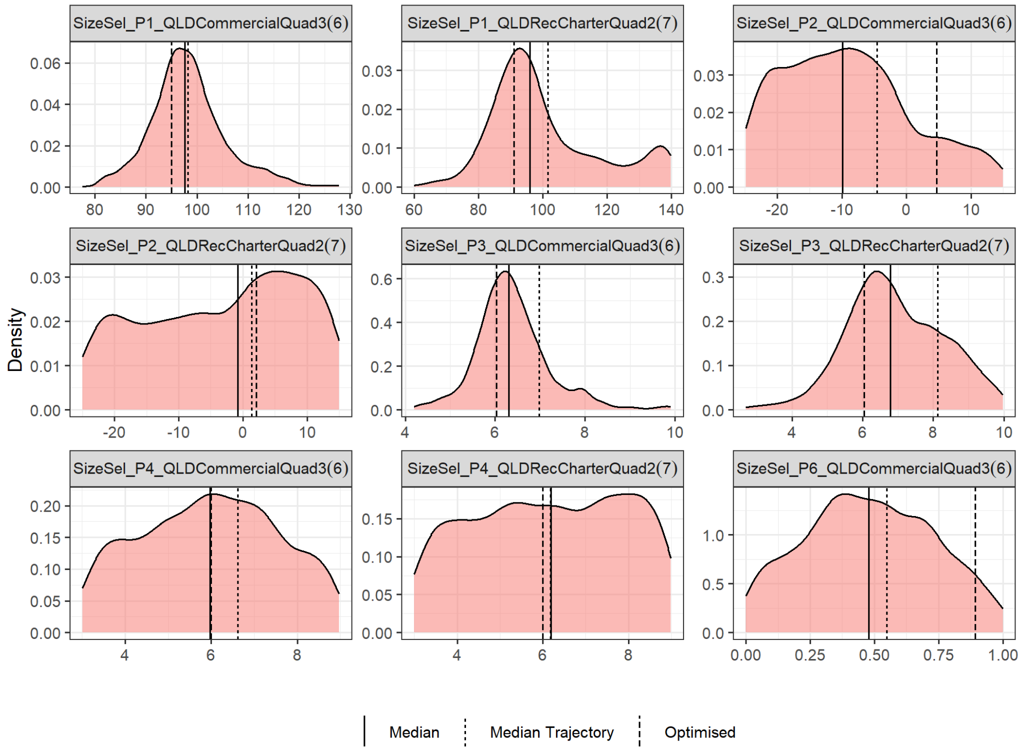

Figure E.139: Scenario 5: Posterior density of MCMC iterations. "Median" line shows median parameter value for MCMC iterations "Optimised" shows the parameter value found from maximum likelihood estimates.

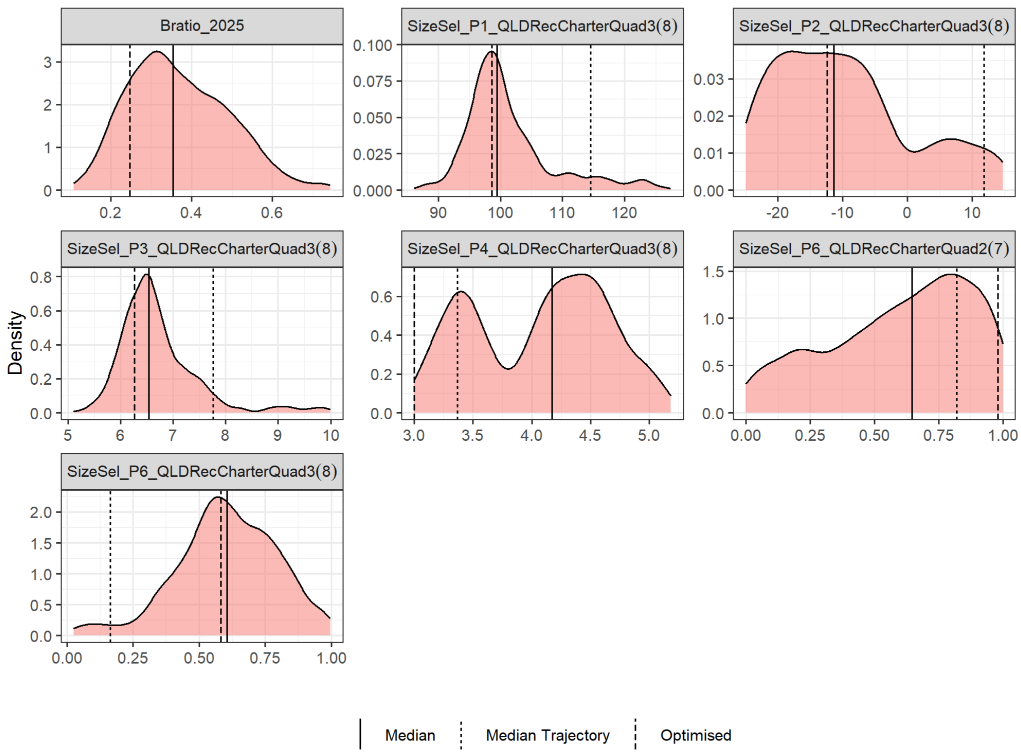

Figure E.140: Scenario 5: Posterior density of MCMC iterations. "Median" line shows median parameter value for MCMC iterations "Optimised" shows the parameter value found from maximum likelihood estimates.

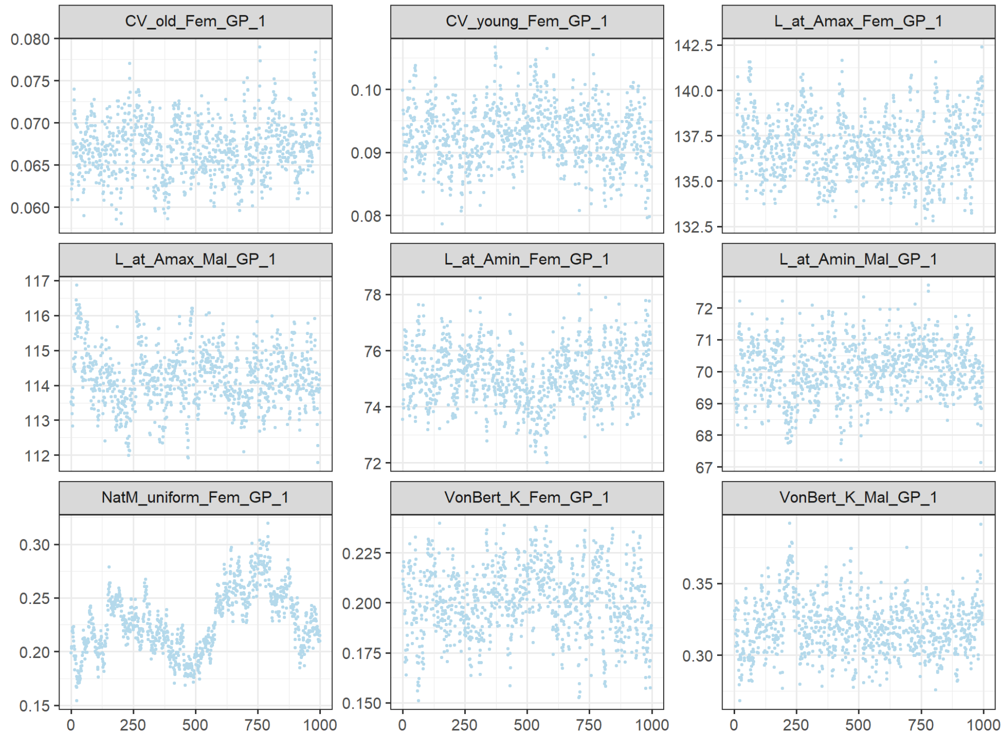

Figure E.141: Scenario 5: Trace plot of MCMC iterations

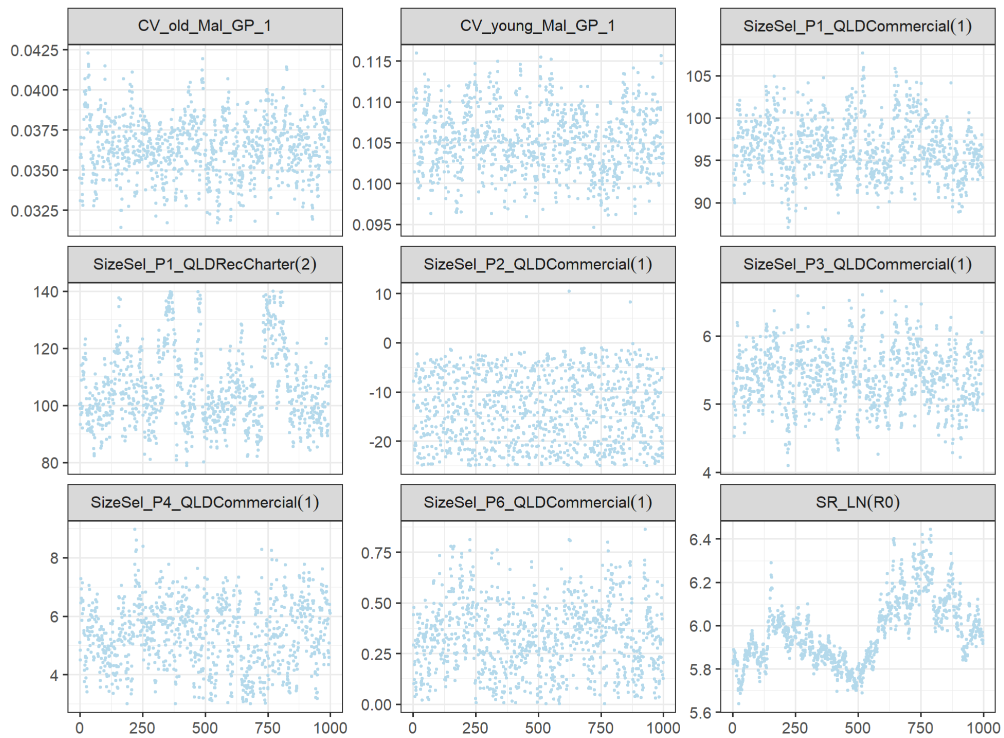

Figure E.142: Scenario 5: Trace plot of MCMC iterations

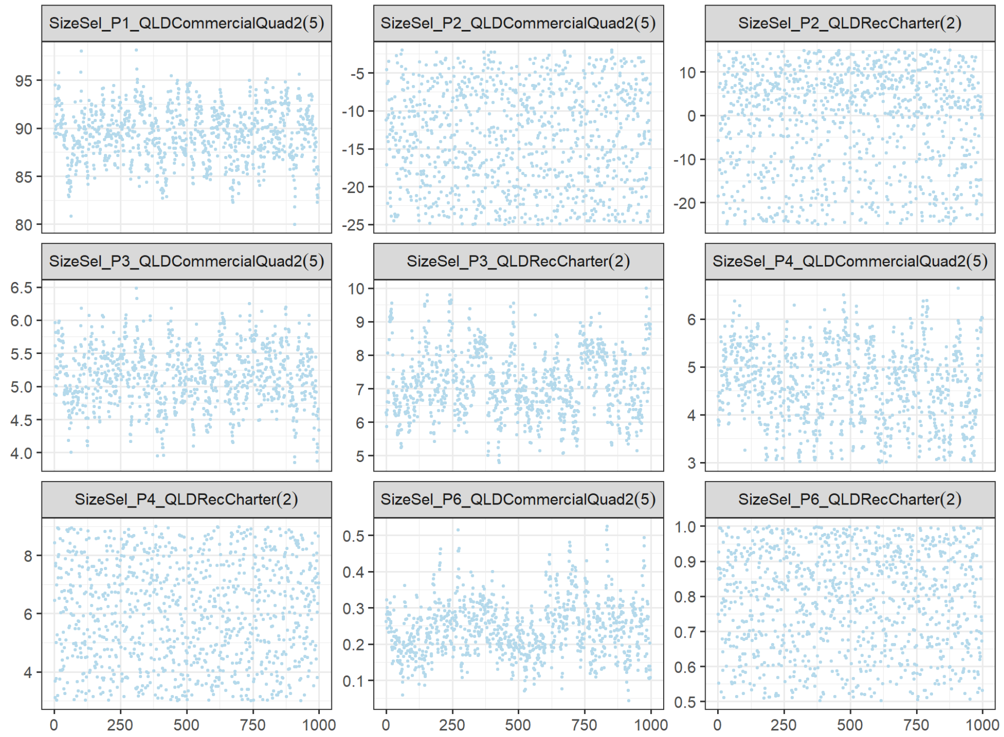

Figure E.143: Scenario 5: Trace plot of MCMC iterations

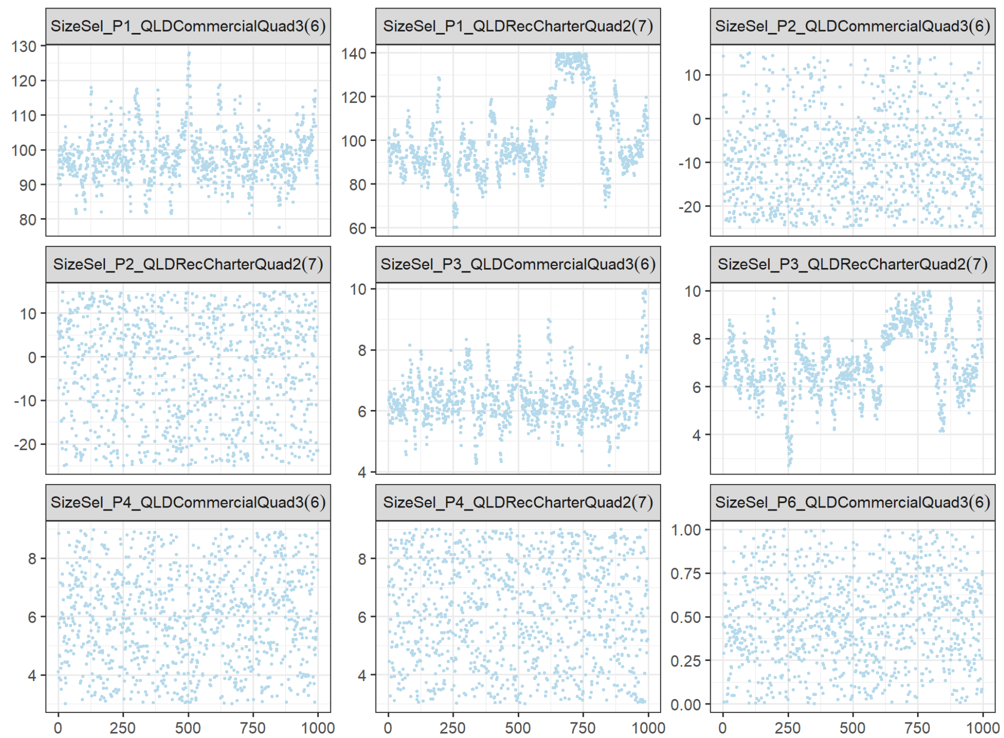

Figure E.144: Scenario 5: Trace plot of MCMC iterations

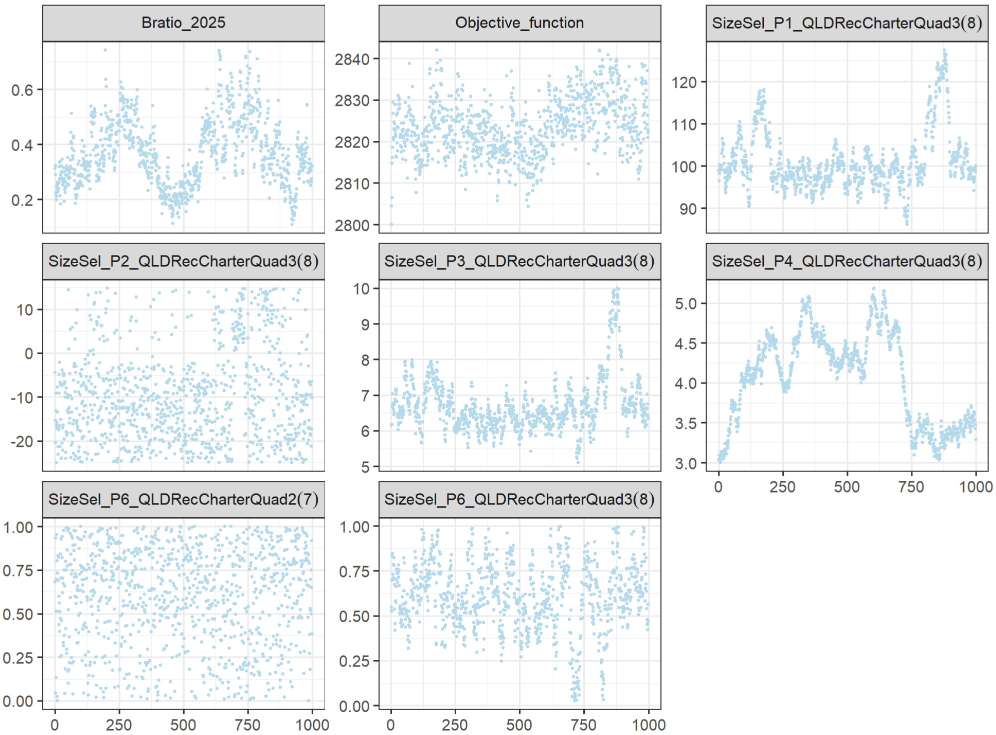

Figure E.145: Scenario 5: Trace plot of MCMC iterations

E.6 Scenario 6

Symbol	Value	Phase	Min	Max	Init	ParmStDev
Natural mortality	0.2	5	0.15	0.4	0.216	0.0208701
Length at minimum age (female)	74.55	3	65	90	75	0.992728
Length at maximum age (female)	135.85	3	130	160	140	1.6173
VonBert growth coefficient (female)	0.21	3	0.05	0.3	0.15	0.0170442
SD of length at minimum age (female)	0.1	3	0.03	0.2	0.09	0.00475477
SD of length at maximum age (female)	0.07	3	0.03	0.2	0.07	0.00336452
Length at minimum age (male)	69.82	3	60	85	70	0.834337
Length at maximum age (male)	113.8	3	105	130	115	0.709074
VonBert growth coefficient (male)	0.32	3	0.15	0.4	0.3	0.0172537
SD of length at minimum age (male)	0.11	3	0.03	0.2	0.085	0.00397229
SD of length at maximum age (male)	0.04	3	0.01	0.15	0.04	0.00167375
Log of number of recruits when unfished	5.8	1	5	7	6.5	0.0967249
Selectivity plateau start, Fleet 1	95.83	2	60	140	90	2.94703
Selectivity plateau width, Fleet 1	-11.6	2	-25	15	-2	153.01
Selectivity asc. width, Fleet 1	5.26	2	0	10	5	0.379725
Selectivity desc. width, Fleet 1	5.73	2	3	9	5	1.06486
Selectivity at max length, Fleet 1	0.27	2	0	1	0.2	0.216698
Selectivity plateau start, Fleet 2	99.96	2	60	140	90	8.4624
Selectivity plateau width, Fleet 2	5.33	2	-25	15	-2	33.2404
Selectivity asc. width, Fleet 2	6.7	2	0	10	5	0.673843
Selectivity desc. width, Fleet 2	6.05	2	3	9	5	67.1246
Selectivity at max length, Fleet 2	0.75	2	0.5	1	0.6	5.59303
Selectivity plateau start, Fleet 5	88.87	2	60	140	90	2.47124
Selectivity plateau width, Fleet 5	-11.84	2	-25	15	-2	152.698
Selectivity asc. width, Fleet 5	4.99	2	0	10	3	0.416133
Selectivity desc. width, Fleet 5	4.76	2	3	9	5	0.677493
Selectivity at max length, Fleet 5	0.24	2	0	1	0.2	0.0717335
Selectivity plateau start, Fleet 6	95.97	2	60	140	90	6.1172
Selectivity plateau width, Fleet 6	4.65	2	-25	15	-2	89.3316
Selectivity asc. width, Fleet 6	6.11	2	0	10	3	0.610965
Selectivity desc. width, Fleet 6	6.09	2	3	9	5	66.9997
Selectivity at max length, Fleet 6	0.89	2	0	1	0.2	3.37038
Selectivity plateau start, Fleet 7	91.63	2	60	140	90	5.56355
Selectivity plateau width, Fleet 7	2.06	2	-25	15	-2	26.0694
Selectivity asc. width, Fleet 7	6.1	2	0	10	3	0.644258
Selectivity desc. width, Fleet 7	6.02	2	3	9	5	67.0735
Selectivity at max length, Fleet 7	0.98	2	0	1	0.6	0.6339
Selectivity plateau start, Fleet 8	97.94	2	60	140	90	5.19413
Selectivity plateau width, Fleet 8	5.4	2	-25	15	-2	28.2904
Selectivity asc. width, Fleet 8	6.45	2	0	10	3	0.492443
Selectivity desc. width, Fleet 8	6.05	2	3	9	5	67.2361
Selectivity at max length, Fleet 8	0.5	2	0	1	0.6	11.1668

Table E.11: Scenario 6: Summary of MLE parameter estimates. Fleet definitions are listed in Table 2.2.

Symbol	MCMC median	MCMC 2.5%	MCMC 97.5%
Natural mortality	0.18	0.15	0.28
Length at minimum age (female)	74.97	72.87	77.53
Length at maximum age (female)	136.8	133.34	140.07
VonBert growth coefficient (female)	0.2	0.16	0.23
SD of length at minimum age (female)	0.09	0.08	0.1
SD of length at maximum age (female)	0.07	0.06	0.08
Length at minimum age (male)	70.28	68.2	71.8
Length at maximum age (male)	114.17	112.22	115.76
VonBert growth coefficient (male)	0.32	0.29	0.37
SD of length at minimum age (male)	0.1	0.1	0.11
SD of length at maximum age (male)	0.04	0.03	0.04
Log of number of recruits when unfished	5.62	5.48	6.21
Selectivity plateau start, Fleet 1	96.7	90.79	103.26
Selectivity plateau width, Fleet 1	-14.08	-24.5	-2.68
Selectivity asc. width, Fleet 1	5.41	4.64	6.08
Selectivity desc. width, Fleet 1	5.39	3.2	6.94
Selectivity at max length, Fleet 1	0.34	0.08	0.61
Selectivity plateau start, Fleet 2	102.49	89.69	124.47
Selectivity plateau width, Fleet 2	0.68	-23.91	14.17
Selectivity asc. width, Fleet 2	7.08	5.9	8.34
Selectivity desc. width, Fleet 2	5.9	3.12	8.84
Selectivity at max length, Fleet 2	0.8	0.51	0.99
Selectivity plateau start, Fleet 5	89.69	84.78	94.86
Selectivity plateau width, Fleet 5	-13.95	-24.37	-3.13
Selectivity asc. width, Fleet 5	5.26	4.35	6.12
Selectivity desc. width, Fleet 5	4.58	3.14	5.89
Selectivity at max length, Fleet 5	0.24	0.14	0.39
Selectivity plateau start, Fleet 6	94.68	81.93	108.46
Selectivity plateau width, Fleet 6	-9.8	-24.18	12.96
Selectivity asc. width, Fleet 6	5.95	4.51	7.35
Selectivity desc. width, Fleet 6	6.29	3.27	8.85
Selectivity at max length, Fleet 6	0.48	0.04	0.97
Selectivity plateau start, Fleet 7	90.62	67.52	114.76
Selectivity plateau width, Fleet 7	1.15	-23.39	14.08
Selectivity asc. width, Fleet 7	6.23	2.88	9.05
Selectivity desc. width, Fleet 7	6.32	3.19	8.88
Selectivity at max length, Fleet 7	0.66	0.05	0.98
Selectivity plateau start, Fleet 8	99.47	90.86	126.66
Selectivity plateau width, Fleet 8	-8.79	-24.34	13.61
Selectivity asc. width, Fleet 8	6.56	5.77	9.02
Selectivity desc. width, Fleet 8	5.02	3.08	8.81
Selectivity at max length, Fleet 8	0.59	0.08	0.96

Table E.12: Scenario 6: Summary of MCMC parameter estimates. Fleet definitions are listed in Table 2.2.

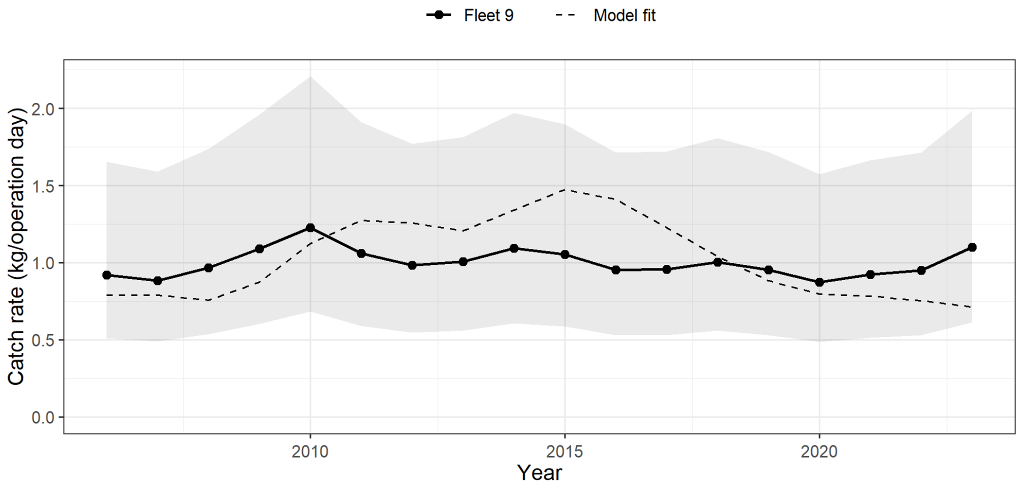

Figure E.146: Scenario 6: Model predictions (dotted line) to standardised catch rates for Australian east coast Spanish mackerel, based on maximum likelihood estimation—grey shade represent the model input and associated uncertainty

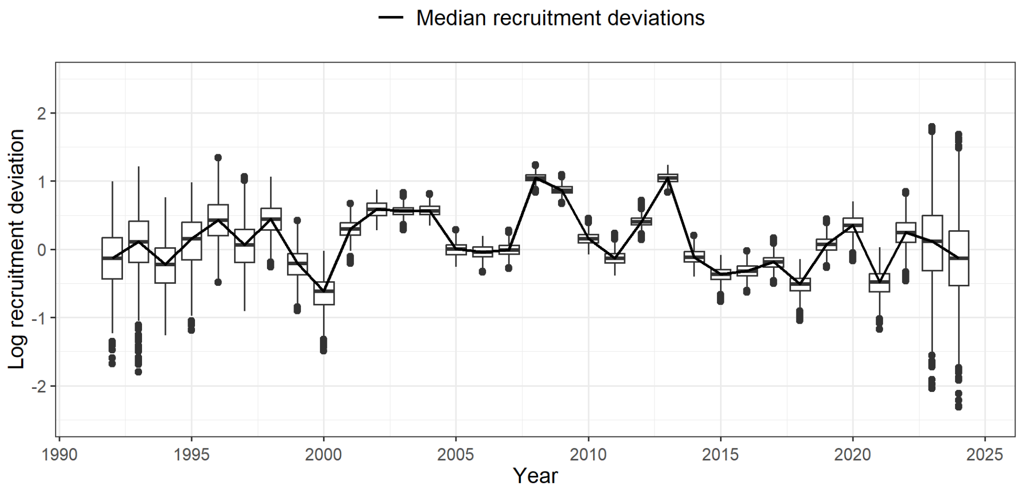

Figure E.147: Scenario 6: Recruitment deviations—whiskers represent 95% credible intervals, boxes represent 50% credible intervals, horizontal bars represent medians, and the points represent outliers

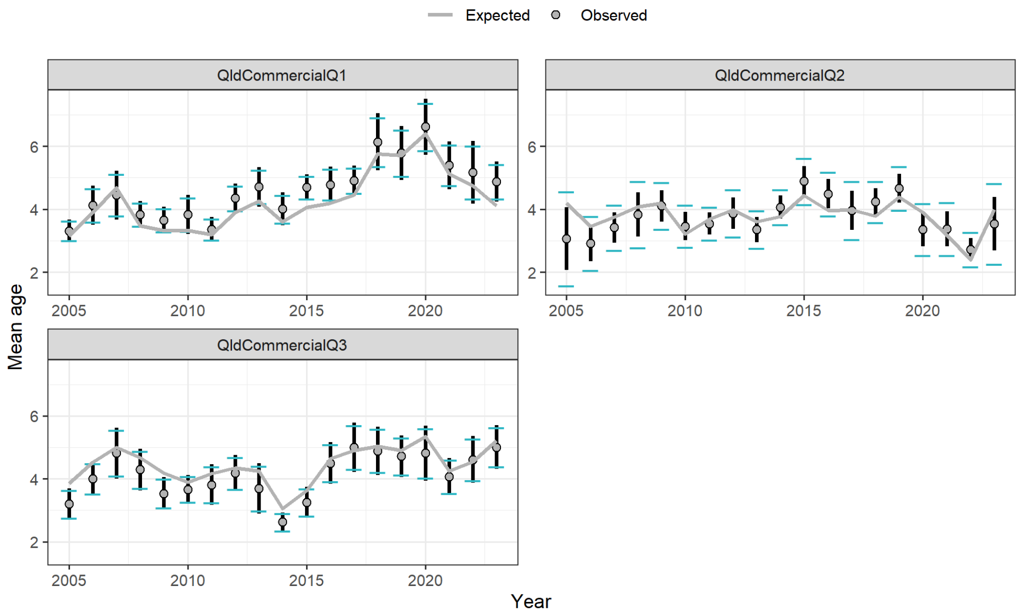

Figure E.148: Scenario 6: Mean age from conditional data (aggregated across length bins) with 95% confidence intervals based on current samples sizes: thinner intervals (with capped ends) show result of further adjusting sample sizes based on suggested multiplier (with 95% interval) for conditional age-at-length data

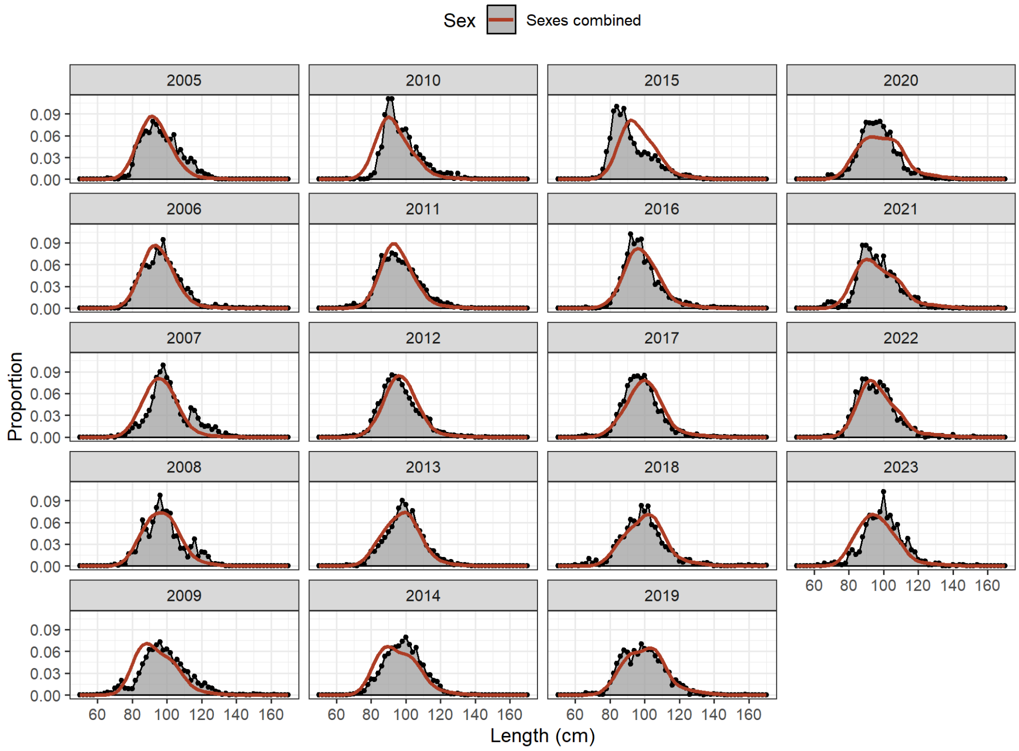

Figure E.149: Scenario 6: Fits to length structures for Fleet 1, based on maximum likelihood estimation—the grey area and black line represent data inputs and the red and blue line represents the model fits for female and male, respectively

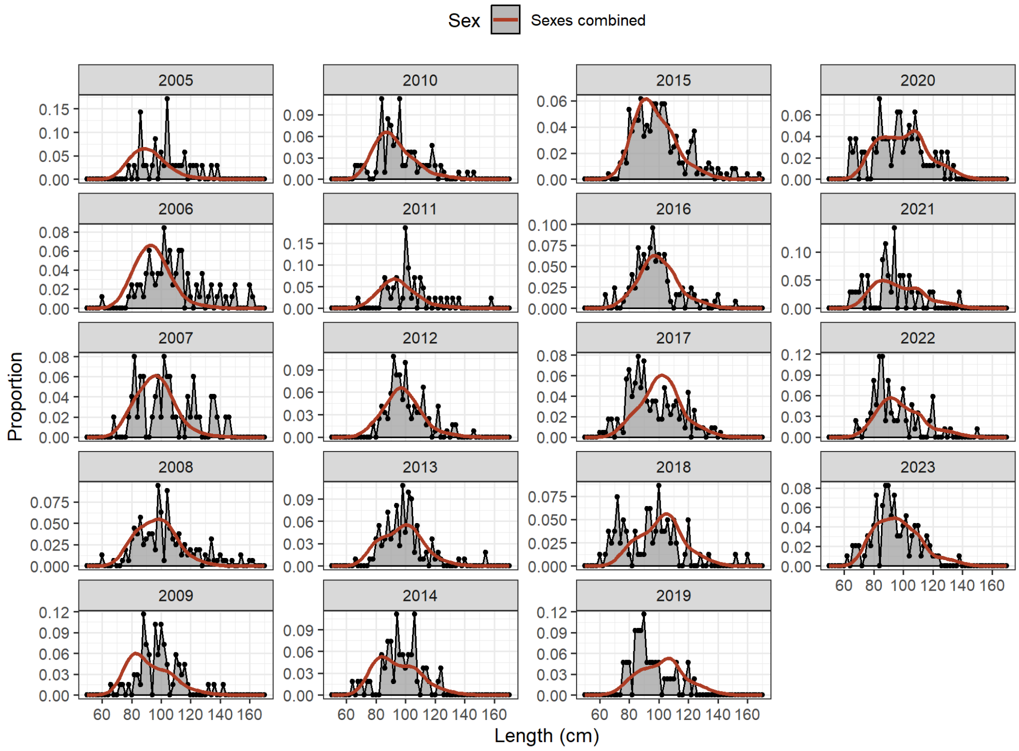

Figure E.150: Scenario 6: Fits to length structures for Fleet 2, based on maximum likelihood estimation—the grey area and black line represent data inputs and the red and blue line represents the model fits for female and male, respectively

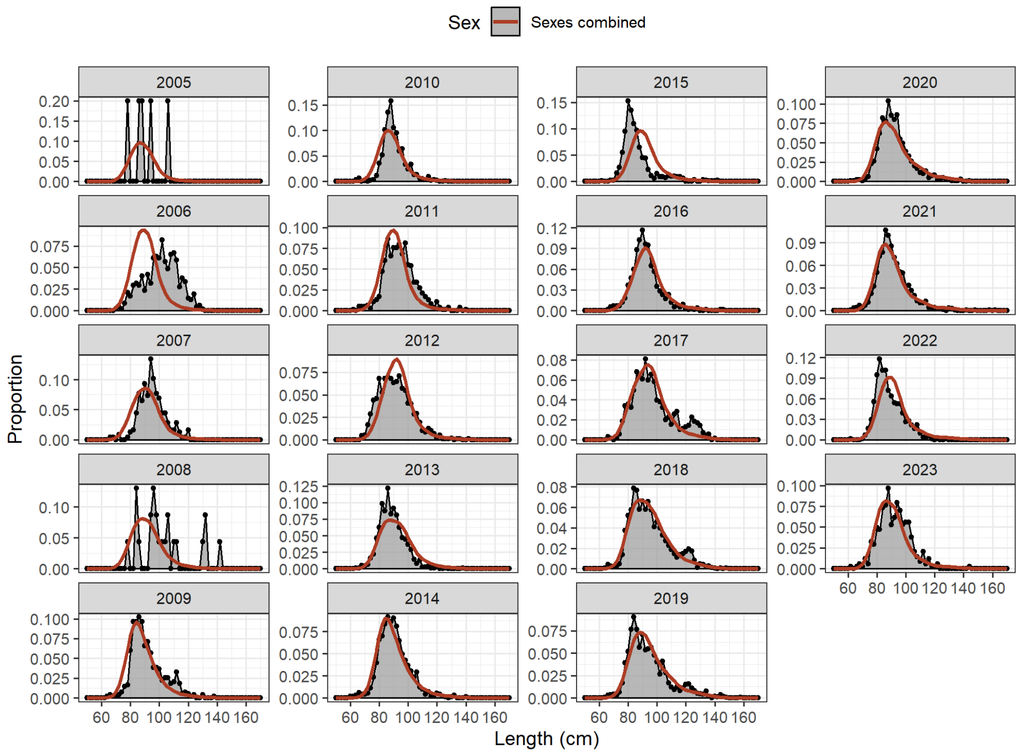

Figure E.151: Scenario 6: Fits to length structures for Fleet 5, based on maximum likelihood estimation—the grey area and black line represent data inputs and the red and blue line represents the model fits for female and male, respectively

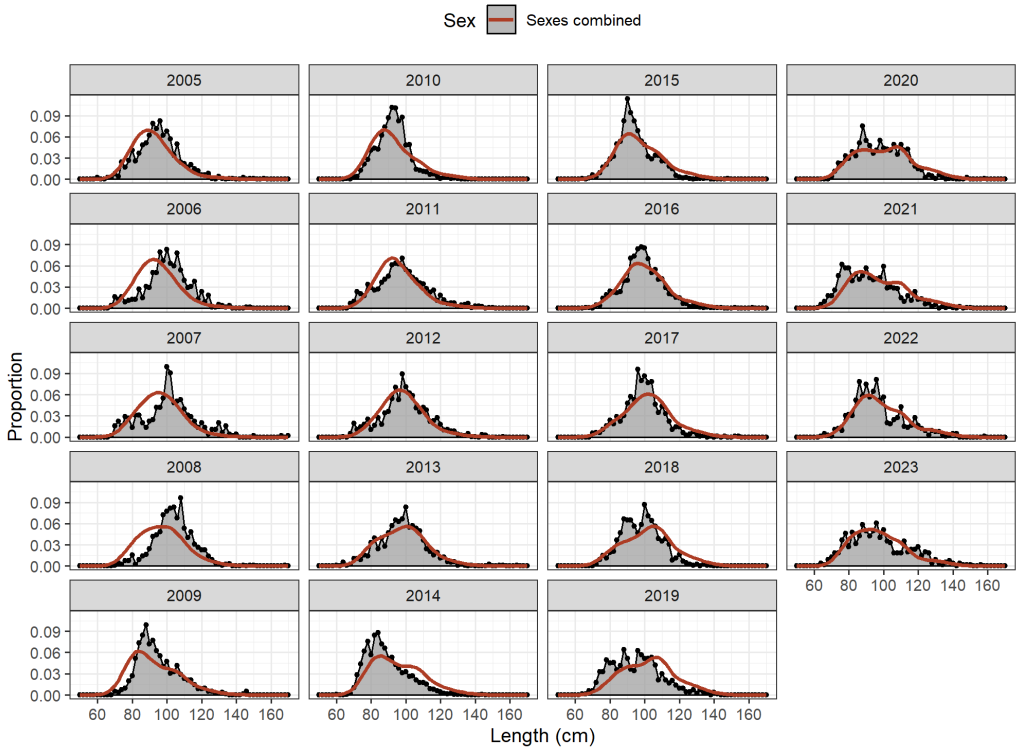

Figure E.152: Scenario 6: Fits to length structures for Fleet 6, based on maximum likelihood estimation—the grey area and black line represent data inputs and the red and blue line represents the model fits for female and male, respectively

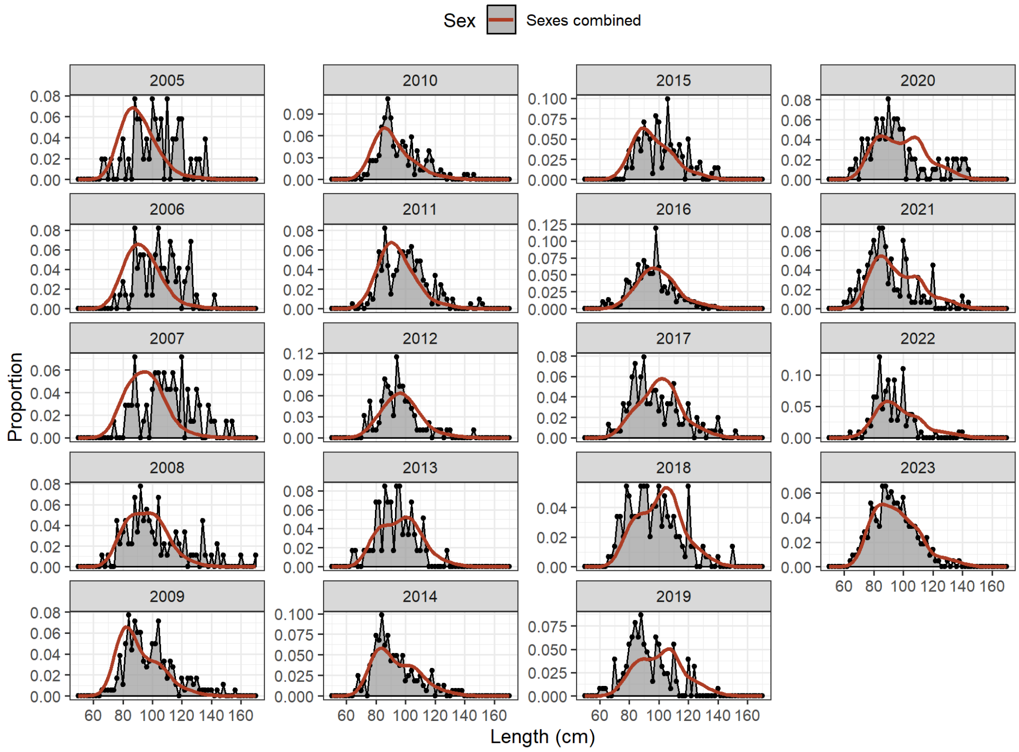

Figure E.153: Scenario 6: Fits to length structures for Fleet 7, based on maximum likelihood estimation—the grey area and black line represent data inputs and the red and blue line represents the model fits for female and male, respectively

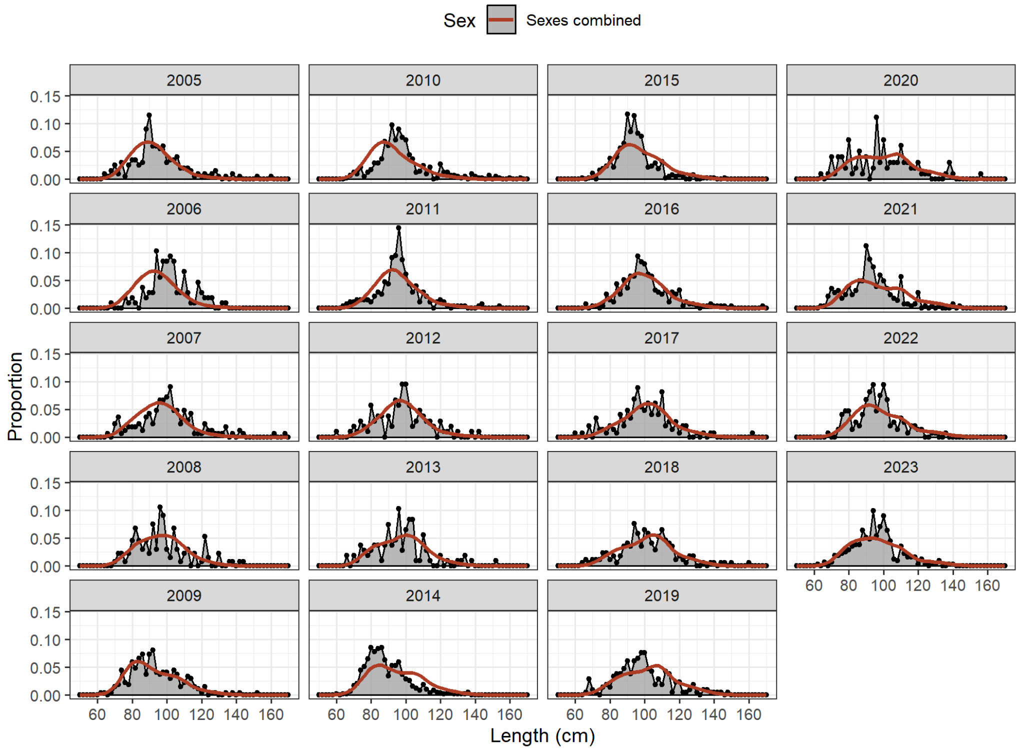

Figure E.154: Scenario 6: Fits to length structures for Fleet 8, based on maximum likelihood estimation—the grey area and black line represent data inputs and the red and blue line represents the model fits for female and male, respectively

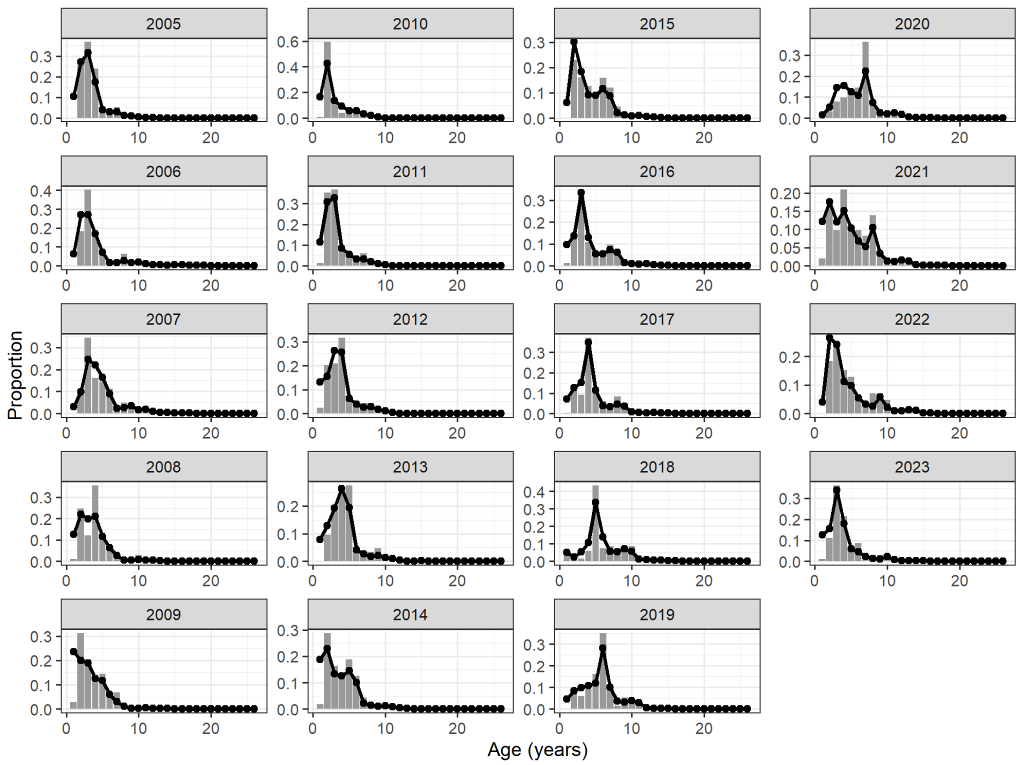

Figure E.155: Scenario 6: Fits to annual age compositions of female Spanish mackerel for Fleet 1

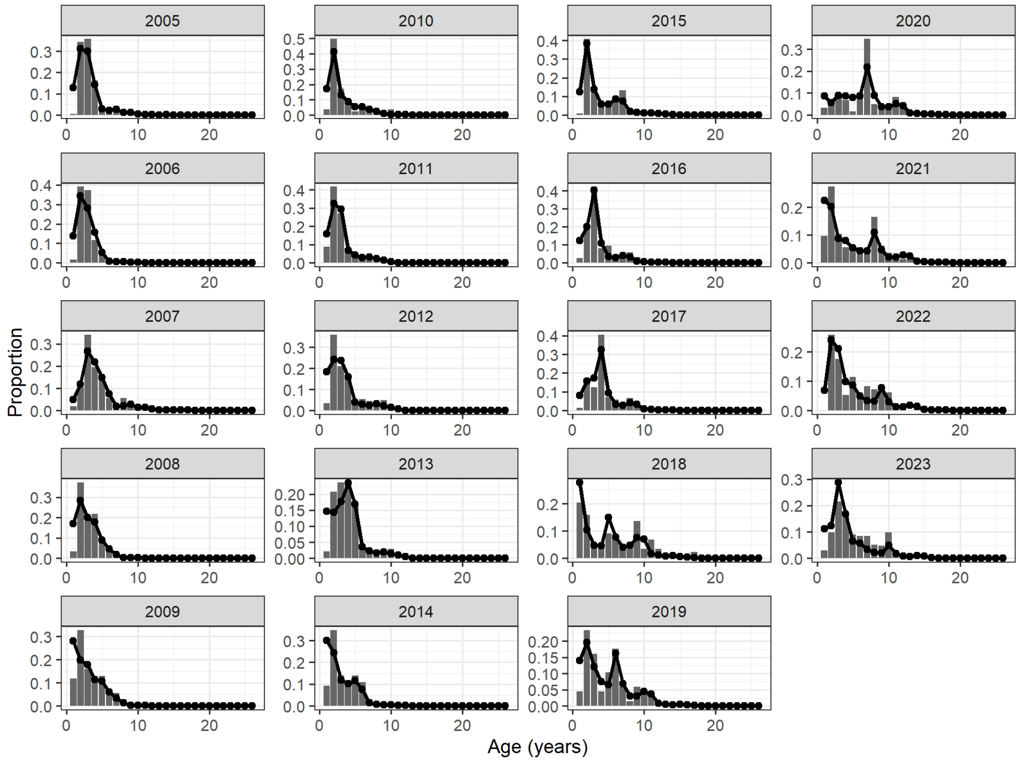

Figure E.156: Scenario 6: Fits to annual age compositions of male Spanish mackerel for Fleet 1

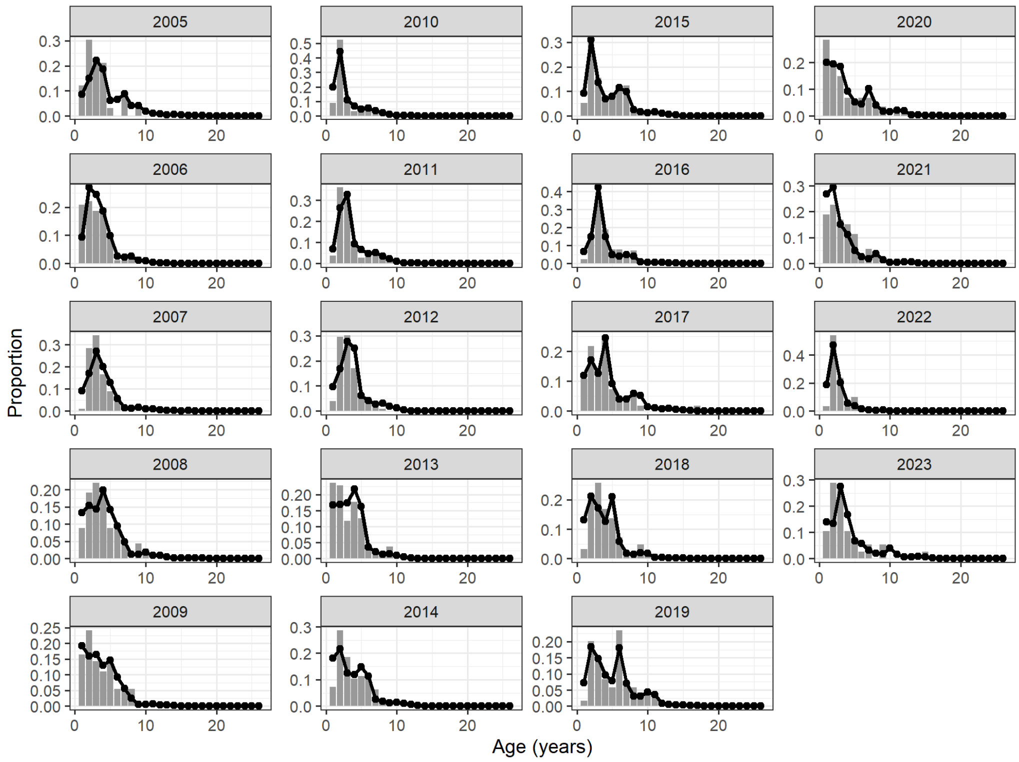

Figure E.157: Scenario 6: Fits to annual age compositions of female Spanish mackerel for Fleet 5

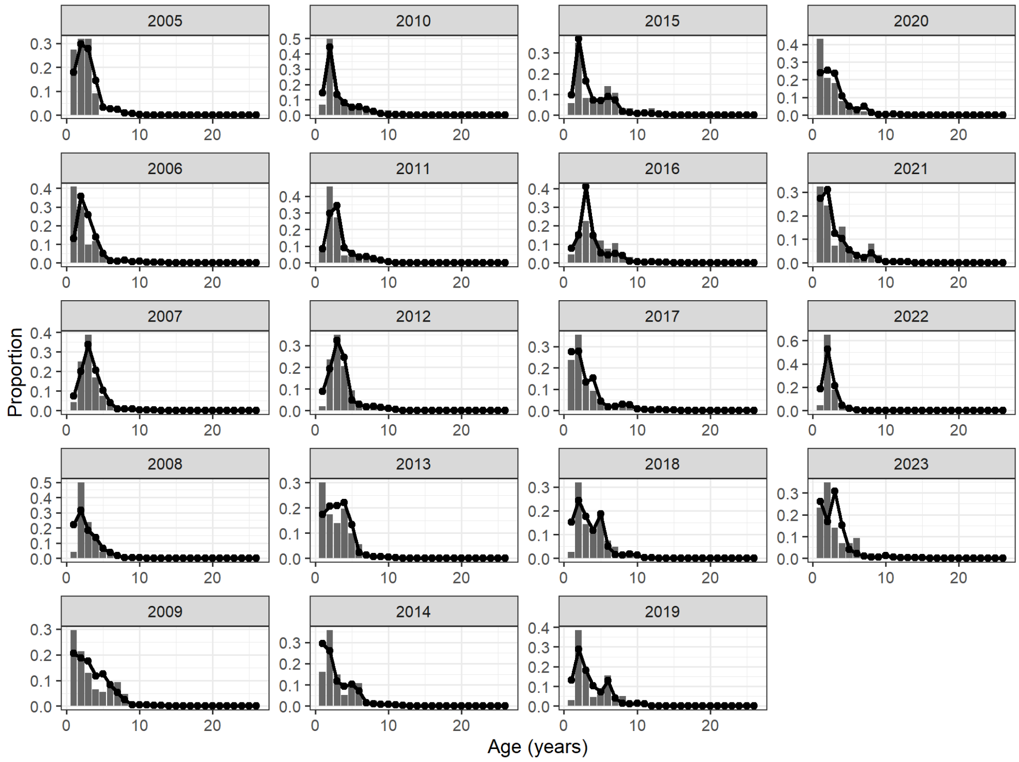

Figure E.158: Scenario 6: Fits to annual age compositions of male Spanish mackerel for Fleet 5

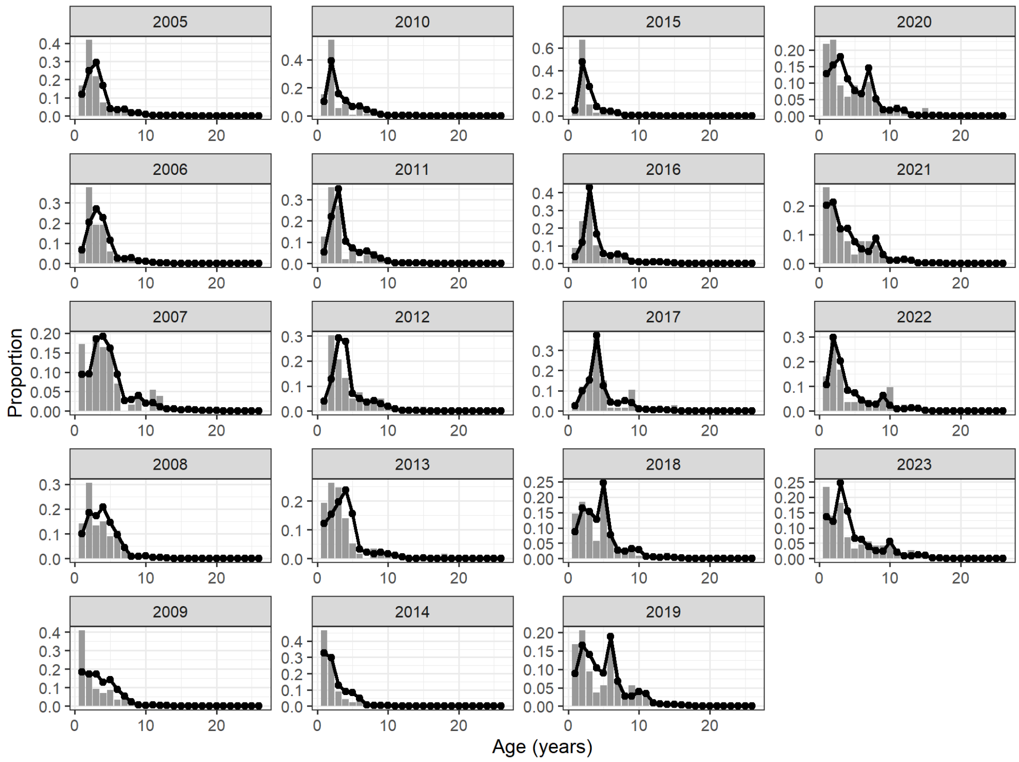

Figure E.159: Scenario 6: Fits to annual age compositions of female Spanish mackerel for Fleet 6

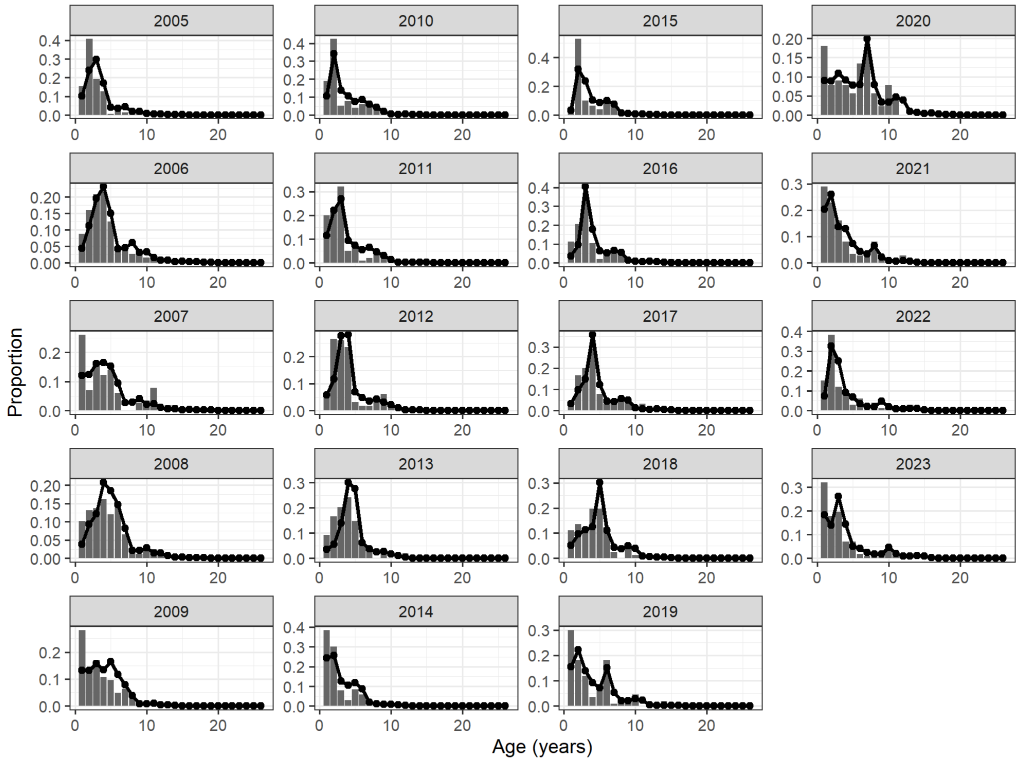

Figure E.160: Scenario 6: Fits to annual age compositions of male Spanish mackerel for Fleet 6

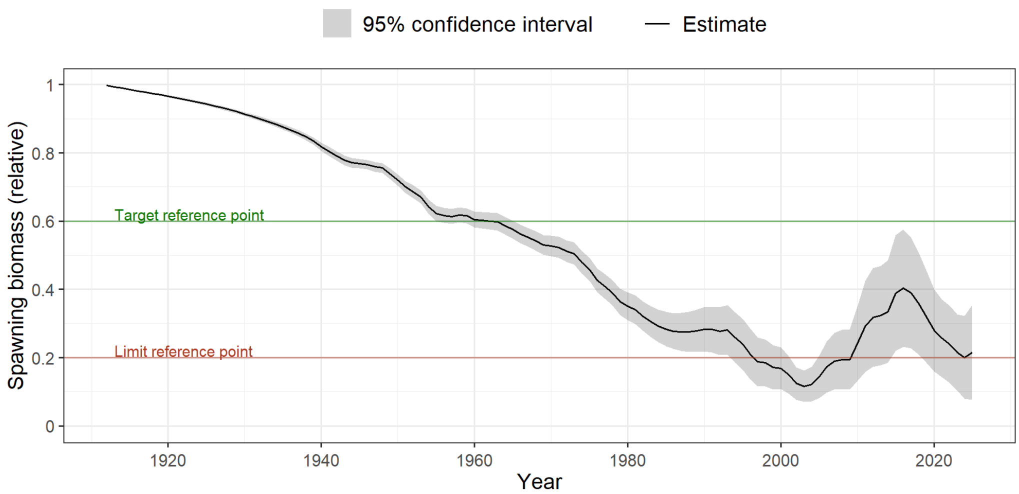

Figure E.161: Scenario 6: Predicted spawning biomass trajectory relative to unfished for Australian east coast Spanish mackerel, based on maximum likelihood estimation

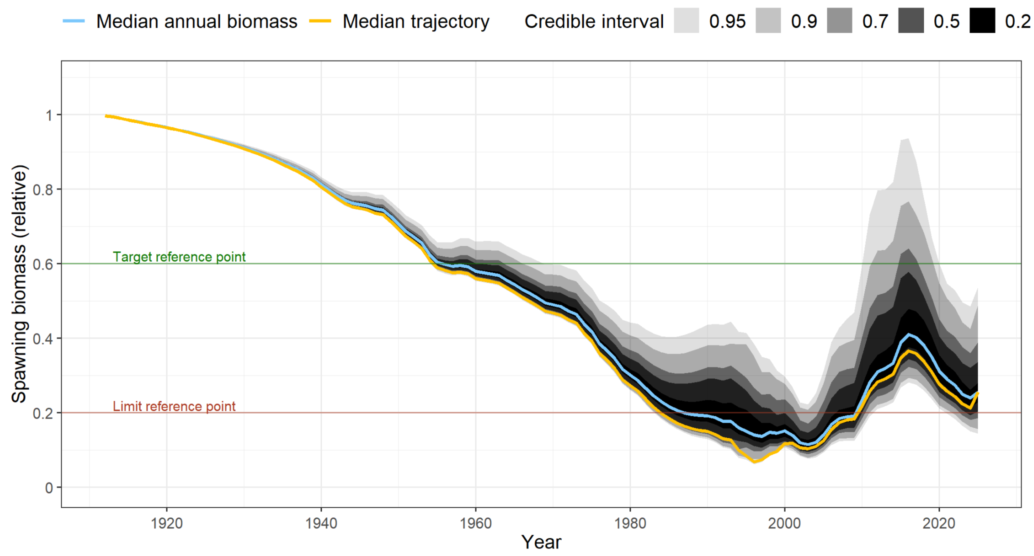

Figure E.162: Scenario 6: Predicted spawning biomass trajectory relative to unfished for Australian east coast Spanish mackerel, based on MCMC

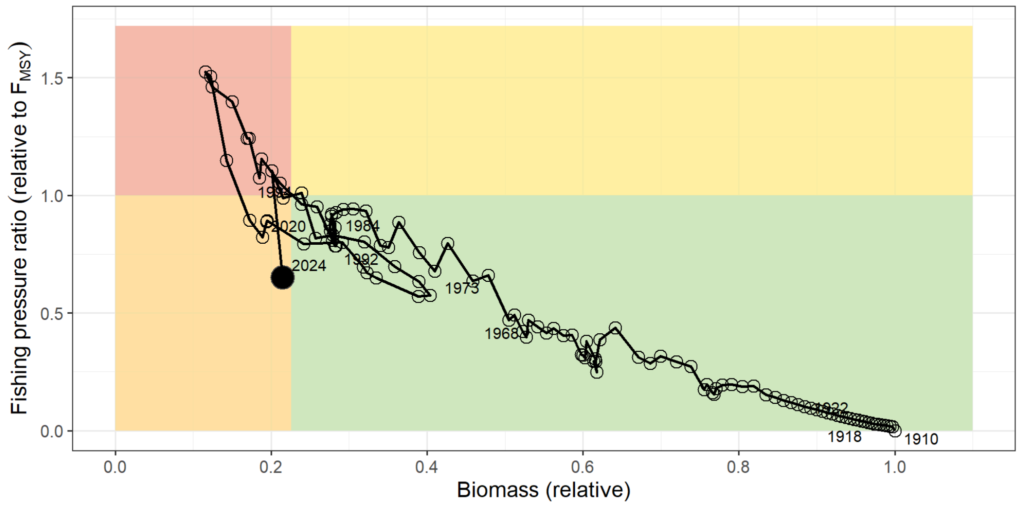

Figure E.163: Scenario 6: Stock status indicator trajectory for Australian east coast Spanish mackerel, based on maximum likelihood estimation

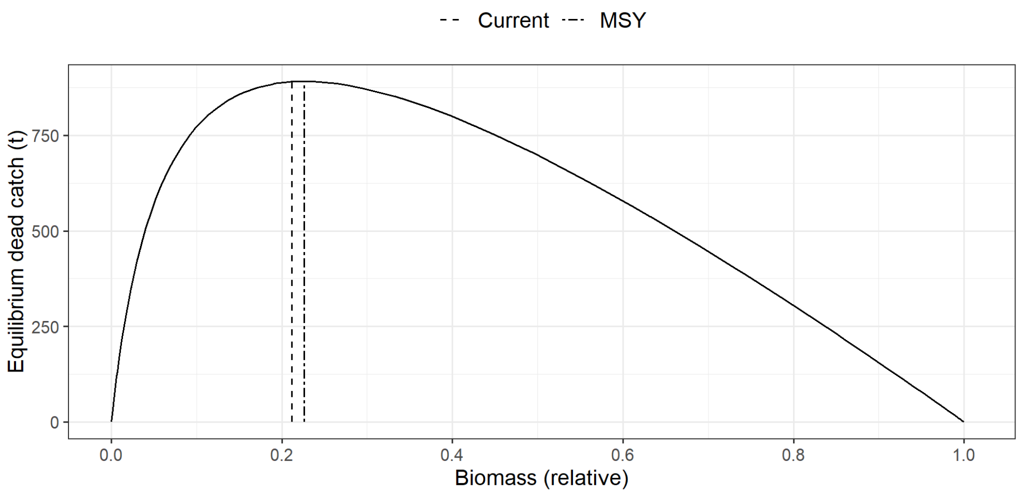

Figure E.164: Scenario 6: Equilibrium dead catch curve for Australian east coast Spanish mackerel, based on maximum likelihood estimation

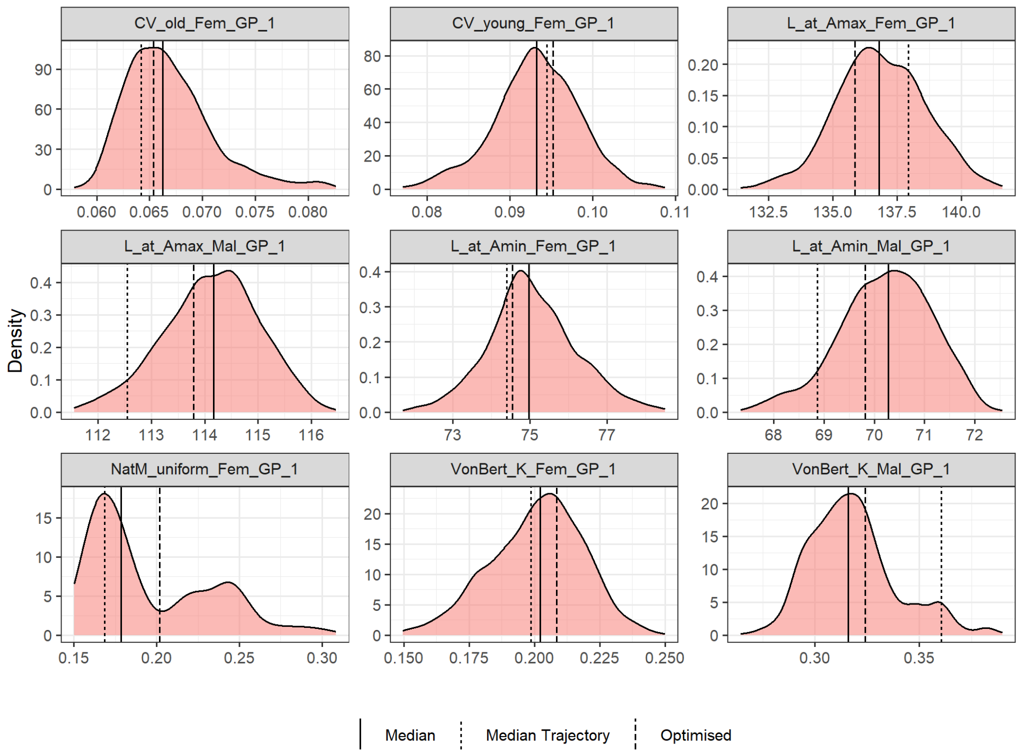

Figure E.165: Scenario 6: Posterior density of MCMC iterations. ”Median” line shows median parameter value for MCMC iterations ”Optimised” shows the parameter value found from maximum likelihood estimates.

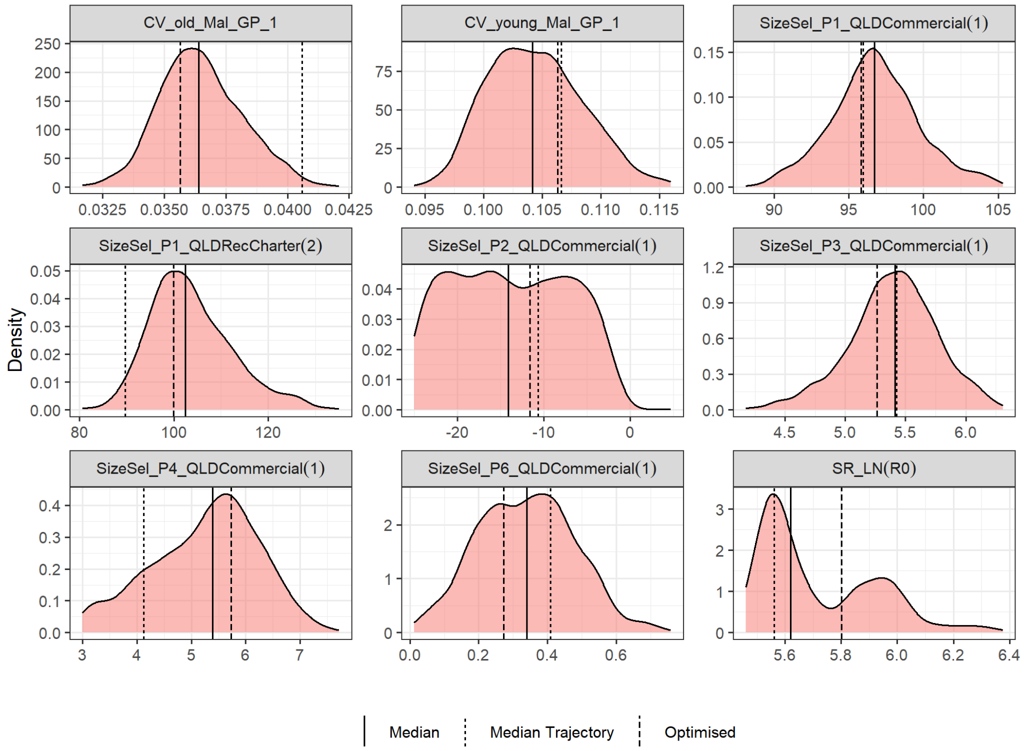

Figure E.166: Scenario 6: Posterior density of MCMC iterations. "Median" line shows median parameter value for MCMC iterations "Optimised" shows the parameter value found from maximum likelihood estimates.

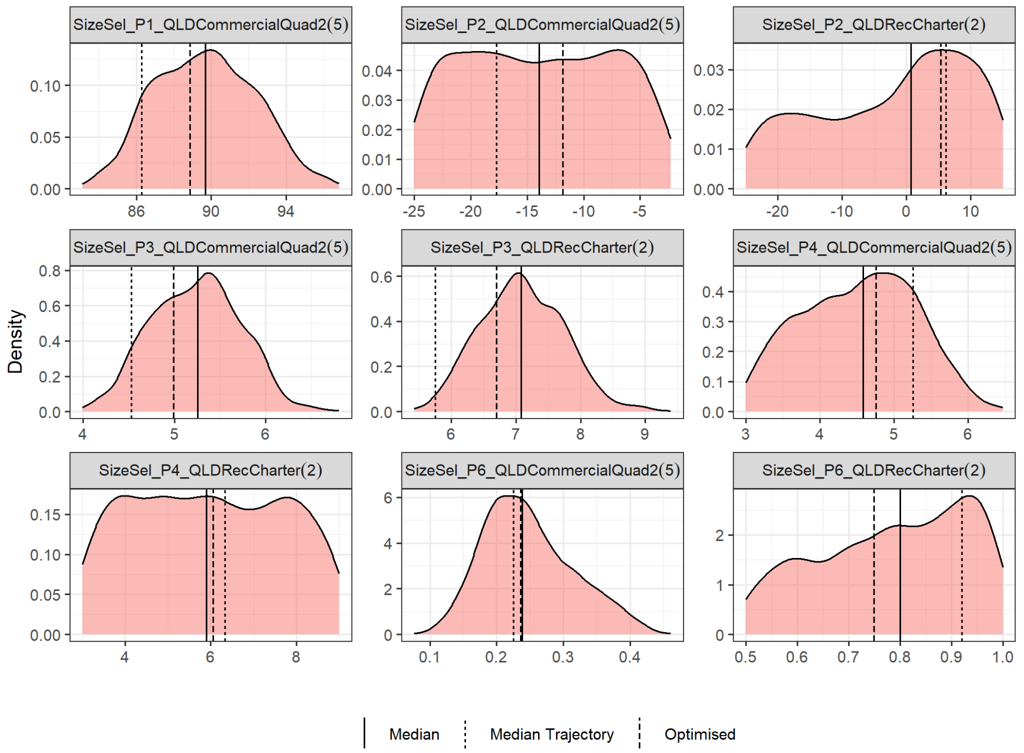

Figure E.167: Scenario 6: Posterior density of MCMC iterations. "Median" line shows median parameter value for MCMC iterations "Optimised" shows the parameter value found from maximum likelihood estimates.

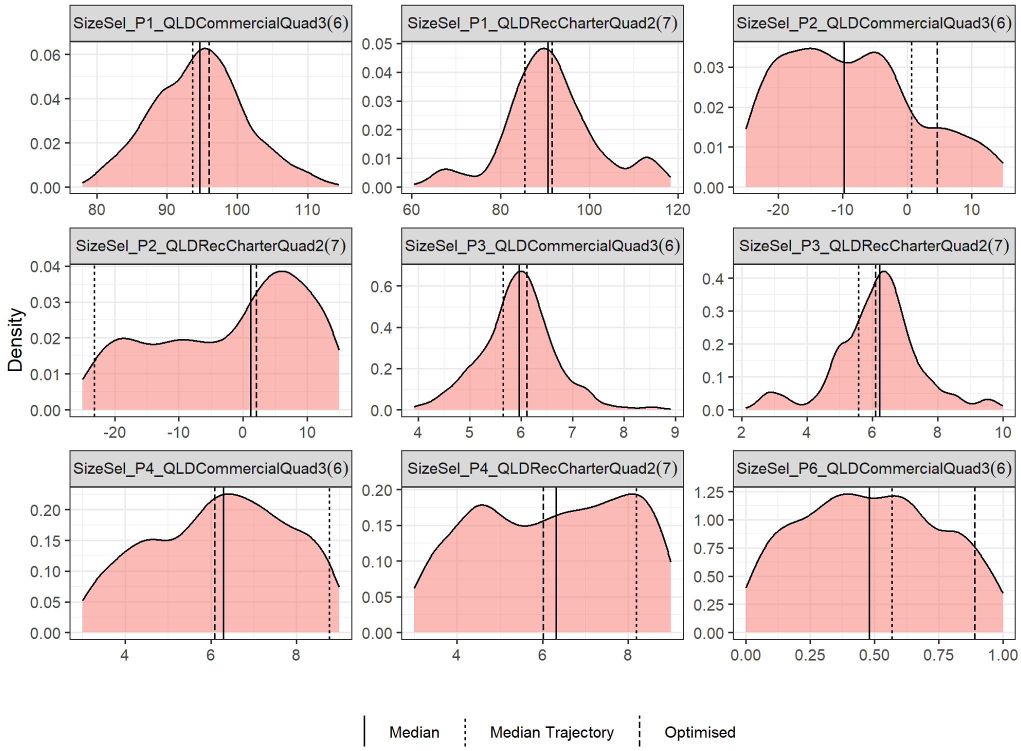

Figure E.168: Scenario 6: Posterior density of MCMC iterations. "Median" line shows median parameter value for MCMC iterations "Optimised" shows the parameter value found from maximum likelihood estimates.

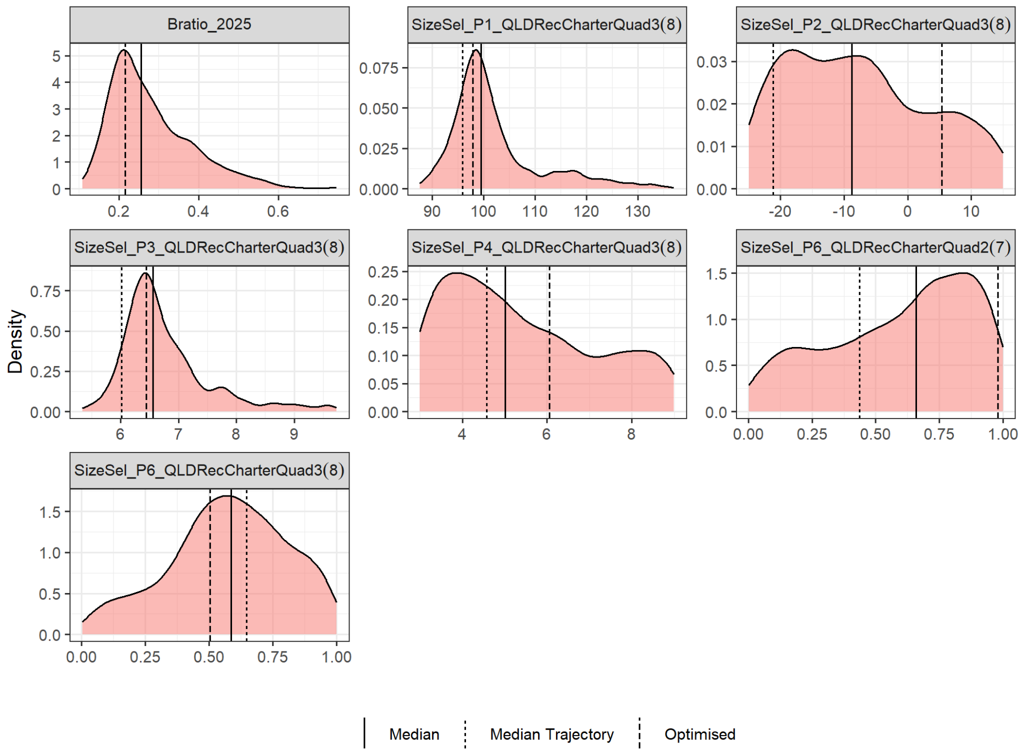

Figure E.169: Scenario 6: Posterior density of MCMC iterations. "Median" line shows median parameter value for MCMC iterations "Optimised" shows the parameter value found from maximum likelihood estimates.

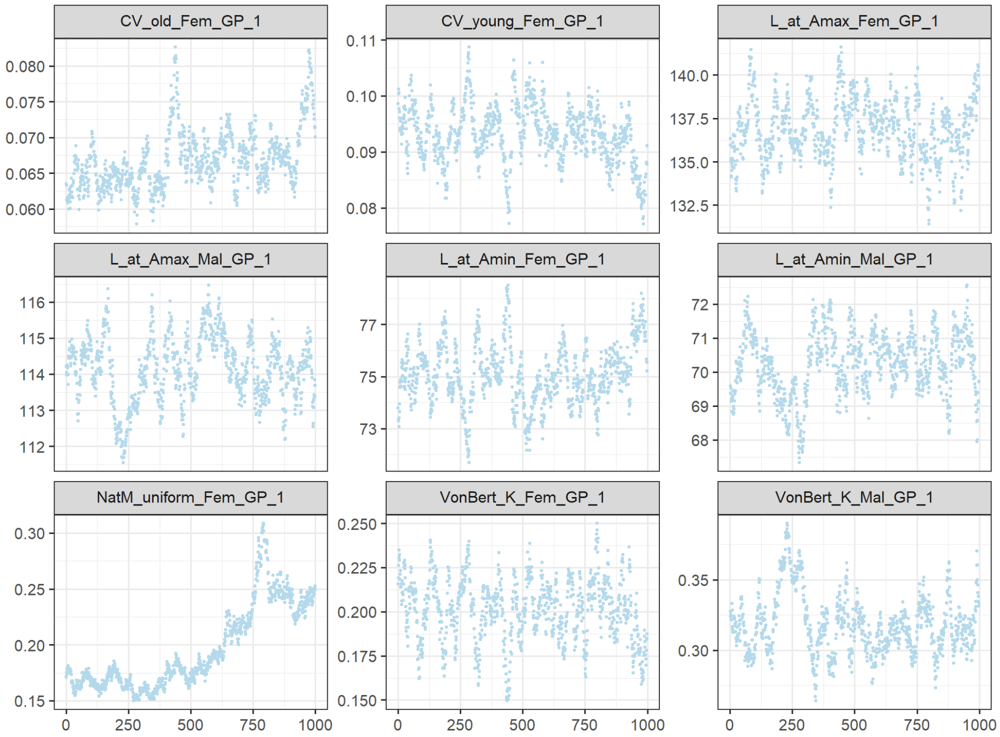

Figure E.170: Scenario 6: Trace plot of MCMC iterations

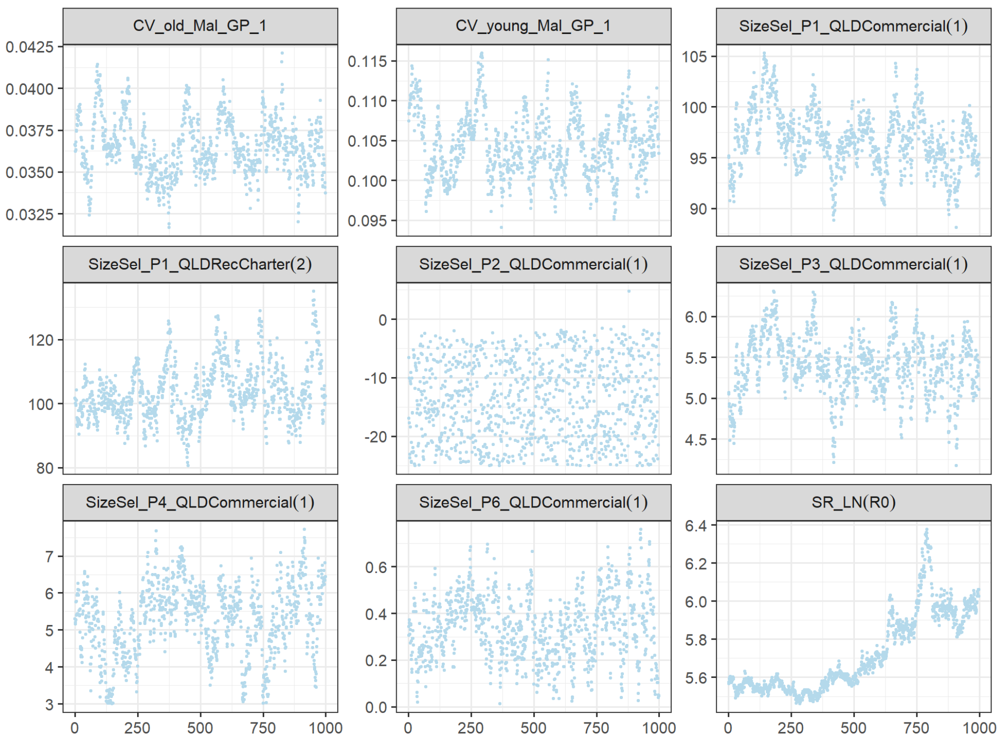

Figure E.171: Scenario 6: Trace plot of MCMC iterations

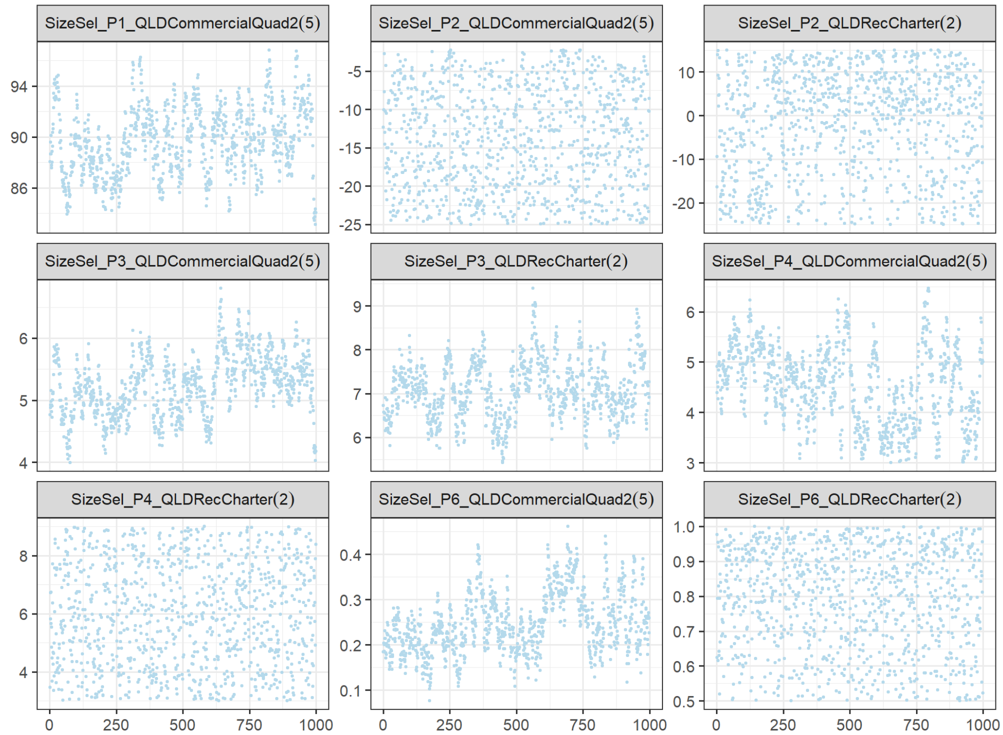

Figure E.172: Scenario 6: Trace plot of MCMC iterations

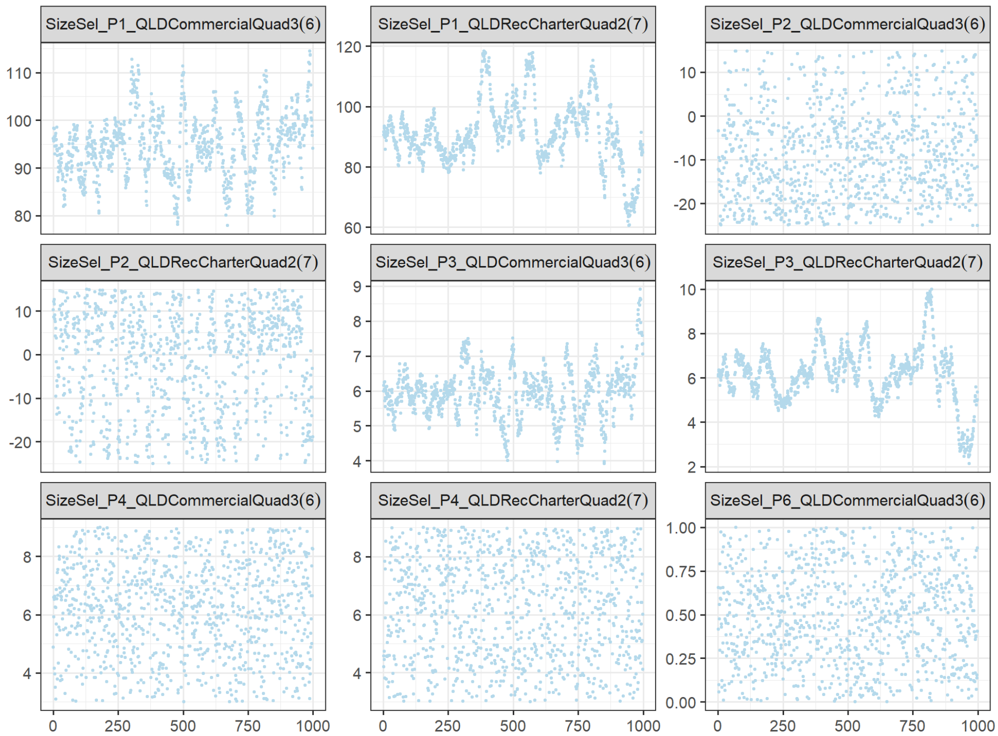

Figure E.173: Scenario 6: Trace plot of MCMC iterations

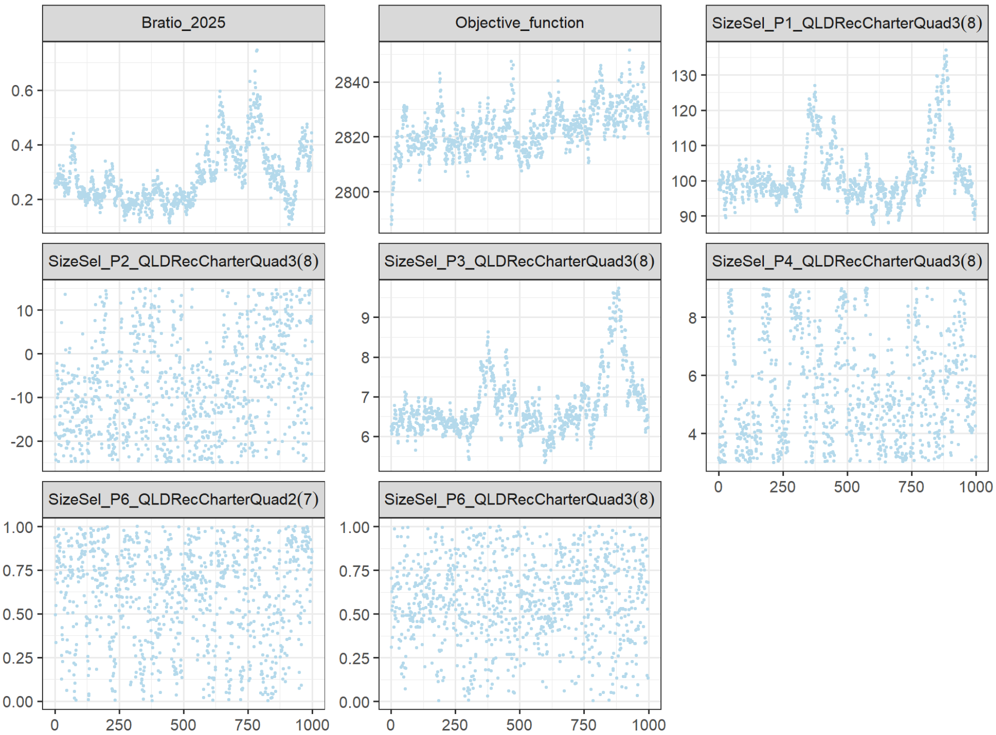

Figure E.174: Scenario 6: Trace plot of MCMC iterations

F Model exploration

Table F.1: Exploratory scenarios tested to determine final model structures and settings, and how they differ from the reference scenario

Scenario	Description
Reference	Scenario 2 from the ensemble
Static depredation	Constant shark depredation is used, instead of a linear increase
Adjusted Fishboard	Fishboard data is adjusted
Environmental drivers	Environmental drivers are included
Time-varying selectivity	Time-varying selectivity is used for all fleets, not just commercial
Low M	M fixed at 0.216
Medium M	M fixed at 0.233
High M	M fixed at 0.266
Decadal catch rates	Decadal catch rates included
Not fleets-as-areas	No spatial-temporal structure in the model
Low h, equal weighting	Equivalent to Scenario 1 but no adjustment to the ESS of the length data
Medium h, equal weighting	Equivalent to Scenario 2 but no adjustment to the ESS of the length dataa
High h, equal weighting	Equivalent to Scenario 3 but no adjustment to the ESS of the length data

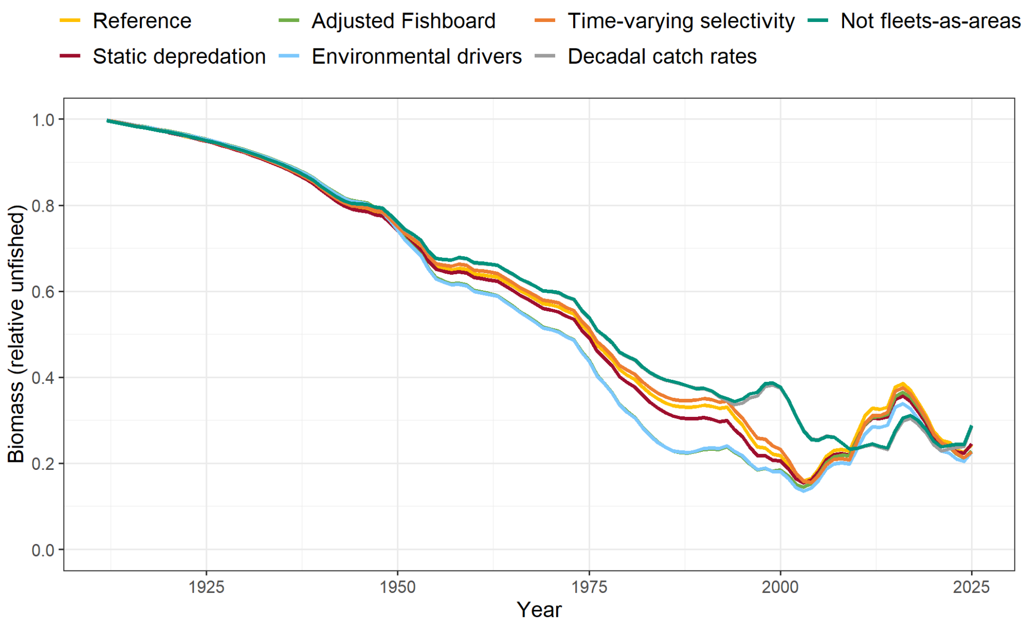

Figure F.1: Spawning biomass trajectory relative to unfished levels estimated in exploratory models, comparing scenarios not included in the ensemble

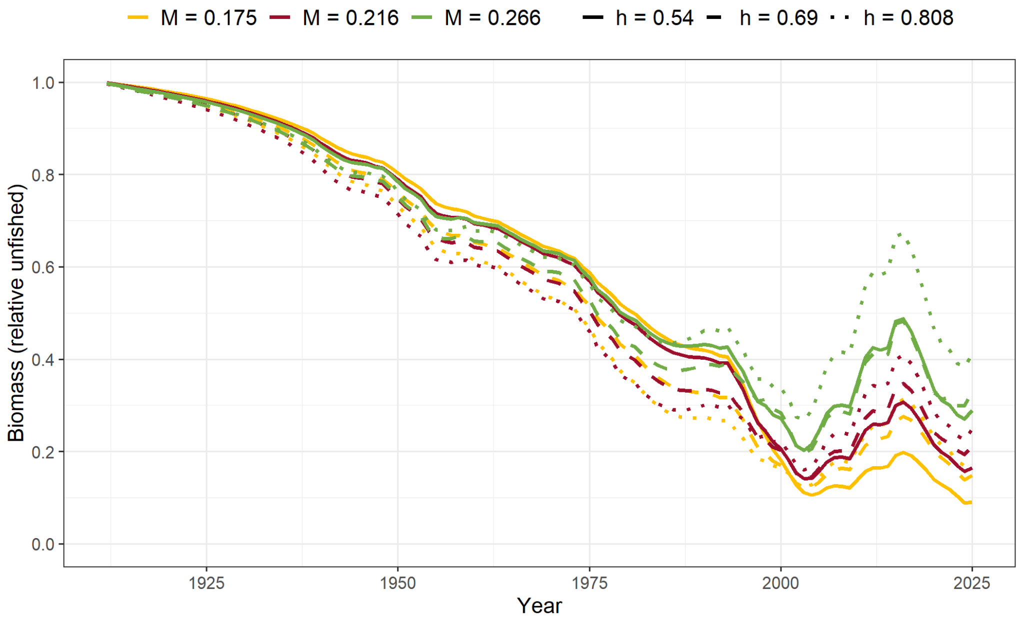

Figure F.2: Spawning biomass trajectory relative to unfished levels estimated in exploratory models, comparing steepness and natural mortality

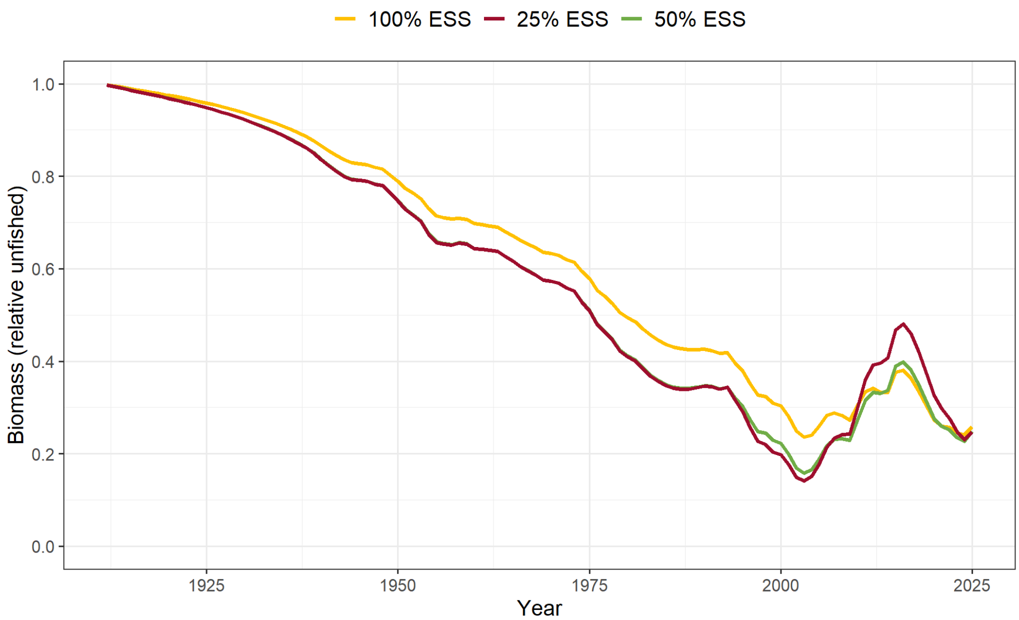

Figure F.3: Spawning biomass trajectory relative to unfished levels estimated in exploratory models, comparing effective sample size of length data

G Alternative length and age data sources

From McPherson (1981), two non-consecutive years (1974 and 1978) of early length composition data were available for commercially caught Queensland east coast Spanish mackerel. These data did not have any associated sampling information (i.e. number of catches sampled). Further, the spatial distribution of sampling differed from the main dataset collected by Fisheries Queensland's contemporary biological monitoring program, with samples collected from reefs between Cairns and Townsville only.

Tobin and Mapleston (2004) collected age and length data from the commercial and recreational sectors between July 2001 and January 2003, separately to Fisheries Queensland's biological monitoring program. The different sampling regime (detailed in the Tobin and Mapleston (2004) report) meant the seasonal and spatial distribution of sample collection differed notably from that of the subsequent monitoring years. In terms of seasonal differences, 2001 and 2003 sampling years were seasonally incomplete (samples only collected for part of the year). Regionally, Tobin and Mapleston (2004) stated that due to logistical and budgetary constraints of the project, sampling was concentrated to the Townsville, Mackay, Rockhampton and South-East Queensland regions. Further, the realised distribution of samples among these regions heavily favoured the Townsville region.

H Quasi bridging analysis

Table H.1: Scenarios tested in quasi bridging analysis: current h = 0.69, previous h = 0.45

Scenario	h	catch rate
I	current	current
II	previous	current
III	current	previous
IV	previous	previous

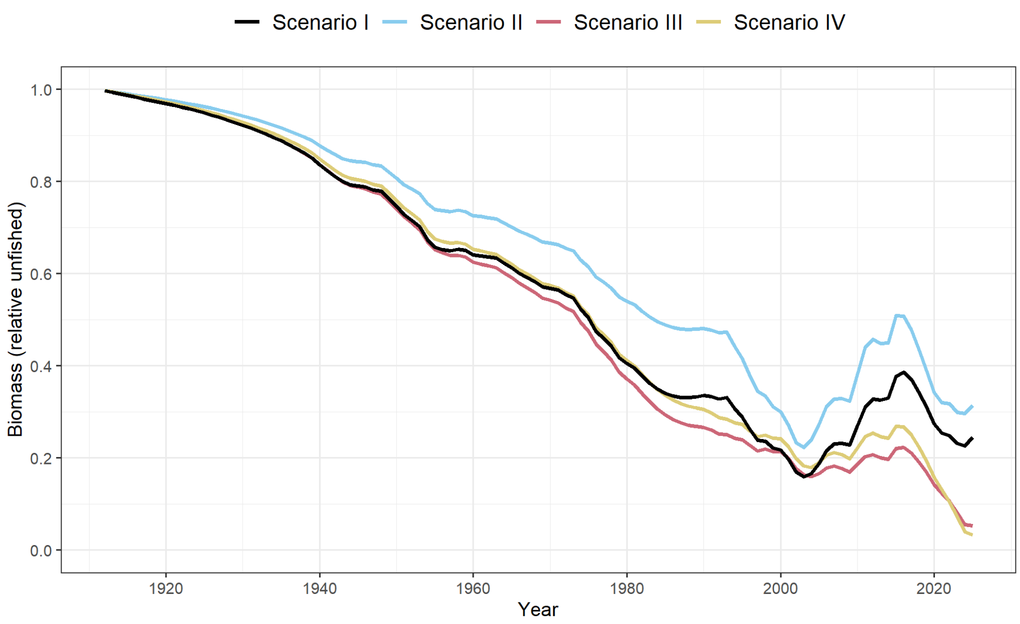

Figure H.1: Spawning biomass trajectory relative to unfished levels estimated in Scenarios I-IV

I Phone survey template

East Coast Spanish Mackerel Stock Assessment
Catch survey

Survey Number: ________________ **Date:**_____________ **Time:**___________

Good morning/afternoon

My name is _______________ and I'm calling from Fisheries Queensland, part of the Department of Primary Industries.

We are currently working on the Spanish mackerel stock assessment and the project team, which includes commercial and recreational fishers, recently had a discussion focused on catch history.

To ground truth the catch information used in the stock assessment, the project team recommended we talk with Spanish mackerel fishers who really know the fishery. Given your history and experience in the fishery, your name came up as someone who could help us.

If you are able to help us, we have a few questions we'd like to ask you about the fishery. The questions are optional and it should take about 5-10 minutes. You can also provide general feedback at the end of the survey.

Information collected during this survey will be aggregated and de-identified to protect your privacy. Your identity and responses may become known to the project team, but will remain anonymous outside of this group unless you indicate otherwise. The information collected in this survey will be used solely for the purpose of improving the stock assessment.

Are you willing to help us by taking the survey?

IF fisher **DECLINES** to take the survey, **thank them for their time** and **end call**.

IF fisher **AGREES** to take the survey -

Do you have time to take the survey now?

IF Yes – *Proceed with Survey*

IF No – **Is there a convenient time that I could call back?**

Agree on suitable date and time (_____________________________)

Thank the client and say you will call back at the agreed time.

START SURVEY

Q1. How would you describe yourself as a fisher?

Prompt *- Current commercial East Coast Spanish mackerel fisher; Retired commercial East Coast Spanish mackerel fisher; Current recreational fisher (regularly catching East Coast Spanish mackerel); Retired recreational fisher (previously catching East Coast Spanish mackerel); Charter operator*

Q2. How many years have you been catching East Coast Spanish mackerel?

Q3. Have you experienced losing fish to sharks during your time fishing?

Yes **(. . . Do you remember a year when it started to change?)**

No

COMMERCIAL FISHER QUESTIONS ONLY

Q4. Was Spanish mackerel your main target species?

Yes

No

Q5. From 1997 to 2004, this was the period between the Investment Warning in 1996 and the introduction of quota in 2005. The commercial logbook data for this period indicated 528 tonnes of East Coast Spanish mackerel was caught in 1997, and 561 tonnes in 2004.

Do you have any general views on how reliable the catches recorded in logbooks during this period were?

Prompt *- Reported catches were about right; catches were lower than reported; catches were higher than reported*

END OF SURVEY

This brings us to the end of the survey. Is there any other information you would like to add based on your experience?

Thank you very much for your time, it is much appreciated.

Additional Notes