Stock assessment of king threadfin (*Polydactylus macrochir*) in the Gulf of Carpentaria, Queensland, Australia, with data to December 2022

June 2024

Queensland Government

This publication has been compiled by A.B. Campbell, M. Tanimoto, O.J. Whybird and A.R. Fox of Fisheries Queensland, Department of Agriculture and Fisheries

Painting on cover page by Alise Fox.

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

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

Interpreter statement

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

Contents

Summary

This stock assessment indicates that the biomass of king threadfin in the Gulf of Carpentaria declined from an assumed unfished state in 1955 to potentially as low as 5% of this level in 1995. The stock level at the end of 2022 was estimated to be between 13% and 44% of unfished biomass.

King threadfin is a large, predatory fish species that is found in foreshore areas of turbid coastal waters, estuaries, tidal rivers and mangrove creeks across northern Australia and southern Papua New Guinea. In Australia, its distribution extends from the Ashburton River in Western Australia, across northern Australia, to the Brisbane River in South East Queensland. It is a protandrous hermaphrodite, beginning as male and later changing to female between about 40 cm to 110 cm total length. It can grow to 150 cm total length and 30 kg in weight. The species lives to at least 20 years of age.

A previous assessment estimated the Gulf of Carpentaria stock to be around 5% of the unfished level, using data through to December 2019.

This assessment differs from the previous assessment in several respects. Firstly, it considers data through to December 2022, and includes additional historical age and length data sets. Secondly, it operated under the guidance of a project team consisting of multiple domain experts including fishery stakeholders. Thirdly, it was externally reviewed and incorporates feedback from that review. Fourthly, key outputs are constructed as an ensemble across several model scenarios rather than selecting a particular preferred scenario.

All assessment inputs and outputs are referenced on a calendar year basis (that is, '2022' means January 2022–December 2022).

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 data spanning the period 1955–2022 including mandatory daily commercial logbook data collected by Fisheries Queensland (1989–2022), collated commercial production returns from the Gulf of Carpentaria (1981–1988), recreational and boat ramp survey data (1997–2022), and age and length data (1988–1994 and 2015–2022).

Over the last five years, 2018 to 2022, total retained catch averaged 222 tonnes per year in the Gulf of Carpentaria (Figure 1). Of the overall harvest, 98% was taken by the commercial sector and 2% by the recreational sector.

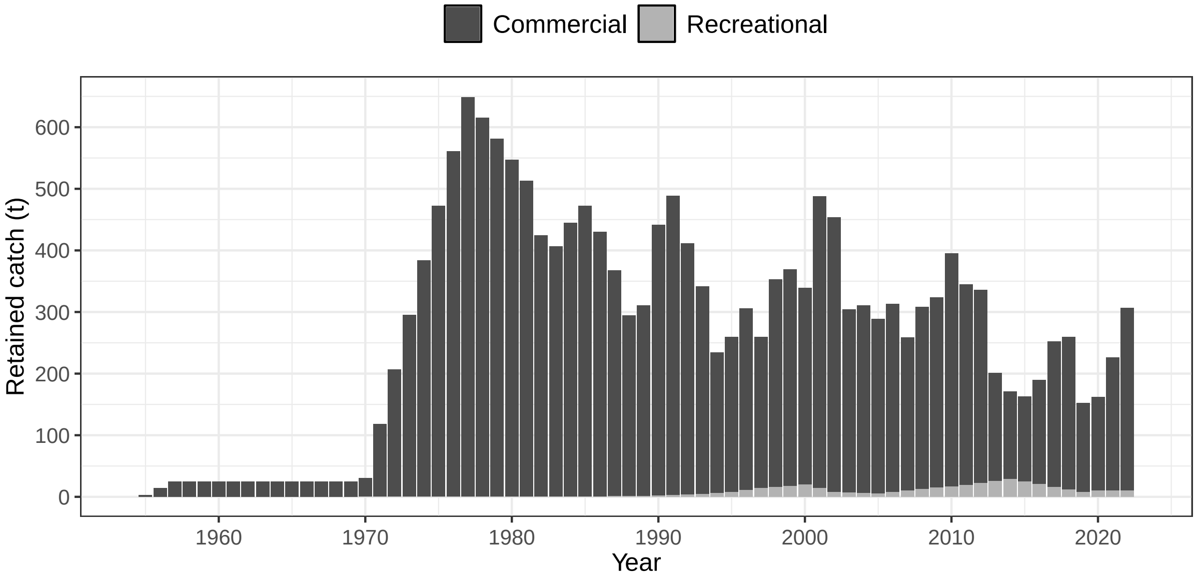

Figure 1: Estimated retained catch between 1955 and 2022 for king threadfin in the Gulf of Carpentaria

The commercial catch rates were standardised to estimate an index of abundance of king threadfin through time (Figure 2). The unit of standardisation was kilograms of king threadfin per fisher per day, and included an adjustment for targeting. The catch rate standardisation model included terms for year, month, location, net mesh size, net length and fisher. Several different methods of spatial weighting were considered when constructing the final index.

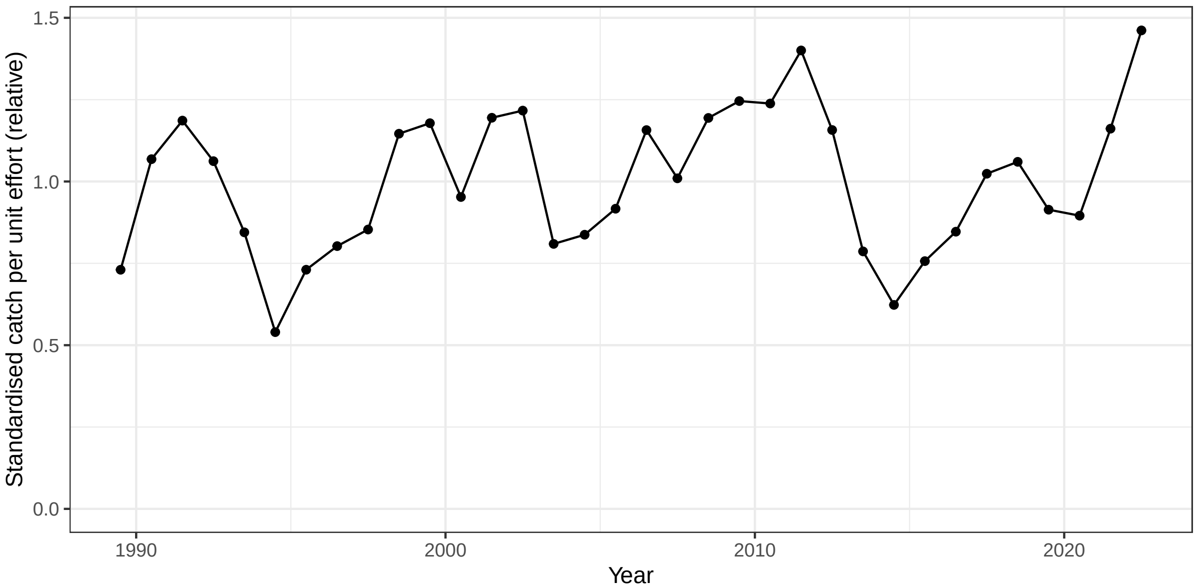

Figure 2: Annual standardised catch rates for king threadfin in the Gulf of Carpentaria

Several scenarios were run to explore different settings of the instantaneous natural mortality rate M, steepness h, catchability increase q_{inc}, spatial data weighting and spatial extent of the stock. From these exploratory scenarios a final ensemble of eight scenarios were chosen for inclusion in summary reporting. This ensemble indicates that the biomass ratio at the beginning of 2023 was between 13% and 44% of unfished levels (95% credible interval). We also report the probability of the 2023 biomass ratio falling into each of the following four biomass ratio categories: below 20%, between 20% and 40%, between 40% and 60%, and above 60% (Table 1; Figures 3 and 4).

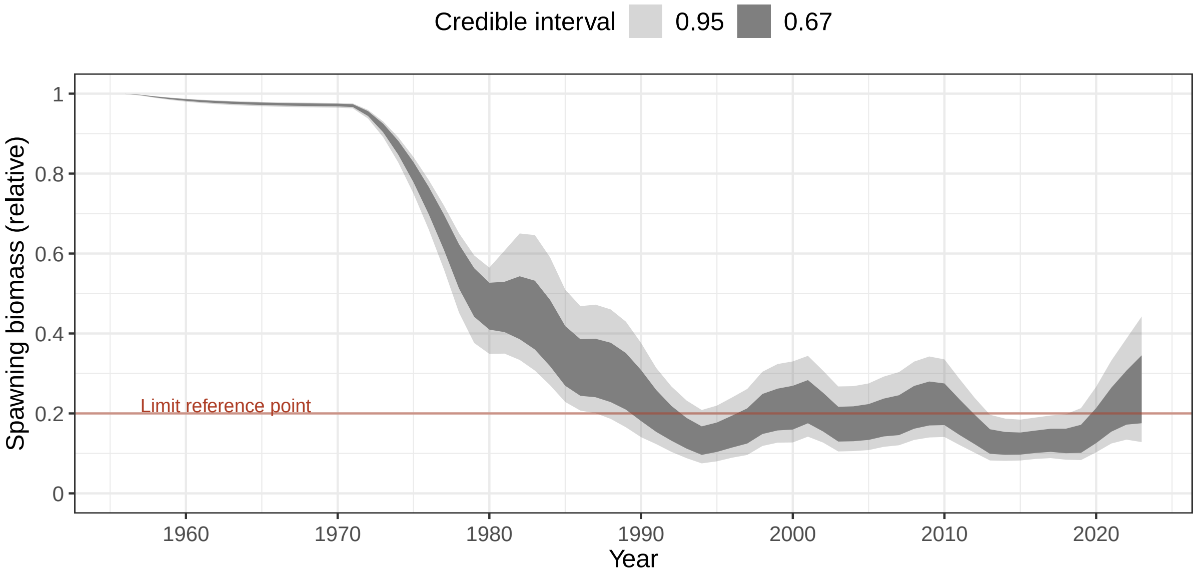

Figure 3: Estimated spawning biomass trajectory relative to unfished, from 1955 to 2022, for king threadfin in the Gulf of Carpentaria

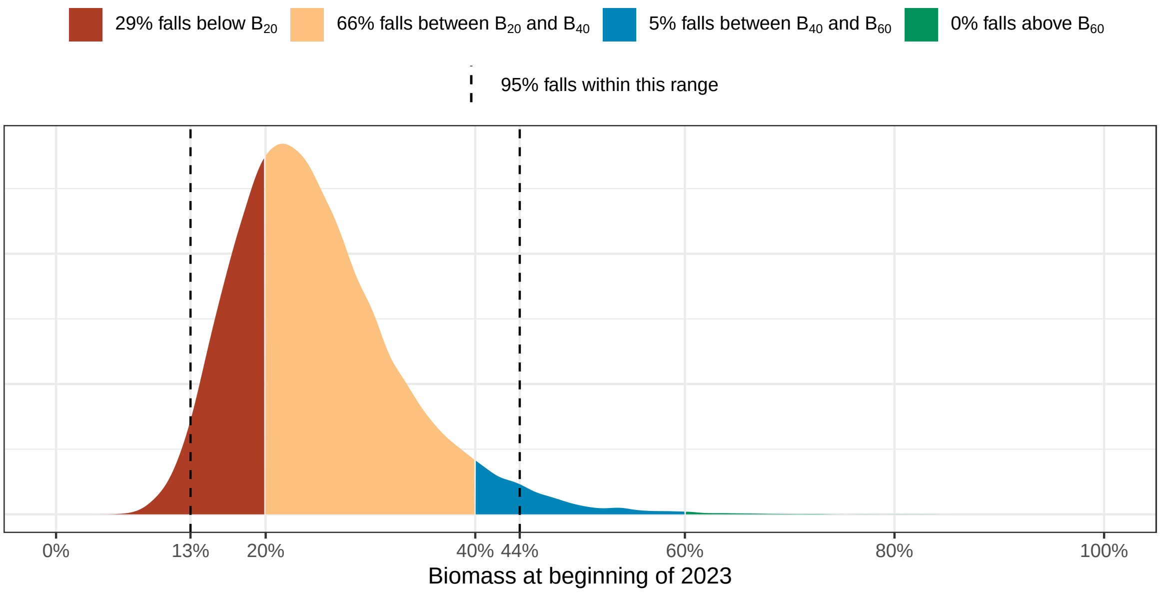

Figure 4: Probability distribution of the biomass ratio at the beginning of 2023 across the full ensemble of scenarios with the credible interval and probability of biomass falling into the four categories indicated

Table 1: Stock status indicators for king threadfin in the Gulf of Carpentaria

Indicator	Value
Biomass ratio (relative to unfished)	
Range (95% credible interval)	13–44%
Probability below 20%	29%
Probability between 20% and 40%	66%
Probability between 40% and 60%	5%
Probability above 60%	0%
Fishing pressure ratio (relative to MSY)	
Range (95% credible interval)	0.51–1.36
Probability exceeds F_{MSY}	32%

Acknowledgements

This stock assessment was guided by a project team with a wide range of skill sets. In addition to managers, scientists, monitoring and data specialists from within the Fisheries Queensland, the team included three fishing industry representatives. The project team operated under a terms of reference designed to ensure a transparent and evidence-based approach. The project team members were: Industry—Claudine Ward (commercial fisher), Jason Stapley (commercial fishing representative) and Ben Bright (charter fisher); Fishery Management—Luke Albury and Madeleine Glacken; Fishery Monitoring—Tyson Martin; Data Team—Jennifer Larkin; Stock Assessment—Michael O'Neill and George Leigh; Animal Science Queensland—Julie Robins. The entire team is thanked for contributing their time and knowledge, and engaging constructively over the course of a sixteeen month-long project.

The authors acknowledge the significant time commitment and deep operational and technical expertise of the industry representatives Claudine Ward, Jason Stapley and Ben Bright. The project has benefited greatly from their input, which has provided a base for continued engagement with industry members to further enhance stock assessments and build collaboration between industry and government.

We also thank external reviewers Simon Hoyle and Alistair Dunn for their in-depth and constructive feedback which greatly added to the robustness of the analyses and the comprehensiveness of the final report.

We are very grateful to Agri-Science Queensland and its staff members Julie Robins and Michelle Sellin for entering 1980s and 1990s age and length data, and providing Michelle's otolith-reading expertise to re-read many of the otoliths to check compliance with modern protocols. This work was funded internally by ASQ.

We thank George Leigh for leading the stock assessment through to the initial draft stage, and for the large amount of work he conducted, including but not limited to: tidal and river flow impacts on catchability, quasi-likelihood approaches to catch rate standardisation, and targeting. His contributions during the review process were particularly valuable in generating additional lines of enquiry.

We also wish to acknowledge and thank the many fishers, fish processors and scientists who have contributed to past and current research on king threadfin.

We also thank Richard Methot, Ian Taylor and Cole Monnahan for quickly helping to diagnose an issue with proper use of the No U-Turn Sampler (NUTS) Markov chain Monte Carlo simulation in Stock Synthesis which facilitated a more robust estimation of the final results.

We acknowledge Alise Fox for giving permission to reproduce her artwork on the cover page of this report.

This assessment was funded by the Department of Agriculture and Fisheries.

Glossary

CI	Confidence interval or credible interval if from Markov chain Monte Carlo
CPUE	Catch per unit effort
DAF	Department of Agriculture and Fisheries, Queensland
Fisher–day	A day of fishing by a fishing operator, which corresponds to a single daily logbook record (commercial) or a single fishing diary page (recreational)
FL	Fork length, measured from the tip of fish's nose to the fork in its tail
Fleet	A population modelling term used to distinguish types of fishing activity: typically a fleet will have its own selectivity curve which characterises the probability of capture of animals of various sizes (or ages)
FRDC	Australian Government's Fisheries Research and Development Corporation
GLM	Generalised linear model
MCMC	Markov chain Monte Carlo - a statistical simulation method for approximating the final ('posterior') distribution of a quantity
MLS	Minimum legal size
MSY	Maximum sustainable yield
NRIFS	National Recreational and Indigenous Fishing Survey, funded by the FRDC (2000–01)
QFB	Queensland Fish Board, marketing authority until 1981
RFish	Recreational fishing surveys conducted by Fisheries Queensland (1997, 1999, 2002, 2005)
SFS	Queensland's Sustainable Fisheries Strategy, 2017–2027
SS	Stock Synthesis software for fishery stock assessment
Stock	A distinct population that breeds only within itself (rough definition)
SRFS	Statewide Recreational Fishing Surveys conducted by Fisheries Queensland (2010–11, 2013–14, 2019–20)
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

1 Introduction

King threadfin (*Polydactylus macrochir*) (Günther 1867), also known as king salmon and Burnett salmon, is a large, predatory fish that can grow to 150 cm total length (TL) and 30 kg in weight (Roelofs 2003). It is found in foreshore areas of turbid coastal waters, estuaries, tidal rivers and mangrove creeks across northern Australia and southern Papua New Guinea (Motomura et al. 2000). In Australia, its distribution extends from the Ashburton River in Western Australia across northern Australia to the Brisbane River in South East Queensland (Motomura et al. 2000). King threadfin spawns in inshore coastal waters (Garrett et al. 1997). It feeds mainly on prawns (family Penaeidae), other crustacea, and small fish (Salini et al. 1998).

King threadfin is a protandrous hermaphrodite, beginning as male, with the majority of individuals in populations in Western Australia and the Gulf of Carpentaria reaching sexual maturity as males in their first year of life (Pember et al. 2005, Project Team members personal communications). They later change to female over a wide range of about 40 cm to 110 cm total length, with median length of sex change around 81 cm. The age at sex change also has a very wide range, from about 2 years to at least 7 years of age, with a median of about 5 years. The species lives to at least 20 years of age.

Species from the family Polynemidae, to which king threadfin belongs, are found in coastal marine waters and estuaries, typically in shallow, turbid, inshore water. In Queensland, habitat and nutrition for king threadfin are provided largely by river systems. Inspection of commercial logbook data indicates that populations of king threadfin flourish in estuarine and shallow coastal areas where flows of nutrients are provided by large drainage basins. Many large basins drain to the southern half of the Gulf of Carpentaria, most notably the Nicholson, Leichhardt, Flinders, Norman, Gilbert, Staaten and Mitchell Basins.

King threadfin is targeted by commercial gillnet fishers and recreational line fishers in the Gulf of Carpentaria Inshore Fishery. Most of the harvest is commercial. Estimated total annual harvest has varied between 150 t and 650 t between the early 1970s and 2022. The estimated recreational component has not exceeded 30 t in any year. King threadfin is second only to barramundi as a species of commercial harvest in the Gulf for the N3 fishery.

For many species, gillnets allow many small and very large fish to escape, either through or along the net. However some of the commercial king threadfin catch is taken by “bridling” in gillnets. In bridling, some king threadfin are not caught around the body as in traditional gillnetting, but around the corners of their mouths. A major advance in gillnetting technology was the introduction of monofilament nets, whose strands are generally invisible to fish and which became widely used in about 1976 (Darcey 1990, pp. 208–210).

The major Queensland species related to king threadfin is blue threadfin (*Eleutheronema tetradactylum*), also known as Cooktown salmon. It belongs to the same family Polynemidae but has shorter, thicker and fewer pectoral filaments, and doesn’t grow as large. Commercial fishers are able to accurately distinguish the two threadfin species. Four other Polynemidae species also occur on the coast of mainland Australia: streamer threadfin (*Parapolynemus verekeri*), striped threadfin (*Polydactylus plebeius*), Australian threadfin (*Polydactylus multiradiatus*) and blackfin threadfin (*Polydactylus nigripinnis*)

(Pember 2006, p. 9). They are generally smaller than both king threadfin and blue threadfin, and are not targeted commercially.

Various management measures have been applied to threadfins in Queensland since the late 19th century (Table 1.1). A minimum legal size (MLS), of 12 inches (30.5 cm) total length, was first imposed in 1914. The first metric MLS was 40 cm TL in 1976. The MLS was increased to 60 cm TL in 1999 in the Gulf. A recreational in-possession limit of 5 king threadfin was introduced in 1999 in the Gulf.

Seasonal closures around the spawning of barramundi *Lates calcarifer* were introduced in 1981 (Quinn 1984; Darcey 1990, p. 144). Currently, the Gulf of Carpentaria is closed to all net fishing from 7 October to 31 January each year. Historically, barramundi has been the primary target species for commercial and recreational fishers in Queensland tropical inshore waters. In recent years the commercial importance of wild-caught barramundi may have declined somewhat, due to competition from aquacultured and imported barramundi.

Numbers of commercial fishers, and hence the amount of net that can be in the water at any one time, are limited by the number of licences available, gear restrictions, and various spatial and temporal closures. Recreational in-possession limits apply to fish held by a fisher at any one time, but there is no practical limit to the total number of fishers or their fishing effort.

The Queensland side of the Gulf of Carpentaria is a single Fishery Management Region.

Table 1.1: Management measures applied to threadfins and “salmons” in Queensland waters
“Bag limit” refers to in-possession limit for recreational fishers only.

Date	Fishery management measure
1877–1974	Numerous measures relating to fishing gear and practices; e.g. mesh size, net length, allowed species, closed seasons, powers of inspectors
3 Dec 1914	Minimum legal size for salmon 12 in. (30.5 cm) TL (*The Fish and Oyster Act of 1914*)
1926–1933	Minimum legal sizes for salmon 13 in. (33.0 cm) TL (Amendments 1926, 1929 and 1933 by Order in Council to *The Fish and Oyster Act of 1914*)
18 Apr 1957	Restate minimum legal sizes for salmon 13 in. (33.0 cm) TL. (*Fisheries Act 1957*)
1959–1964	Minimum legal sizes for threadfins 16 in. (40.6 cm) TL, said to be giant threadfin *Eleutheronema tetradactylum* and striped threadfin *Polynemus sheridani* (Subordinate Legislation to *Fisheries Act 1957*)
16 Dec 1976	Minimum legal sizes 40 cm TL for threadfins, specified as Burnett salmon *Polydactylus sheridani* and Cooktown salmon *Eleutheronema tetradactylum* (*Fisheries Act 1976*)
1 Nov 1981	Seasonal net fishing closure in Gulf of Carpentaria (currently set as 7 October to 31 January), and seasonal prohibition of targeting of wild barramundi on the East Coast (currently set as 1 November to 31 January) (Quinn 1984; Darcey 1990, p. 144)
	Minimum gillnet mesh size 150 mm in Gulf of Carpentaria and East Coast north of Cape Flattery (approx. 15 °S)
1989	Minimum gillnet mesh size 150 mm in rivers and creeks
	Maximum gillnet mesh size 245 mm, Gulf and East Coast

	Closure to net fishing of Mulgrave River, Russell River, Johnstone River, Haughton River, Plantation Creek, Burdekin River, Prosperpine River, Pioneer River, Cawarral Creek
	Opening of Barratta Creek to net fishing
1 Jul 1993	Restate minimum legal sizes from 1976. (*Fishing Industry Organization and Marketing Amendment Regulation No. 3*, Subordinate Legislation 1993 No. 235)
1 Dec 1995	Closure to commercial net fishing of most of Moreton Bay foreshore and waterways in the City of Brisbane (Brighton to Manly); Great Sandy Strait, all foreshore south of Double Island Point and all of Moreton Bay at weekends
	Restate minimum legal sizes set in 1976. (*Fisheries Regulation 1995*, 1995 No. 325)
6 Mar 1998	Specification of Dugong Protection Areas, with restrictions on fishing, by insertion of Sections 257 to 278 into Schedule 2 of *Fisheries Regulation 1995*
7 May 1999	Regulations for the Gulf of Carpentaria: Minimum legal sizes 60 cm TL for king threadfin, 40 cm TL for blue threadfin. Bag limits 5 for king threadfin, 20 for blue.
	Minimum mesh sizes 162.5 mm, maximum 245 mm. Maximum net length 120 m in a river or creek, 600 m on a foreshore or offshore; maximum combined length of multiple nets for one fisher 360 m in a river or creek, 600 m on a foreshore. (*Fisheries (Gulf of Carpentaria Inshore Fin Fish) Management Plan 1999*, 1999 No. 55)
2 Jul 1999	Declaration of Dugong Protection Areas (*Nature Conservation (Dugong) Conservation Plan 1999*, 1999 No. 155)
5 Nov 2004	Declaration of Princess Charlotte Bay as a Special Management Area for dugong protection (*Marine Parks (Great Barrier Reef Coast) Zoning Plan 2004*, 2004 No. 240, Part 3, Division 4)
1 Apr 2008	Restate king threadfin bag limit 5, minimum legal size 60 cm TL; blue threadfin (Cooktown salmon) bag limit 20 in Gulf of Carpentaria only, restate minimum legal size 40 cm TL set in 1976; entry for "Burnett salmon" *Polydactylus sheridani* (*Fisheries Regulation 2008*, 2008 No. 83)
13 Jun 2008	Restate king threadfin bag limit 5 in the Gulf only; minimum legal sizes 60 cm TL in the Gulf, 40 cm TL on the East Coast. (*Fisheries Amendment Regulation (No. 2)*, 2008 No. 156)
20 Oct 2008	Closure of 16% of the area of Moreton Bay Marine Park to all fishing and a further 8% to net fishing; this Marine Park is not confined to Moreton Bay itself and includes ocean beaches. (*Marine Parks (Moreton Bay) Zoning Plan 2008*, 2008 No. 343)
1 Mar 2009	King threadfin bag limit 5 and minimum legal size 60 cm TL on East Coast. Restate that these also apply in the Gulf. Blue threadfin bag limits 20 in the Gulf, 10 on the East Coast, restate minimum legal size 40 cm TL set in 1976. (*Fisheries Amendment Regulation (No. 5)*, 2008 No. 448)
22 May 2009	Restate bag and size limits set on 1 Mar 2009. (*Fisheries Legislation Amendment Regulation (No. 2)*, 2009 No. 61)
1 Nov 2015	Net Free Zones commenced around Cairns (Trinity Bay – Cairns), Mackay (St Helens Beach – Cape Hillsborough – North of Mackay) and the Fitzroy River (Yeppoon – Keppel Bay – Fitzroy River – Capricorn Coast) (*Fisheries and Another Regulation Amendment Regulation (No. 1)*, 2015 No. 125)

28 May 2019	King threadfin minimum legal size increased to 65 cm TL on East Coast; restate bag limits and MLS's of blue threadfin and Gulf king threadfin from 2009. (*Fishery Declaration 2019*, 2019 No. 76)

In 2020, the Queensland Department of Agriculture and Fisheries commenced a stock assessment for king threadfin in the Gulf of Carpentaria which used data through to the end of 2019, and provided a 'most likely' estimate of biomass relative to unfished of 5% (Leigh et al. 2021). In 2023, the Department 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 determine catch rates, length compositions, and create annual harvests. The assessment period began in 1955 up until and including 2022 based on available information.

Table 2.1: Data inputs for the assessment

Data	Years	Source	References
Commercial logbook	1989–2022	Compulsory commercial logbook database (CFISH)	
Charter logbook	1996–2022	Charter logbook database, compulsory only for vessels that fish offshore (CFISH)	
Gulf logbook	1981–1989	Collated commercial production returns from the Gulf of Carpentaria	Quinn (1987)
RFish surveys	1997, 1999, 2002, 2005	RFish recreational telephone and diary surveys conducted by Fisheries Queensland	Higgs (1999), Higgs (2001), Higgs et al. (2007), McInnes (2008)
NRIFS survey	2000	National Recreational and Indigenous Fishing Survey, recreational telephone and diary survey	Henry and Lyle (2003)
SRFS surveys	2011, 2014, 2019	Statewide Recreational Fishing Surveys, telephone and diary surveys conducted by Fisheries Queensland	Taylor et al. (2012), Webley et al. (2015), Teixeira et al. (2021)
Boat Ramp Surveys	2015–2022	Species and length data from recreational sampling conducted by Fisheries Queensland	Fisheries Queensland (2017)
Historical biological data	1986–1994	Length and age data collected by historical research projects	Bibby and McPherson (1997), Garrett (1992), Garrett (1988) plotted in Kailola et al. (1993, p. 335)
Fishery Monitoring	2015–2022	Length and age data 2015–2022	

2.2 Stock identification information

The stock structure of king threadfin was investigated by Welch et al. (2010) in a project which gave rise to articles on spatial demography (Moore et al. 2011) and concerns of overexploitation of king threadfin in the Gulf of Carpentaria (Moore et al. 2017). The project used techniques of genetics, otolith microchemistry and parasite identification to find that threadfins form regional stocks. Most of the analysis for Queensland stocks was conducted on fish from only three locations in the Gulf of Carpentaria (Albert, Flinders and Kendall Rivers) and two on the East Coast (Townsville and the Fitzroy River). There were no major differences between the samples from the Gulf.

Tagging data show that some king threadfin move hundreds of kilometres. In the Gulf, one fish moved 600 km from Weipa in the northern Gulf of Carpentaria to the Flinders River beyond Karumba in the southern Gulf (Infofish 2014).

One hypothesis is that king threadfin forms multitudinous stocks of spatial extents less than 100 km (see, e.g., Welch et al. 2010, pp. 148–150), but much remains to be done to establish stock structuring relevant to stock assessment models.

Hoyle and Dunn (2024, Section 2.1) details additional relevant background, including perspective from fishers and fishery stakeholders.

Cadrin et al. (2023) asks two key questions in regards to spatial structuring of fishery stock assessments: how well does stock identification match the management unit (in this case the Queensland portion of the Gulf of Carpentaria), and how well does it match the assessment unit?

Project team discussion in the first meeting focussed on these questions (Appendix A). The decision to proceed with a stock assessment spatial scale that matches the current management unit was difficult particularly for the western 'boundary' and was ultimately a practical one in light of our current state of knowledge. Improving this is a major driver for further research into Gulf king threadfin populations (Robins 2024).

2.3 Retained catch estimates

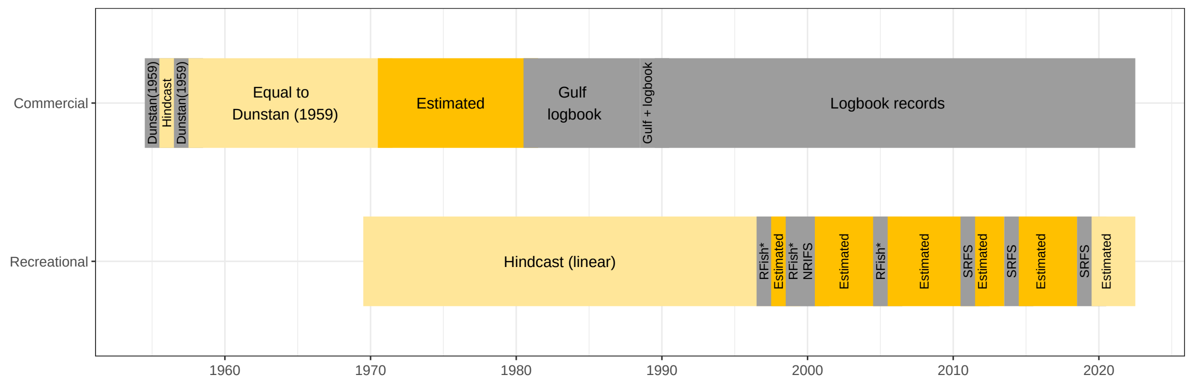

Figure 2.1: Overview of the methods used to reconstruct the history of king threadfin retained catch

2.3.1 Commercial

Few QFB data were available for the Gulf Catch Rate Regions. Therefore they were not used to reconstruct historical harvest in the Gulf. No source of harvest size in the Gulf of Carpentaria was available prior to the Gulf logbook introduced in 1981.

An alternative to reconstructing the historical harvest size was to reconstruct the historical fishing effort of net fisheries in the Gulf using oral histories, and use a few point-in-time references for barramundi catch (see Campbell et al. 2017). Similar methods and assumptions were applied to estimate a time series of king threadfin harvest in the Gulf of Carpentaria. There are a few point-in-time reference years:

- Dunstan (1959) reported the total Gulf catch for 1955 as 22 389 lb and that approximately 200 000 lb of headed and gutted fish (of which 70% was barramundi) was exported from the Gulf in 1957. We assumed that 25% of the total catch (i.e., most of the remaining catch) was king threadfin, and we applied a conversion factor of 1.1 from headed-and-gutted fish to whole fish weight. This equates to 2793 kg and 24 948 kg of king threadfin catch in 1955 and 1957, respectively.

- Campbell et al. (2017) assumed no expansion of the Gulf net fishery between 1957 and 1970, but thereafter a rapid increase in the effort and catch of barramundi, peaking in 1977. The peak of the Gulf fishery in 1977–78 is described in some detail by Gulf commercial fisher Bill Kehoe (Darcey 1990, p. 142).
- Quinn (1987) records that 306 master fishermen applied to enter the Gulf barramundi fishery in 1980, and 191 of those eligible obtained endorsement for 1981. This indicated that 115 more fishermen were potentially catching king threadfin during the late 1970s compared to 1981.

Our reference estimate of the king threadfin harvest series used the fishing effort data from the 2017 barramundi assessment. In the 2021 assessment this became the "high" harvest scenario. The simplest estimate of the peak catch in 1977 is an inflation of the 1981 Gulf logbook catch by the fisher ratio ($306/191$ = 1.6). However, the fishers who left the fishery were considered to be less committed to the Gulf inshore net fishery (taking smaller catches) than those who were successfully endorsed in 1981; indeed, some may have left because they could not meet the catch and effort thresholds for endorsement. Therefore, half of the increase fraction (1.3) was applied to the 1981 Gulf logbook catch of 512 997 kg. Another point to consider is that the catch per unit effort (CPUE) may have been higher in the 1970s when the stock was nearer to virgin state than it was in the 1980s.

A decrease in CPUE of 5% per year was assumed from 1977 to 1981. Therefore, the peak king threadfin catch in 1977 was calculated as 512 997 $\times$ 1.3 (fisher factor) $\times$ 1.2 (CPUE factor) = 800 275 kg.

In summary, the following rules were used in the reference estimate of commercial harvest in the Gulf:

- Set to 2792.6 kg in 1955, 24 947.5 kg in 1957, and interpolate linearly between those two years.
- Set constant from 1957 to 1970.
- Increase linearly from 1970 to the estimated peak catch in 1977.
- Decrease linearly from 1977 to the first recorded Gulf logbook value in 1981.
- Set to the sum of Gulf logbook records from 1981 to 1988.
- Set to the sum of Gulf logbook records and CFISH commercial records in 1989.
- Set to the sum of CFISH commercial records from 1990 to 2019.

For the 2020 king threadfin assessment, after discussion with the 2020 Project Team, largely about the feasibility of transporting and marketing harvests of the projected size, the above reference estimate was used as a high scenario. Other scenarios were defined as constant catch from 1977 to 1981 (i.e., 512 997 kg, low scenario) and half-way between the high and low scenarios (middle scenario). The middle scenario was used as the base case for the population model, for reporting the results and the sensitivity to different values of the model parameters. The validity of concerns about transport and marketing remained unclear, as substantial fractions of king threadfin catches in the 1970s could have been discarded dead and not required transport or marketing.

For the 2023 assessment, the Project Team did not consider the high catch scenario to be plausible. The assessment used only the middle catch scenario (base case from the 2020 assessment) and focussed sensitivity anlayses on different settings for the natural mortality rate (M), steepness (h) and fishing-power q_{inc}.

2.3.2 Recreational

Data sources for recreational harvest comprise

- RFish data in 1997, 1999, 2002 and 2005,
- The National Recreational and Indigenous Fishing Survey (NRIFS) in 2000, and
- Statewide Recreational Fishing Survey (SRFS) in 2011, 2014, and 2019.

The NRIFS also measured catch taken by coastal Indigenous communities, which in Queensland was about 11.6% of the corresponding recreational catch of king threadfin. The Indigenous harvest was not included in either the 2020 assessment or this one. We recommend that it be included in future assessments, but keeping it current will require dedicated data collection.

All recreational surveys provided estimates of the number of fish harvested and discarded per trip, and combined this with demographic information to estimate annual totals for each species (or species group) at regional scales. King threadfin was reported to either individual species level ("King threadfin") and species group level ("Threadfin salmon", "Threadfin & Australian salmon" or "Threadfin salmons—unspecified"). The latter records were assumed to comprise only king threadfin and blue threadfin. Species identification in recreational surveys, although less of a problem for king threadfin than for many other Queensland fish species, has generally improved over time. When species composition is lacking in earlier surveys, it can be inferred from later ones.

When king and blue threadfin were not distinguished, the species composition was inferred from the Boat Ramp Survey data in the 2020 assessment (Leigh et al. 2021). Given the small proportion of the recreational catch in the Gulf, and the absence of SRFS surveys since the previous assessment, recreational catch data from the 2020 assessment were not updated for the 2023 assessment. Catches for 2020–2022 were assumed to be equal to that for 2019.

RFish estimates were used only for trend, not as absolute harvest estimates. The following steps were taken to convert them to harvest estimates:

- The statewide RFish estimates from 1999 and 2002 were interpolated linearly to obtain a candidate estimate for the year 2000.
- The rescale factor was calculated as the NRIFS estimate for the year 2000, divided by the candidate estimate.
- This RFish estimates in each year were multiplied by the rescale factor.

Once king threadfin harvest estimates were obtained in each survey year, extrapolations to earlier years and interpolations to intermediate years in which surveys were not carried out were made as follows:

- Set to zero in 1969, and increase linearly to reach the rescaled RFish estimate in 1997.
- Set to the rescaled RFish estimates in 1999, 2002, and 2005.
- Set to the NRIFS and SRFS estimates in 2000, 2011, 2014 and 2019.
- Interpolate linearly between survey years to produce estimates for 1998, 2001, 2003–2004, 2006–2010, 2012–2013 and 2015–2018.
- Set to the 2019 catch in 2020, 2021 and 2022.
- Convert from numbers to estimated retained (landed) harvest using the mean king threadfin weight calculated from the Boat Ramp Survey length-frequency data and the length–weight relationship (Section 2.5.4), aggregated over all years and regions.

2.4 Standardised indices of abundance

Catch per unit effort was modelled with a two-stage hurdle or delta modelling approach where catch-rate is modelled conditional on a positive encounter (Lo et al. 1992; Hoyle et al. 2024). This was implemented using the *mgcv* package (Wood 2012).

The statistical observation unit was a ‘fisher–day’. So each observation or data record in the analysis represented a single day of fishing by a single fisher (i.e. authority chain number). This data record was constructed to label just one location (the one in which the most king threadfin were caught) and a separate field for each relevant species group.

Stage-one, or ‘delta’ covariates included: Year, Month, Net (net length), Mesh (net mesh size), Interval (spatial ‘interval’, described further below), and Fisher (fisher identifier, derived from a combination of authority information and boatmark). The form of the delta model was:

$$NonZero \sim Year + Month + Net + Mesh + Interval + Fisher \tag{2.1}$$

where NonZero was a binary variable indicating whether king threadfin was caught by that fisher on that day (NonZero=TRUE meaning king threafin was caught).

The stage-two model was a log-normal with the same covariates but a different model form:

$$log(TfKing) \sim Year * Interval + Month : Interval + Month + Net + Mesh + Fisher \tag{2.2}$$

where TfKing was the catch in kilograms of king threadfin for that record (by that fisher on that day).

Predictions of both models were made for reference levels of Month, Net, Mesh, and Fisher, and for all combinations of Interval and Year, using *mgcv*’s predict function. The second stage is conditional on the first, so the predicted TfKing for each Interval and Year is multiplied by the first stage, the modelled probability that any king threadfin was caught by that fisher on that day.

These spatially disaggregated predictions were then combined to create the final catch rate time series, and four different possibilities for spatially weighting each interval’s contribution were considered:

1. Weighting based on sample size
2. Equal weighting
3. Weighting by total length of rivers and coastline within the interval (based on shapefiles)
4. Weighting by number of distinct 6 min grids fished within that interval between 1989 and 2022

For the final model inputs, Method 4 was chosen as the preferred weighting option.

Intervals and how they map onto 30 min fishing grids are shown in Figure 3.7. The idea is that each interval is a segment of a one-dimensional strip that follows the coastline, moving west from the Northern Territory border with ‘AG-AH-AI’ (grouped due to sample size) to ‘AF’ then ‘AE’ then ‘AD’ then moving north with ‘17’, ‘16’, ‘15’ etc. For the letter-named intervals, all grids of the same longitude can contribute data, whereas for the number-named grids the condition is latitude.

Targeting was handled by pre-filtering the data set to constrain what would be considered by the analysis as a ‘zero’ (i.e. NonZero=FALSE in the delta model). Zero catches of king threadfin were registered when species groups commonly associated with king threadfin were caught. These associated species groups were decided on the basis of the average catch of king threadfin over records in which a particular other species group was caught (Table 2.2). Positive association is indicated if the average catch of king threadfin is relatively high on fisher–days when the associated species group is caught, and becomes higher again on fisher–days when the catch of the associated group is greater than or equal to the mean nonzero catch of that group.

Table 2.2: Associated species for catch-rate analysis (Av. KTF = average king threadfin catch in a fisher–day)

Species group	Catch (t)	Av. KTF (kg) when catch > 0	Av. KTF (kg) when catch ≥ mean	Association
King threadfin	7669.5	63.4	173.8	–
Other threadfin	1561.5	45.0	66.2	Positive
Grunter	445.9	38.5	46.4	Positive
Jewfish	920.1	55.8	81.5	Positive
Barramundi	16328.7	27.3	36.3	Weak
Trevally	403.6	25.8	28.3	Weak
Shark	4968.5	22.4	9.3	Negative
Catfish	104.0	21.0	15.6	Negative
Grey mackerel	7506.5	7.6	2.7	Negative
Other scombrids	518.2	6.8	3.8	Negative

Conversely, catch records were omitted when species negatively associated with king threadfin were caught. Negative association is indicated by a low average catch of king threadfin on fisher–days when the other species group is caught, which becomes lower again on fisher–days when the catch of the other group is greater than or equal to its mean nonzero catch.

Species positively associated with king threadfin in the Gulf were other threadfins, grunter and jewfish. Records containing these species were included in the catch-rate analysis even when they contained no king threadfin: they were counted as genuine zero catches of king threadfin, where fishers could reasonably have been expected to catch king threadfin but did not actually catch any.

Negatively associated species were shark, catfish, grey mackerel, and other scombrids (mackerel and tuna). Records containing these species were excluded, even when they contained king threadfin: they were counted as accidental catches of king threadfin, where fishers were targeting other species and were not fishing in locations where king threadfin are usually caught.

Fishing power increases beyond those picked up by the Fisher term were considered through a catchability increase term in the population model.

2.5 Biological relationships

2.5.1 Fork length and total length

The assessment's population model expressed all measurements as fork length (FL). Minimum legal sizes were set in total length (TL), so had to be converted to fork length. Also, in the Fishery Monitoring data set, a few measurements made only in TL had to be converted to FL.

Length data collected by the Department of Agriculture and Fisheries (DAF) Fishery Monitoring team between 2015 and 2022 were used to estimate the relationship between FL and TL for the Gulf:

$$\log_e \mathrm{FL} = -0.2204 + 1.00745 \times \log_e \mathrm{TL}$$

where FL denotes fork length (measured in cm) and TL denotes total length (also in cm). This equation has been updated since the previous assessment. The above relationship comes from a loglinear regression fitted to 878 data records. The R^2 value was 0.99648, and the residual standard error (measure of the accuracy of the TL to FL conversion) was 0.0.01425 (approximately 1.425% relative error).

2.5.2 Fork length and jaw length

Within the Fishery Monitoring data set, where the only measurement available was jaw length (JL) these were converted to FL. Length data collected by the Fishery Monitoring team were used to estimate the relationship between FL and JL for the Gulf:

$$\mathrm{FL} = 90.5558 + 5.0636 * \mathrm{JL} + 0.0238 * \mathrm{JL}^2$$

where FL denotes fork length (measured in cm) and JL denotes upper jaw length (also in cm). The above relationship comes from a quadratic regression fitted to 851 data records. The R^2 value was 0.9708, and the residual standard error (measure of the accuracy of the JL to FL conversion) was 26.64443.

2.5.3 Maturity and fecundity

Maturity fractions in the population model were age-based, based on the study of king threadfin in Western Australia by Pember et al. (2005):

- 0% mature at age 0 (time of birth)
- 60% at age 1 (end of first year of life)
- 100% from age 2 (end of second year of life).

These figures are different from those used in the 2020 assessment, which did not match observations in the Gulf.

The above figures are for male fish, based on the work of Pember in Western Australia, and comments from Project Team members that immature male fish are very rarely encountered in the Gulf fishery. The population model is a single-sex model. The reasoning for the single-sex model is that sex ratio is assumed to be socially controlled, so that the age at sex change from male to female is not fixed. Fish are assumed to change sex at a younger age when there is a scarcity of females, and at an older age when there are already plenty of females. Such social control in king threadfin has been inferred previously by Welch et al. (2010) and Moore et al. (2017) but not validated. An alternate mechanism for sex change could be body condition, driven by food availability and growth rates, after a juvenile stage.

Fecundity of mature fish was assumed to be proportional to body weight.

2.5.4 Weight and length

McPherson (1997, Table 5.2) estimated the length–weight relationship for king threadfin in the Gulf of Carpentaria:

$$W = 2.37 \times 10^{-5} \times \mathrm{FL}^{2.81}$$

where W denotes fish weight (kg) and FL is fork length (cm). The relationship came from a regression of $\log_e W$ on $\log_e \mathrm{FL}$, based on 169 fish with fork lengths from 20.5 to 101 cm. Its R^2 value was 0.99.

2.6 Length and age data

2.6.1 DAF Fishery Monitoring program

Routine, fishery-dependent biological data collection for king threadfin in the Gulf of Carpentaria commenced under the Fishery Monitoring (DAF) program in 2016. The introduction of the routine program followed a pilot study in 2015.

Earlier sampling programs (see Table 2.1 above) came from relatively short-term research projects and more limited spatial ranges, and did not follow the structured sampling protocols of the DAF Fishery Monitoring program. As a result, the quality of age and length data has improved over time.

We note that careful preparation of data from earlier projects was undertaken before these data were made available for this assessment. This ensured, as far as possible, that comparable ageing protocols were followed for each data set, and that biased length samples were identified as such and excluded from length frequencies input to the population model. Preparation of the 1986–1994 data included re-reading some of the otoliths to check that the assigned ages were compatible with current protocols.

Age-at-length samples were assumed to be unbiased. Any year-specific sampling bias that operated was assumed to be on length, not age. For example, a 120 cm fish of age 12 in the catch had the same probability of being sampled as a 120 cm fish of age 6, because sampling was based only on length.

The DAF Fishery Monitoring program's primary objective is to gather comprehensive 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 Fishery Monitoring staff access to fish within the supply chain, measuring or supplying samples from their own catches, and accommodating Fishery Monitoring staff aboard their vessels during fishing operations. Data from recreational and charter catches also involves voluntary cooperation, to allow Fishery Monitoring staff to measure fish at boat ramps, or fishers to provide samples of their own catches. The great majority of sampling of king threadfin in the Gulf of Carpentaria is from the commercial fishery.

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 fisher or multiple fishers working together. The program is designed to collect data from the fishery of the entire genetic stock by setting targets for the number of commercial catches to be sampled in each region per year, and the number of recreational fishing surveys to undertake at key boat ramps throughout a year. For commercially caught king threadfin, the desired target is 1400 fish to be measured, from at least 80 different catches. This target is divided into regions based on recent catch history reported in commercial fishing logbooks. Fishery Monitoring specified only one region for the southern Gulf of Carpentaria and did not distinguish between the Mornington, Karumba and Gilbert Catch Rate Regions.

Fishing sector, catch date, location and fishing method is are recorded for each catch. Location can be reported at various levels, including Fishery Monitoring region, 30 minute CFISH grid reference, or major river or bay. This recording preserves the confidentiality of the exact fishing location whilst enabling the data collected to be aggregated to a suitable spatial scale.

Fish size is recorded as fork length (nose to caudal fork) whenever accurate measurement is feasible. In cases where the fish is damaged or incomplete (e.g., head only), total length (nose to end of tail) or jaw length (tip of the upper jaw to the end of the maxilla) measurements are taken. Alternative measurements are converted to fork length using stock-specific equations. Where a catch has been identified as size biased, it is flagged for exclusion from analysis that requires representative length frequency data.

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

Where possible, gonads are examined macroscopically to determine sex, relying on colour, structure, and texture of the gonad. Fish are classified as male, female, transitional (in the process of changing from male to female), or unknown sex.

Otoliths (fish ear bones) are used to estimate the age of a fish. Each year, Fishery Monitoring aims to collect some otoliths from retained fish in every observed length class and 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. To estimate the age of each fish, otoliths are dried and then encased in a resin block. A thin section is then cut through the core of the otolith, and mounted onto a glass slide. A trained reader examines the otolith section using a microscope, and 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 common birthday 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.

Each year, the number of catches sampled and the quantity of biological data collected varies. Sampling is heavily influenced by participation from fishers and processors, logistical considerations regarding access to the fish, and markets. The form in which fish are sold, e.g., whole, gilled and gutted, filleted, significantly influences what data can be collected. All of these factors vary between years, seasons and regions, and are particularly pronounced in the Gulf of Carpentaria which is characterised by long distances from markets, remote fishing locations, and seasonal road closures due to flooding.

2.6.2 Input to the population model

Length and age samples from all regions south of 13 degrees South were considered, based in part on Project Team discussions. From the early 1980s and 1990s data sets, data from years 1986 to 1990 was used for the construction of final length composition data sets, and data from years 1988 to 1990 were adopted for the construction of conditional age-at-length compositions. The trial year of 2015 from the modern Fishery Monitoring data set was dropped and years 2016 to 2022 were used. Initial sample sizes for the latter period were based on the the Fishery Monitoring sampling unit of a 'catch', described in the previous section. Initial sample sizes for the earlier data were experimented with and ultimately set to 15 samples per year for the length compositions and 0.5 samples per year per length bin for the conditional age-at-length compositions.

Length data were input to the population model in one-centimetre length bins.

2.7 Population model

2.7.1 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.

2.7.2 Model assumptions

The following list summarises the major assumptions made in the population modelling:

- The Gulf can be considered a single stock with no immigration or emmigration. In reality the Northern Territory border and Cape York peninsula possible act as sources or sinks or both.
- At finer spatial scales demographic differences can be handled through spatial stratification and weighting of input data.
- Fish swim freely and mix instantaneously across the Gulf. In reality, the time-scale of mixing is unknown but obviously slower.

- Random recruitment deviations are an important cause of variation in abundance of king threadfin. In reality, changes in fish behaviour and survival from environmental causes, as well as changes in catchability, probably had significant non-random (and currently unmodelled) impacts.
- The instantaneous natural mortality rate M is constant and does not depend on age or year.
- Log-catchability increases linearly over time (1989–2022) according to a q_{inc} parameter.
- Catch rates once spatially weighted over intervals are proportional to whole-Gulf abundance.
- All legal-sized king threadfin caught by fishers are retained. Fish are returned to the water only when they are below minimum legal size.
- Selectivity of king threadfin by fishing depends on length, and not on age. This assumption is different to the 2020 assessment.
- Length at age follows a single growth curve. In reality, length at age may depend on environmental variables, especially annual variation in food supply.

2.7.3 Model parameters

Model parameters are listed in Table 2.3. Years in which recruitment deviations were estimated were chosen partly to ensure that the series of recruitment deviations did not begin or end suddenly with a large value, as such an occurrence would have made the results depend on the choice of recruitment-deviation years to an unacceptable degree.

Natural mortality rate M was fixed in some scenarios and estimated in others, steepness h was fixed in all scenarios at two different values.

Table 2.3: Parameters included in the population model

Symbol	Description	Estimated or fixed
M	Natural mortality	Estimated (Scenarios 1–4) and Fixed at 0.27 (Scenarios 5–8)
L_{min}	Mean length of fish at minimum age (cm FL)	Estimated
L_{max}	Mean length of fish at maximum age (cm FL)	Estimated
K	Von Bertalanffy growth coefficient (yr^{-1})	Estimated
SD_{young}	Standard deviation of length at minimum age (cm FL)	Estimated
SD_{old}	Standard deviation of length at maximum age (cm FL)	Estimated
h	Steepness	Fixed at 0.7 (Scenarios 1,3,5,7) or 0.8 (Scenarios 2,4,6,8)
$\ln R_0$	Log of number of recruits when unfished	Estimated
$\ln q$	Log of catchability	Estimated
QextraSD	Extra standard deviation on catchability	Estimated
L_{50}	Length at 50% selectivity (cm FL)	Estimated
$L_{95\text{width}}$	Difference in lengths at 50% and 95% selectivity (cm)	Estimated
recdev	Recruitment deviations between 1978 and 2022	Estimated

2.7.4 Sensitivity tests

Eight model runs were undertaken to determine the model's sensitivity to different parameter values and assumptions (Table 2.4).

Table 2.4: Scenarios tested to determine sensitivity to parameter values and assumptions

Scenario	M (yr^{-1})	h	q_{inc} (yr^{-1})
1	Estimated	0.7	0%
2	Estimated	0.7	1%
3	Estimated	0.8	0%
4	Estimated	0.8	1%
5	Fixed at 0.27	0.7	0%
6	Fixed at 0.27	0.7	1%
7	Fixed at 0.27	0.8	0%
8	Fixed at 0.27	0.8	1%

Natural mortality rate M was set up across the eight scenarios with:

- four scenarios estimating M using a strong prior with median 5.4/Amax (Hamel and Cope 2022), where Amax was set at 20 years, s.d. 0.239 (log-scale)
- four scenarios with M fixed at 5.4/Amax, again with Amax at 20 years

Steepness was centred around the value used in the previous assessment, $h = 0.75$.

The catchability increase parameter q_{inc} was fixed at zero and 0.01 yr^{-1}.

3 Results

3.1 Model inputs

3.1.1 Data availability

Model inputs are described for Gulf of Carpentaria king threadfin. Model outputs in this section relate to Scenario 5 as a reference scenario (as defined in Table 2.4). Results from all scenarios are presented in Appendix E .

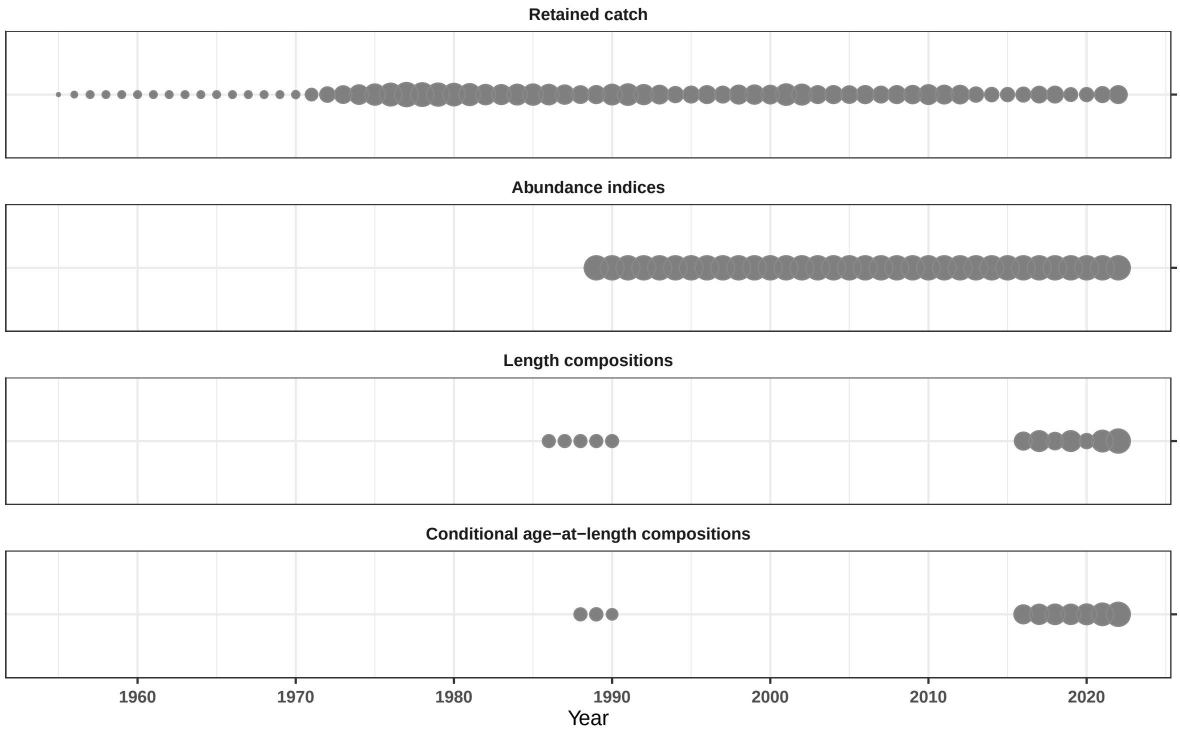

Figure 3.1: Data presence by year for each category of data type for king threadfin in the Gulf of Carpentaria

3.1.2 Retained catch estimates

Time series of king threadfin retained catch are shown by fishing sectors (Figure 3.2) and by historical Gulf commercial returns 'grid' (Figure 3.4). The overall retained catch was mainly taken by the commercial sector. The estimates indicate that the total retained catch in the Gulf increased rapidly in the early 1970s, reaching a peak in late 1970s with approximately 650 tonnes per year. Since the 1980s, the reported catch has gradually declined with some fluctuations, down to about 150 tonnes in 2019. The catch has increased in the last few years, reaching approximately 300 tonnes in 2022.

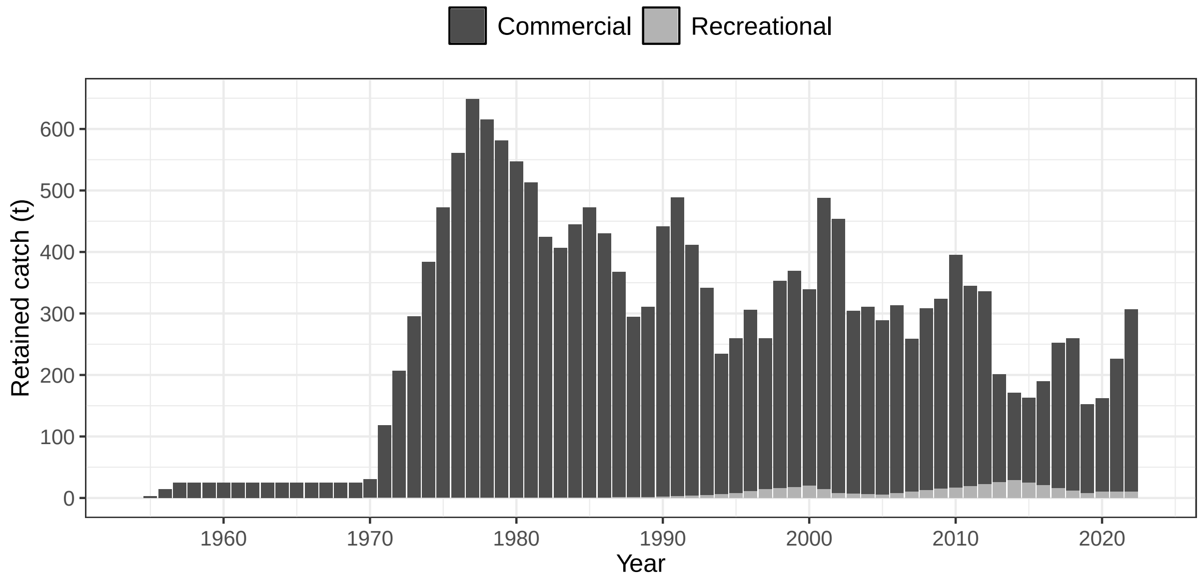

Figure 3.2: Estimated retained catch by sector between 1955 and 2022

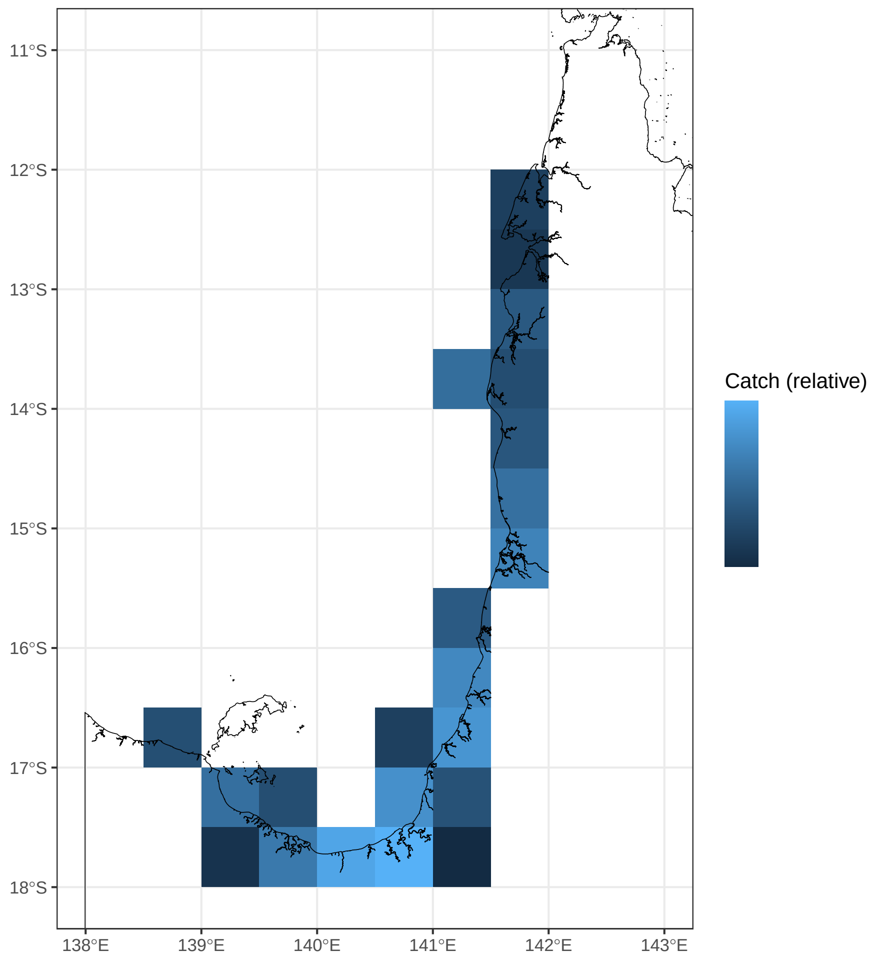

Figure 3.3: Relative retained catch by 30 minute grid between 1989 and 2022 where the darker blues represent low catch and lighter blues represent high catch

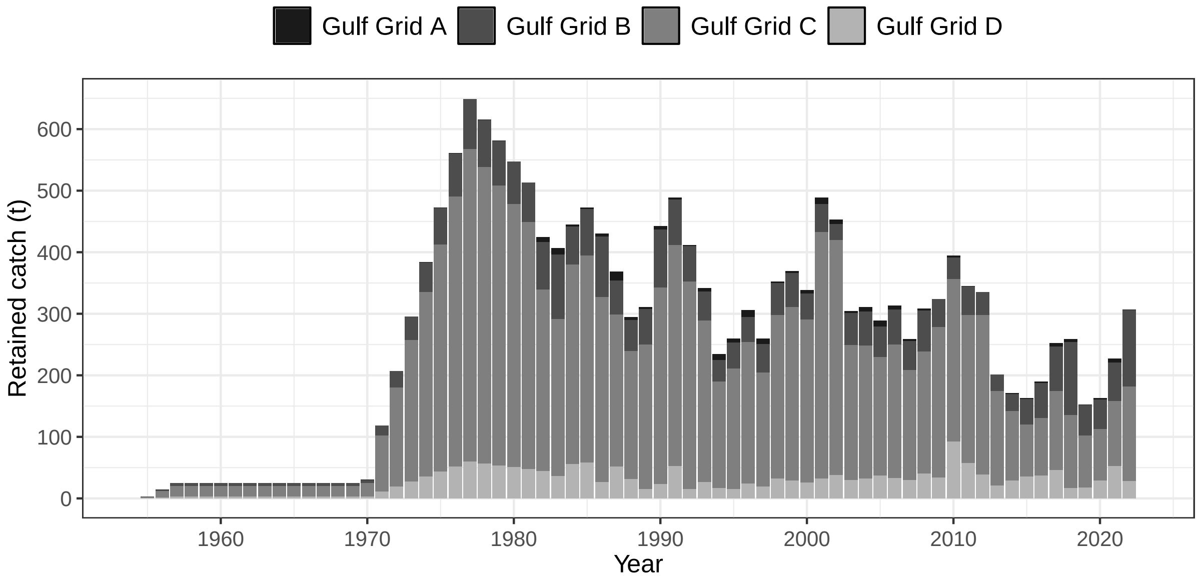

Figure 3.4: Estimated retained catch by Gulf grid between 1955 and 2022, using grids defined in Figure 3.5

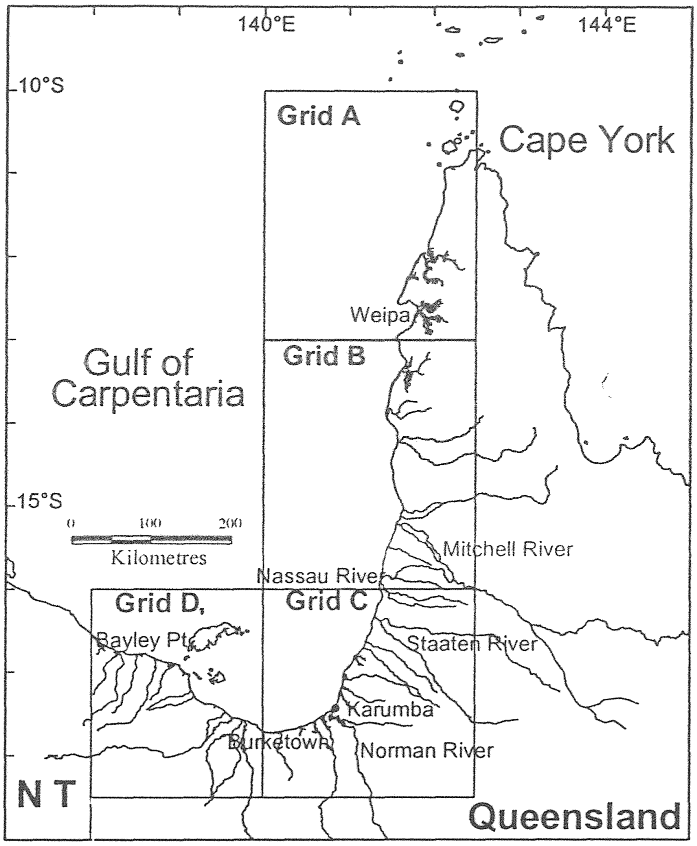

Figure 3.5: Spatial resolution of the Gulf logbook, 1981–1989, with Areas A, B, C and D (Source: Garrett et al. (1997))

3.1.3 Standardised indices of abundance

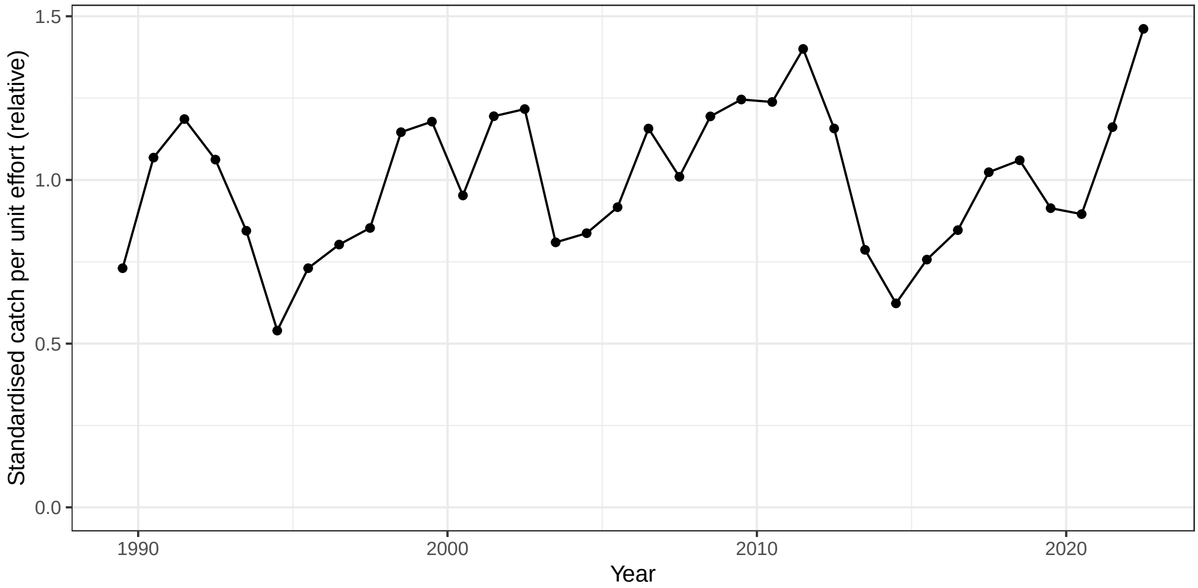

Figure 3.6: Annual standardised catch rates for king threadfin in the Gulf of Carpentaria

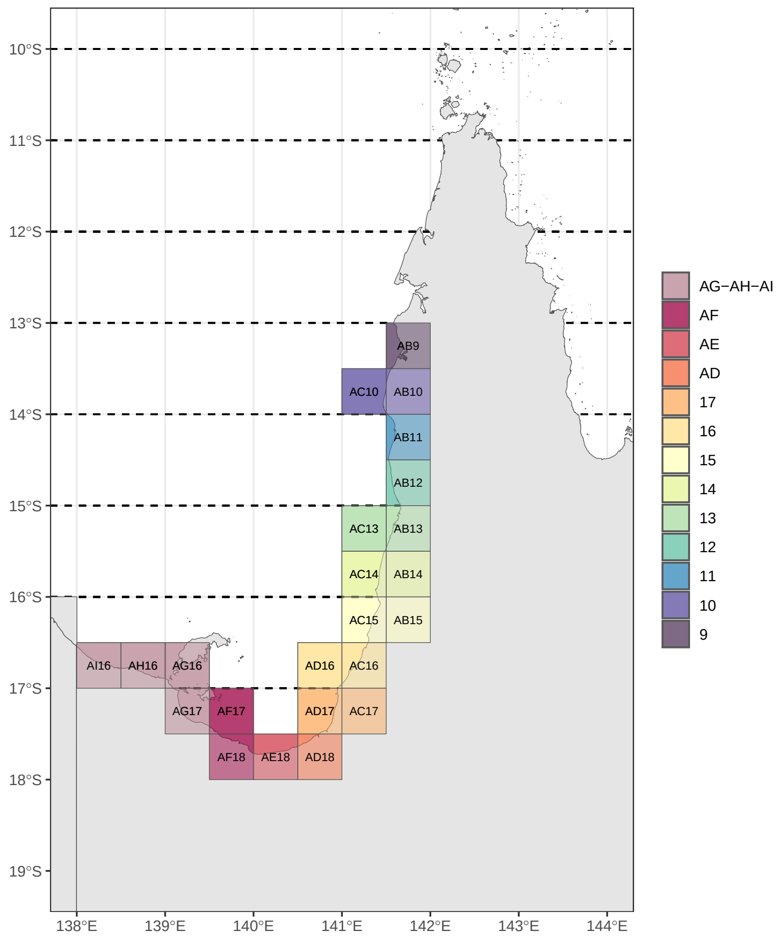

Figure 3.7: A map of the spatial intervals used in the catch rate analysis

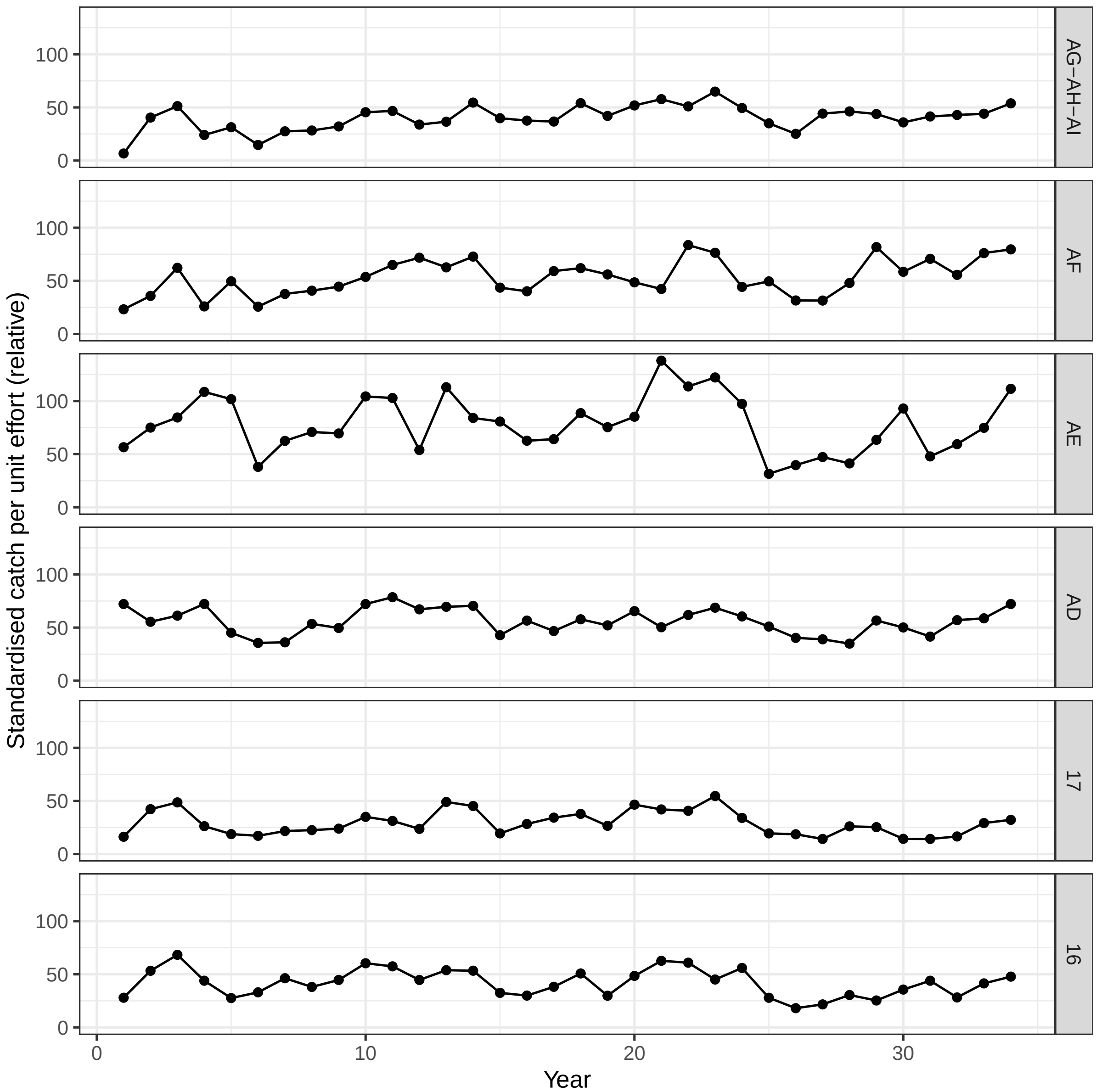

Figure 3.8: Annual standardised catch rates for king threadfin in six contiguous spatial intervals, as defined in Figure 3.7—other intervals shown in Figure 3.9

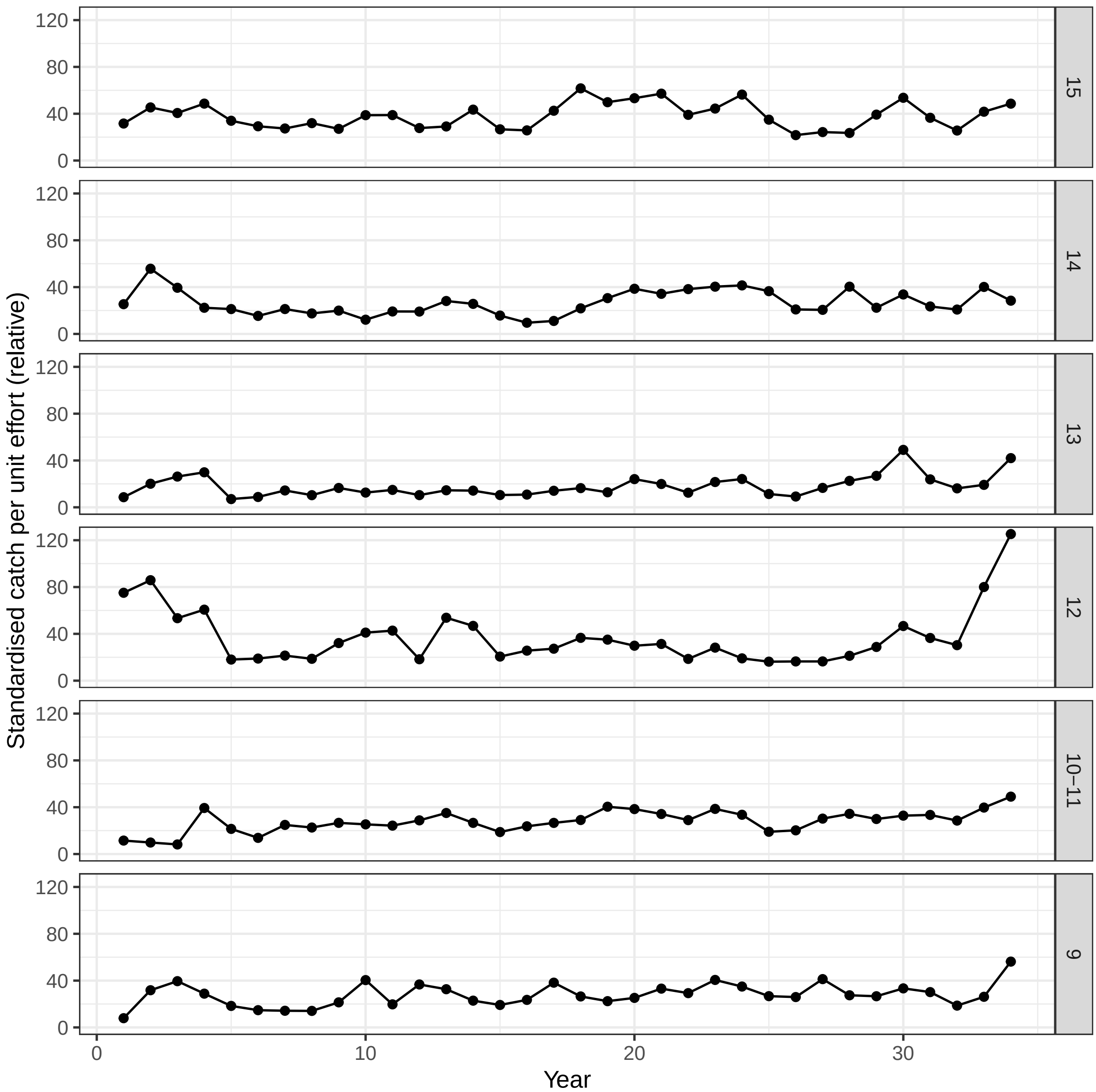

Figure 3.9: Annual standardised catch rates for king threadfin in six contiguous spatial intervals, as defined in Figure 3.7—other intervals shown in Figure 3.8

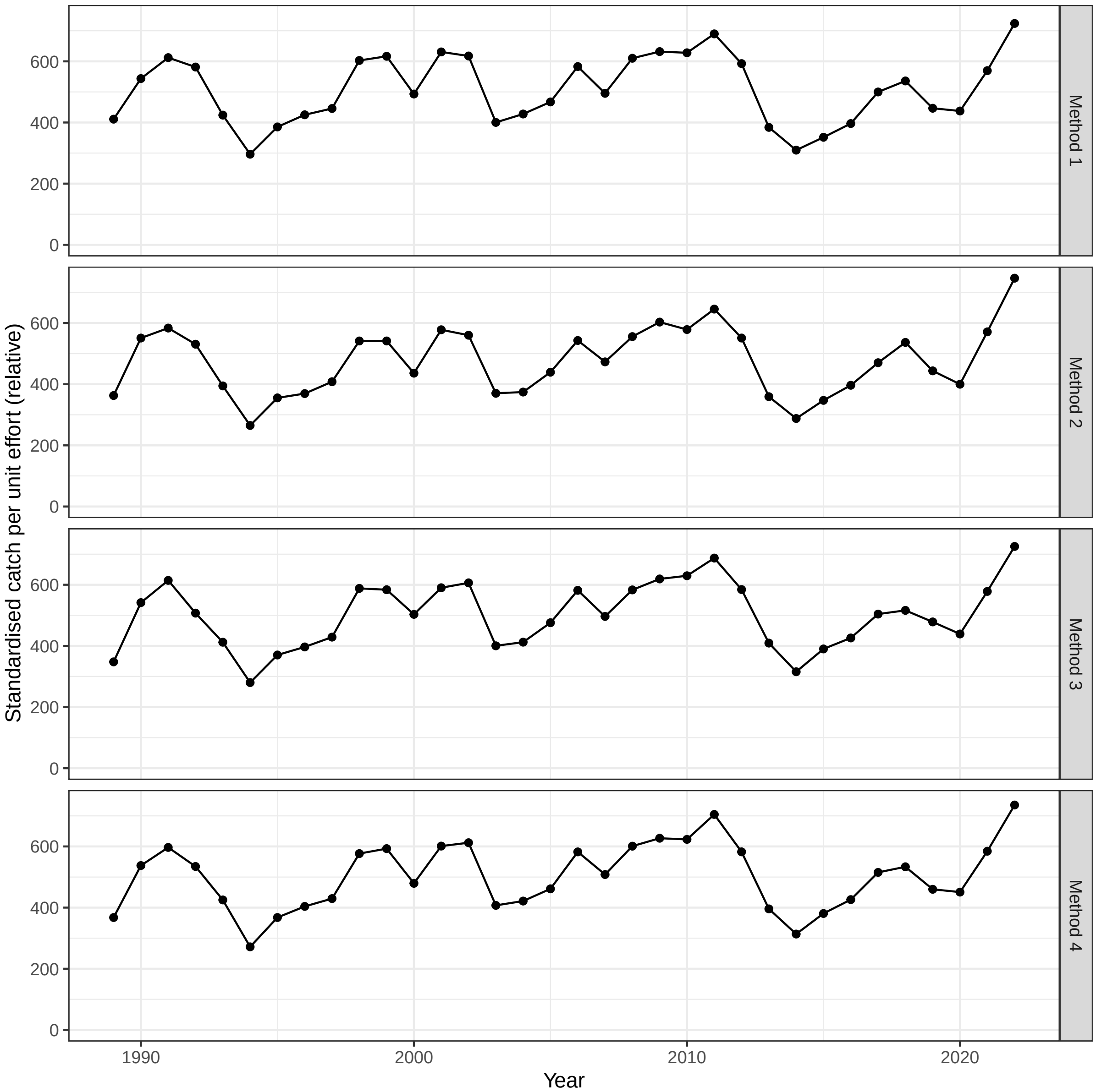

Figure 3.10: Annual standardised catch rates comparing different weighting methods: Method 1 (weighting based on sample size), Method 2 (equal weighting), Method 3 (weighting by total length of rivers and coastline within the interval) and Method 4 (weighting by number of distinct 6 min grids fished within that interval between 1989 and 2022)

3.1.4 Length composition

The length data input to the model are plotted in Figure 3.11. The 1 cm length bins in the population model ranged from 0.5 to 122.5 cm fork length. Any fish above 122.5 cm were combined into the top bin.

Initial sampling weight (Punt 2023, Table 2) for both length and age data are listed in Appendix C, Section C.1.

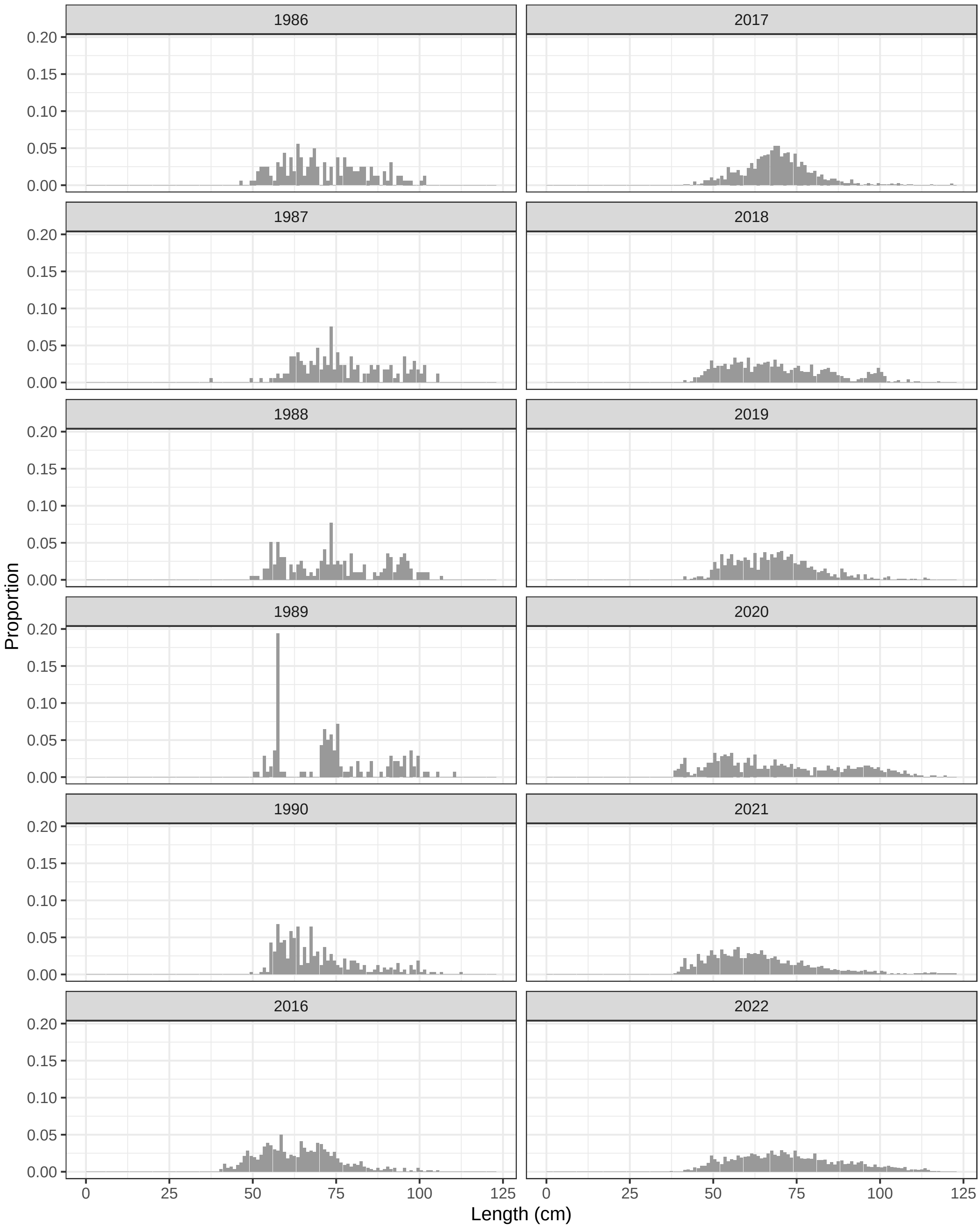

Figure 3.11: Annual length compositions of king threadfin

3.1.5 Age composition

Figure 3.12 show the age structures of the population. Age data were input to the model through the conditional age-at-length data sets.

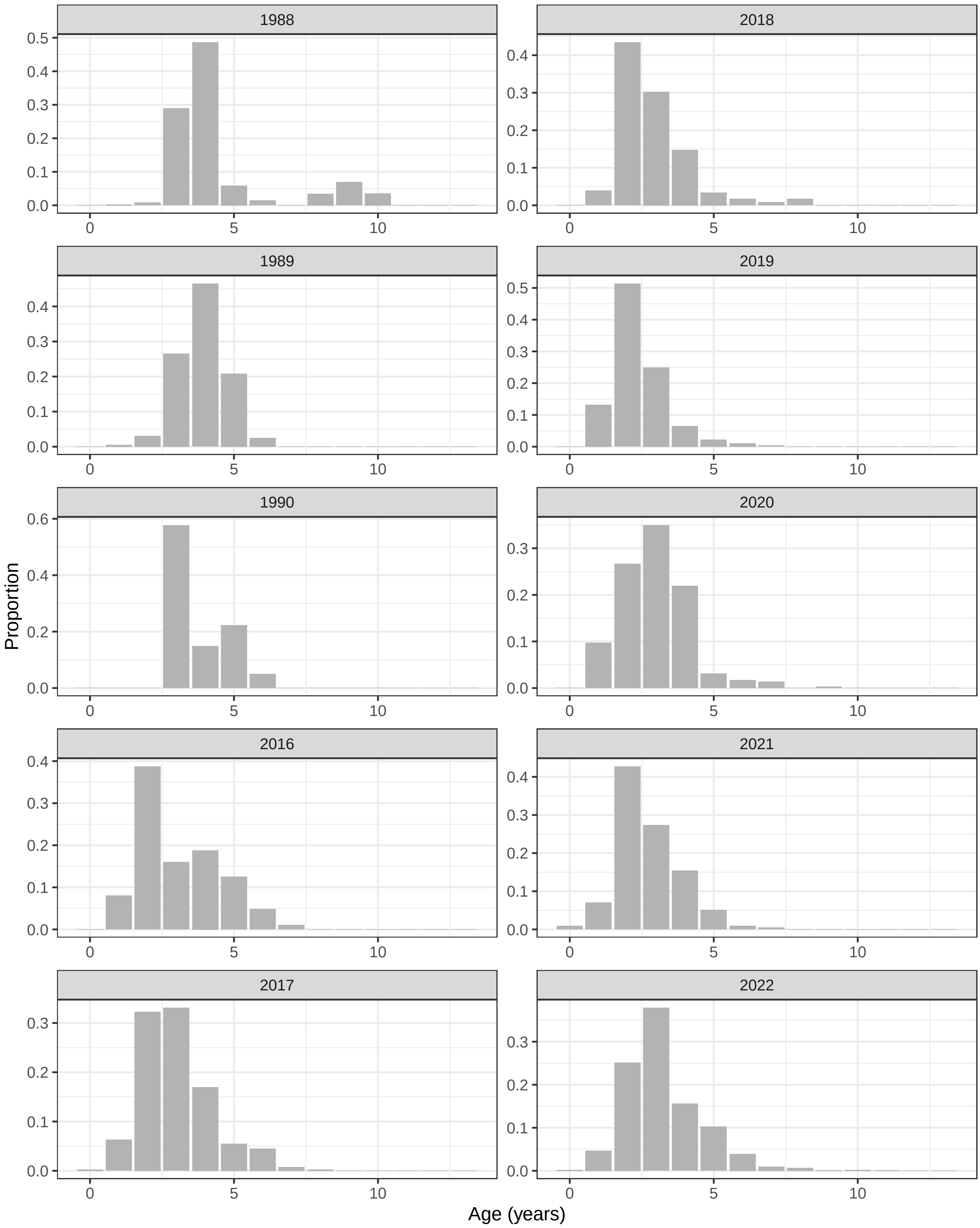

Figure 3.12: Annual age compositions of king threadfin

3.1.6 Other model inputs

Fixed biological relationships are plotted in Appendix C (section C.3, Figures C.2–C.5). These include the length–weight relationship, maturity at age, and individual spawning output (maturity multiplied by fecundity) by age and by length.

3.2 Model outputs

3.2.1 Model parameters

Parameter estimates across the ensemble (see Table 2.4) are listed in Table 3.1. For M, summaries are presented only for Scenarios 1 to 4 where the parameter was estimated.

Symbol	MCMC median	MCMC 2.5%	MCMC 97.5%
M	0.31	0.25	0.36
L_{min}	26.64	21.22	31.42
L_{max}	89.88	77.07	105.91
K	0.33	0.23	0.50
SD_{young}	13.10	10.98	15.41
SD_{old}	21.35	17.06	27.75
$\ln R_0$	6.10	5.80	6.50
$\ln q$	-5.99	-6.45	-5.51
QextraSD	0.16	0.09	0.24
L_{50}	54.46	41.63	64.99
$L_{95\text{width}}$	30.70	6.49	54.42

Table 3.1: Summary of parameter estimates for king threadfin from the ensembled scenarios. MCMC Median is median parameter value from robust MCMC scenarios. MCMC 2.5% and 97.5% indicates 95% credible interval.

3.2.2 Model fits

Plots of fit for the model to abundance indices, length compositions, age compositions and conditional age-at-length are provided in Appendix E.

Tables D.1 and D.2 (Section D.1) show diagnostics that indicate good model convergence for all scenarios.

3.2.3 Selectivity

Parameters for length-based selectivity to fishing were estimated within the model (Table 3.1). The resulting selectivity function (Figure 3.13) represents the relative proportion of king threadfin of a given length that can be caught by the fishing gear deployed by a fleet (ranging from zero to 100%).

The retention function for whether fishers retain the fish that they catch was fixed to a length of 50% retention equal to the minimum legal size (MLS, 60 cm TL $\approx$ 49.6 cm FL), with a small amount of variation about this length. The only discards were assumed to be fish that were selected but not retained because fishers considered them to be smaller than the MLS.

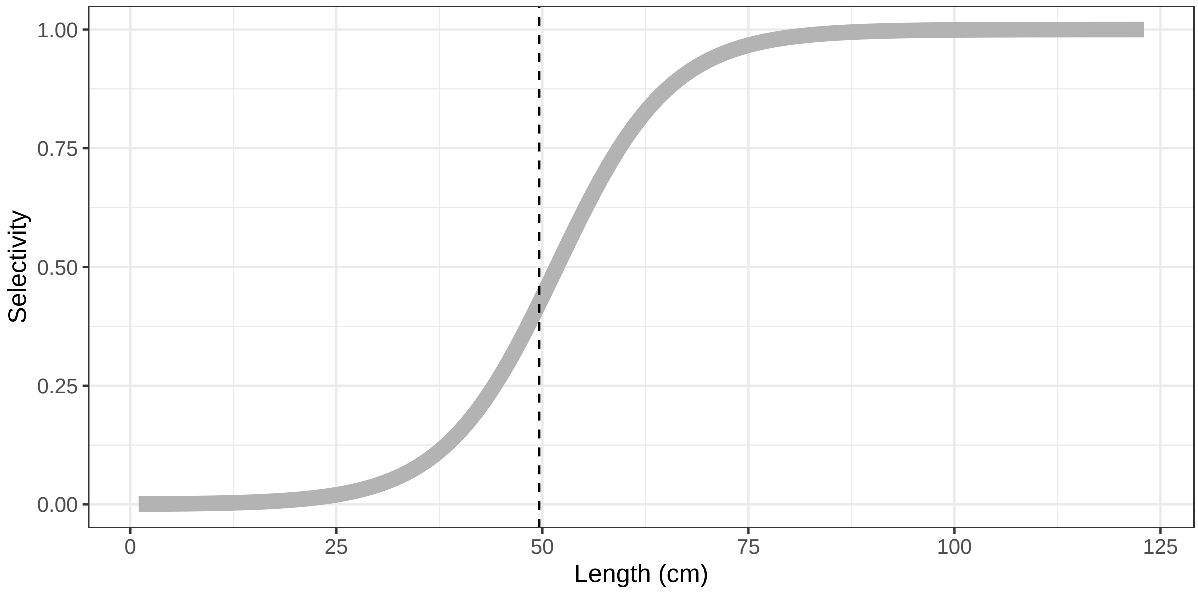

Figure 3.13: Model estimated length-based selectivity in 2022 for the representative MLE model (scenario 5)—the dashed line shows the current minimum legal size of 60 cm in fork length (≈ 49.6 cm)

3.2.4 Growth curves

Parameters for the von Bertalanffy growth curve, including standard deviations about the mean length for both old and young fish, were estimated within the model (Table 3.1).

The resulting curve, fitted inside the model, shows a high level of variation in the lengths of individual fish at a given age (Figure 3.14). This variation may be partly due to fluctuation in annual environmental conditions and food availability.

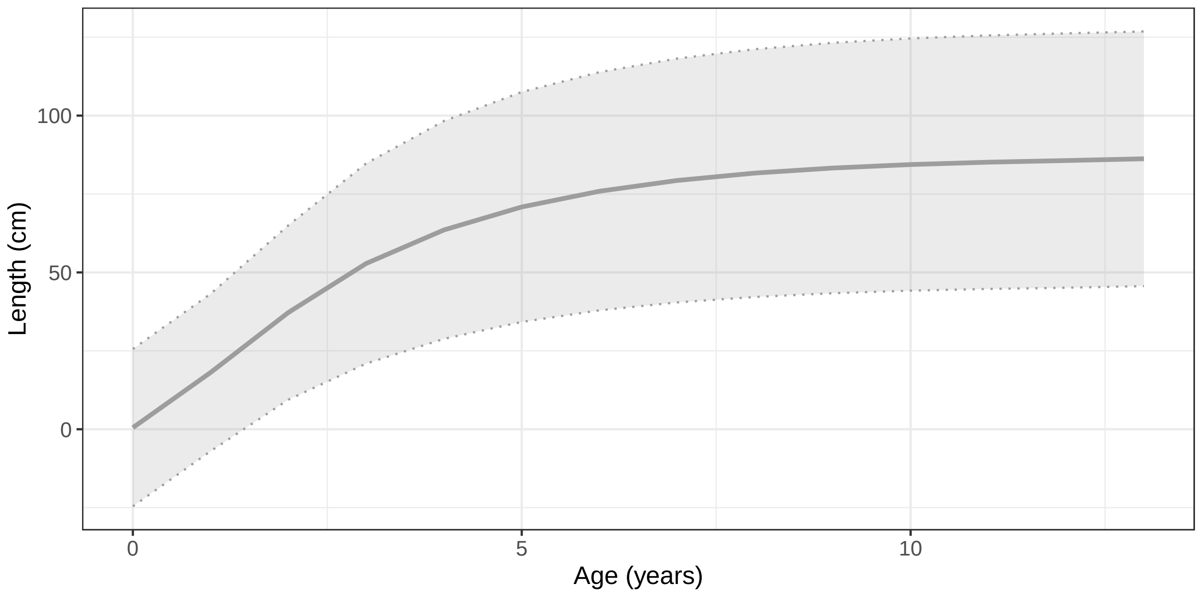

Figure 3.14: Estimated growth of king threadfin (95% confidence intervals) for the representative MLE model (scenario 5)

3.2.5 Biomass

The time series of estimated spawning biomass ratio from all the scenarios listed in Table 2.4, relative to the unfished state, are shown in Figures 3.15 (Markov chain Monte Carlo results) and 3.17 (maximum likelihood estimates and MCMC results) and Table 3.2.

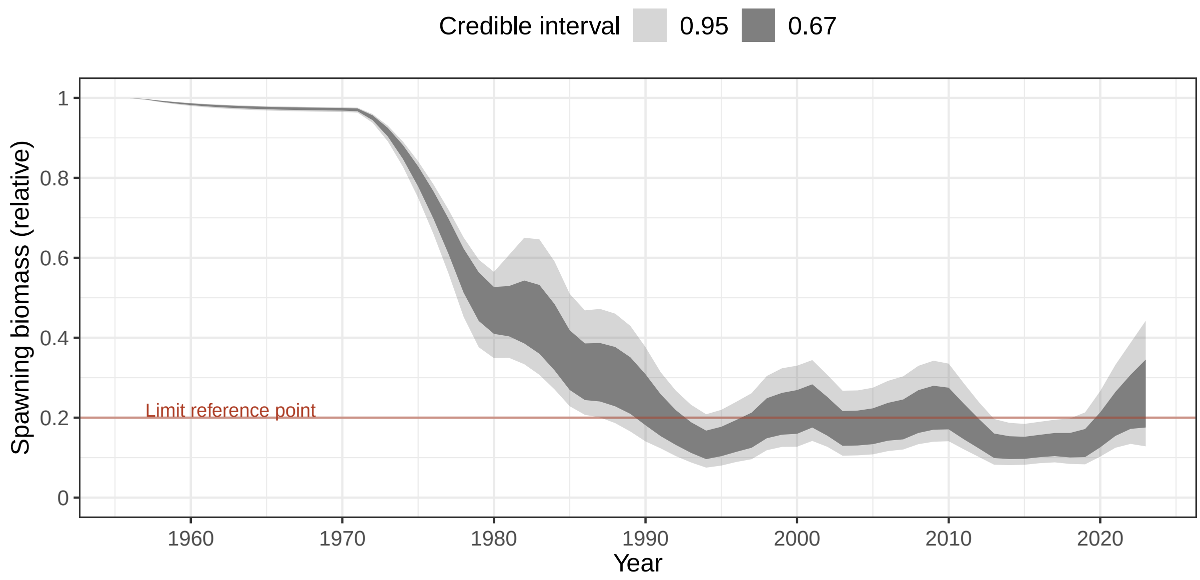

Figure 3.15: Predicted spawning biomass trajectory relative to unfished for king threadfin in the Gulf of Carpentaria, from MCMC ensemble scenarios

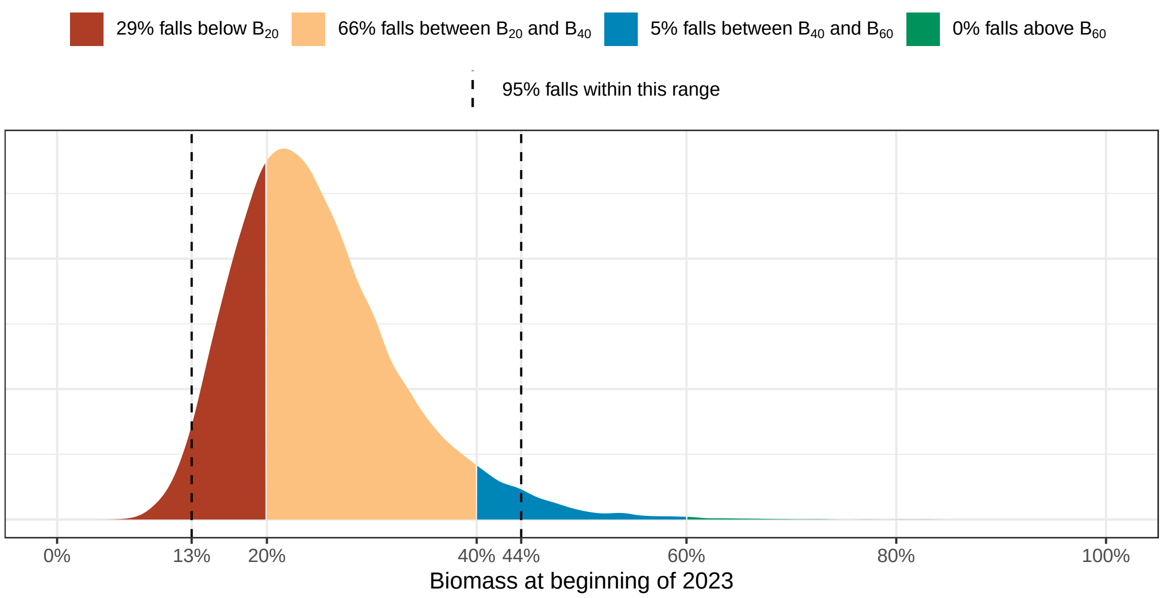

Figure 3.16: Probability distribution of the biomass ratio at the beginning of 2023 across the full ensemble of scenarios with the credible interval and B_{20} risk threshold indicated

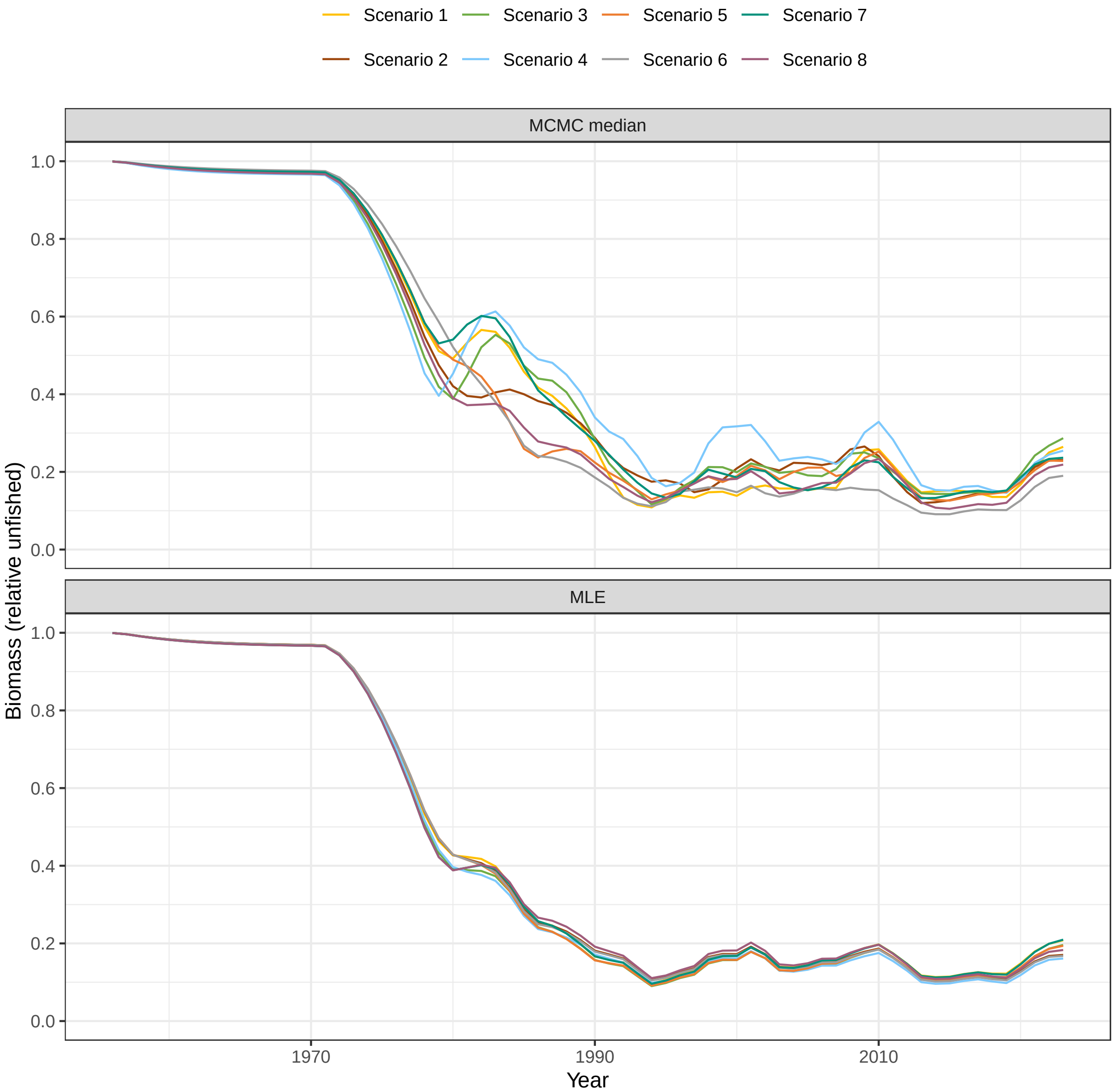

Figure 3.17: Estimated spawning biomass trajectory relative to unfished levels for king threadfin in the Gulf of Carpentaria from 1955 to 2022, for all scenarios. The upper panel displays the "MCMC median" (i.e. iteration that produced the median value for biomass at the beginning of 2023) and the lower panel is the optimised maximum likelihood estimate

Table 3.2: Stock status indicators for king threadfin in the Gulf of Carpentaria

Indicator	Value
Biomass at beginning of 2023 (% of unfished)	24% (13–44%)
Biomass at MSY (% of unfished)	29% (26–32%)
MSY (dead catch) (t/yr)	409 (337–494)
FMSY	0.36 (0.26–0.51)
Fishing pressure ratio (relative to MSY) (2019–2022 average)	0.9 (0.51–1.36)
Fishing pressure ratio (relative to MSY) (2019–2022 average) threshold risk	32%

Table 3.3: Summary of model outcomes for all scenarios. $B_{2023}\%$ is the most likely biomass in 2023 relative to unfished in 1955 with the 95 % confidence interval for maximum likelihoods estimations and 95 % credible interval for MCMC estimations.

Scenario	MLE			MCMC		
	$B_{2023}\%$	$B_{2023,lower}\%$	$B_{2023,upper}\%$	$B_{2023}\%$	$B_{2023,lower}\%$	$B_{2023,upper}\%$
1	0.21	0.09	0.32	0.26	0.15	0.48
2	0.17	0.08	0.26	0.23	0.13	0.42
3	0.20	0.09	0.31	0.29	0.16	0.52
4	0.16	0.07	0.25	0.25	0.14	0.46
5	0.19	0.11	0.28	0.23	0.13	0.40
6	0.17	0.09	0.24	0.19	0.11	0.31
7	0.21	0.11	0.31	0.24	0.12	0.42
8	0.18	0.10	0.27	0.22	0.12	0.36

4 Discussion

4.1 Stock status

Stock status at the beginning of 2023 was estimated to be between 13% and 44% of unfished (95% credible interval over the MCMC ensemble). The probability that the biomass was below 20% at this time was estimated to be 29%.

4.2 Performance of the population model

Parameter estimation occurred using two methodologies across eight scenarios: maximum likelihood estimation (MLE) and Markov chain Monte Carlo (MCMC) estimation. Convergence diagnostics for all scenarios for MLE were good. Convergence diagnostics for MCMC can be seen in Tables D.1 and D.2 in Section D.1. Each scenario was run with 4 chains for 48 hours of computation time using the No U-Turn Sampler (NUTS) implementation of MCMC. Convergence is reasonable for most scenarios, but not great, and particularly poor for scenario seven. Additional MCMC runs, not reproduced here, indicate this is a general convergence issue rather than necessarily implying scenario seven is plausible.

The MLE and MCMC outputs differed, with MLE outputs generally having lower biomass (Figure 3.17). MLE required a strong 'bias adjustment ramp' (Methot and Taylor 2011) and we have greater confidence in the MCMC method of estimation despite the convergence challenges.

Fits to modern (2016–2022) age and length data (e.g. Figure E.3 and Figure E.4) were significantly better than fits to the early period (1986–1990). It is likely that sampling complexities played a significant role in the relative lack of fit to the early data, however it is also possible that this represents demographic changes over time that have not been captured in the models. Many alternative model and data formulations were explored to improve this, with limited success, although current goodness of fit is improved over earlier attempts. See Hoyle and Dunn (2024) and Campbell et al. (2024) for more detail on this work. A key recommendation of Hoyle and Dunn (2024) is 'Identify hypotheses to explain why the model cannot fit the ages-at-length in the early period, and develop alternative models based on these' and this remains a challenge for the next assessment.

4.3 Unmodelled influences

The impact of environmental influences (rainfall and river flow especially) remain a key source of uncertainty.

4.4 Recommendations

4.4.1 Stock assessment

Key recommendations from the review that have not yet been implemented are summarised in Campbell et al. (2024).

4.4.2 Monitoring

A recommendation for monitoring is to consider the monitoring programs' design to optimise age-length composition data for stock assessment population models. Age-length data is used to inform fishery-dependent processes like selectivity as well as fishery-independent processes like growth, mortality and recruitment. Particularly with spatial complexity, these different uses place different requirements on optimal survey design. Maunder et al. (2020) recommend the construction of two different age-length data sets for input to the population model: one aimed at informing fishery-dependent processes, which is spatially weighted by a proxy for habitat-area (identically to CPUE spatial weighting), and one aimed at informing fishery-independent processes, which is spatially weighted by catch size. Monitoring programs designed to be spatially representative rather than representative of where harvest is occurring spatially, would allow the information to be used in both ways through appropriate weighting. This assessment and its review process (Hoyle and Dunn 2024; Campbell et al. 2024) has highlighted the importance of understanding as much as possible about the spatial origin of length and age samples, and of collecting samples in a way that is representative across diverse spatial regions and habitats. For Gulf king threadfin, and possibly more broadly, it is important to understand optimal monitoring designs with respect to this issue. A cost benefit analysis of data collection strategies and the amount and scale of the data achieved should be considered, factoring in aspects relating to the involvement of fishers, the challenges of remote locations, and staff safety.

4.4.3 Research

Better information about reproductive spatial connectivity and functional/reproductive extent of king threadfin in the Gulf is needed, better information on key life history parameters is needed, and a better understanding of the relationship between observed catch rates and population abundance is needed. An FRDC research project, Robins (2024), has been proposed to provide maximal support for stock assessment given our current state of knowledge. This project has three objectives:

1. Evaluate the fine scale stock structure and level of functional connectivity of king threadfin between regions within the Gulf of Carpentaria to inform meta-population dynamics.
2. Quantify life history parameters of king threadfin across regions within the Gulf of Carpentaria relevant to inform stock assessment.
3. Evaluate factors influencing the relationship between catch (rate) and population abundance to inform catch rate standardisation.

4.4.4 Management

This assessment highlights that the stock is highly unlikely to be at Sustainable Fisheries Strategy target levels, and has a substantial probability (>20%) of being below 20% biomass at the beginning of 2023. It also highlights the degree of uncertainty is large and that there is insufficient information currently available regarding the suitability of the spatial management unit.

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.

4.5 Conclusions

This stock assessment was commissioned to establish the status of the Gulf of Carpentaria king threadfin stock and inform the management of the Gulf of Carpentaria inshore fishery. Biomass was estimated to be between 13% and 44% at the beginning of 2023, relative to an assumed unfished state in 1955. This interval was generated over an ensemble of eight scenarios. Some recommendations for future assessment and monitoring have been made.

References

Bibby, Jeff M. and Geoffrey R. McPherson (July 1997). “Age and growth of five target fish species in the Gulf of Carpentaria inshore gillnet fishery”. In: *Biology and harvest of tropical fishes in the Queensland Gulf of Carpentaria gillnet fishery.* Ed. by Rod N. Garrett. Brisbane: Queensland Department of Primary Industries. Final Report of FRDC project no. 92/145, pp. 87–103.

Cadrin, Steven X, Daniel R Goethel, Aaron Berger, and Ernesto Jardim (2023). “Best practices for defining spatial boundaries and spatial structure in stock assessment”. In: *Fisheries Research* 262.106650.

Campbell, Alexander B., Julie Robins, and F. O’Neill Michael (2017). *Assessment of the barramundi* (Lates calcarifer) *fishery in the Southern Gulf of Carpentaria, Queensland, Australia.* Project Report. Brisbane, Queensland: Agri-Science Queensland.

Campbell, Alexander B., Mai Tanimoto, and Olivia J. Whybird (May 2024). *Response to ‘Review of the 2024 Stock Assessment for King Threadfin (*Polydactylus macrochir*) in the Gulf of Carpentaria, Queensland’*. Fisheries Queensland, Department of Agricluture and Fisheries.

Darcey, Jack (1990). *An oral history of the Australian fishing industry*. Final report, FRDC project number 1987-021.090. Canberra: Fisheries Research and Development Corporation.

Dunstan, D. J. (1959). *The barramundi* Lates calcarifer *(Bloch) in Queensland waters*. en-AU. Publisher: Division of Fisheries and Oceanography. Melbourne: CSIRO Division of Fisheries and Oceanography, Technical Paper No. 5.

Fisheries Queensland (2017). *Fisheries Queensland Boat Ramp Survey Sampling Protocol: Section 2*. Brisbane, Australia.

Garrett, Rod N. (Aug. 1992). *Biological Investigations of King Salmon* Polydactylus sheridani *in the Gulf of Carpentaria: A Summary Report*. Cairns: Queensland Department of Primary Industries.

Garrett, Rod N., J. M. Bibby, Clive P. Keenan, Geoffrey R. McPherson, and Lew E. Williams (July 1997). *Biology and harvest of tropical fishes in the Queensland Gulf of Carpentaria gillnet fishery*. Final Report of FRDC project no. 92/145. Brisbane: Queensland Department of Primary Industries.

Günther, Albert (1867). “VIII.—Additions to the knowledge of Australian reptiles and fishes”. In: *Annals and Magazine of Natural History* 20.115. Publisher: Taylor & Francis, pp. 45–67.

Hamel, Owen S and Jason M Cope (2022). “Development and considerations for application of a longevity-based prior for the natural mortality rate”. In: *Fisheries Research* 256, p. 106477.

Henry, Gary W. and Jeremy M. Lyle (2003). *The National Recreational and Indigenous Fishing Survey*. Canberra: Australian Government Department of Agriculture, Fisheries and Forestry.

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

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

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

Hoyle, Simon D., Robert A. Campbell, Nicholas D. Ducharme-Barth, Arnaud Grüss, Bradley R. Moore, James T. Thorson, Laura Tremblay-Boyer, Henning Winker, Shijie Zhou, and Mark N. Maunder (2024). “Catch per unit effort modelling for stock assessment: A summary of good practices”. In: *Fisheries Research* 269.106860.

Hoyle, Simon D. and Alistair Dunn (Mar. 2024). *Review of the 2024 stock assessment for king threadfin* (Polydactylus macrochir) *in the Gulf of Carpentaria, Queensland*. Nelson, NZ: Hoyle Consulting Ltd.

Infofish (Aug. 2014). *Weipa tagging 1985–2014*. Infofish Australia.

Kailola, P. J., M. J. Williams, P. C. Stewart, R. E. Reichelt, A. McNee, and C. Grieve (1993). "Australian Fisheries Resources". In: *Bureau of Resource Sciences and the Fisheries Research and Development Corporation*. Type: Journal Article, p. 422.

Leigh, George M., Mai Tanimoto, and Olivia J. Whybird (2021). *Stock assessment of king threadfin (*Polydactylus macrochir*) in Queensland, Australia*. Brisbane: Department of Agriculture and Fisheries.

Lo, N. Chyan-huei, Larry D. Jacobson, and James L. Squire (1992). "Indices of Relative Abundance from Fish Spotter Data based on Delta-Lognormal Models". In: *Canadian Journal of Fisheries and Aquatic Sciences* 49.12, pp. 2515–2526. eprint: `https://doi.org/10.1139/f92-278`.

Maunder, Mark N., James T. Thorson, Haikun Xu, Ricardo Oliveros-Ramos, Simon D. Hoyle, Laura Tremblay-Boyer, Hui Hua Lee, Mikihiko Kai, Shui-Kai Chang, Toshihide Kitakado, Christoffer M. Albertsen, Carolina V. Minte-Vera, Cleridy E. Lennert-Cody, Alexandre M. Aires-da-Silva, and Kevin R. Piner (2020). "The need for spatio-temporal modeling to determine catch-per-unit effort based indices of abundance and associated composition data for inclusion in stock assessment models". In: *Fisheries Research* 229, p. 105594.

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

McPherson, Geoffrey R. (July 1997). "Reproductive biology of five target fish species in the Gulf of Carpentaria inshore gillnet fishery". In: *Biology and harvest of tropical fishes in the Queensland Gulf of Carpentaria gillnet fishery.* Ed. by Rod N. Garrett. Brisbane: Queensland Department of Primary Industries. Final Report of FRDC project no. 92/145, pp. 87–103.

Methot R. D., Jr. and Ian G Taylor (2011). "Adjusting for bias due to variability of estimated recruitments in fishery assessment models". In: *Canadian Journal of Fisheries and Aquatic Sciences* 68.10, pp. 1744–1760.

Methot R. D., Jr., C. R. Wetzel, I. G. Taylor, and K. Doering (2024). *Stock Synthesis User Manual Version 3.30.22.1*. NOAA Processed Report NMFS-NWFSC-PR-2020-05. U.S. Department of Commerce.

Methot R. D., Jr. and C.R. Wetzel (2013). "Stock Synthesis: A biological and statistical framework for fish stock assessment and fishery management". In: *Fisheries Research* 142, pp. 86–99.

Moore, Bradley, David Welch, and Colin Simpfendorfer (Jan. 2011). "Spatial patterns in the demography of a large estuarine teleost: King threadfin, Polydactylus macrochir". In: *Marine and Freshwater Research* 62, pp. 937–951.

Moore, Bradley R., Jason M. Stapley, Ashley J. Williams, and David. J. Welch (Mar. 2017). "Overexploitation causes profound demographic changes to the protandrous hermaphrodite king threadfin (Polydactylus macrochir) in Queensland's Gulf of Carpentaria, Australia". In: *Fisheries Research* 187, pp. 199–208.

Motomura, Hiroyuki, Yukio Iwatsuki, Seishi Kimura, and Tetsuo Yoshino (Jan. 2000). "Redescription of Polydactylus macrochir (Günther, 1867), a senior synonym of P. sheridani (Macleay, 1884) (Perciformes: Polynemidae)". In: *Ichthyological Research* 47, pp. 327–333.

Pember, M.B., Stephen J. Newman, S. A. Hesp, G. C. Young, C. L. Skepper, N. G. Hall, and I. C. Potter (2005). *Biological parameters for managing the fisheries for blue and king threadfin salmons, estuary rockcod, malabar grouper and mangrove jack in north-western Australia*. Final report of FRDC Project 2002-003. Perth: Murdoch University.

Pember, Matthew B. (2006). “Characteristics of fish communities in coastal waters of north-western Australia, including the biology of the threadfin species *Eleutheronema tetradactylum* and *Polydactylus macrochir*”. PhD. Perth, WA: Murdoch University.

Punt, André E. (2023). “Those who fail to learn from history are condemned to repeat it: A perspective on current stock assessment good practices and the consequences of not following them”. In: *Fisheries Research* 261, p. 106642.

Quinn, R.H. (1987). “Analysis of fisheries logbook information from the Gulf of Carpentaria, Australia”. In: *Management of Wild and Cultured Sea Bass/Barramundi (*Lates calcarifer*). Proceedings of an International Workshop held at Darwin, Australia, 24–30 September 1986*. Australian Centre for Agricultural Research, Proceedings no. 20, pp. 92–95.

Quinn, Ross H. (Oct. 1984). “Successful barramundi logbook program assists management”. In: *Australian Fisheries*, pp. 11–13.

Robins, Julie B. (2024). *Gulf of Carpentaria King Threadfin (Polydactylus macrochir) - addressing the knowledge gaps to support assessment, management and sustainable harvest*. FRDC Funding Application, Project Number: 2023-199. Queensland Department of Agriculture and Fisheries.

Roelofs, A (2003). *Ecological Assessment of the Gulf of Carpentaria Inshore Finfish Fishery A report to Environment Australia on the sustainable management of a multi-species tropical gillnet fishery. Information series QI03045*. Brisbane, Australia: Queensland Department of Primary Industries, p. 184.

Salini, J. P., D. T. Brewer, and S. J. M. Blaber (June 1998). “Dietary Studies on the Predatory Fishes of the Norman River Estuary, with Particular Reference to Penaeid Prawns”. en. In: *Estuarine, Coastal and Shelf Science* 46.6, pp. 837–847.

Taylor, Stephen, James Webley, and Kirrily McInnes (2012). *2010 Statewide Recreational Fishing Survey*. Brisbane: Department of Agriculture, Fisheries and Forestry.

Teixeira, Daniella, Rachel Janes, and James Webley (Jan. 2021). *2019/20 Statewide Recreational Fishing Survey Key Results*. Project Report. Brisbane.

Webley, James A. C., Kirrily McInnes, Daniella Teixeira, Ashley Lawson, and Ross Quinn (2015). *Statewide Recreational Fishing Survey 2013–14*. Brisbane: Department of Agriculture and Fisheries.

Welch, David J., Aaron C. Ballagh, Stephen J. Newman, R. J. G. Lester, Bradley Moore, Lynne van Herwerden, J. Horne, Q. Allsop, Thor Saunders, Jason Stapley, and Neil A. Gribble (2010). *Defining the stock structure of northern Australia’s threadfin salmon species*. en. Final report for FRDC project no. 2007-032. Canberra: Fisheries Research and Development Corporation.

Wood, Simon (Oct. 2012). *mgcv: Mixed GAM Computation Vehicle with GCV/AIC/REML smoothness estimation*. English. Other.

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. From mid-2022, representatives from industry were included as project team members on all Queensland Fisheries assessments providing valuable advice and knowledge about the fishery.

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

A.1 Mesh size

Recommendation: The mesh size used in the fishery decreased in approximately the early 1980s. This change may have caused fishers to catch smaller fish from the 1980s onwards. The stock assessment should take account of this effect. (Meeting 2, 13 Mar. 2023)

Recommendation: Stock assessment team to produce figures showing changed selectivity through time, after 1986–1994 data have been entered. (Meeting 1, 7 Feb. 2023)

Response: The change in mesh size appears to pre-date all of the length data available for this assessment, so had little effect on the assessment results. No data were available to compare selectivity before and after the change in mesh size.

In the Karumba region (the only one for which a sufficient quantity of old length data were available), king threadfin caught in recent years actually tended to be slightly larger than those caught in the period 1986–1994.

A.2 Stock structure

Decision: There is insufficient information to decide whether the Mornington (western Gulf) region is part of a separate stock of king threadfin. (Meeting 1, 7 Feb. 2023)

Decision: There is also insufficient information on whether the northern Gulf regions are a separate stock. (Meeting 1, 7 Feb. 2023)

Response: The whole of the Queensland Gulf was modelled as a single stock.

A.3 Migration

Recommendation: The implication of age-specific migration between Karumba and other regions, which was used to explain the scarcity of older fish (four years old or more) in the northern Gulf in the 2020 assessment, is inconsistent with the known biology of king threadfin. (Meeting 1, 7 Feb. 2023)

Response: After discussion with the Project Team, it appeared that older fish were present in the northern Gulf, but were not sampled by the DAF Fishery Monitoring program.

Age-length from northern of 13 degrees (Weipa and Mapoon) was not included in the final models.

A.4 Tagging data

Recommendation: After updated tag-recapture data become available (e.g., from Infofish Australia), the stock assessment team presents a short summary of how the tagging dataset is or is not useful to the assessment.

Response: Updated tag-recapture data did not become available during the course of the assessment, so this was not possible.

A.5 Suspect commercial catch data

Decision: Stock assessment team to show the Project Team commercial catch totals of logbook data that were considered suspect and were flagged for omission from the catch records input to the assessment. (Meeting 1, 7 Feb. 2023)

Response: Catch totals of suspect data from the northern Gulf in the period 1999–2002 were shown to the Project Team, and the Project Team accepted that they should be omitted from the assessment. (Decision of meeting 2, 13 Mar. 2023)

After the conclusion of the Project Team process, further suspect data were identified from the Karumba region in 2022. These data were omitted from the assessment runs conducted after that time.

A.6 Indigenous catch

Recommendation: Indigenous catch data are lacking, in both time and space. The only data we have are for the period 2000–2001 from the National Recreational and Indigenous Fishing Survey (Henry and Lyle 2003), and they provide only a state-wide total, not localised to the Gulf or the East Coast. Consider how to include Indigenous data in the assessment. (Meeting 1, 7 Feb. 2023)

Response: Indigenous data were not included in this assessment, but are flagged for inclusion when king threadfin is next assessed. This may require a dedicated Indigenous sampling program.

A.7 Catch reconstruction

Clarification: Does the assessment use the total dead catch of king threadfin, including non-retained catch? (Meeting 2, 13 Mar. 2023)

Response: Yes, it does.

Recommendation: The high catch scenario from the 2020 assessment is not plausible. (Meeting 2, 13 Mar. 2023)

Response: This scenario was omitted from the assessment, along with the low scenario from the previous assessment to free up sensitivity analysis resources for other important issues. Assessment models used base case from the previous assessment.

Action: Check the Queensland Fish Board data from the 1970s. Most of the Gulf catch sold to the Fish Board was sold to East Coast receiving stations, not the Weipa station. (Meeting 2, 13 Mar. 2023)

Response: There were noticeable spikes in the East Coast receiving station records, which were attributable to catch from the Gulf. The spikes were, however, much smaller than the 1981 Gulf catch.

They were considered too small to represent the total Gulf catch. It was concluded that the Fish Board data were not useful in reconstructing the Gulf catch of king threadfin.

Decision: Gulf-specific data on recreational catch are sparse and uncertain. Don't update the recreational catch from the 2020 assessment. Keep it constant from 2019 to 2022, as there are no new data. (Meeting 3, 11 May 2023)

A.8 Associated species

Action item: Stock assessment team to show a list of positively associated species (often co-caught with king threadfin) used for the catch-rate analysis in the assessment. (Meeting 2, 13 Mar. 2023)

Response: Positively associated species categories are other threadfins, grunter and jewfish. The major individual species are blue threadfin, javelinfish (grunter) and "jewel fish" (*Nibea squamosa*). Project Team agreed with these findings.

Suggestion: Trips that target grey mackerel catch hardly any king threadfin. Catch-rate analysis could omit records in which grey mackerel were caught.

Response: Fisher–days on which grey mackerel were caught were omitted.

A.9 Tidal data in catch-rate analysis

Decision: Height of high tide is likely to be the most influential tidal variable in the catch-rate analysis. Include both high tide level and the tidal range.

Response: In the final models following independent review, tidal data were not included in the catch rate models because a single catch rate time series was constructed for the entire Gulf region.

A.10 Catchability increase over time

Decision: Stock assessment team to construct scenarios of plausible catchability increase (fishing power increase) agreed upon by the Project Team. (Meeting 2, 13 Mar. 2023)

Project Team comments that discard rates have fallen over time, and fishers generally catch what they target. Markets tend to influence target species. Crew size has reduced over time, which may reduce net time in the water. (Meeting 3, 11 May 2023)

Response: Catchability increase was discussed extensively in Project Team meetings. In the final models, following independent review, catchability was sensitivity tested at 0% and 1% increase.

A.11 River flow data

Decision: Review potentially missing rainfall data during floods, when the measuring device is submerged. (Meeting 3, 11 May 2023)

Result: Actual measurements are sometimes replaced by estimates in the data from flow measuring stations. Inspection of the data indicates that these estimates are sensible. There is no evidence that the estimated flow measurement is too low when the measuring device is submerged.

Suggestion: Check effect of river flow on recruitment. (Meeting 3, 11 May 2023)

Recommendation: The 2019 flood in Karumba region, although short in duration, had a major effect. The assessment should take account of that. (Meeting 4, 23 Aug. 2023)

Response: In the final models following independent review, river flow was not included in the catch rate analyses due to insufficient understanding of the mechanisms by which river flow affects king threadfin populations.

A.12 Regions used for catch-rate analysis

Decision: Include catch-rate series from Pormpuraaw and Aurukun regions in model inputs.

Response: In the final models following independent review, a single-fleet single-region population model was used. For more detail, see Hoyle and Dunn (2024) and Campbell et al. (2024).

B Diagnostics for standardised indices of abundance

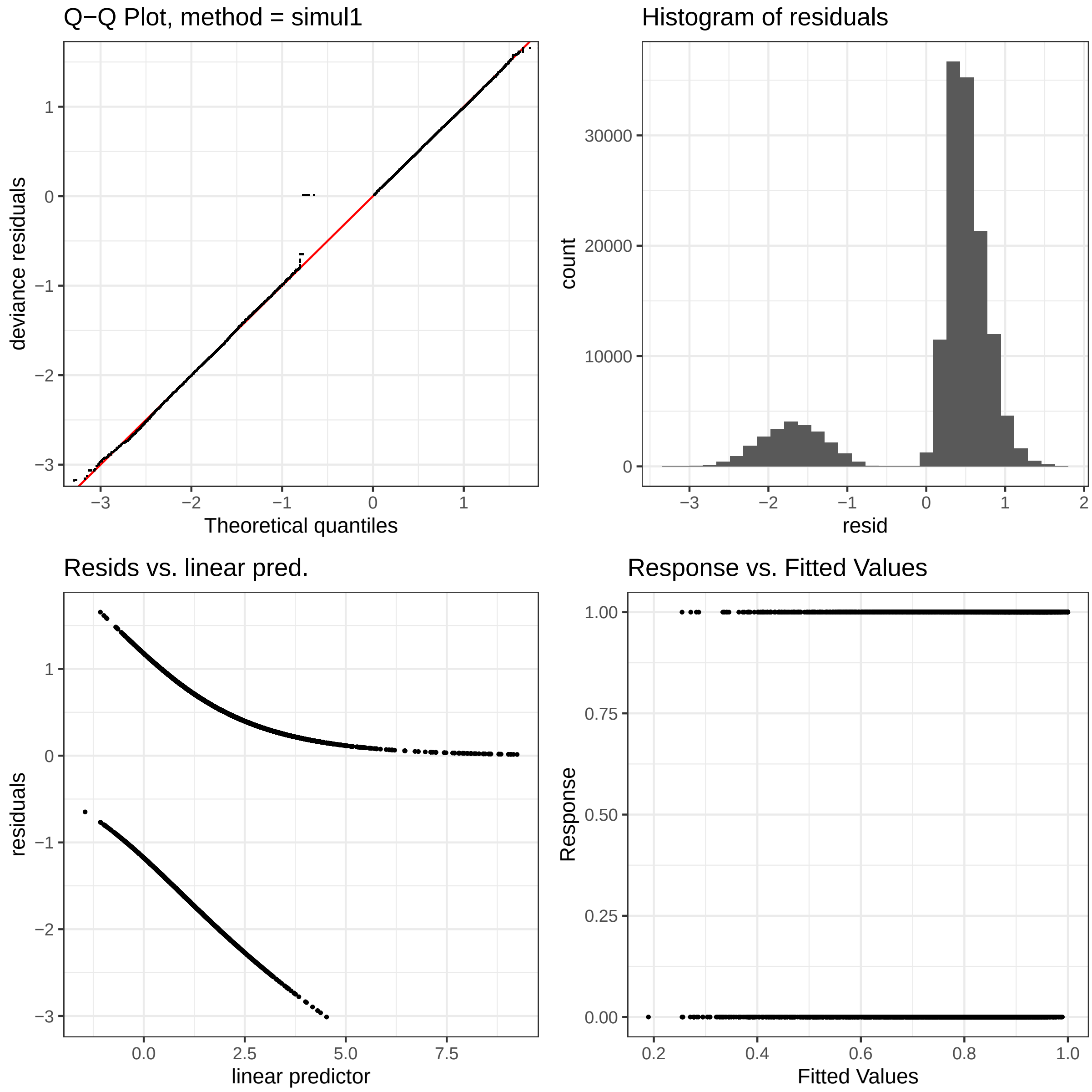

Figure B.1: Analysis of residuals for delta model

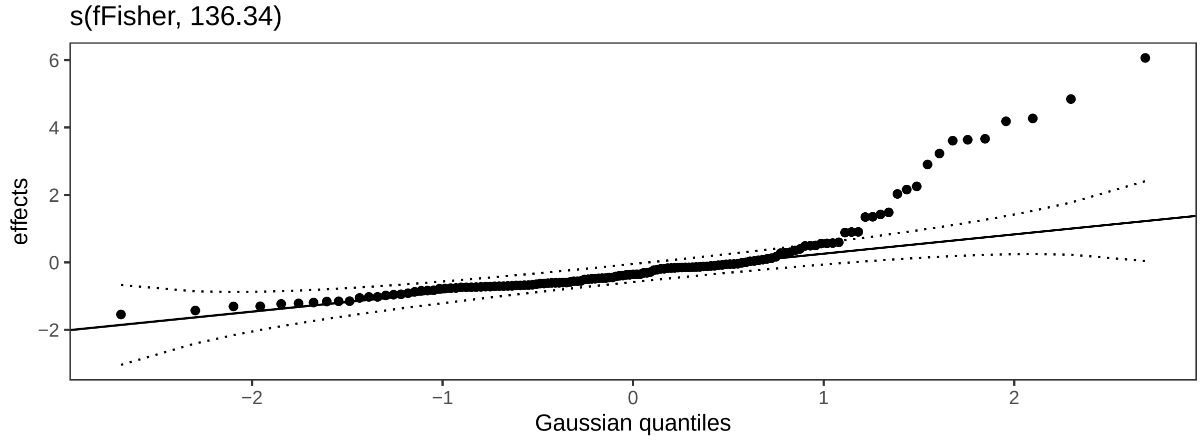

Figure B.2: Delta model effect plot: Fisher effect

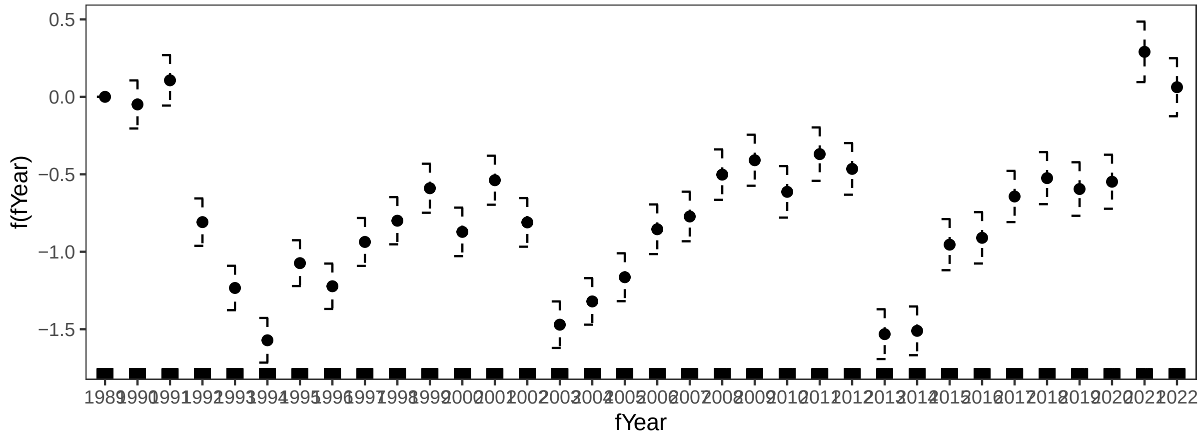

Figure B.3: Delta model effect plot: Year effect

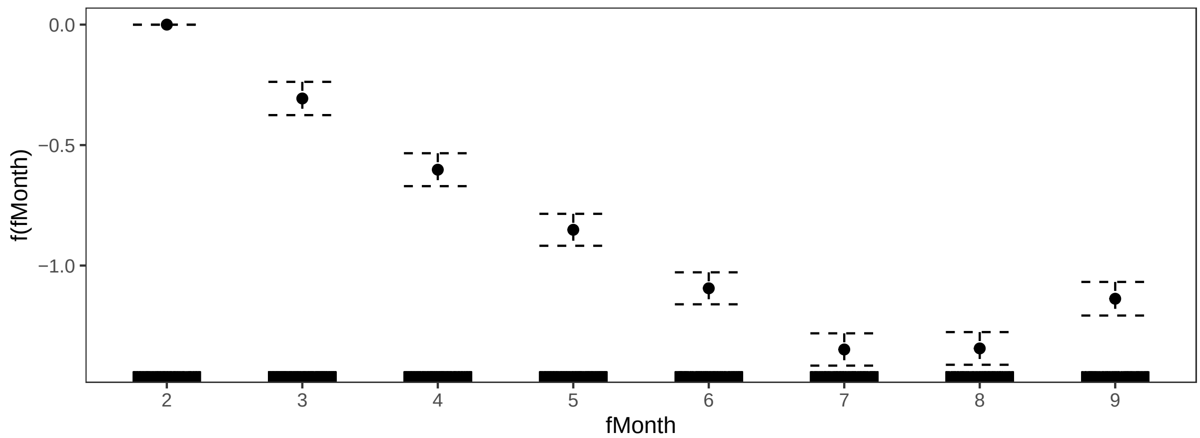

Figure B.4: Delta model effect plot: Month effect

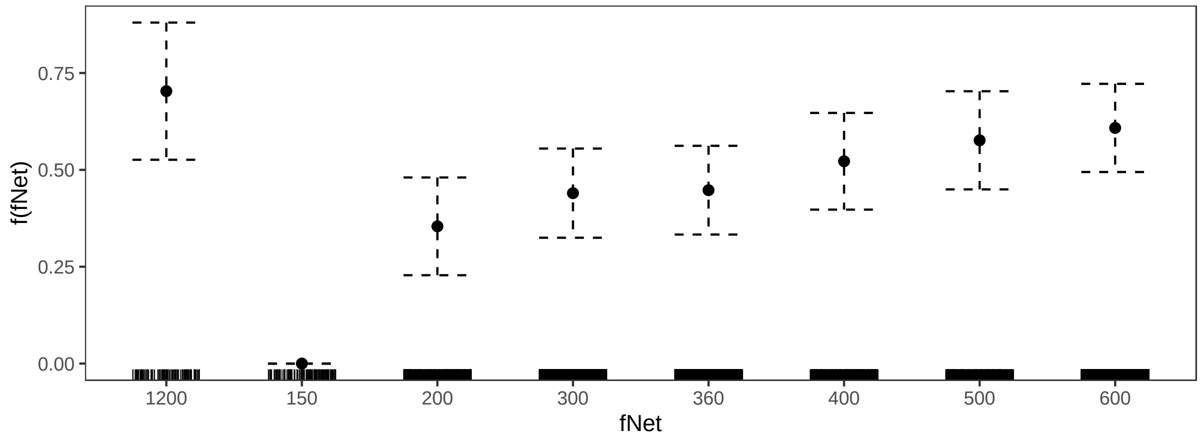

Figure B.5: Delta model effect plot: Net effect

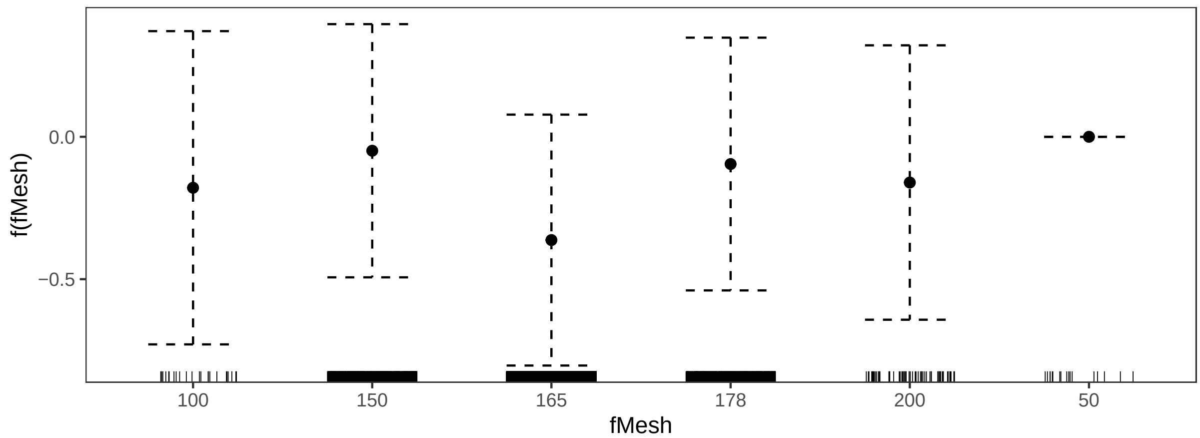

Figure B.6: Delta model effect plot: Mesh effect

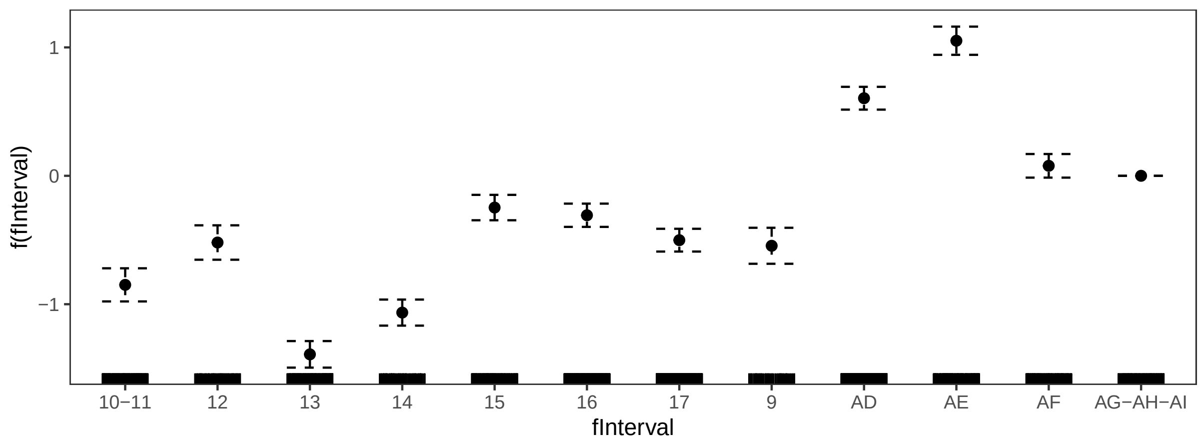

Figure B.7: Delta model effect plot: Interval effect

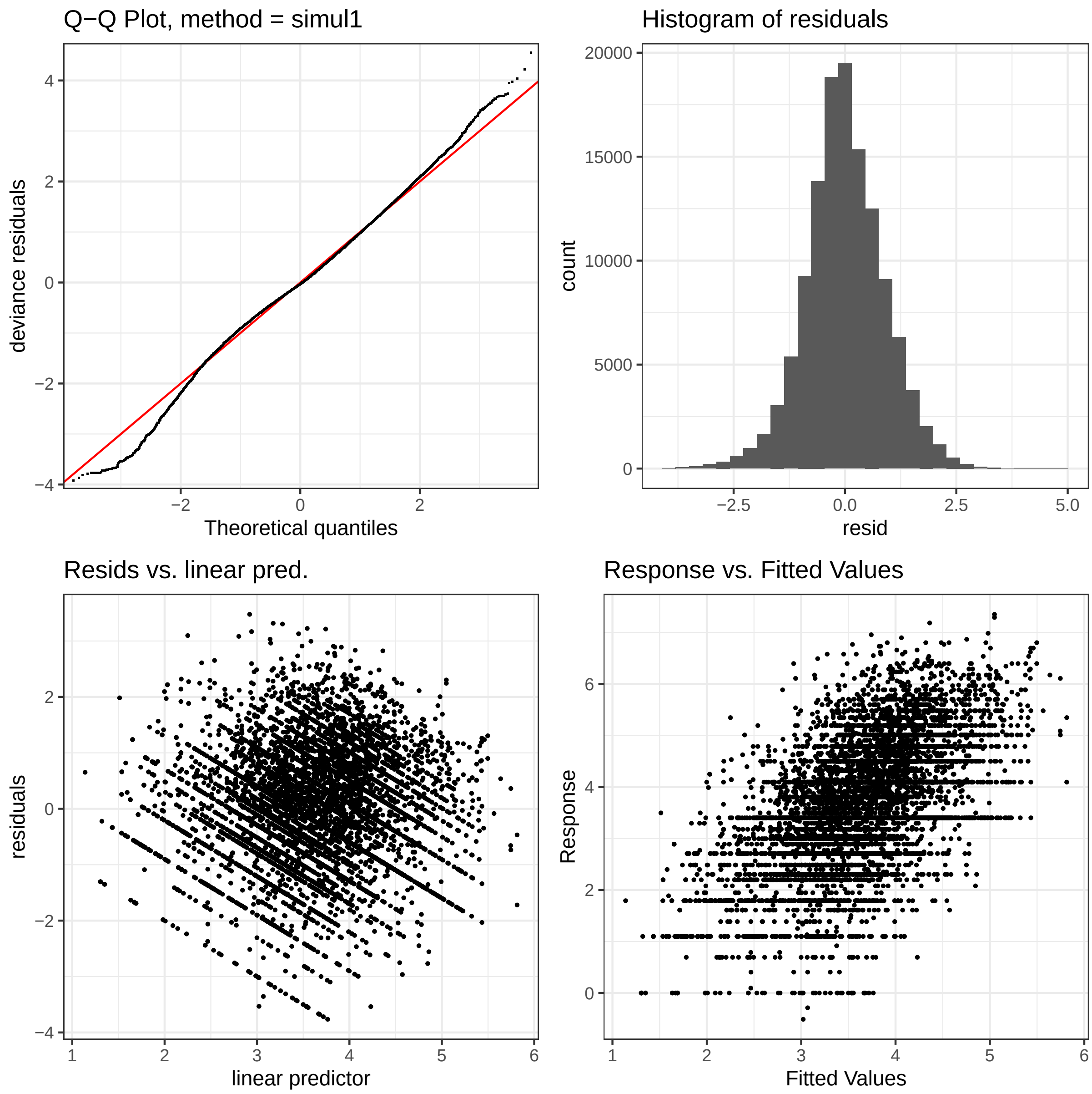

Figure B.8: Analysis of residuals for log-normal model

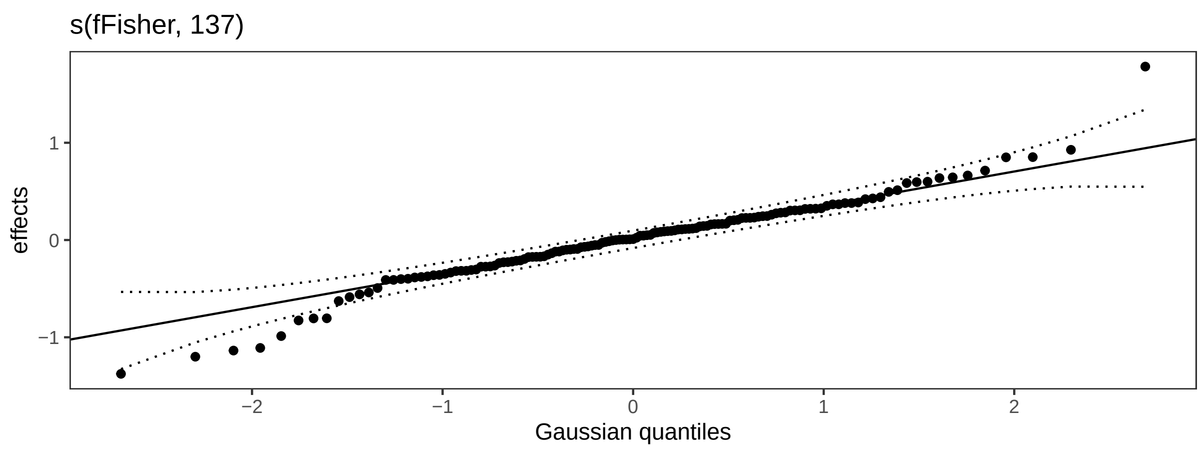

Figure B.9: Log-normal model effect plot: Fisher effect

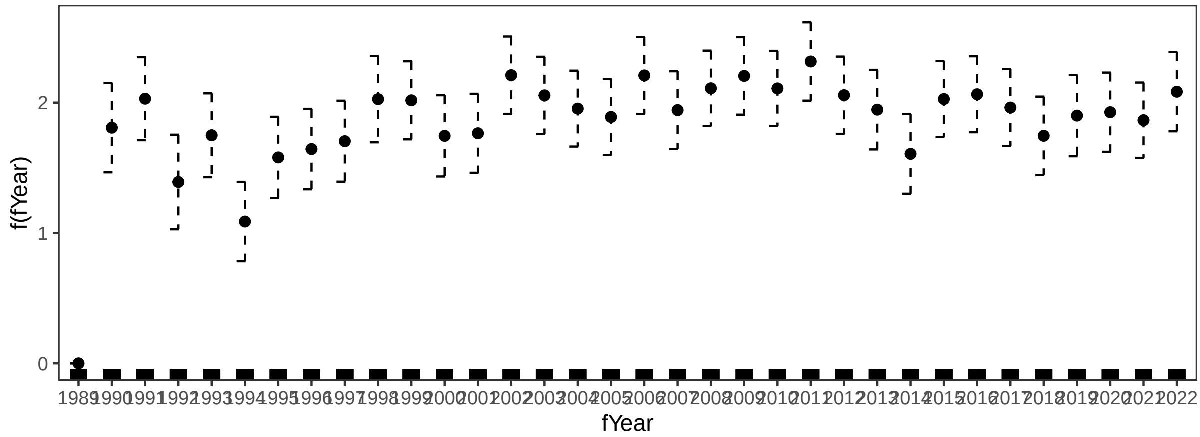

Figure B.10: Log-normal model effect plot: Year effect

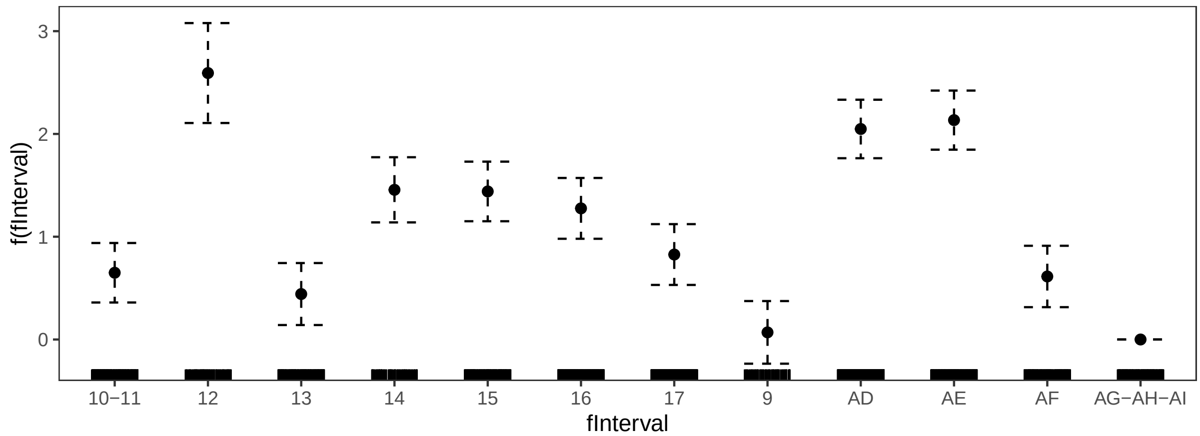

Figure B.11: Log-normal model effect plot: Interval effect

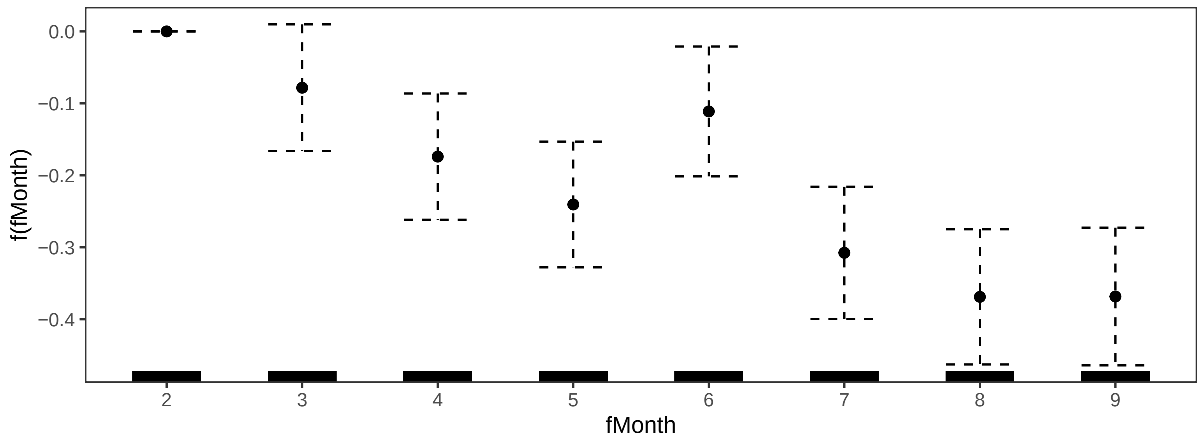

Figure B.12: Log-normal model effect plot: Month effect

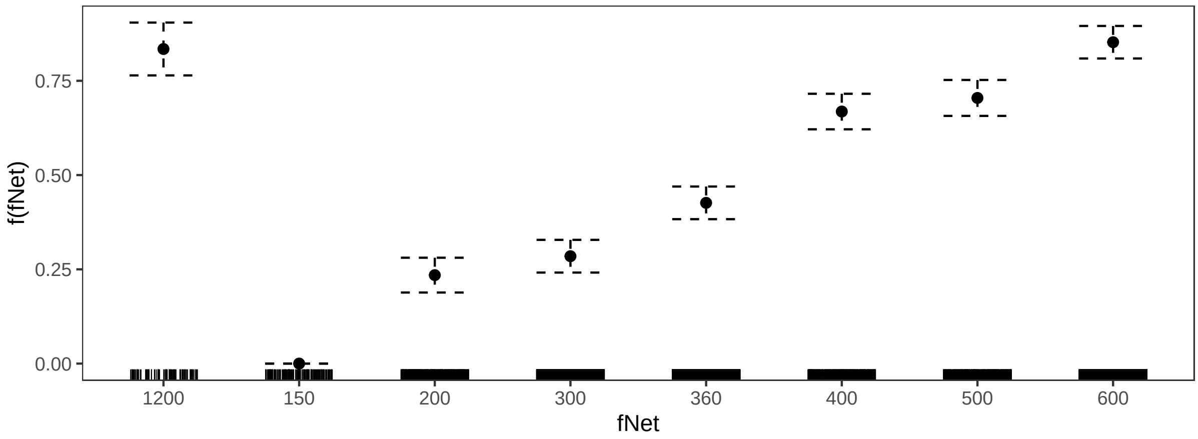

Figure B.13: Log-normal model effect plot: Net effect

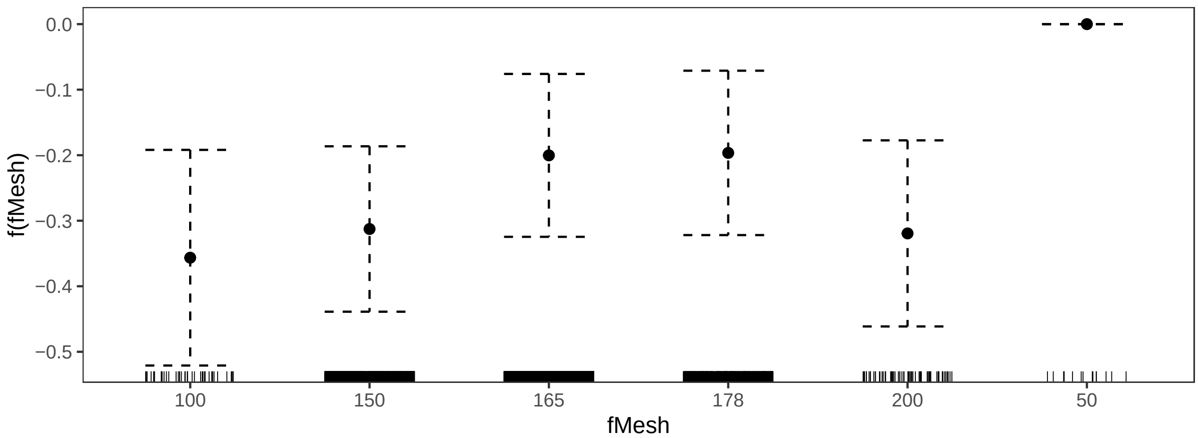

Figure B.14: Log-normal model effect plot: Mesh effect

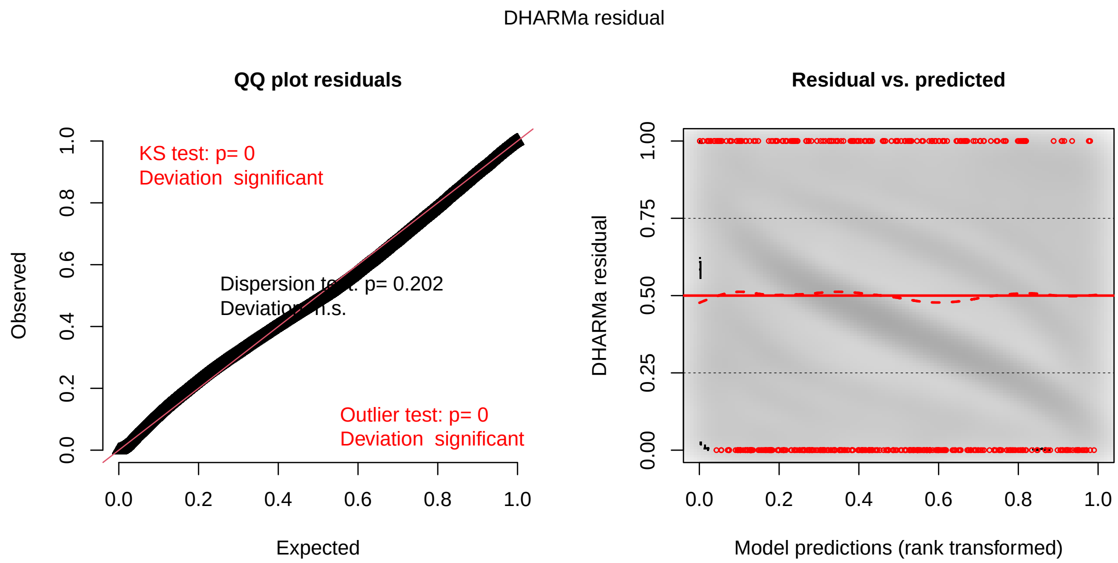

Figure B.15: Analysis of residuals for log-normal model from DHARMa package

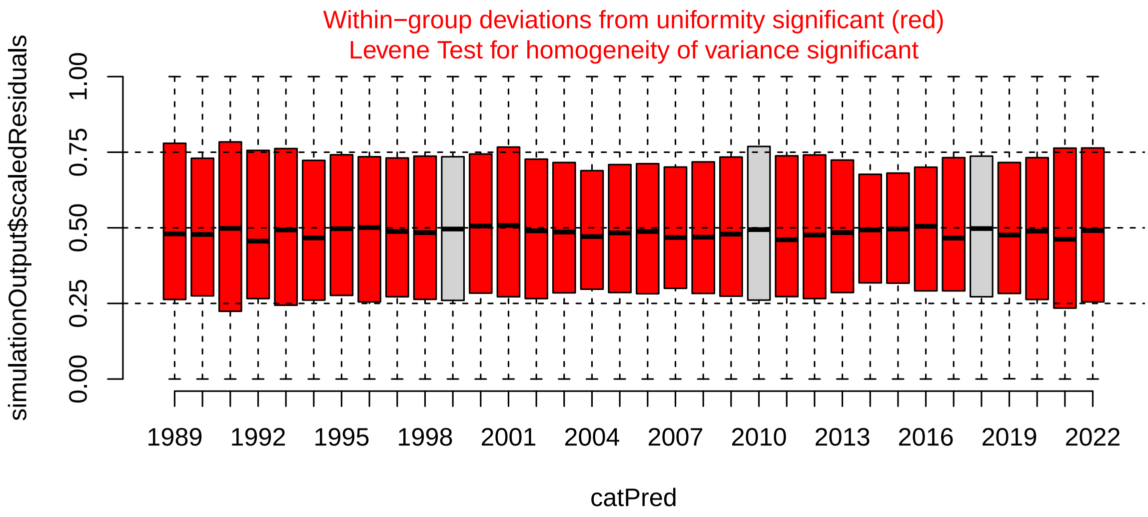

Figure B.16: Analysis of residuals for log-normal model for Year covariate

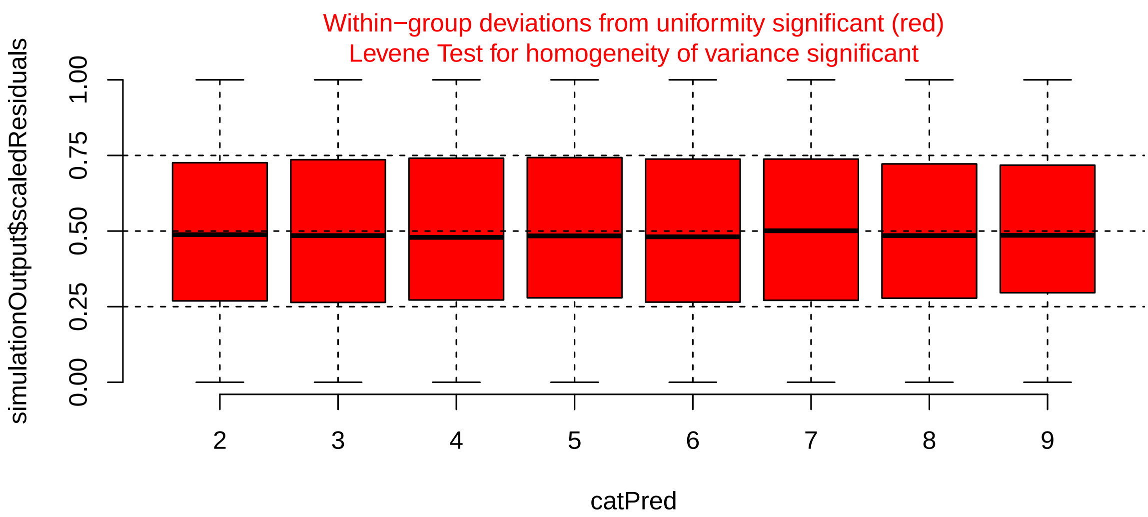

Figure B.17: Analysis of residuals for log-normal model for Month covariate

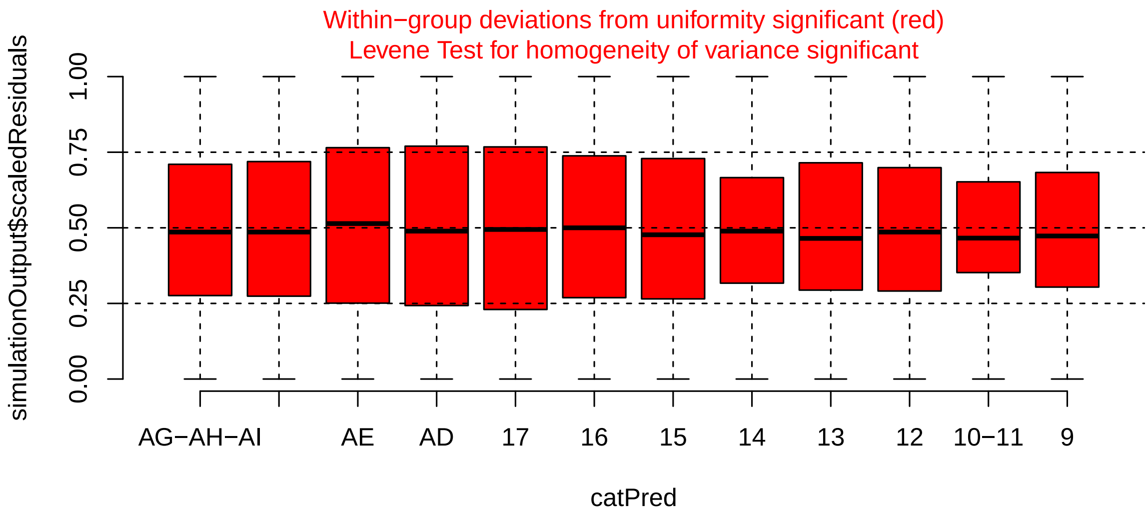

Figure B.18: Analysis of residuals for log-normal model for Interval covariate

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	Length	Age
1986	15	
1987	15	
1988	15	15
1989	15	16
1990	15	10
2016	36	36
2017	52	52
2018	33	33
2019	52	52
2020	23	23
2021	58	58
2022	75	75

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

C.2 Conditional age-at-length

Age data were input to the population model in the form of conditional age-at-length data (Figure C.1).

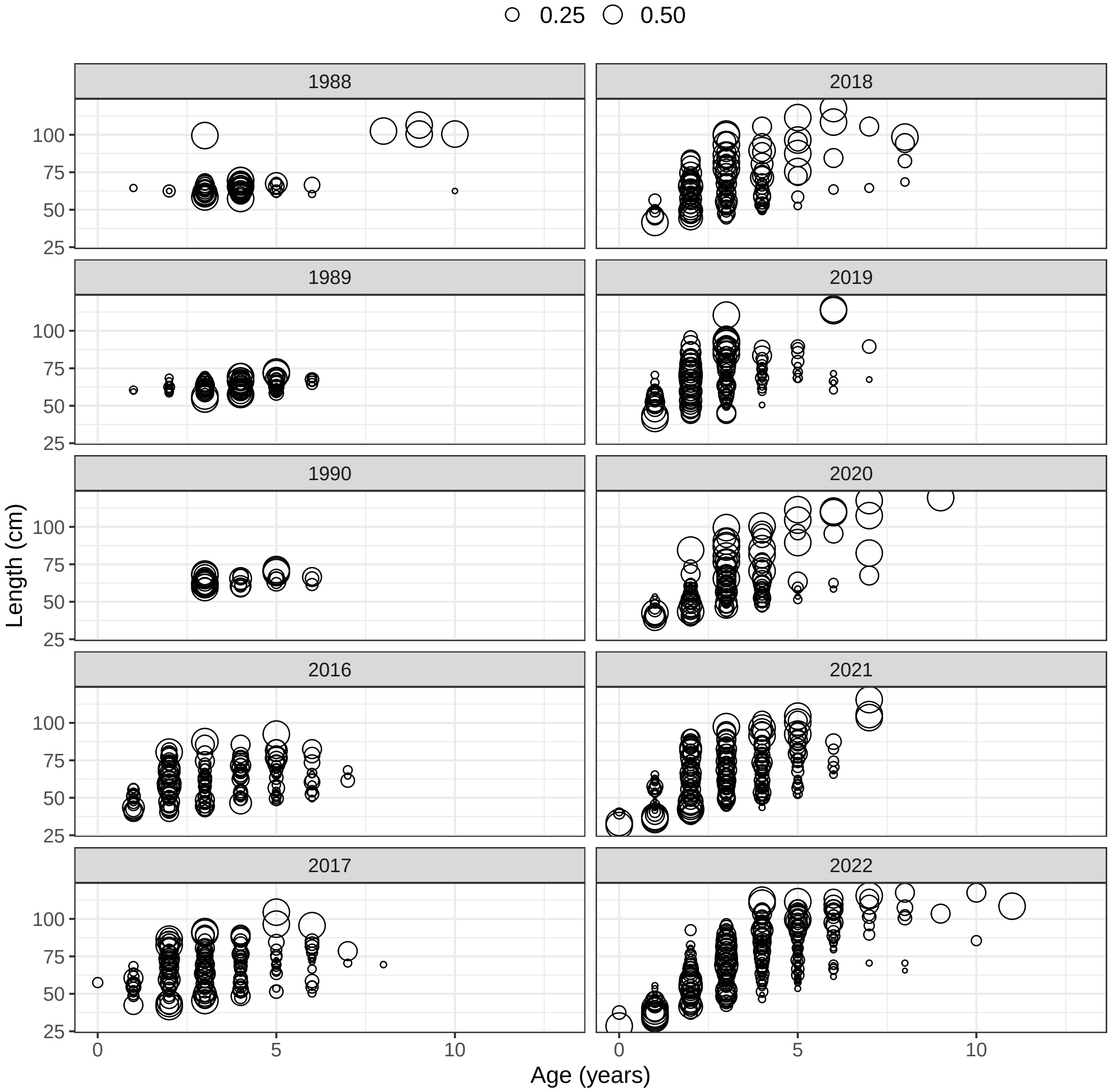

Figure C.1: Conditional age-at-length compositions for king threadfin between 1988 and 2022—circle size is proportional to relative sample size in each bin across rows (i.e. for a given length bin)

C.3 Biological data

C.3.1 Weight and length

The length–weight relationship for king threadfin in the Gulf of Carpentaria comes from McPherson (1997, Table 5.2)

$$W = 2.37 \times 10^{-5} \times \mathrm{FL}^{2.81} \quad \text{(C.1)}$$

where W denotes fish weight (kg) and FL is fork length (cm). The relationship came from a regression of $\log_e W$ on $\log_e \mathrm{FL}$, based on 169 fish with fork lengths from 20.5 to 101 cm. Its R^2 value was 0.99.

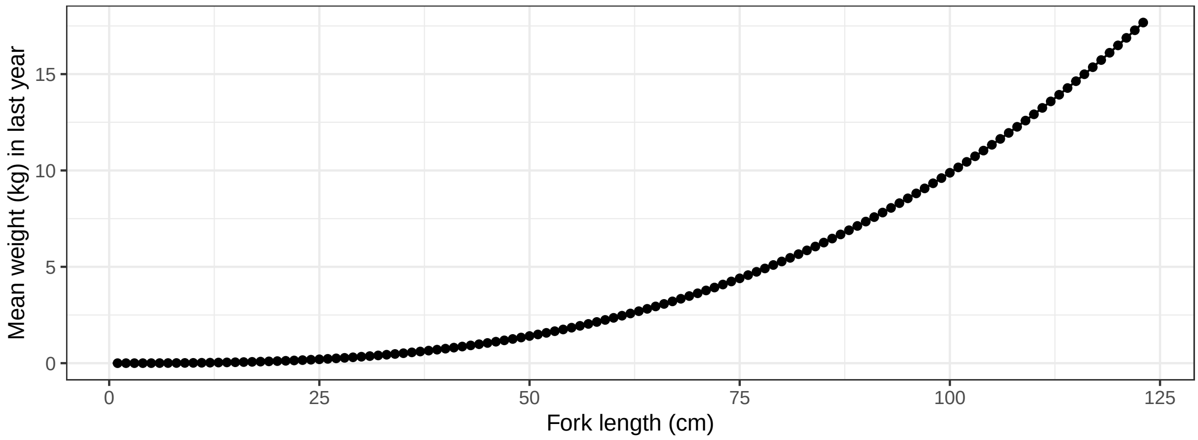

Figure C.2: Weight–length relationship for king threadfin in the Gulf of Carpentaria

C.3.2 Fecundity and maturity

Maturity is based on Pember et al. (2005).

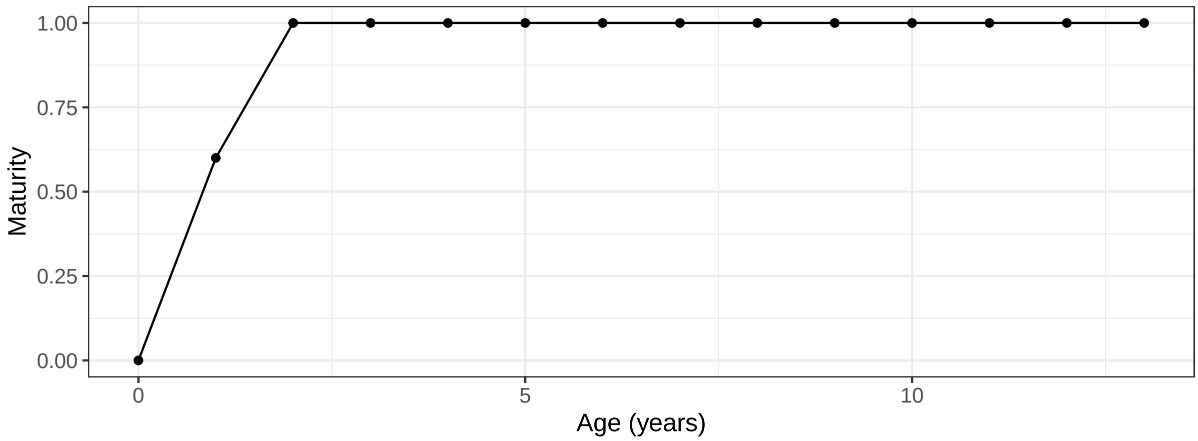

Figure C.3: Maturity at age for king threadfin in the Gulf of Carpentaria

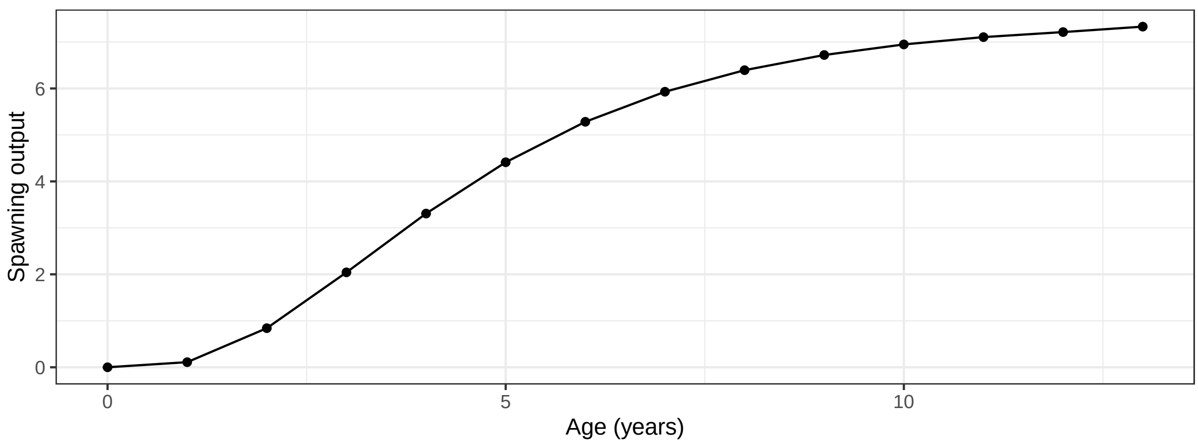

Figure C.4: Spawning output (maturity multiplied by fecundity) at age for king threadfin in the Gulf of Carpentaria

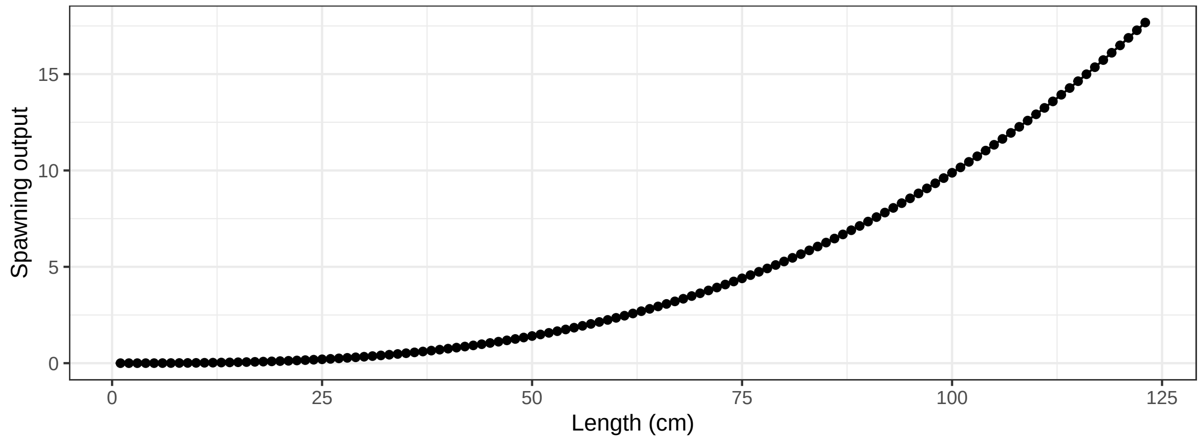

Figure C.5: Spawning output (maturity multiplied by fecundity) at length for king threadfin in the Gulf of Carpentaria

D Model outputs

D.1 MCMC diagnostics

Tables D.1 and D.2 show the potential scale reduction factor (R-hat) and effective sample sizes from the MCMC analysis for scenarios 1 to 8.

Parameter	Scen 1	Scen 2	Scen 3	Scen 4	Scen 5	Scen 6	Scen 7	Scen 8
M	1.02	1.02	1.04	1.02				
Lmin	1.07	1.01	1.01	1.01	1.01	1.01	1.02	1.01
Lmax	1.08	1.01	1.04	1.02	1.02	1.05	1.04	1.01
K	1.04	1.01	1.01	1.00	1.01	1.02	1.02	1.01
SD young	1.08	1.00	1.01	1.01	1.00	1.01	1.05	1.00
SD old	1.03	1.01	1.06	1.00	1.01	1.01	1.04	1.01
ln R0	1.03	1.01	1.02	1.01	1.01	1.04	1.28	1.00
ln Q	1.04	1.02	1.07	1.02	1.05	1.05	1.22	1.02
Q extra SD	1.03	1.01	1.03	1.00	1.00	1.03	1.04	1.00
L50	1.07	1.04	1.12	1.03	1.03	1.04	1.06	1.02
L 95width	1.02	1.01	1.06	1.02	1.03	1.05	1.22	1.01

Table D.1: Potential scale reduction factor (R-hat) values among the scenarios for Gulf of Carpentaria king theadfin—model is likely converged if R-hat is less than 1.05

Parameter	Scen 1	Scen 2	Scen 3	Scen 4	Scen 5	Scen 6	Scen 7	Scen 8
M	308	294	80	509				
Lmin	55	496	575	890	366	303	194	423
Lmax	62	244	267	850	179	111	55	157
K	90	663	215	1172	312	204	201	341
SD young	73	652	627	1088	386	440	351	481
SD old	267	676	68	997	239	278	282	773
ln R0	215	419	374	467	246	117	14	501
ln Q	153	144	27	637	99	93	7	150
Q extra SD	160	570	100	777	517	218	57	560
L50	60	162	11	175	112	94	70	139
L 95width	178	238	24	415	113	75	7	161

Table D.2: Effective sample size of each parameter among the scenarios for Gulf of Carpentaria king theadfin

D.2 Other outputs

D.2.1 Likelihood profile

Likelihood profile on R0, steepness and natural mortality was conducted on scenario 5 as reference.

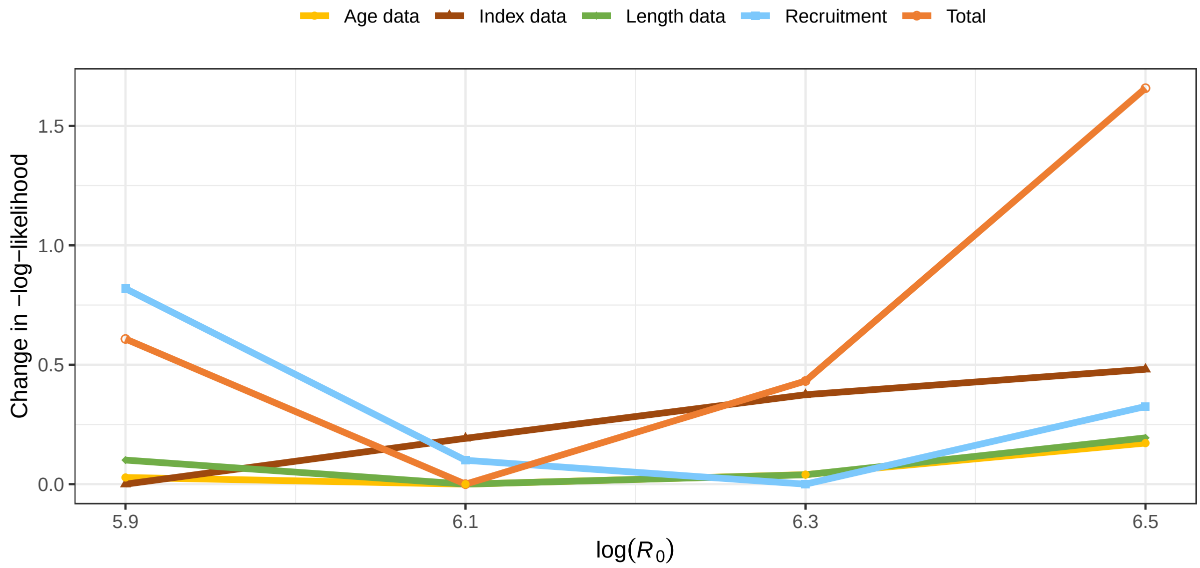

Figure D.1: Likelihood profile for ln(R0)

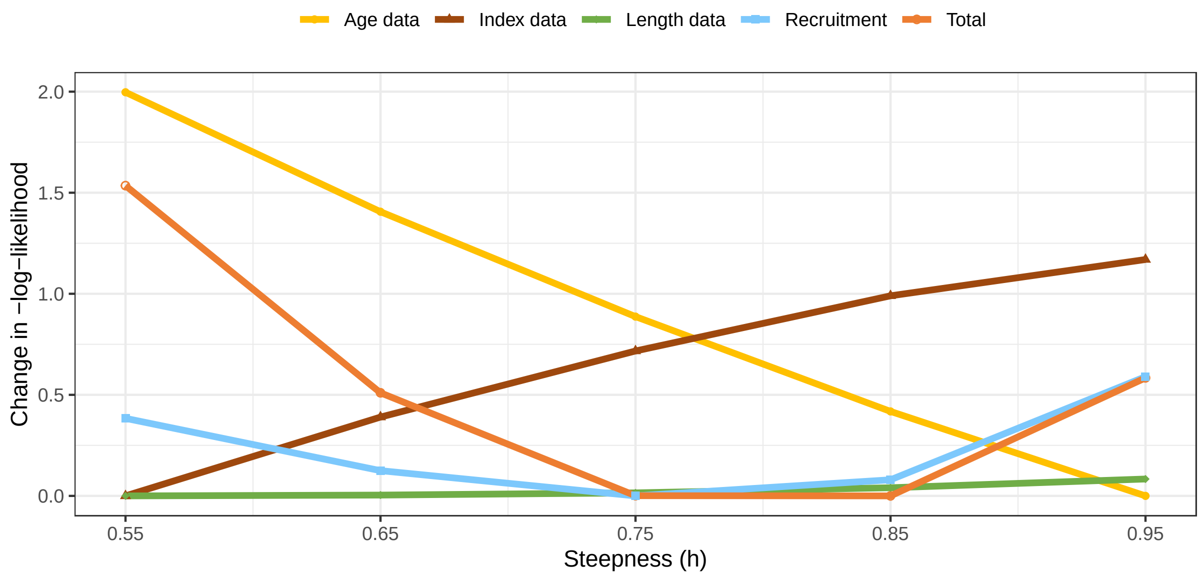

Figure D.2: Likelihood profile for steepness (h)

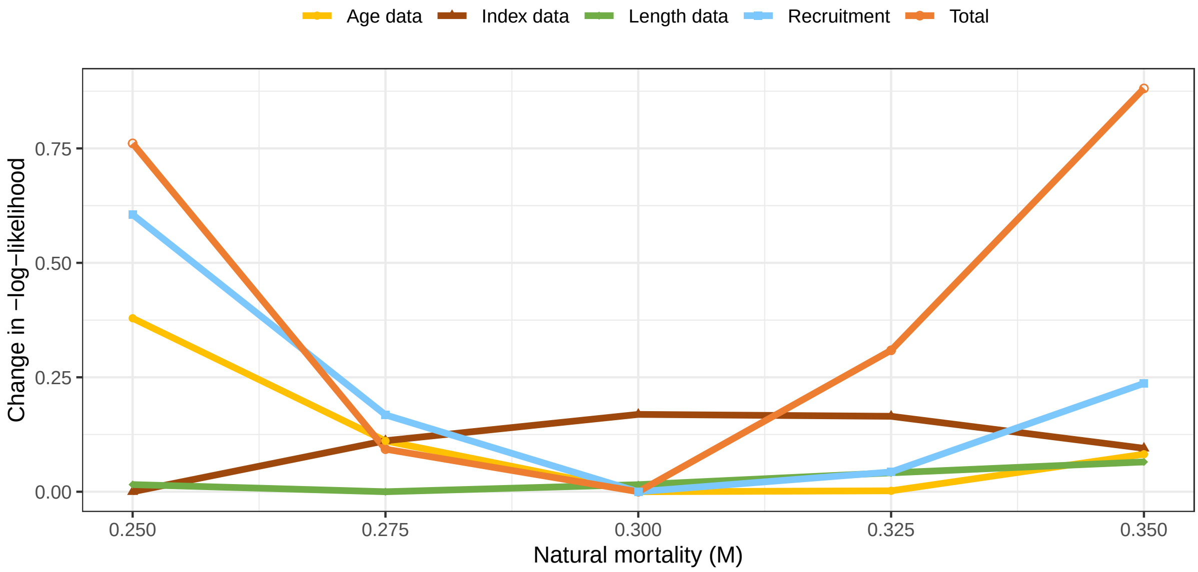

Figure D.3: Likelihood profile for natural mortality (M)

D.2.2 Stock-recruit curve

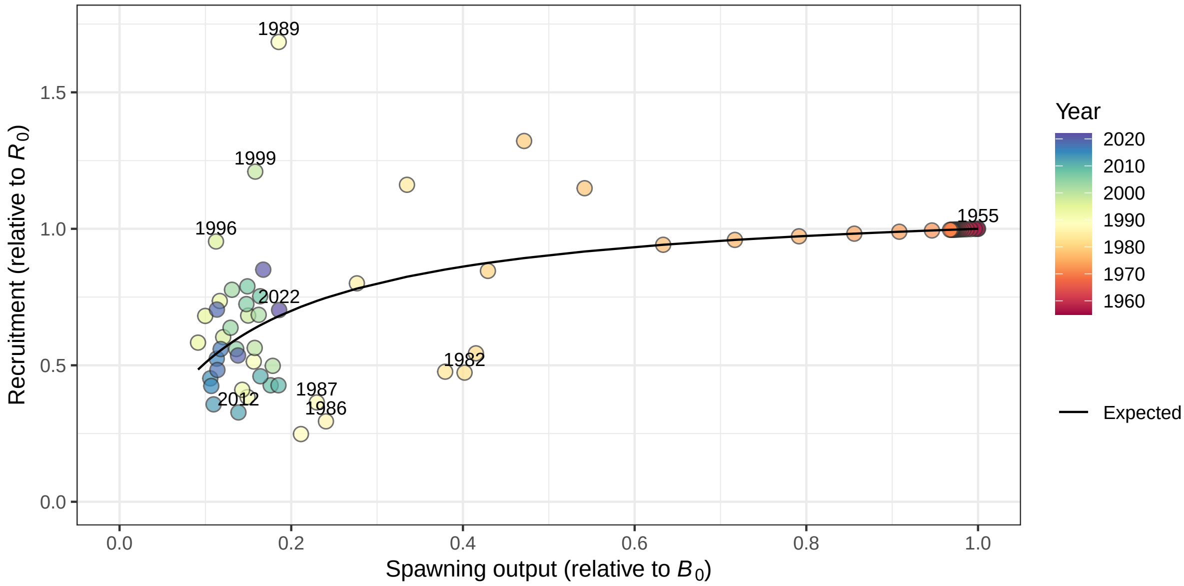

Figure D.4: Stock-recruit curve for king threadfin in the Gulf of Carpentaria based on the reference scenario 5 —point colors indicate year, with warmer colors indicating earlier years and cooler colors in showing later years

D.2.3 Fishing mortality

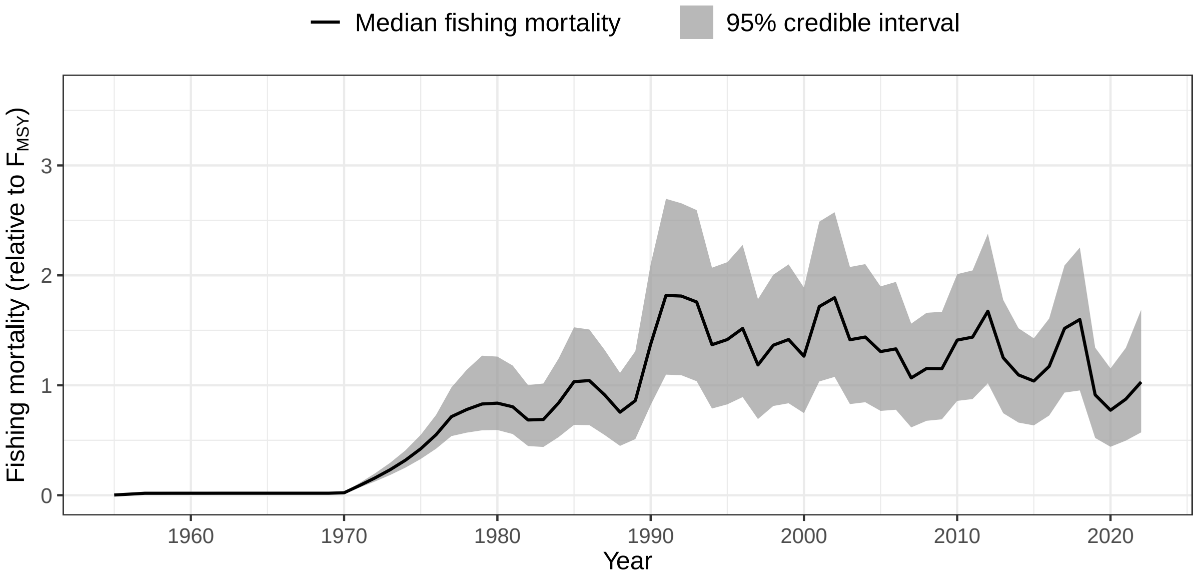

Figure D.5: Time series of fishing mortality ratio (F/F_{MSY}) from the ensemble model

D.2.4 Recruitment deviations

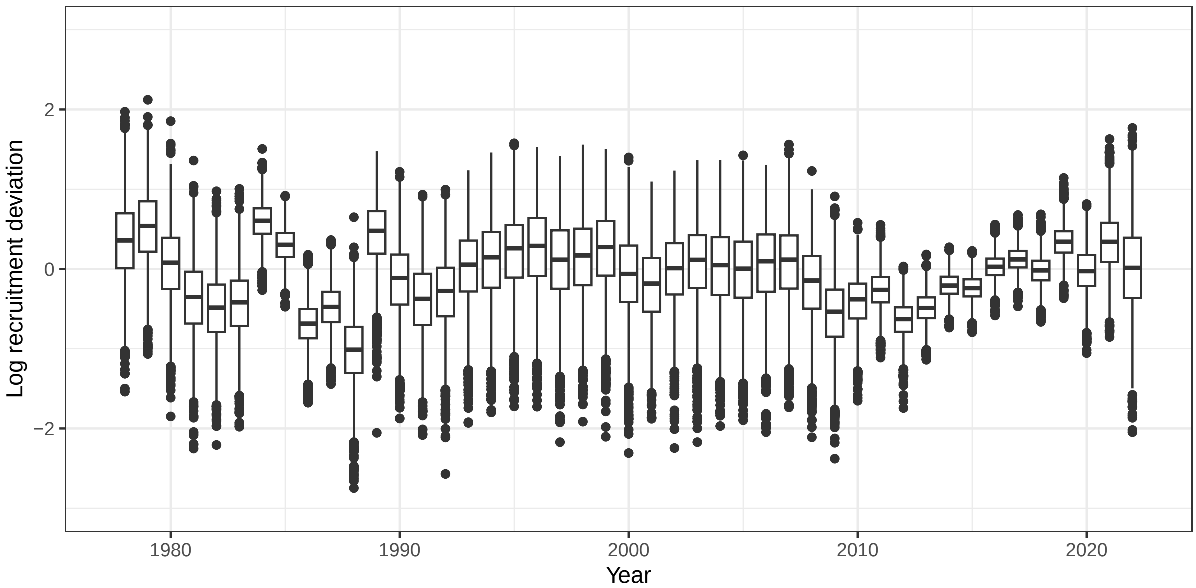

Figure D.6: Recruitment deviations from the ensemble model—whiskers represent 95% credible intervals, boxes represent 50% credible intervals, horizontal bars represent medians, and the points represent outliers

D.2.5 Sensitivity: parameter estimates and derived quantities

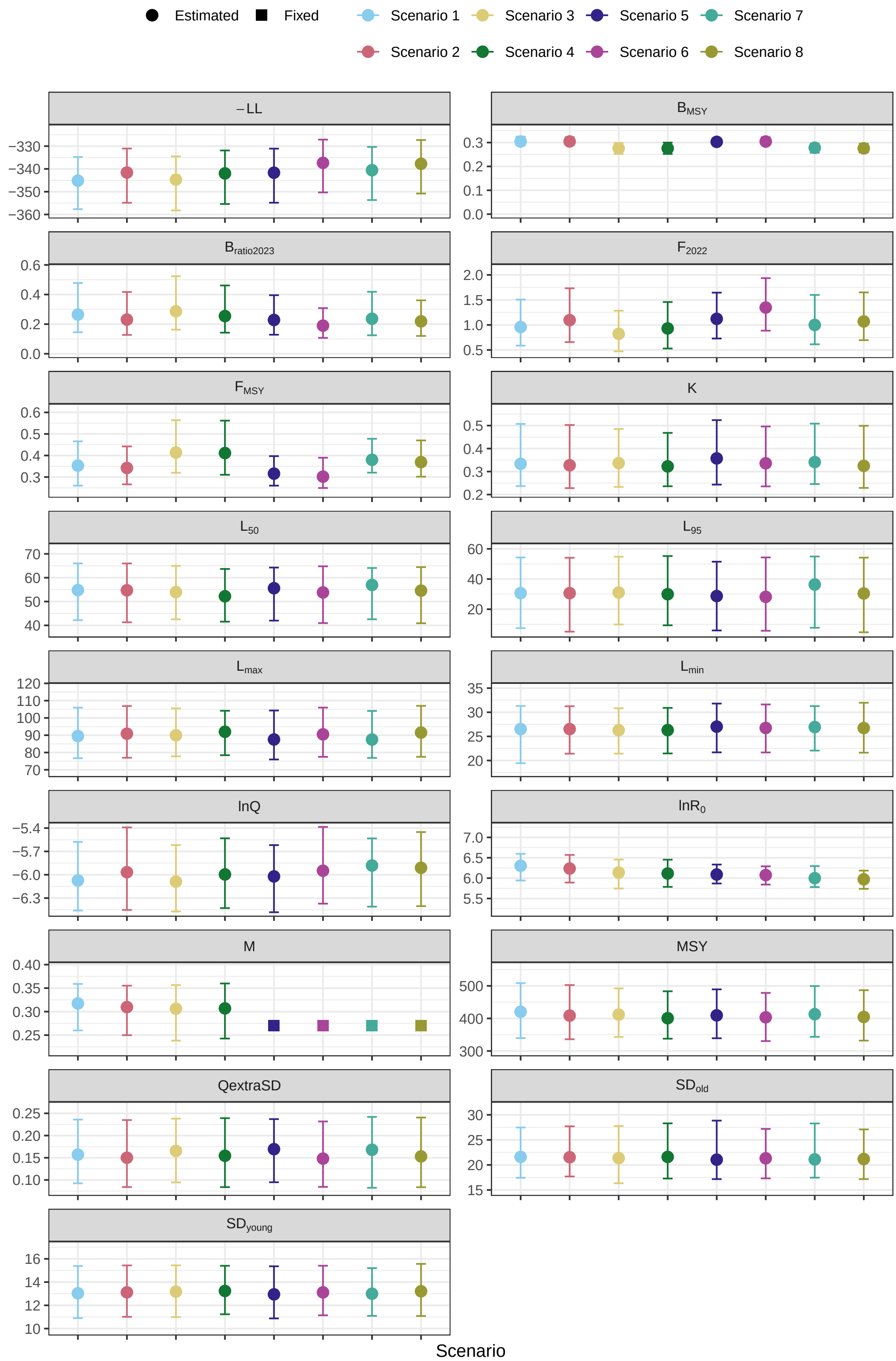

Figure D.7: Comparison of parameter estimates and derived quantities amongst the 8 scenarios included in the ensemble model

E Detailed model outputs

E.1 Scenario 1

Parameter	Estimate	Phase	Min	Max	Initial value	Standard deviation
M	0.29	6	0.21	0.38	0.27	0.04
L_{min}	26.71	2	15.00	33.00	20.00	2.51
L_{max}	86.60	2	65.00	110.00	75.00	6.52
K	0.37	3	0.20	0.70	0.40	0.07
SD_{young}	12.83	3	8.00	18.00	13.00	1.11
SD_{old}	20.91	3	15.00	35.00	20.00	2.68
$\ln R_0$	6.08	1	5.00	8.00	7.00	0.19
$\ln q$	-5.92	1	-6.50	-5.20	-6.00	0.23
QextraSD	0.08	7	0.00	0.50	0.10	0.03
L_{50}	51.66	4	30.00	70.00	55.00	4.73
$L_{95\text{width}}$	20.59	4	1.00	60.00	25.00	8.28

Table E.1: Stock Synthesis parameter estimates for Scenario 1 population model for king threadfin in the Gulf of Carpentaria, based on maximum likelihood estimation

Symbol	MCMC median	MCMC 2.5%	MCMC 97.5%
M	0.32	0.26	0.36
L_{min}	26.51	19.44	31.29
L_{max}	89.52	76.71	105.94
K	0.33	0.24	0.51
SD_{young}	13.04	10.90	15.38
SD_{old}	21.60	17.44	27.47
$\ln R_0$	6.30	5.94	6.60
$\ln q$	-6.07	-6.46	-5.58
QextraSD	0.16	0.09	0.24
L_{50}	54.78	42.19	65.98
$L_{95\text{width}}$	30.69	7.43	54.29

Table E.2: Stock Synthesis parameter estimates for Scenario 1 population model for king threadfin in the Gulf of Carpentaria, based on MCMC estimation

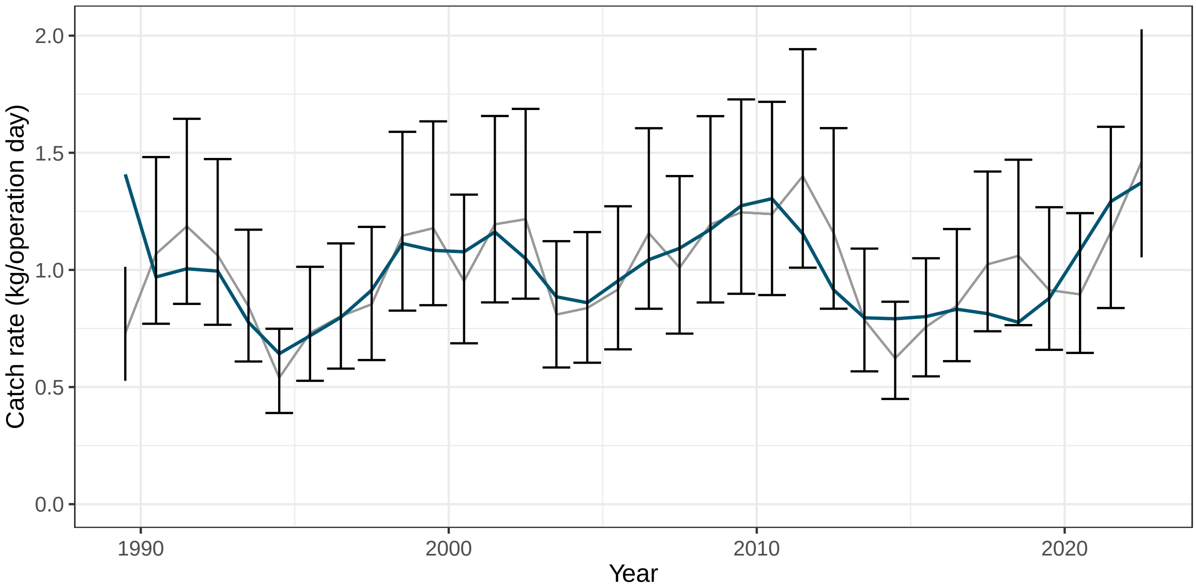

Figure E.1: Scenario 1: Model predictions (blue line) to standardised catch rates for king threadfin in the Gulf of Carpentaria, based on maximum likelihood estimation—grey line and error bars represent the model input and associated uncertainty

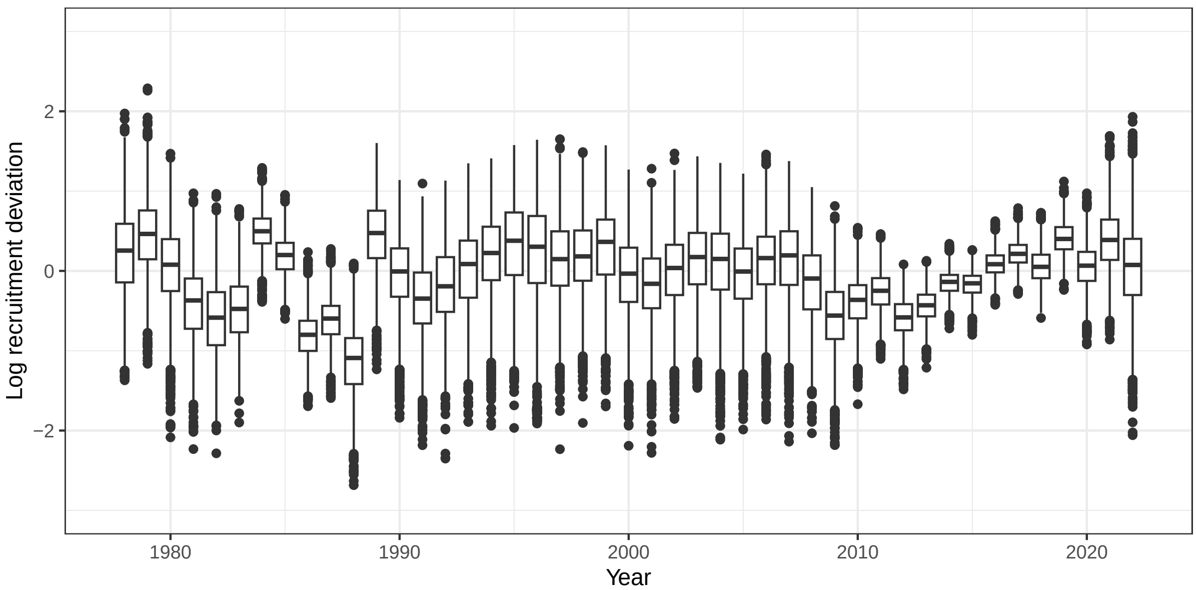

Figure E.2: Scenario 1: Recruitment deviations—whiskers represent 95% credible intervals, boxes represent 50% credible intervals, horizontal bars represent medians, and the points represent outliers

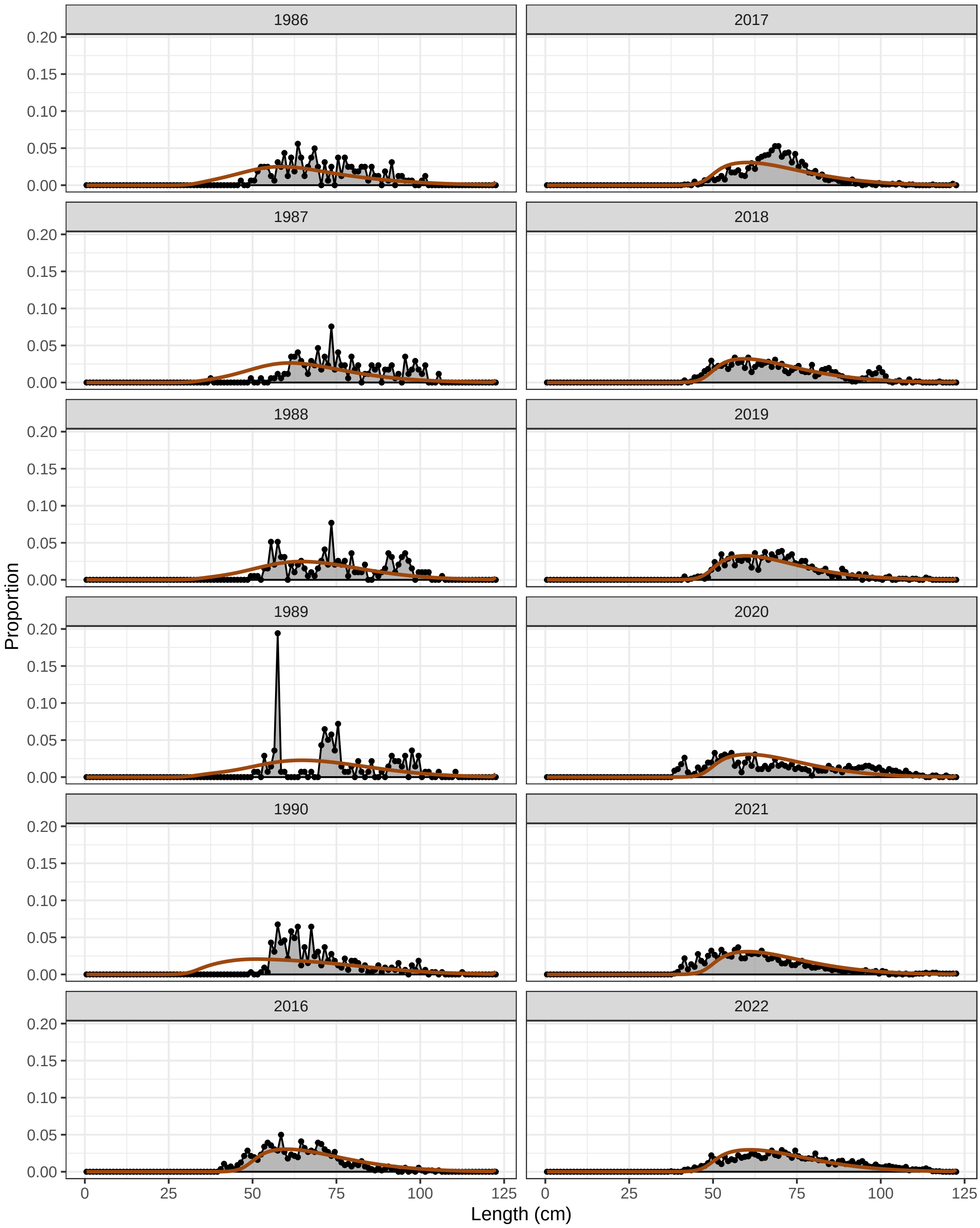

Figure E.3: Scenario 1: Fits to length structures, based on maximum likelihood estimation—the grey area and black line represent data inputs and the red line represents the model fits

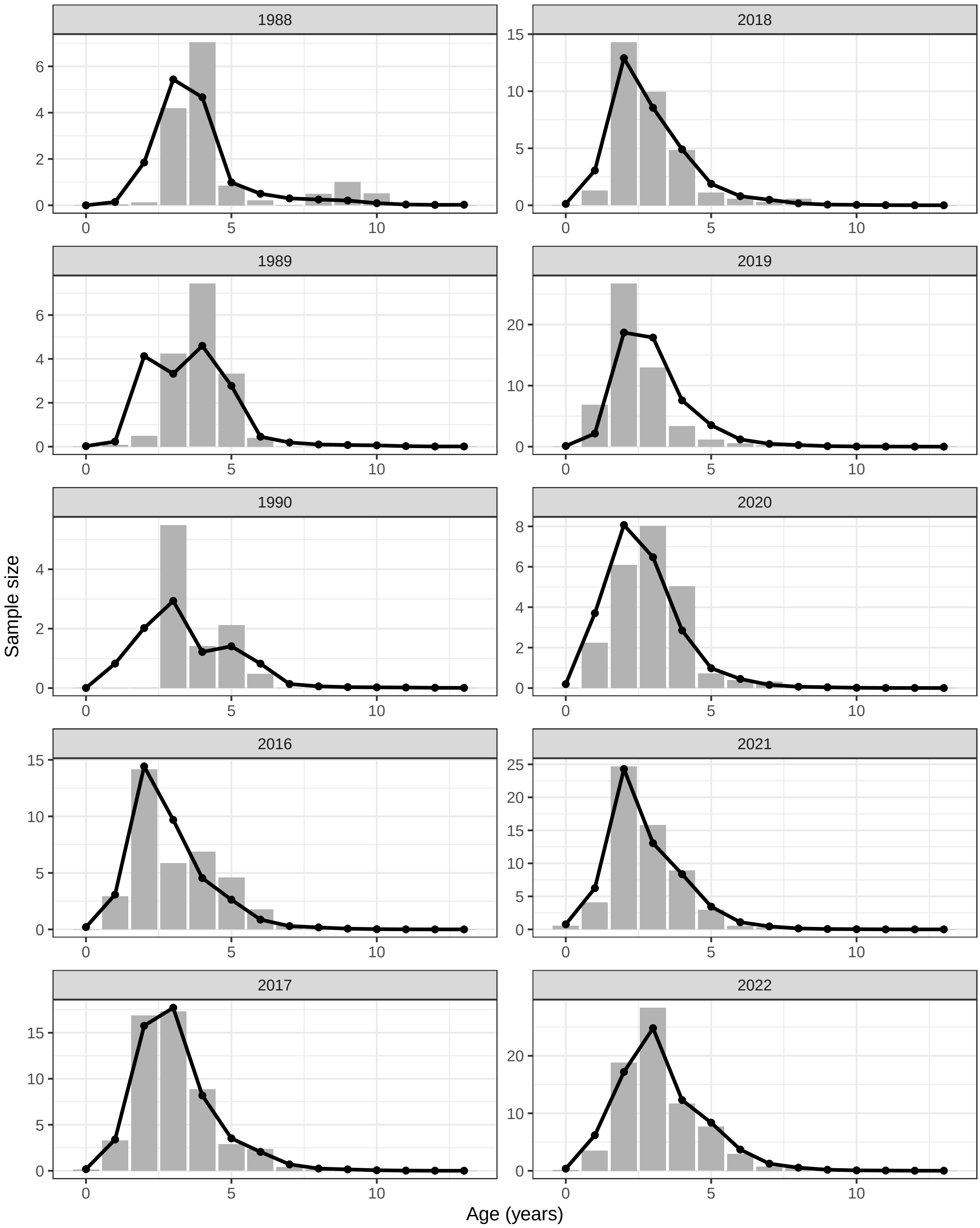

Figure E.4: Scenario 1: Fits to age structures, based on maximum likelihood estimation—grey bars represent input data and black line and points represent model fits

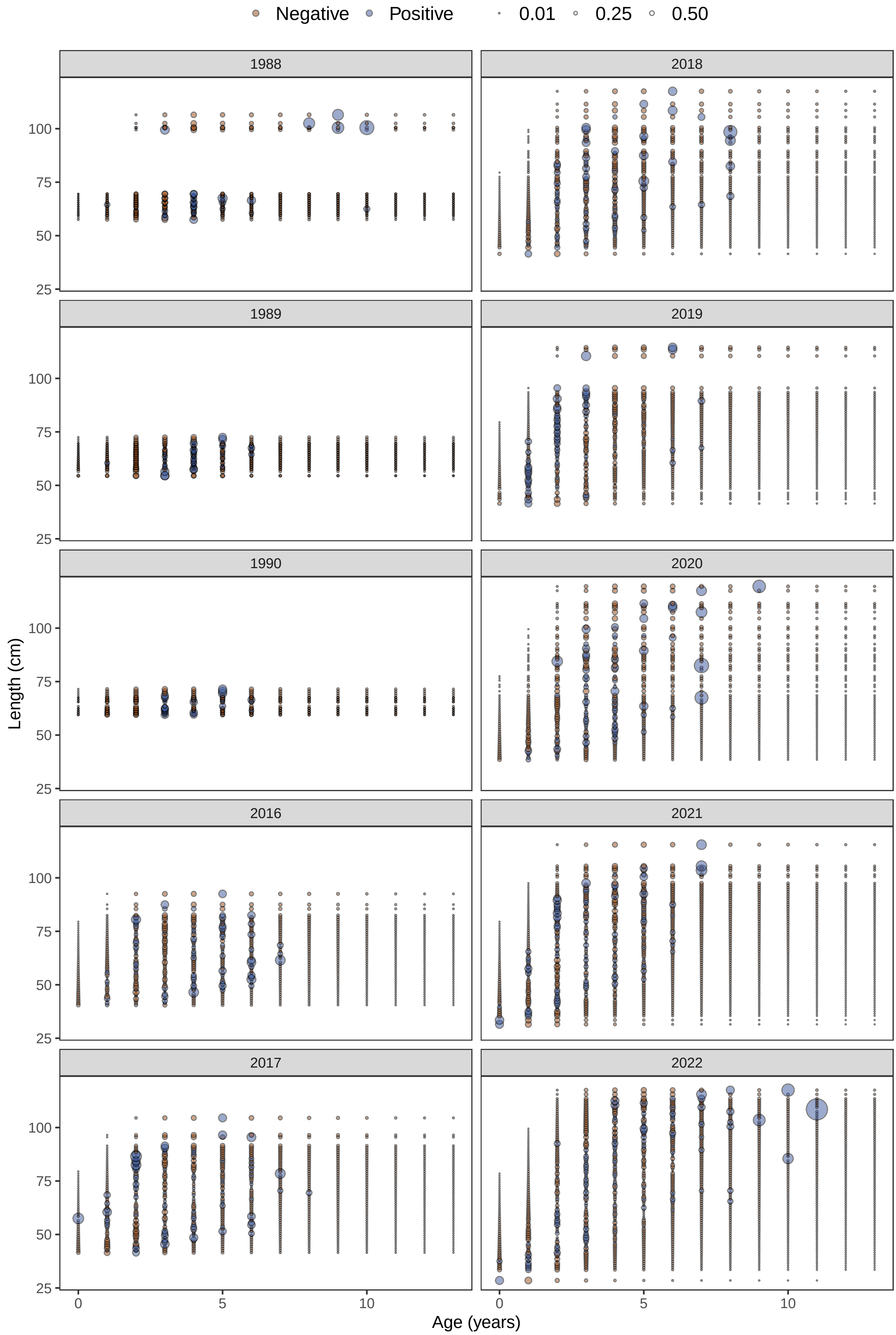

Figure E.5: Scenario 1: Pearson residuals for age-at-length compositions, based on maximum likelihood estimation—circle size represents the magnitude of the Pearson residual

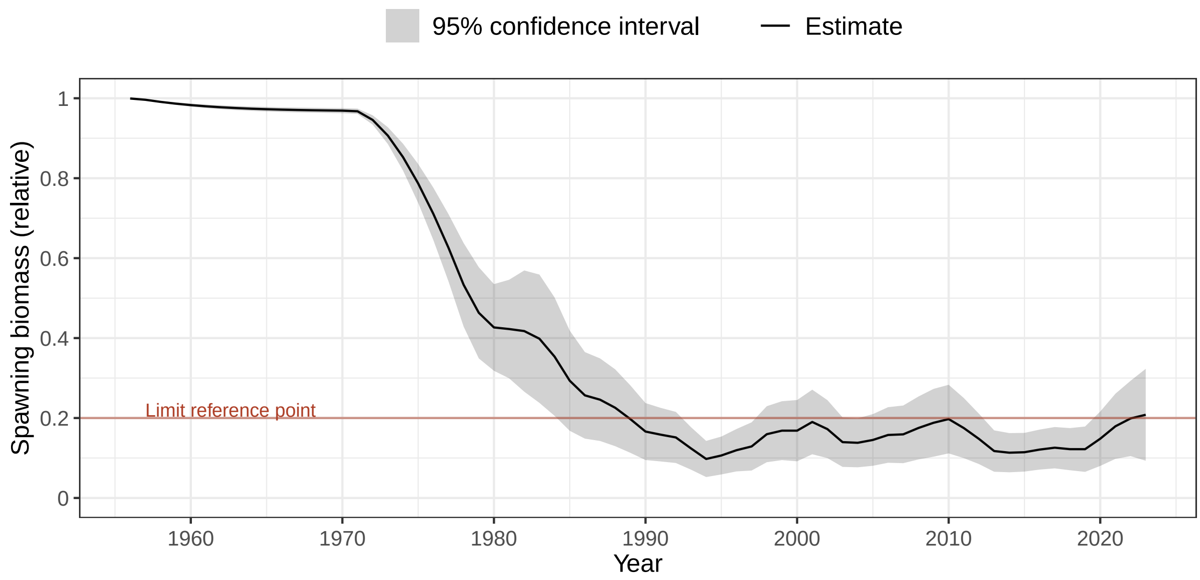

Figure E.6: Scenario 1: Predicted spawning biomass trajectory relative to unfished for king threadfin in the Gulf of Carpentaria, based on maximum likelihood estimation

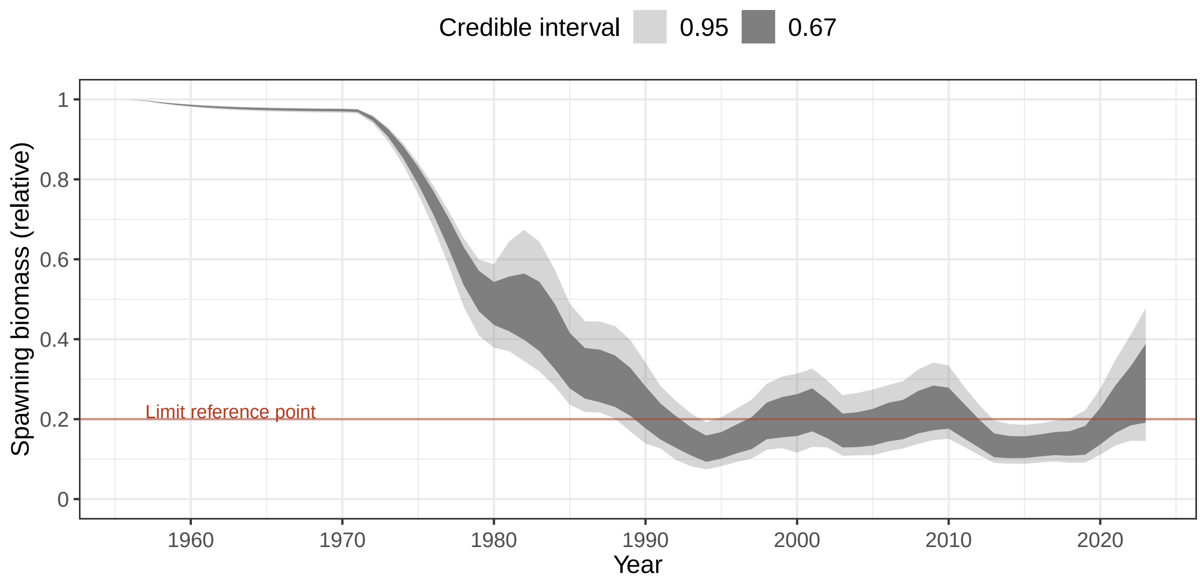

Figure E.7: Scenario 1: Predicted spawning biomass trajectory relative to unfished for king threadfin in the Gulf of Carpentaria, based on MCMC

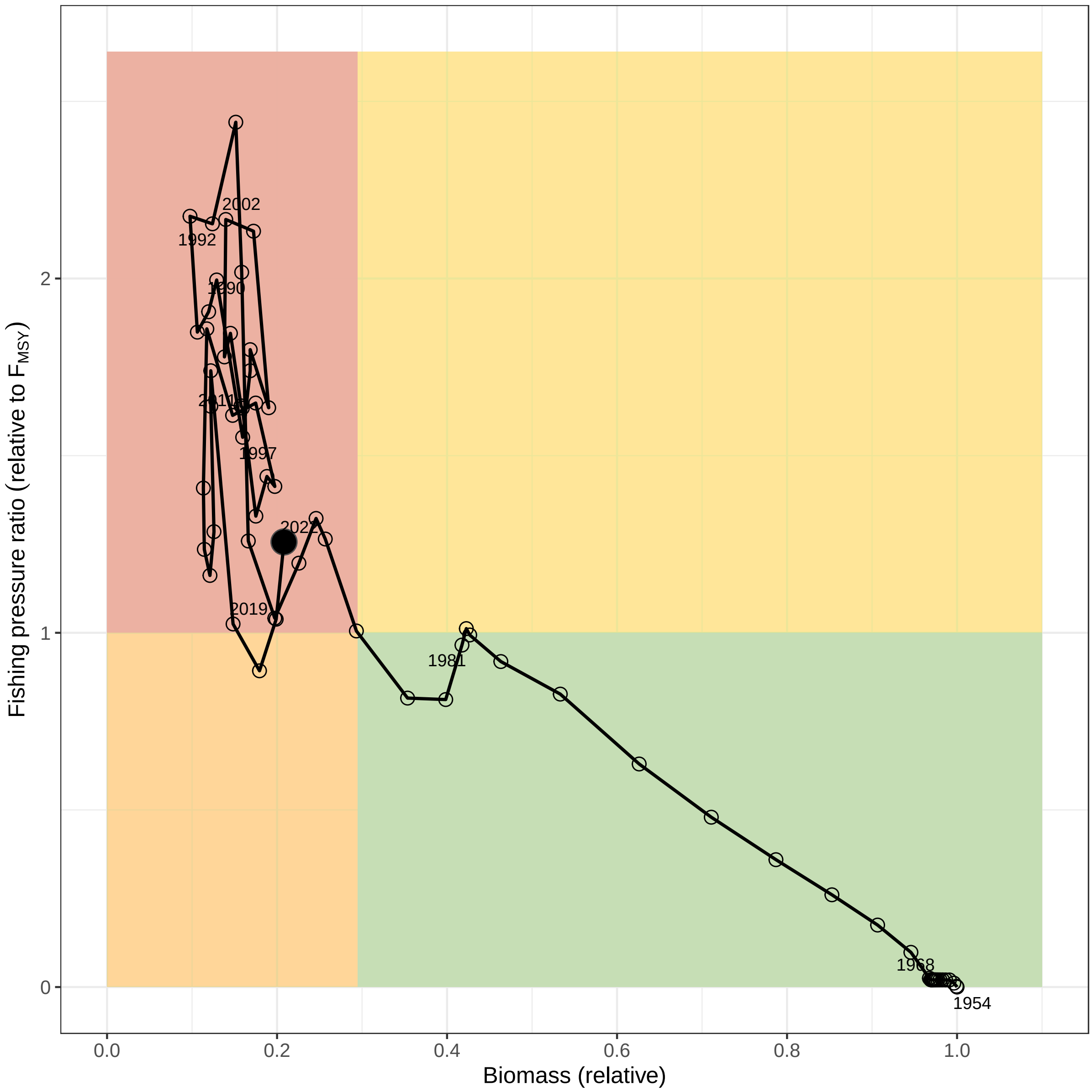

Figure E.8: Scenario 1: Stock status indicator trajectory for king threadfin in the Gulf of Carpentaria, based on maximum likelihood estimation

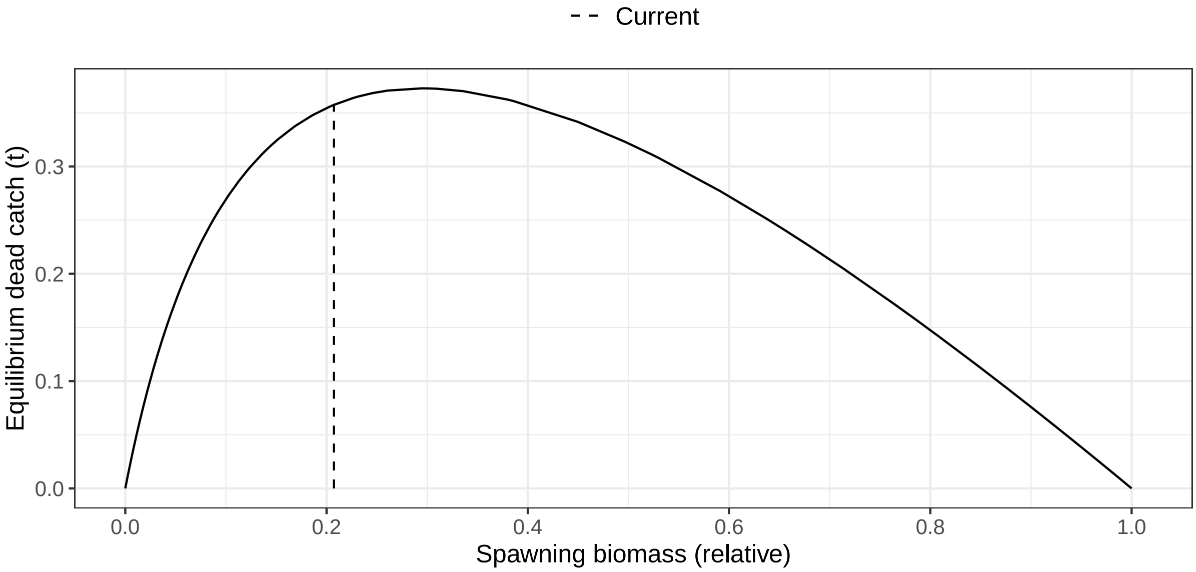

Figure E.9: Scenario 1: Equilibrium dead catch curve for king threadfin in the Gulf of Carpentaria, based on maximum likelihood estimation

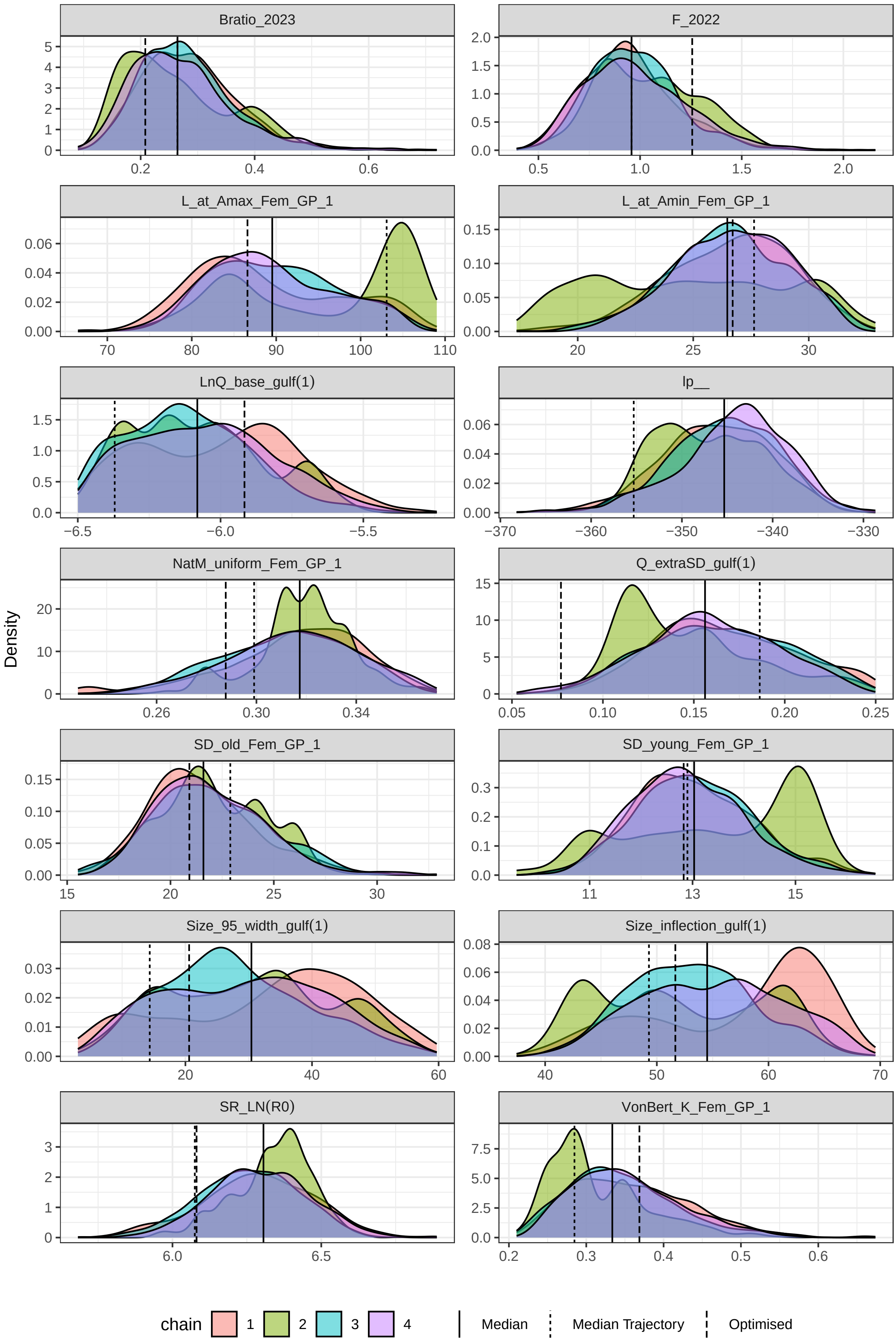

Figure E.10: Scenario 1: Posterior density of MCMC iterations. “Median” line shows median parameter value for MCMC iterations “Optimised” shows the parameter value found from maximum likelihood estimates.

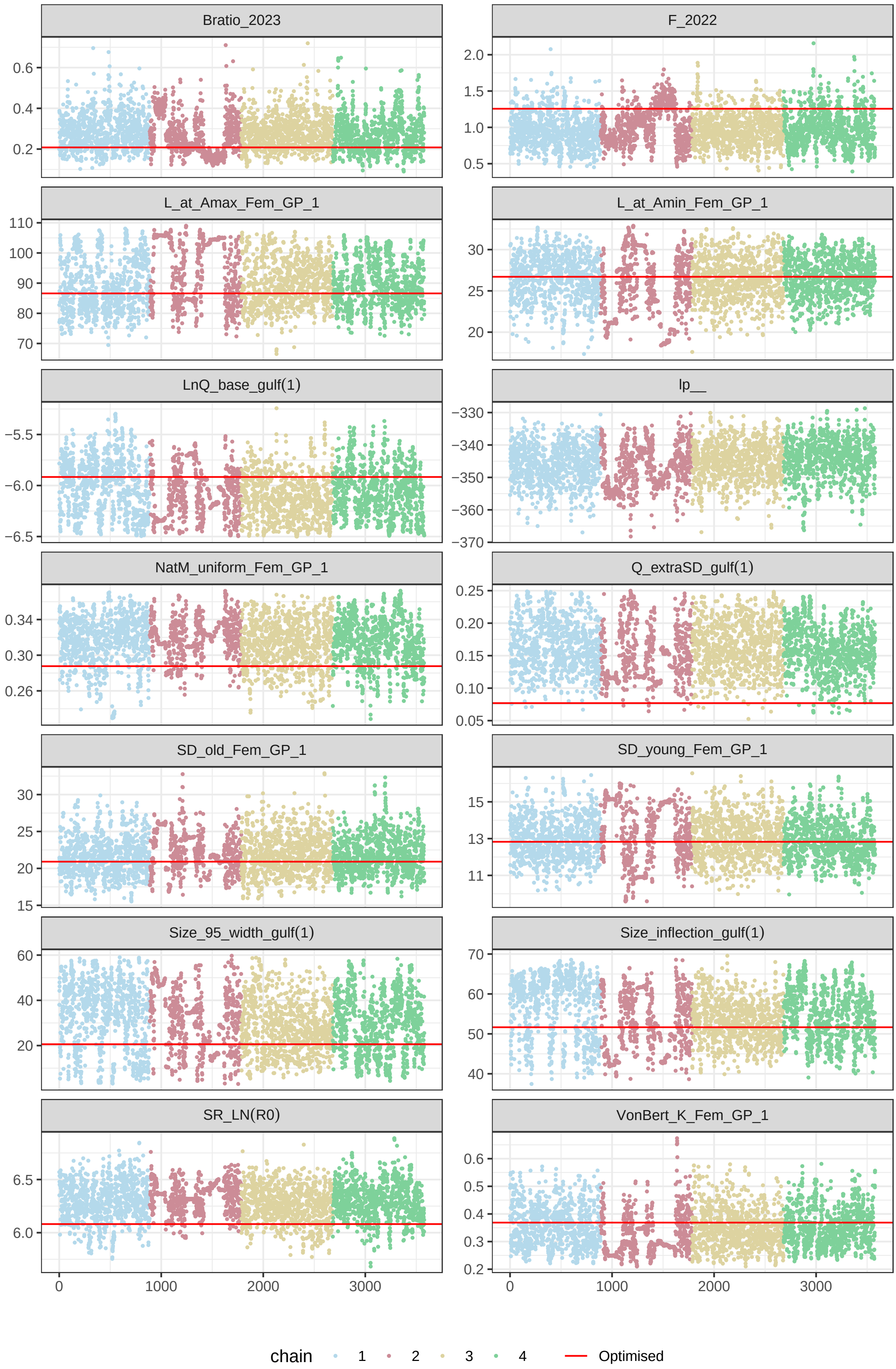

Figure E.11: Scenario 1: Trace plot of MCMC iterations—“Optimised” shows the parameter value found from maximum likelihood estimates

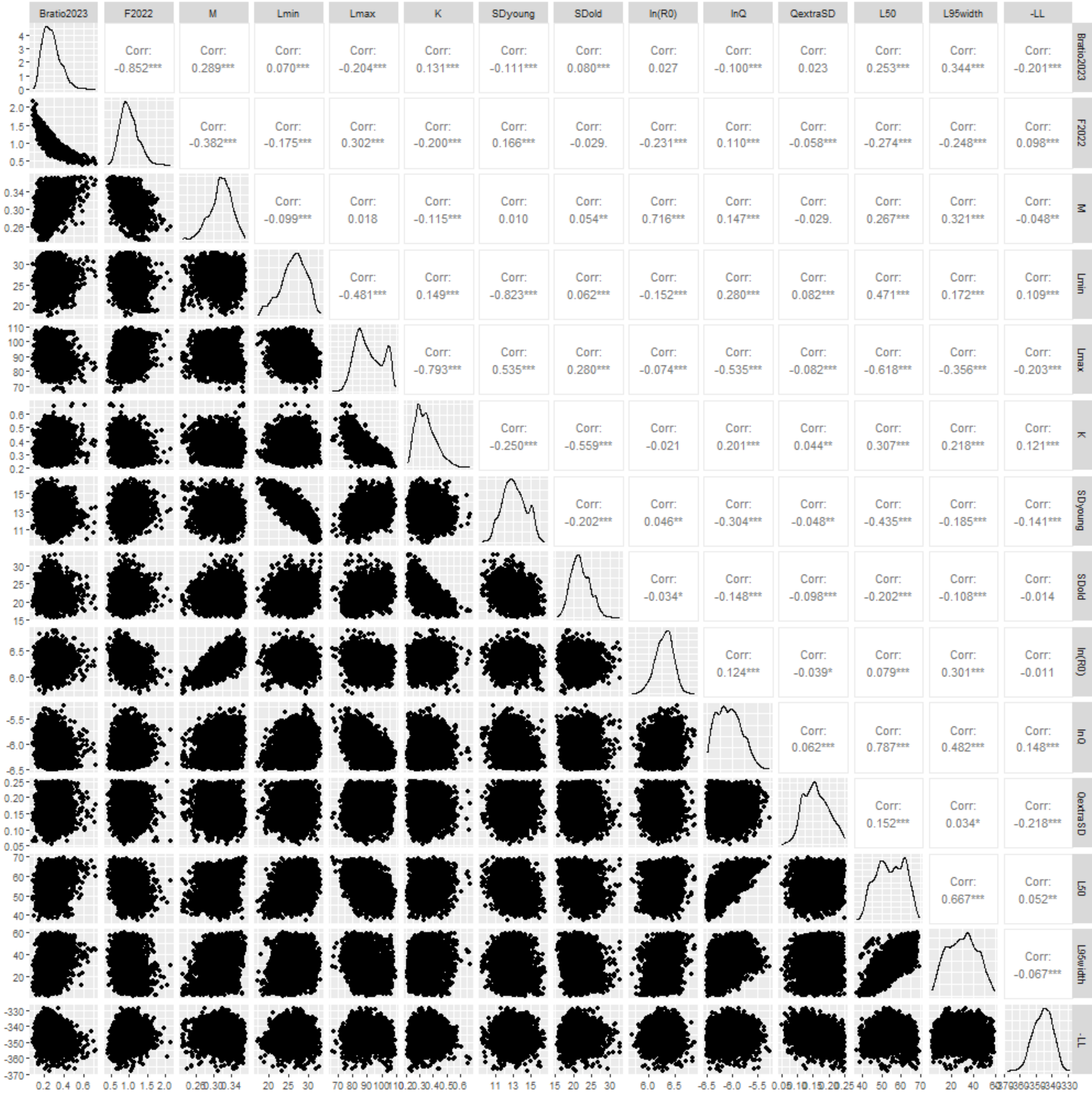

Figure E.12: Scenario 1: Correlation plot of MCMC iterations

E.2 Scenario 2

Parameter	Estimate	Phase	Min	Max	Initial value	Standard deviation
M	0.27	6	0.21	0.38	0.27	0.03
$L_{\min}$	26.67	2	15.00	33.00	20.00	2.53
$L_{\max}$	87.29	2	65.00	110.00	75.00	6.50
K	0.36	3	0.20	0.70	0.40	0.07
$\mathrm{SD}_{\mathrm{young}}$	12.95	3	8.00	18.00	13.00	1.13
$\mathrm{SD}_{\mathrm{old}}$	20.61	3	15.00	35.00	20.00	2.60
$\ln R_0$	6.02	1	5.00	8.00	7.00	0.19
$\ln q$	-5.79	1	-6.50	-5.20	-6.00	0.21
QextraSD	0.07	7	0.00	0.50	0.10	0.03
L_{50}	51.34	4	30.00	70.00	55.00	4.73
$L_{95\mathrm{width}}$	20.98	4	1.00	60.00	25.00	8.64

Table E.3: Stock Synthesis parameter estimates for Scenario 2 population model for king threadfin in the Gulf of Carpentaria, based on maximum likelihood estimation

Symbol	MCMC median	MCMC 2.5%	MCMC 97.5%
M	0.31	0.25	0.36
$L_{\min}$	26.52	21.41	31.25
$L_{\max}$	90.88	76.96	106.87
K	0.33	0.23	0.50
$\mathrm{SD}_{\mathrm{young}}$	13.12	11.01	15.43
$\mathrm{SD}_{\mathrm{old}}$	21.54	17.70	27.71
$\ln R_0$	6.24	5.89	6.57
$\ln q$	-5.97	-6.45	-5.39
QextraSD	0.15	0.08	0.23
L_{50}	54.72	41.29	65.98
$L_{95\mathrm{width}}$	30.67	5.15	54.12

Table E.4: Stock Synthesis parameter estimates for Scenario 2 population model for king threadfin in the Gulf of Carpentaria, based on MCMC estimation

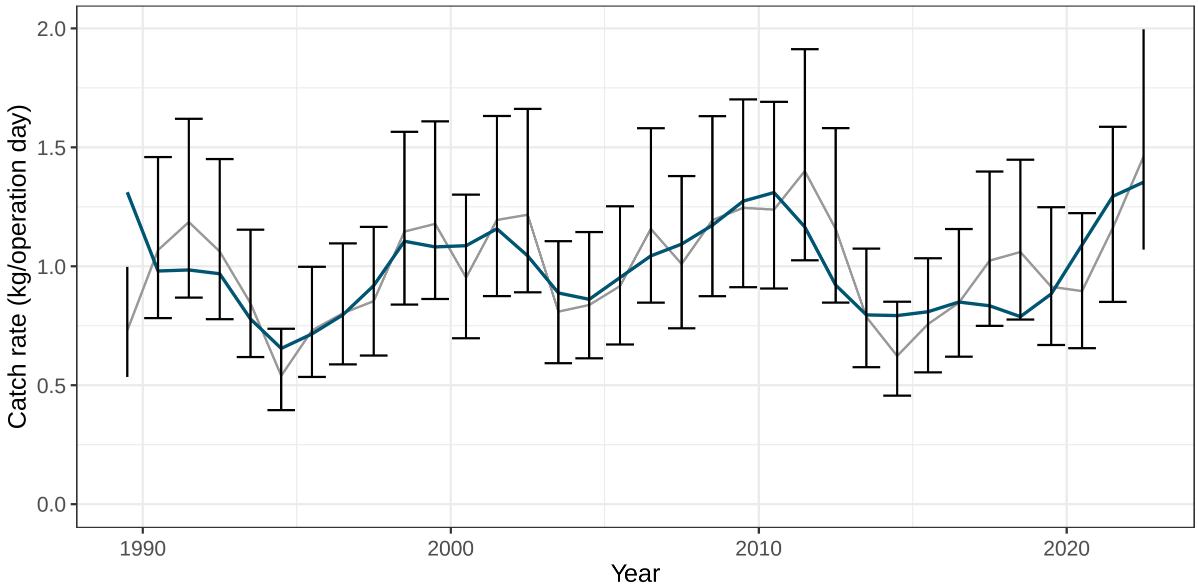

Figure E.13: Scenario 2: Model predictions (blue line) to standardised catch rates for king threadfin in the Gulf of Carpentaria, based on maximum likelihood estimation—grey line and error bars represent the model input and associated uncertainty

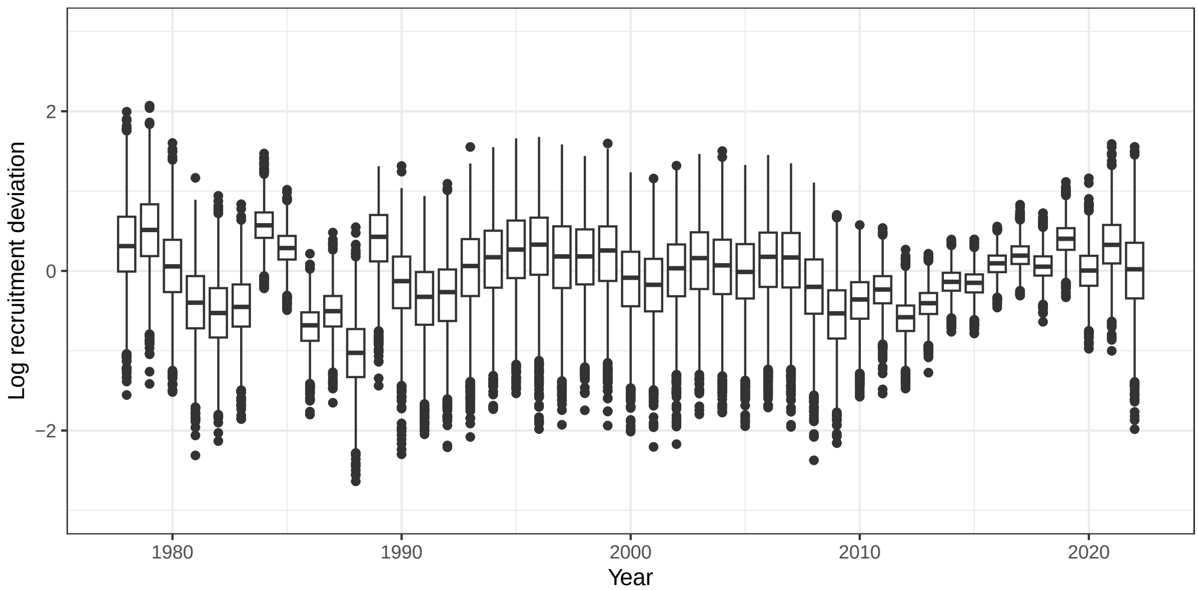

Figure E.14: Scenario 2: Recruitment deviations—whiskers represent 95% credible intervals, boxes represent 50% credible intervals, horizontal bars represent medians, and the points represent outliers

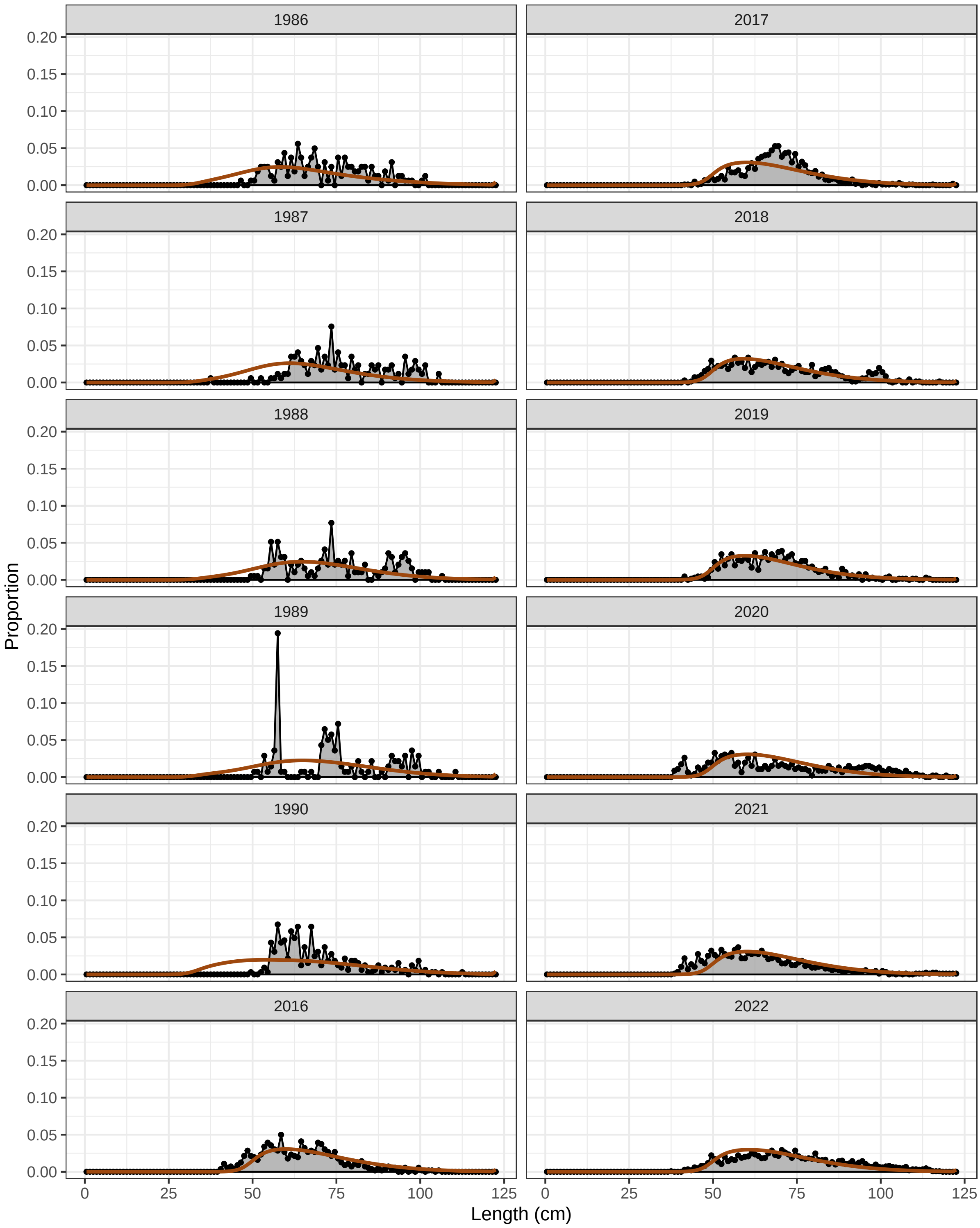

Figure E.15: Scenario 2: Fits to length structures, based on maximum likelihood estimation—the grey area and black line represent data inputs and the red line represents the model fits

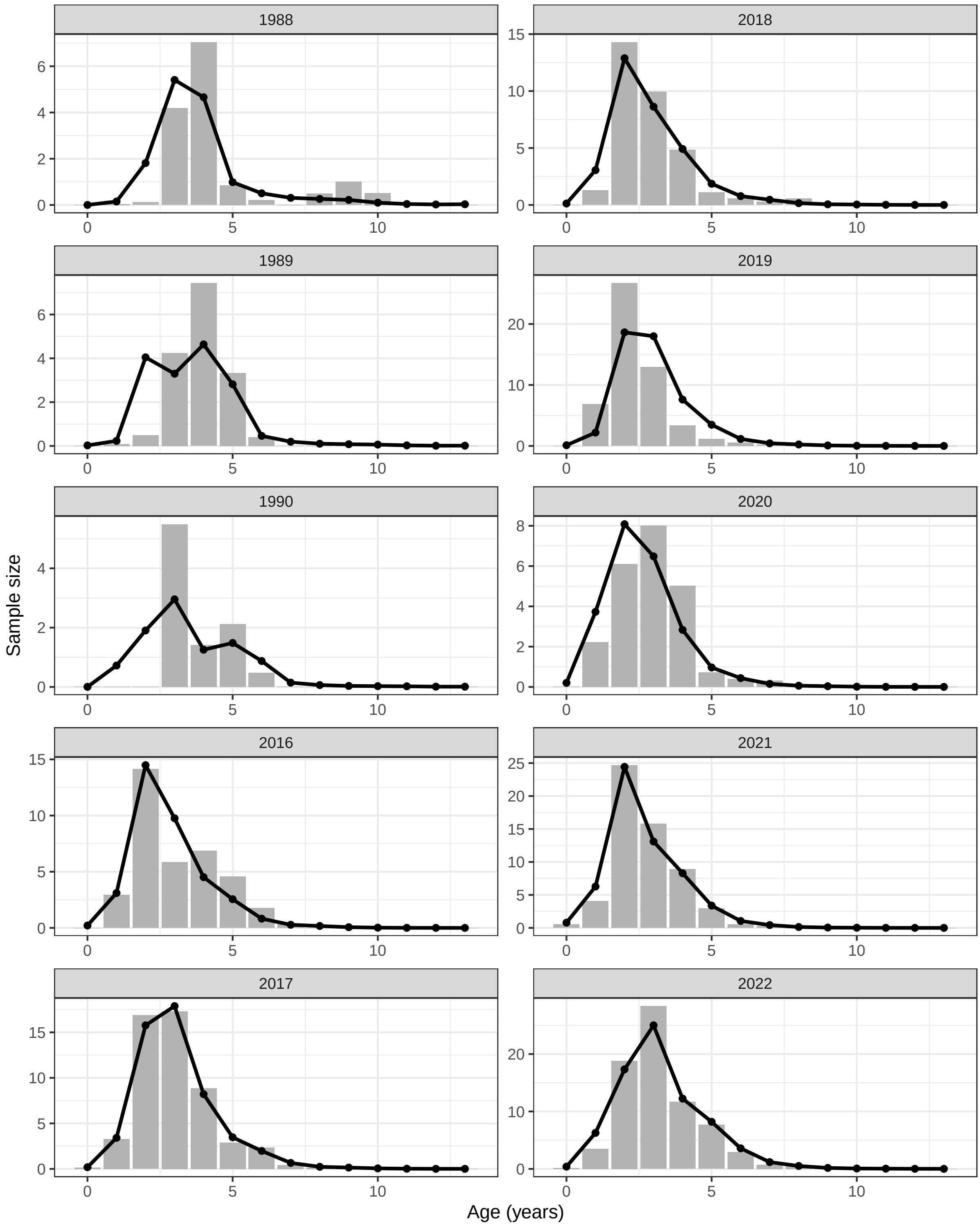

Figure E.16: Scenario 2: Fits to age structures, based on maximum likelihood estimation—grey bars represent input data and black line and points represent model fits

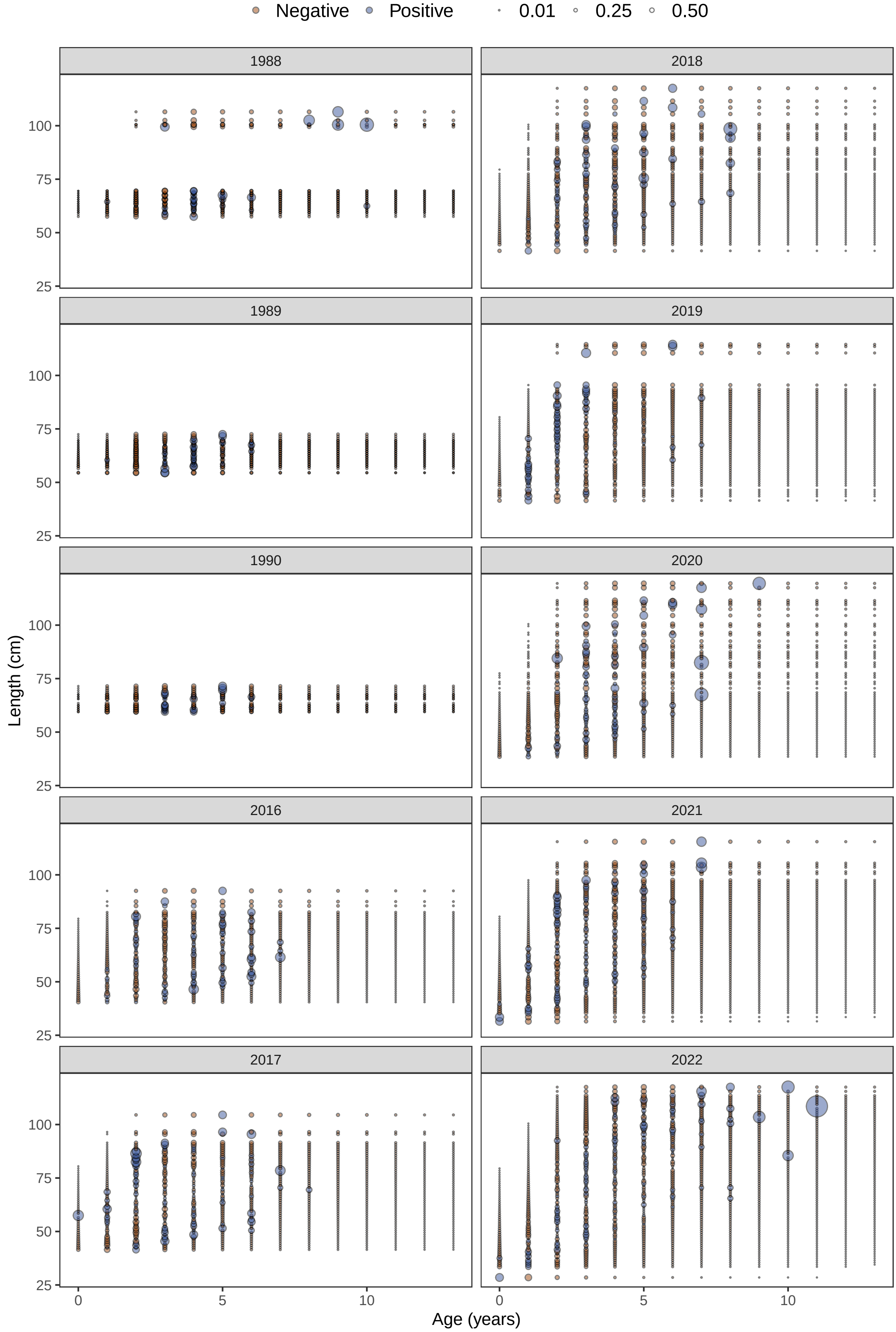

Figure E.17: Scenario 2: Pearson residuals for age-at-length compositions, based on maximum likelihood estimation—circle size represents the magnitude of the Pearson residual

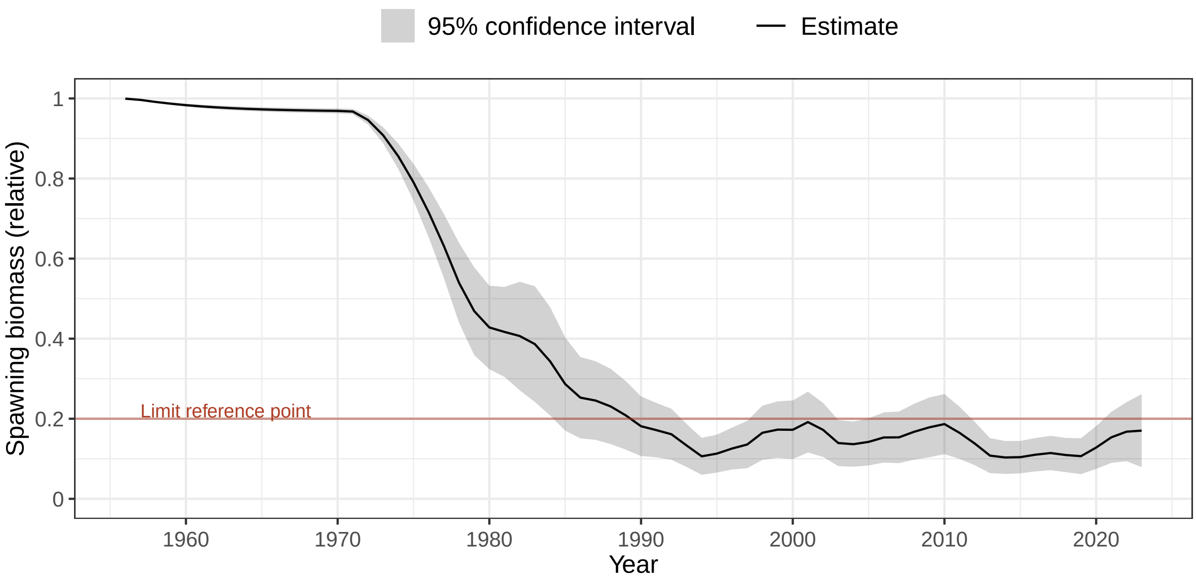

Figure E.18: Scenario 2: Predicted spawning biomass trajectory relative to unfished for king threadfin in the Gulf of Carpentaria, based on maximum likelihood estimation

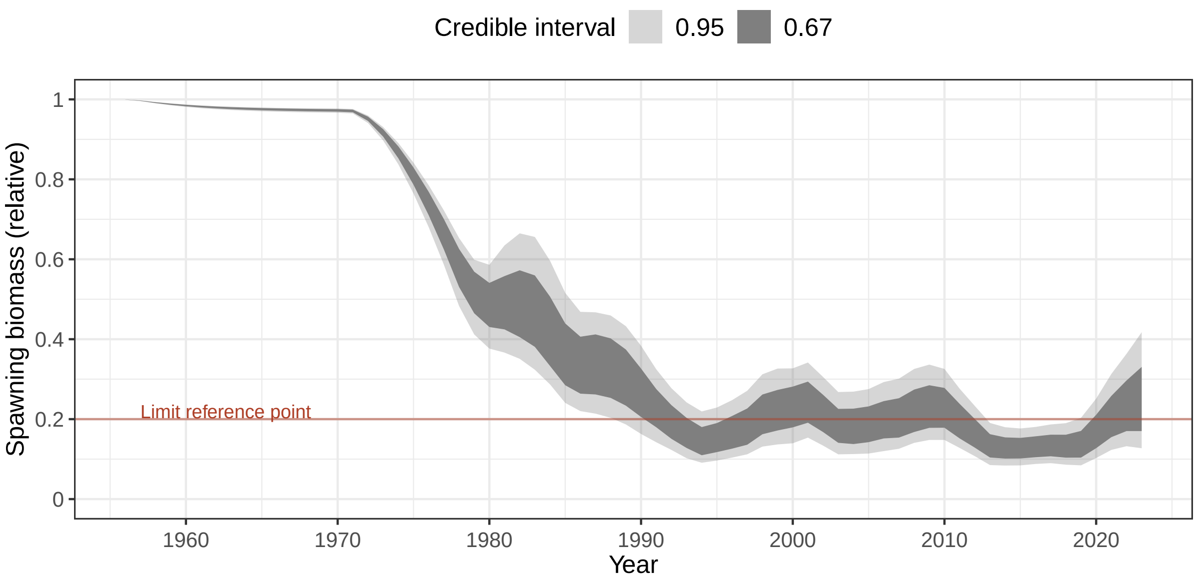

Figure E.19: Scenario 2: Predicted spawning biomass trajectory relative to unfished for king threadfin in the Gulf of Carpentaria, based on MCMC

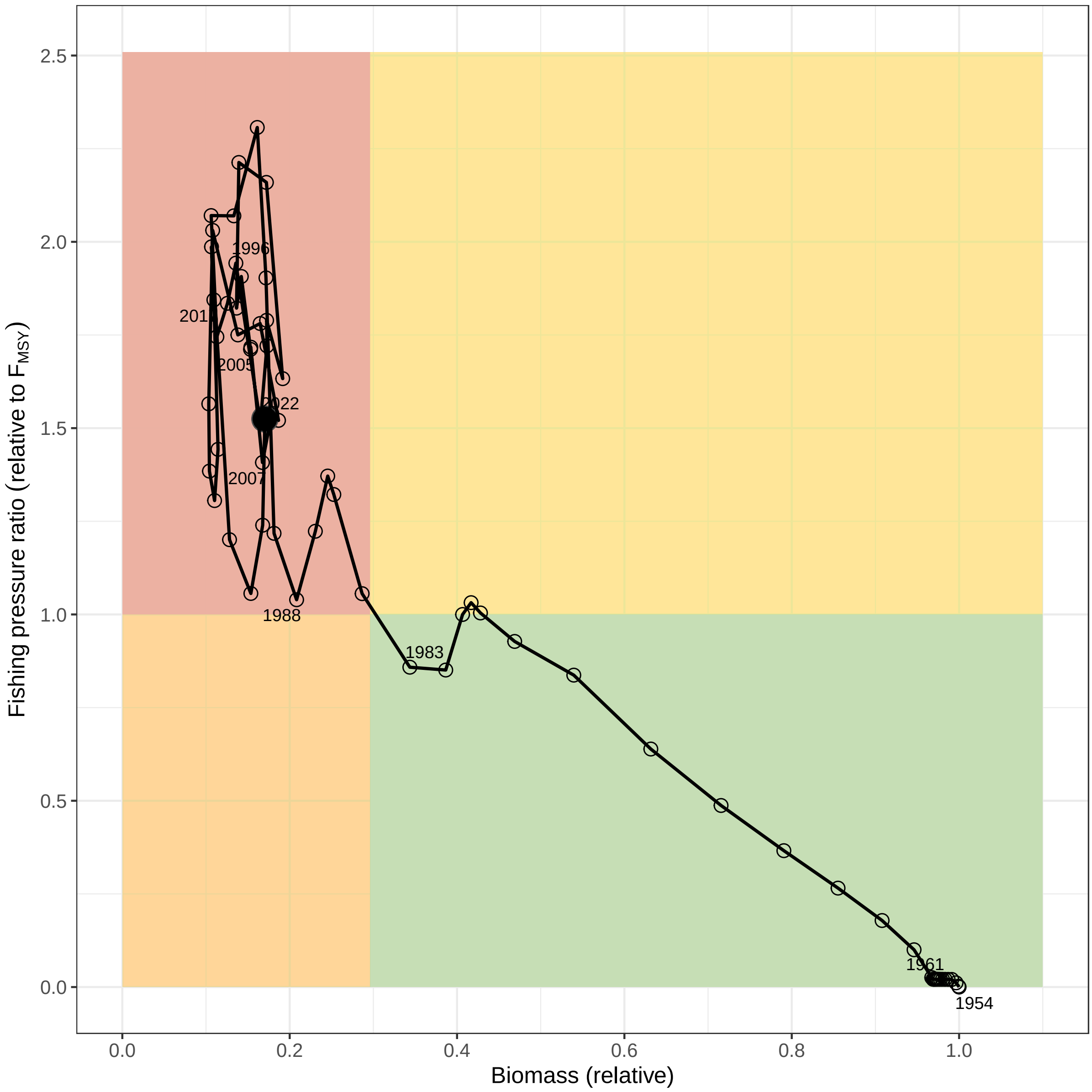

Figure E.20: Scenario 2: Stock status indicator trajectory for king threadfin in the Gulf of Carpentaria, based on maximum likelihood estimation

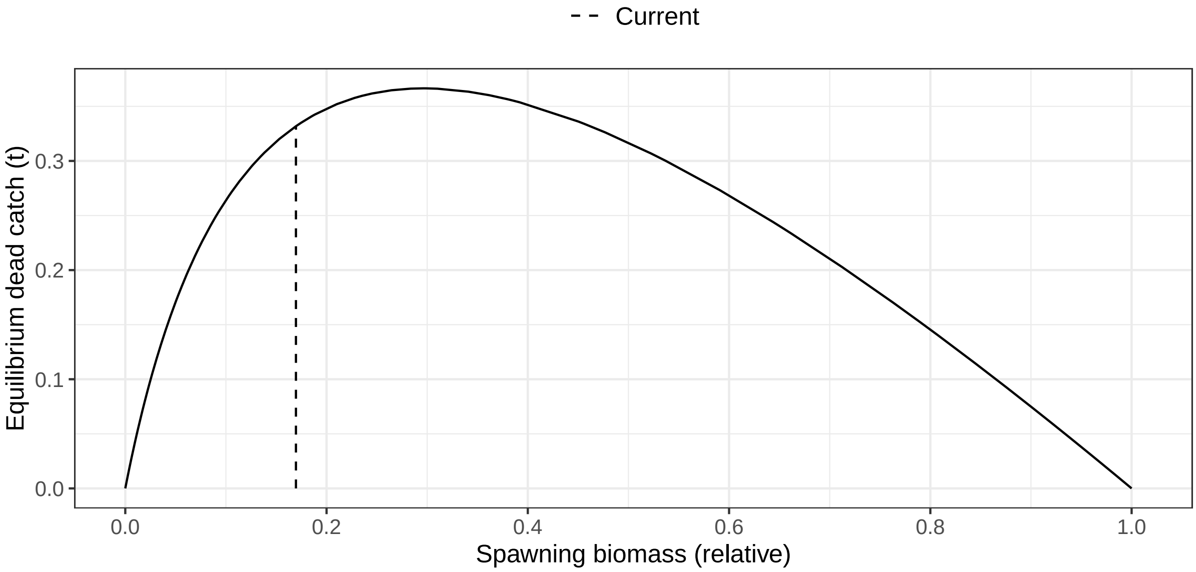

Figure E.21: Scenario 2: Equilibrium dead catch curve for king threadfin in the Gulf of Carpentaria, based on maximum likelihood estimation

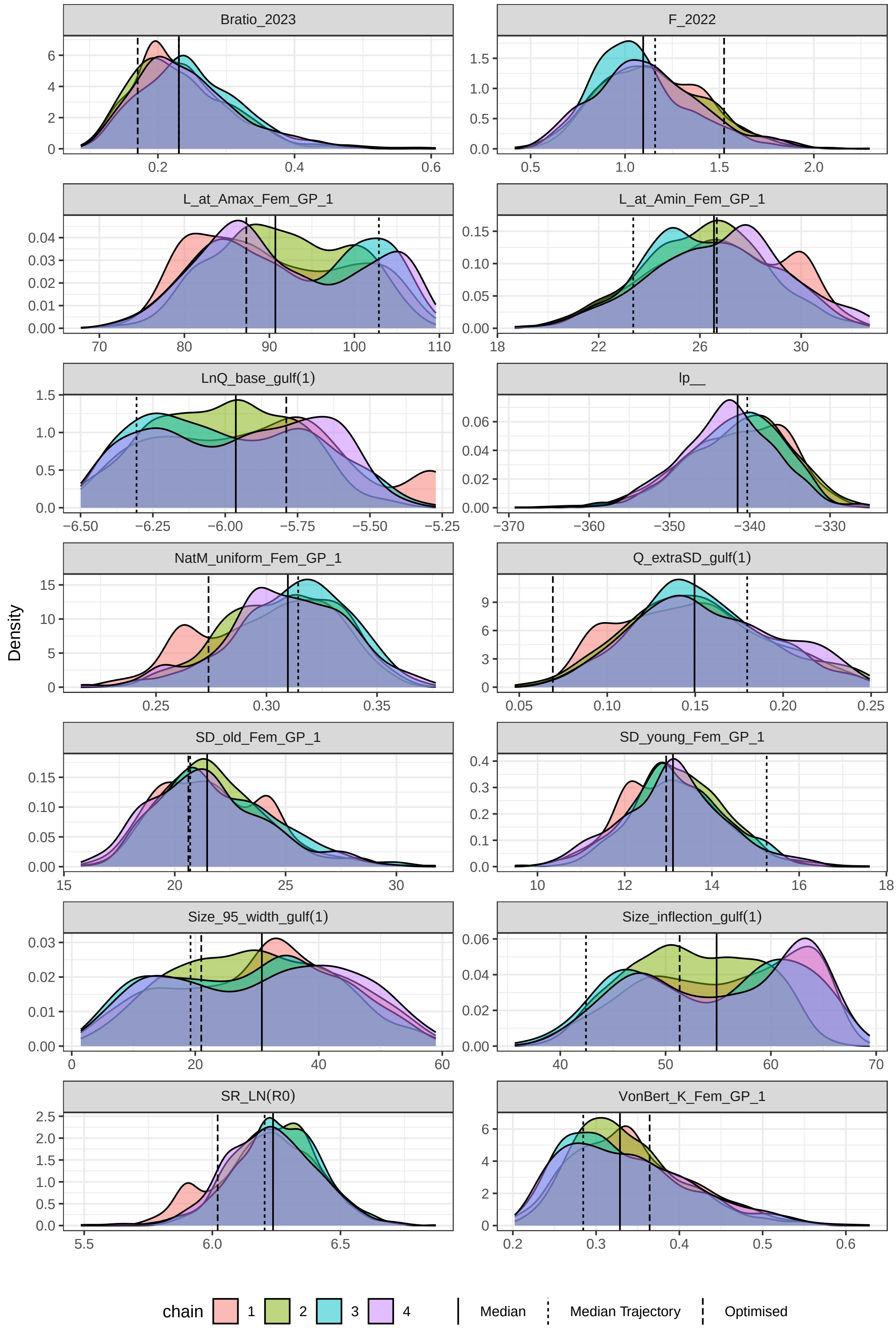

Figure E.22: Scenario 2: Posterior density of MCMC iterations. "Median" line shows median parameter value for MCMC iterations "Optimised" shows the parameter value found from maximum likelihood estimates.

Figure E.23: Scenario 2: Trace plot of MCMC iterations—“Optimised” shows the parameter value found from maximum likelihood estimates

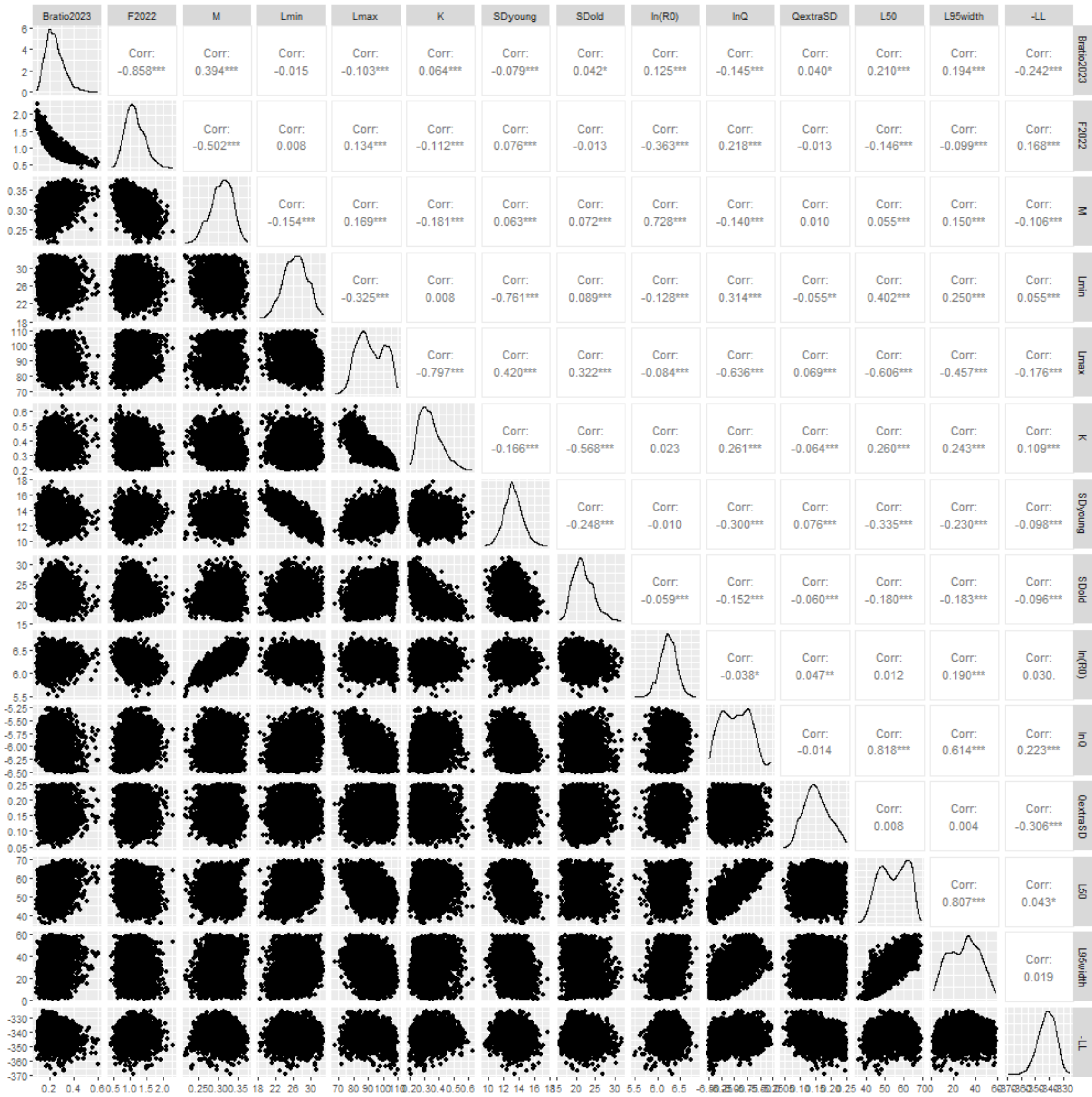

Figure E.24: Scenario 2: Correlation plot of MCMC iterations

E.3 Scenario 3

Parameter	Estimate	Phase	Min	Max	Initial value	Standard deviation
M	0.26	6	0.21	0.38	0.27	0.04
L_{min}	26.69	2	15.00	33.00	20.00	2.52
L_{max}	87.73	2	65.00	110.00	75.00	6.54
K	0.36	3	0.20	0.70	0.40	0.07
$\mathrm{SD}_{\mathrm{young}}$	12.93	3	8.00	18.00	13.00	1.12
$\mathrm{SD}_{\mathrm{old}}$	20.86	3	15.00	35.00	20.00	2.67
$\ln R_0$	5.84	1	5.00	8.00	7.00	0.19
$\ln q$	-5.86	1	-6.50	-5.20	-6.00	0.21
QextraSD	0.08	7	0.00	0.50	0.10	0.03
L_{50}	50.97	4	30.00	70.00	55.00	4.60
$L_{95\mathrm{width}}$	20.38	4	1.00	60.00	25.00	8.52

Table E.5: Stock Synthesis parameter estimates for Scenario 3 population model for king threadfin in the Gulf of Carpentaria, based on maximum likelihood estimation

Symbol	MCMC median	MCMC 2.5%	MCMC 97.5%
M	0.31	0.24	0.36
L_{min}	26.28	21.44	30.83
L_{max}	89.94	77.78	105.53
K	0.34	0.23	0.49
$\mathrm{SD}_{\mathrm{young}}$	13.18	10.99	15.44
$\mathrm{SD}_{\mathrm{old}}$	21.37	16.33	27.77
$\ln R_0$	6.14	5.75	6.45
$\ln q$	-6.09	-6.47	-5.62
QextraSD	0.17	0.09	0.24
L_{50}	53.96	42.56	64.97
$L_{95\mathrm{width}}$	31.05	9.91	54.80

Table E.6: Stock Synthesis parameter estimates for Scenario 3 population model for king threadfin in the Gulf of Carpentaria, based on MCMC estimation

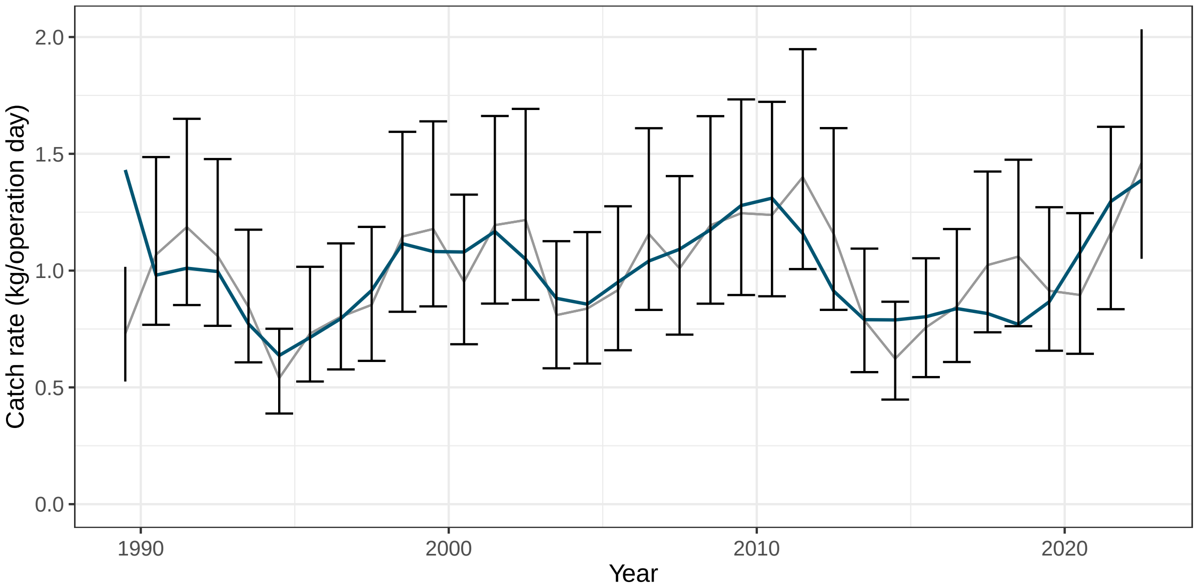

Figure E.25: Scenario 3: Model predictions (blue line) to standardised catch rates for king threadfin in the Gulf of Carpentaria, based on maximum likelihood estimation—grey line and error bars represent the model input and associated uncertainty

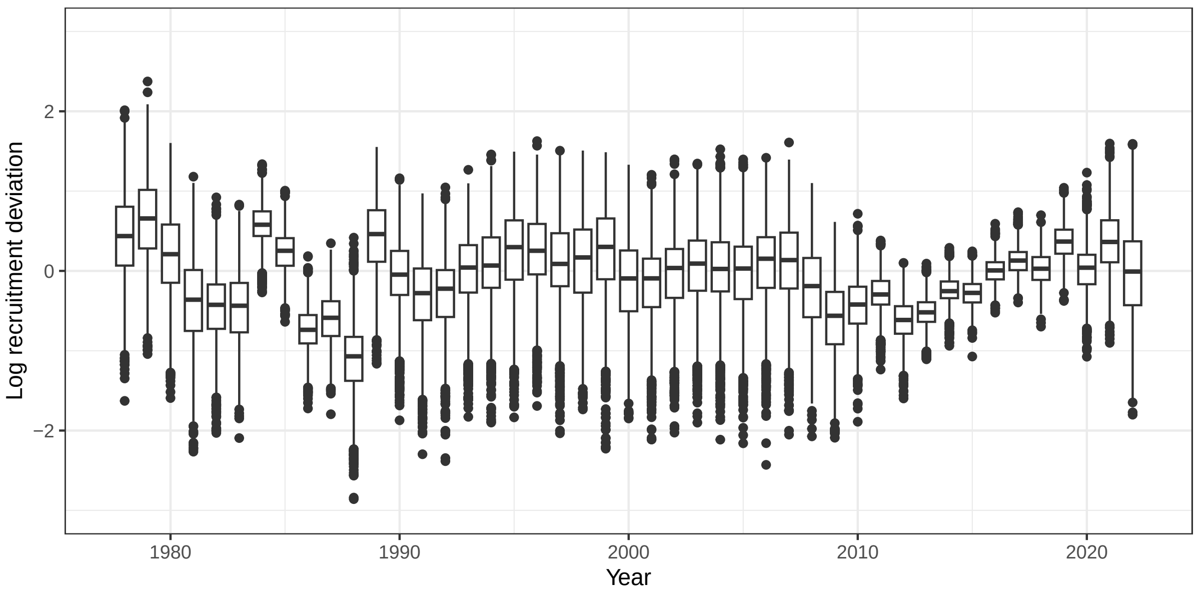

Figure E.26: Scenario 3: Recruitment deviations—whiskers represent 95% credible intervals, boxes represent 50% credible intervals, horizontal bars represent medians, and the points represent outliers

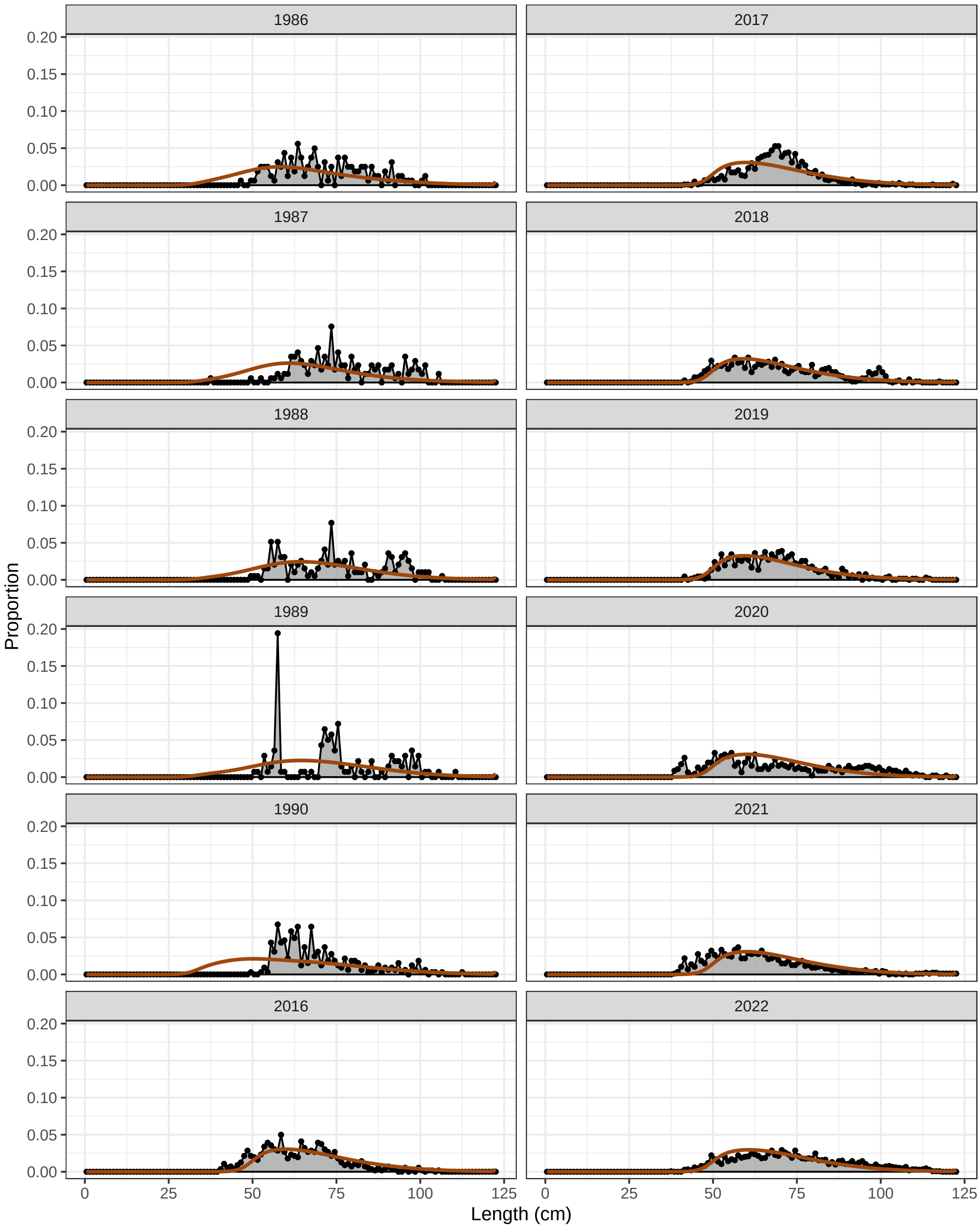

Figure E.27: Scenario 3: Fits to length structures, based on maximum likelihood estimation—the grey area and black line represent data inputs and the red line represents the model fits

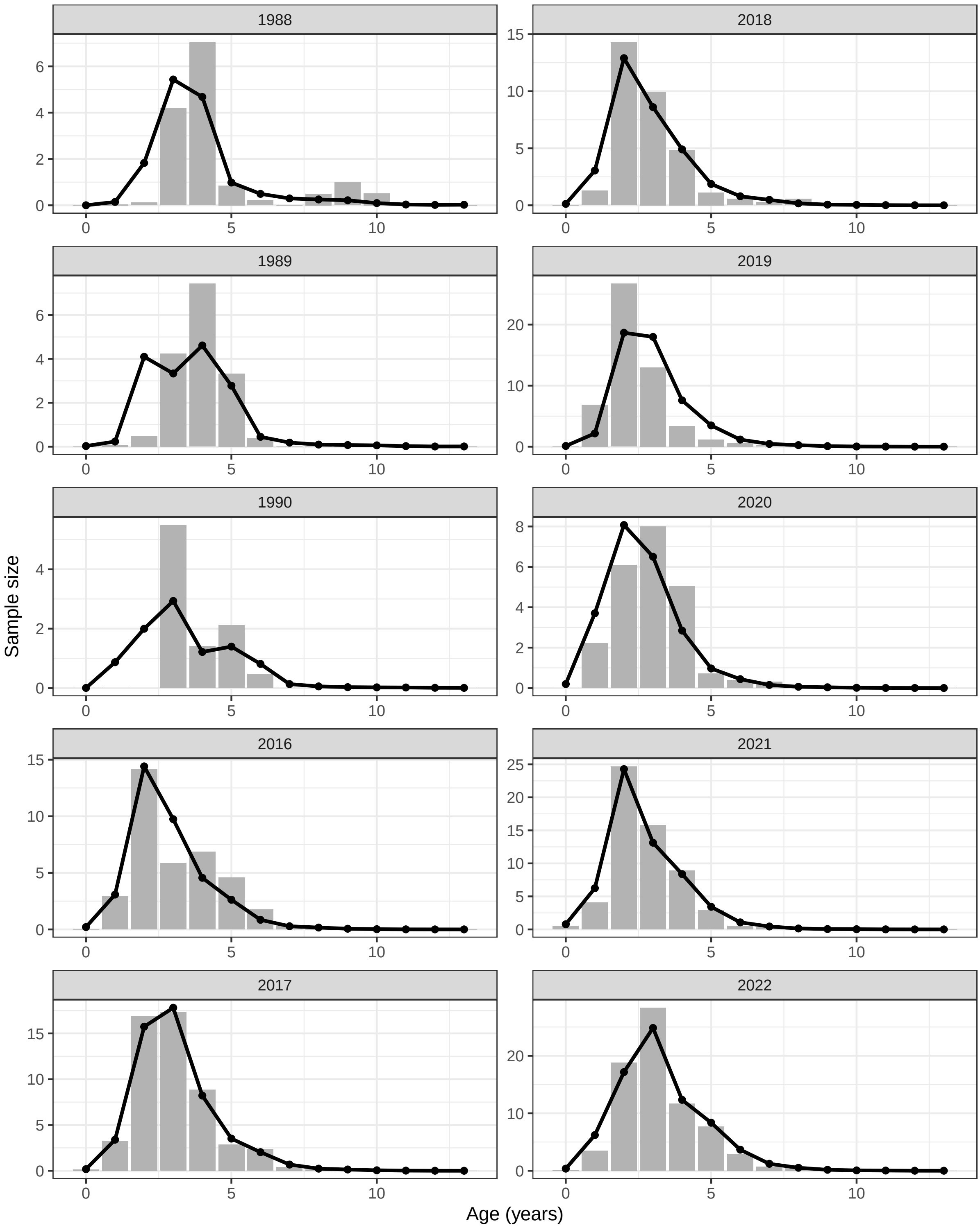

Figure E.28: Scenario 3: Fits to age structures, based on maximum likelihood estimation—grey bars represent input data and black line and points represent model fits

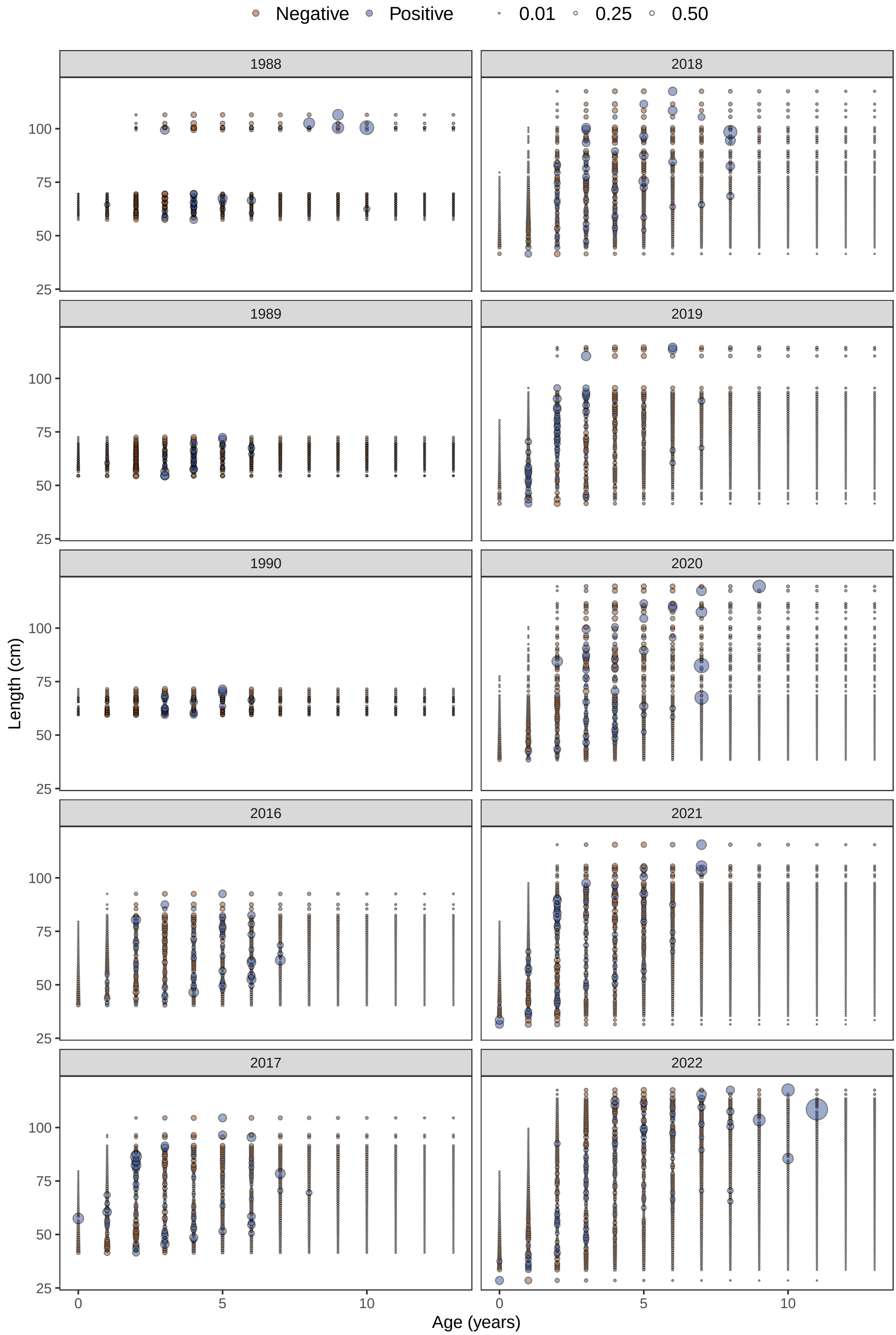

Figure E.29: Scenario 3: Pearson residuals for age-at-length compositions, based on maximum likelihood estimation—circle size represents the magnitude of the Pearson residual

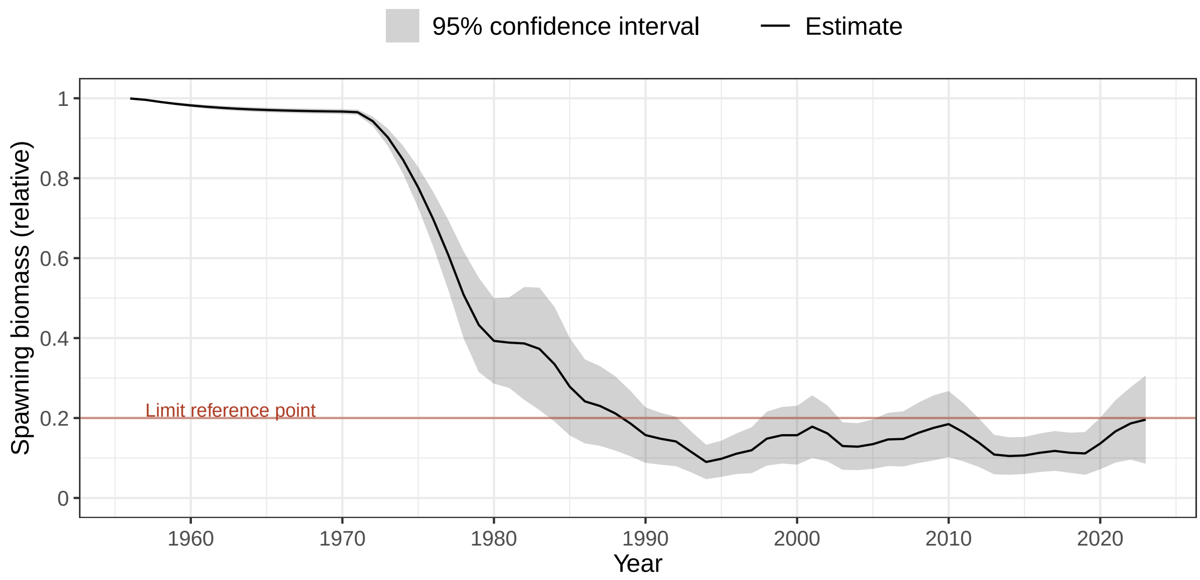

Figure E.30: Scenario 3: Predicted spawning biomass trajectory relative to unfished for king threadfin in the Gulf of Carpentaria, based on maximum likelihood estimation

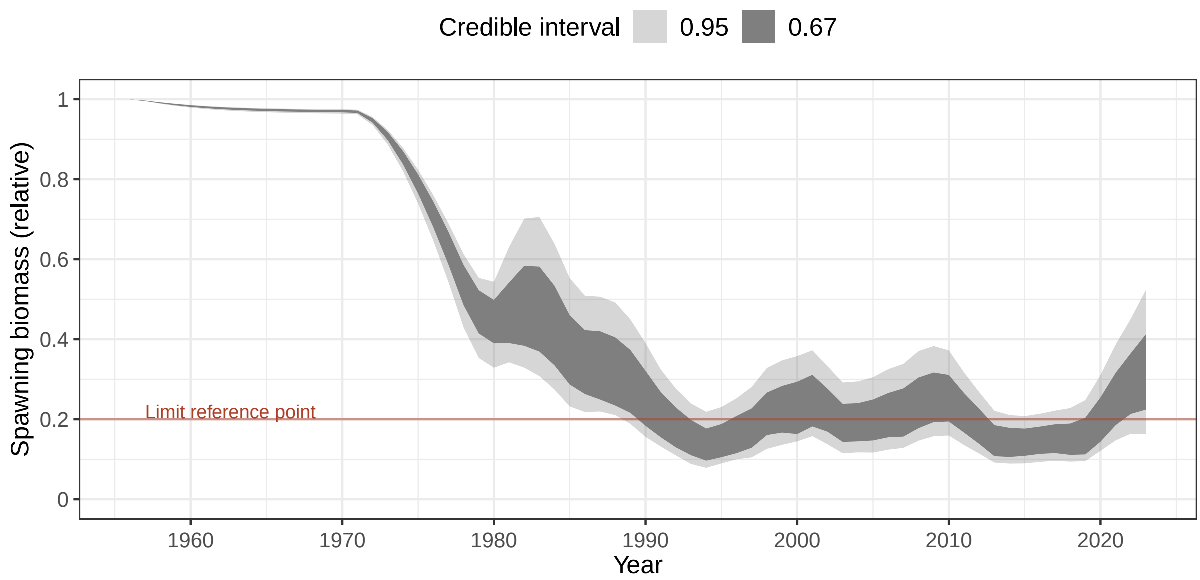

Figure E.31: Scenario 3: Predicted spawning biomass trajectory relative to unfished for king threadfin in the Gulf of Carpentaria, based on MCMC

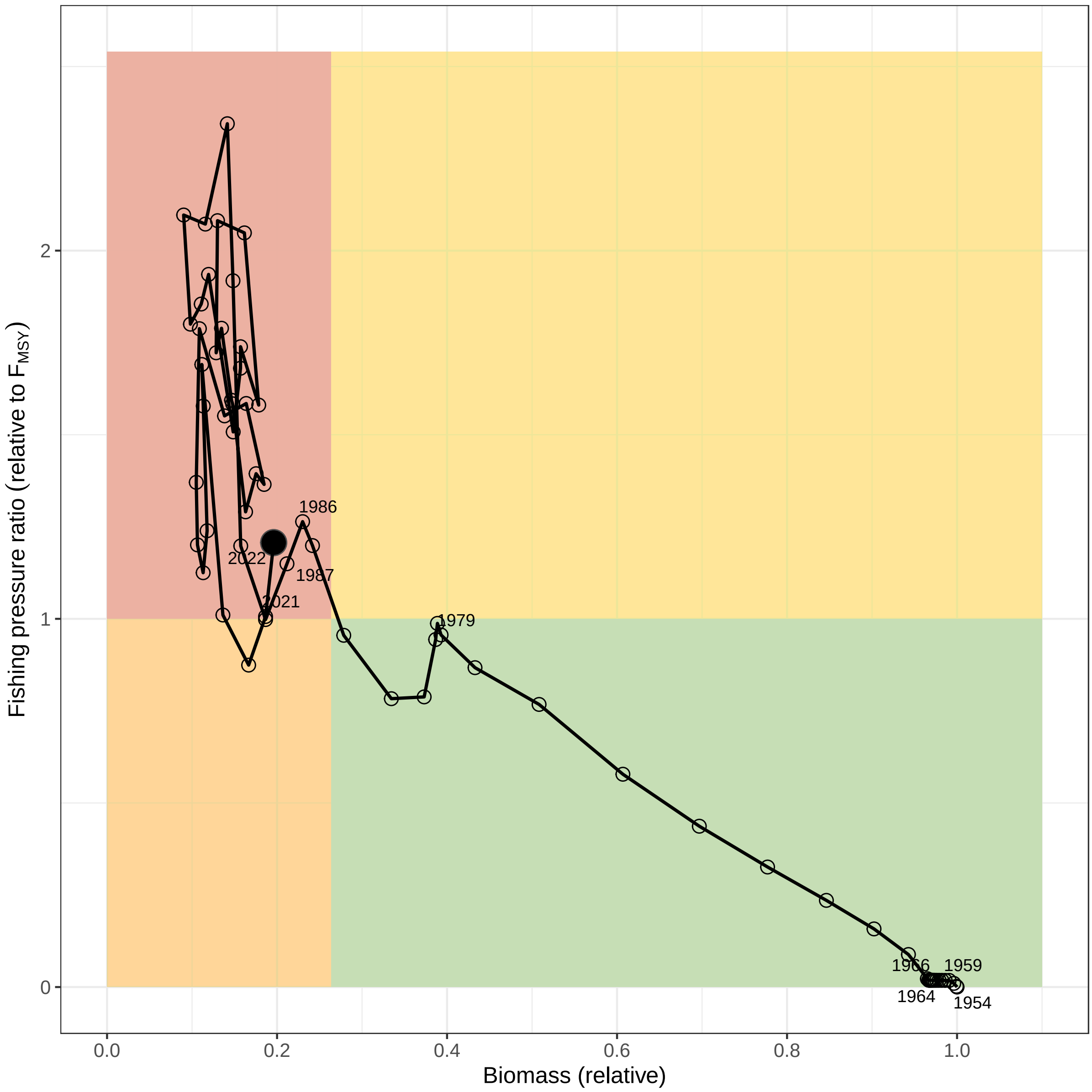

Figure E.32: Scenario 3: Stock status indicator trajectory for king threadfin in the Gulf of Carpentaria, based on maximum likelihood estimation

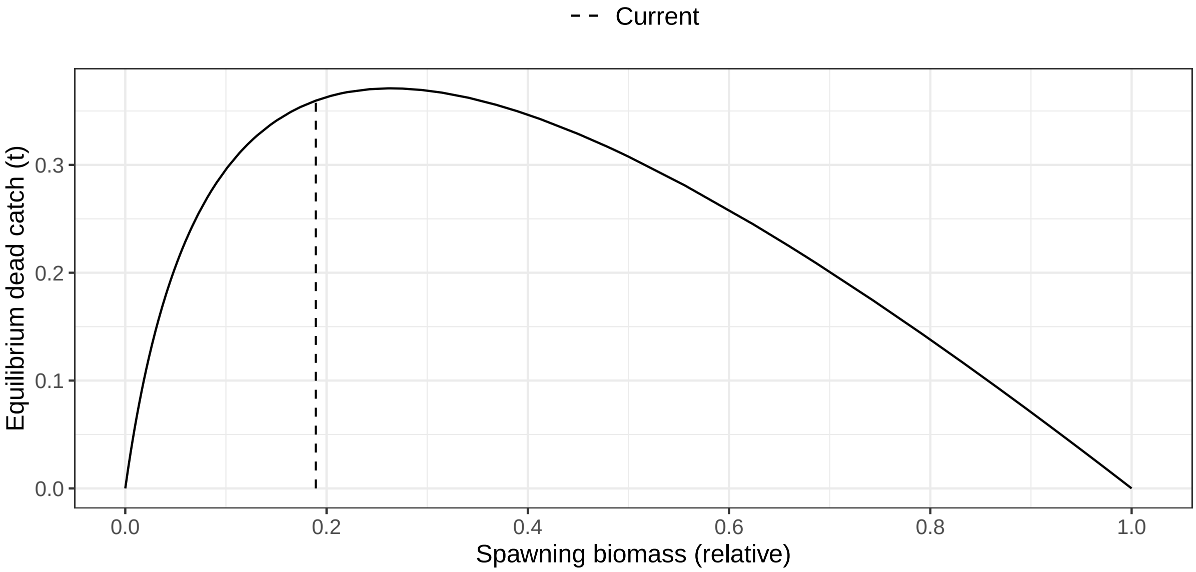

Figure E.33: Scenario 3: Equilibrium dead catch curve for king threadfin in the Gulf of Carpentaria, based on maximum likelihood estimation

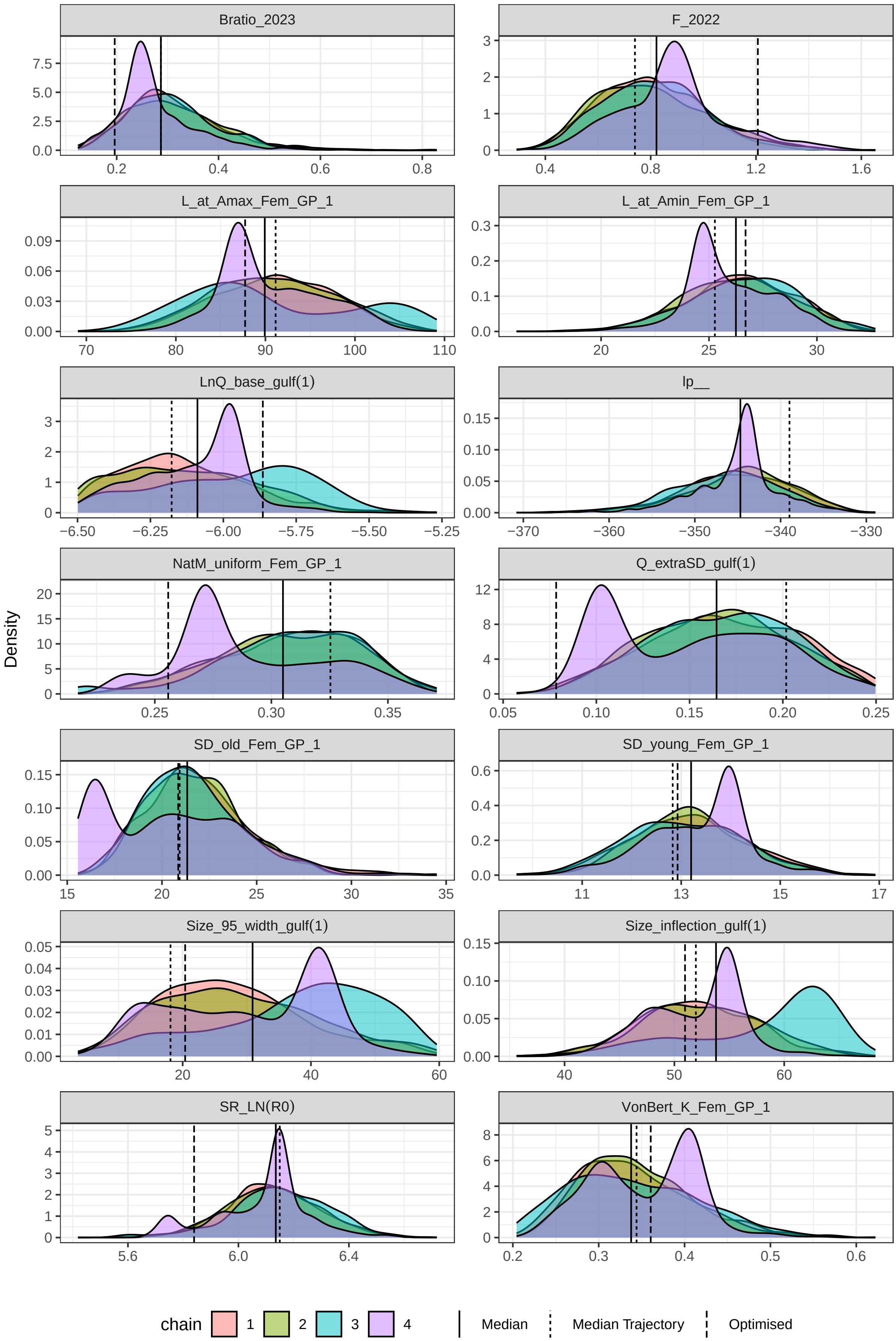

Figure E.34: Scenario 3: Posterior density of MCMC iterations. "Median" line shows median parameter value for MCMC iterations "Optimised" shows the parameter value found from maximum likelihood estimates.

Figure E.35: Scenario 3: Trace plot of MCMC iterations—“Optimised” shows the parameter value found from maximum likelihood estimates

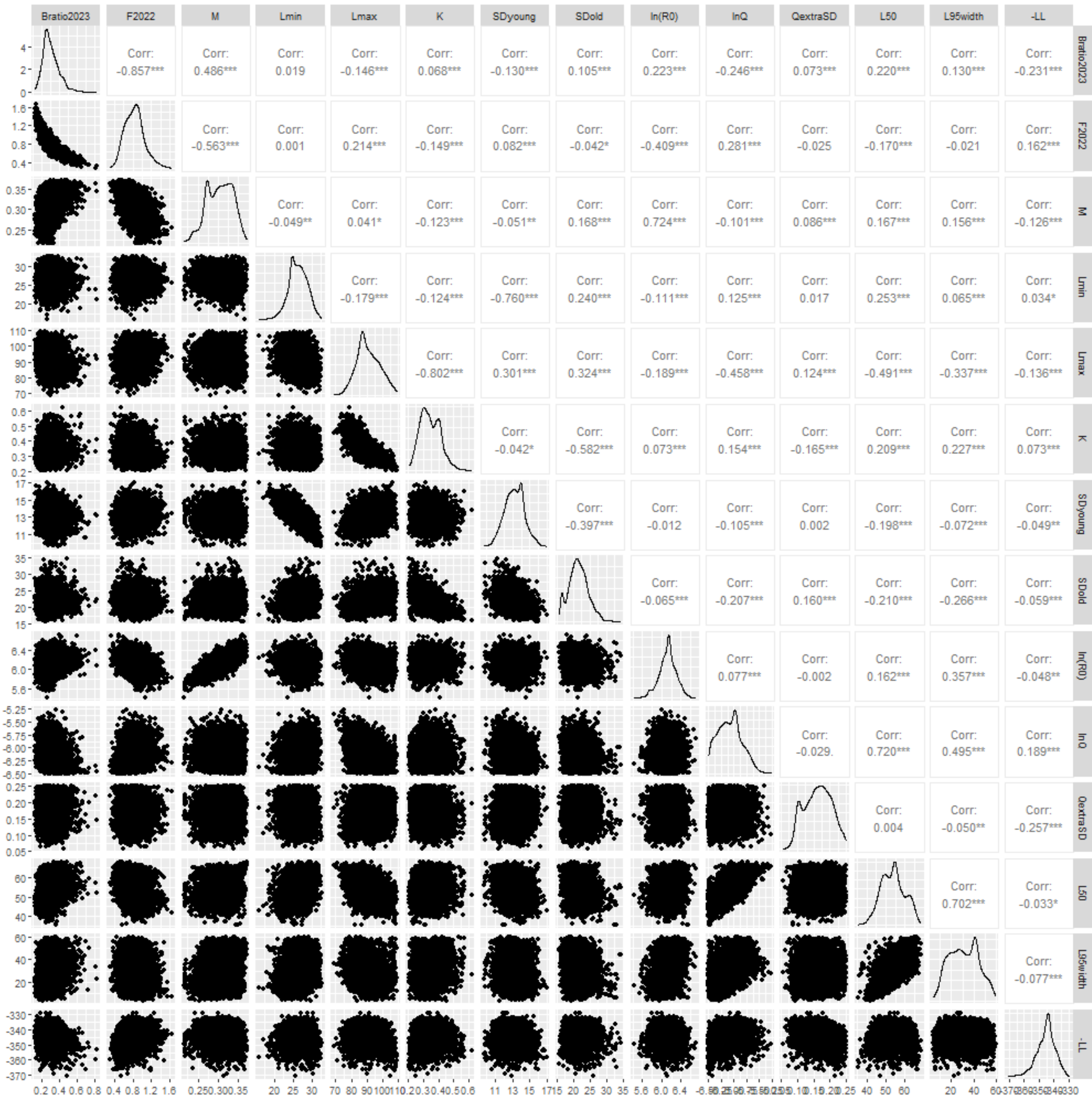

Figure E.36: Scenario 3: Correlation plot of MCMC iterations

E.4 Scenario 4

Parameter	Estimate	Phase	Min	Max	Initial value	Standard deviation
M	0.24	6	0.21	0.38	0.27	0.03
L_{min}	26.63	2	15.00	33.00	20.00	2.53
L_{max}	88.46	2	65.00	110.00	75.00	6.55
K	0.36	3	0.20	0.70	0.40	0.07
$\mathrm{SD}_{\mathrm{young}}$	13.05	3	8.00	18.00	13.00	1.14
$\mathrm{SD}_{\mathrm{old}}$	20.57	3	15.00	35.00	20.00	2.60
$\ln R_0$	5.78	1	5.00	8.00	7.00	0.19
$\ln q$	-5.74	1	-6.50	-5.20	-6.00	0.20
QextraSD	0.07	7	0.00	0.50	0.10	0.03
L_{50}	50.62	4	30.00	70.00	55.00	4.62
$L_{95\mathrm{width}}$	20.86	4	1.00	60.00	25.00	8.97

Table E.7: Stock Synthesis parameter estimates for Scenario 4 population model for king threadfin in the Gulf of Carpentaria, based on maximum likelihood estimation

Symbol	MCMC median	MCMC 2.5%	MCMC 97.5%
M	0.31	0.24	0.36
L_{min}	26.30	21.46	30.90
L_{max}	91.99	78.43	104.14
K	0.32	0.24	0.47
$\mathrm{SD}_{\mathrm{young}}$	13.24	11.23	15.40
$\mathrm{SD}_{\mathrm{old}}$	21.59	17.28	28.30
$\ln R_0$	6.11	5.79	6.45
$\ln q$	-6.00	-6.43	-5.53
QextraSD	0.15	0.08	0.24
L_{50}	52.21	41.56	63.68
$L_{95\mathrm{width}}$	29.95	9.35	55.24

Table E.8: Stock Synthesis parameter estimates for Scenario 4 population model for king threadfin in the Gulf of Carpentaria, based on MCMC estimation

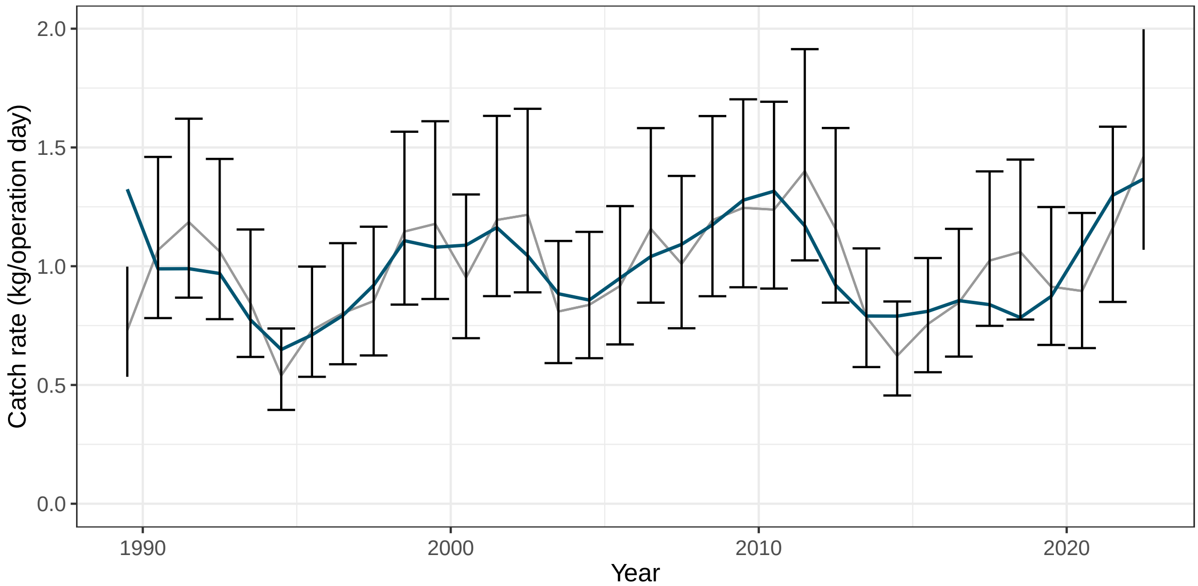

Figure E.37: Scenario 4: Model predictions (blue line) to standardised catch rates for king threadfin in the Gulf of Carpentaria, based on maximum likelihood estimation—grey line and error bars represent the model input and associated uncertainty

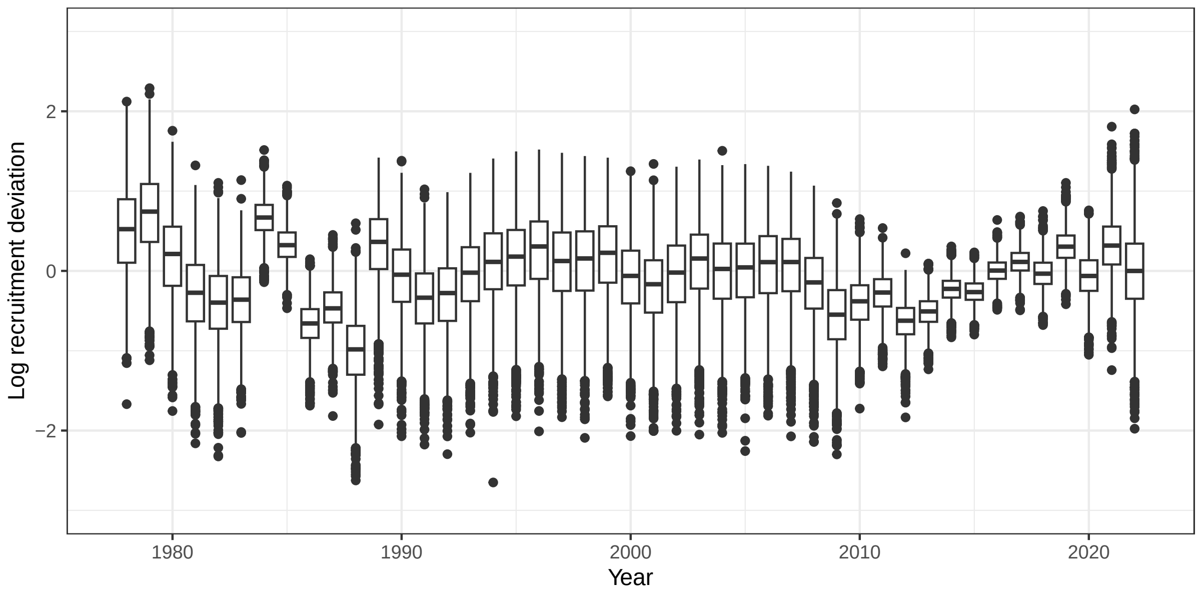

Figure E.38: Scenario 4: Recruitment deviations—whiskers represent 95% credible intervals, boxes represent 50% credible intervals, horizontal bars represent medians, and the points represent outliers

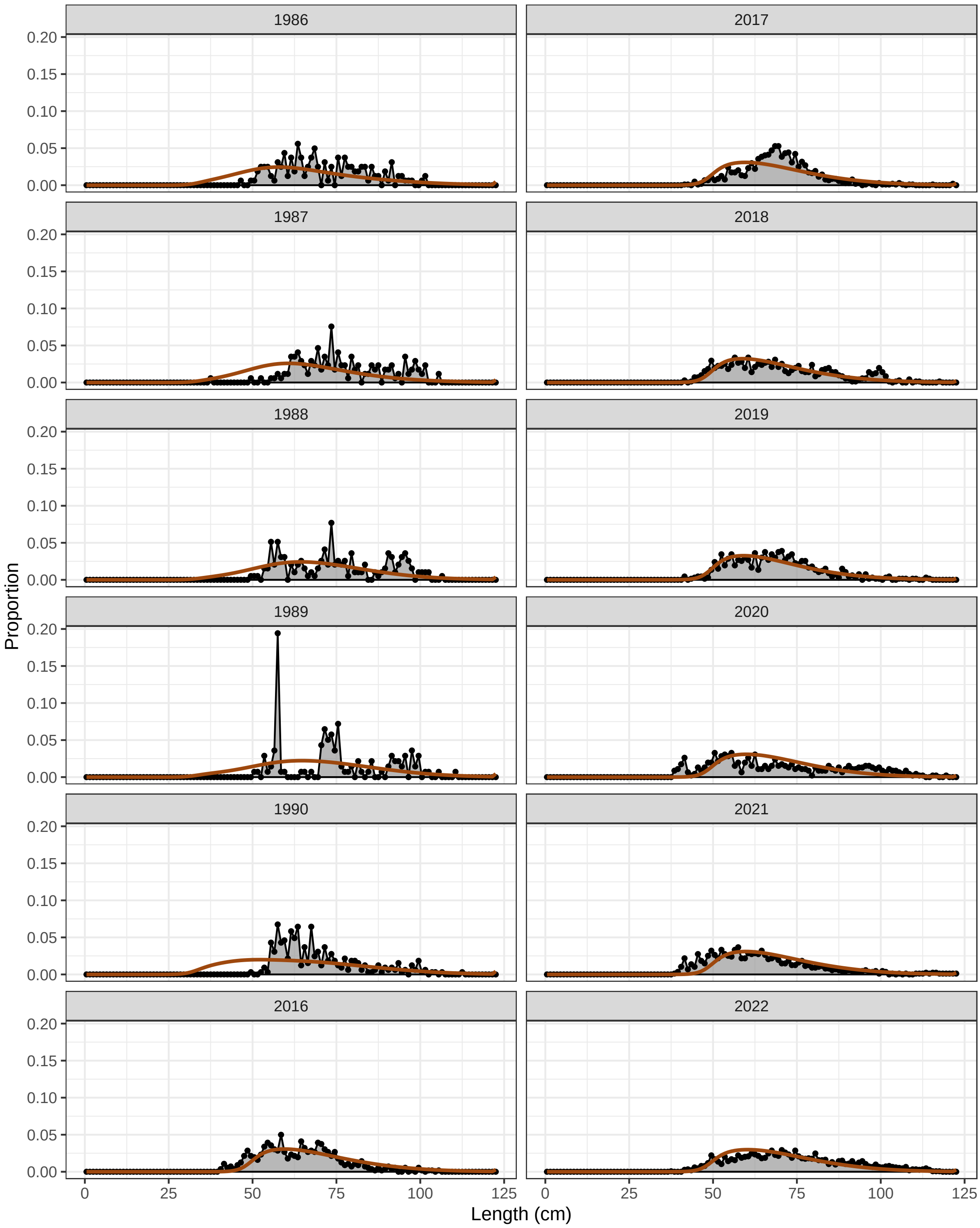

Figure E.39: Scenario 4: Fits to length structures, based on maximum likelihood estimation—the grey area and black line represent data inputs and the red line represents the model fits

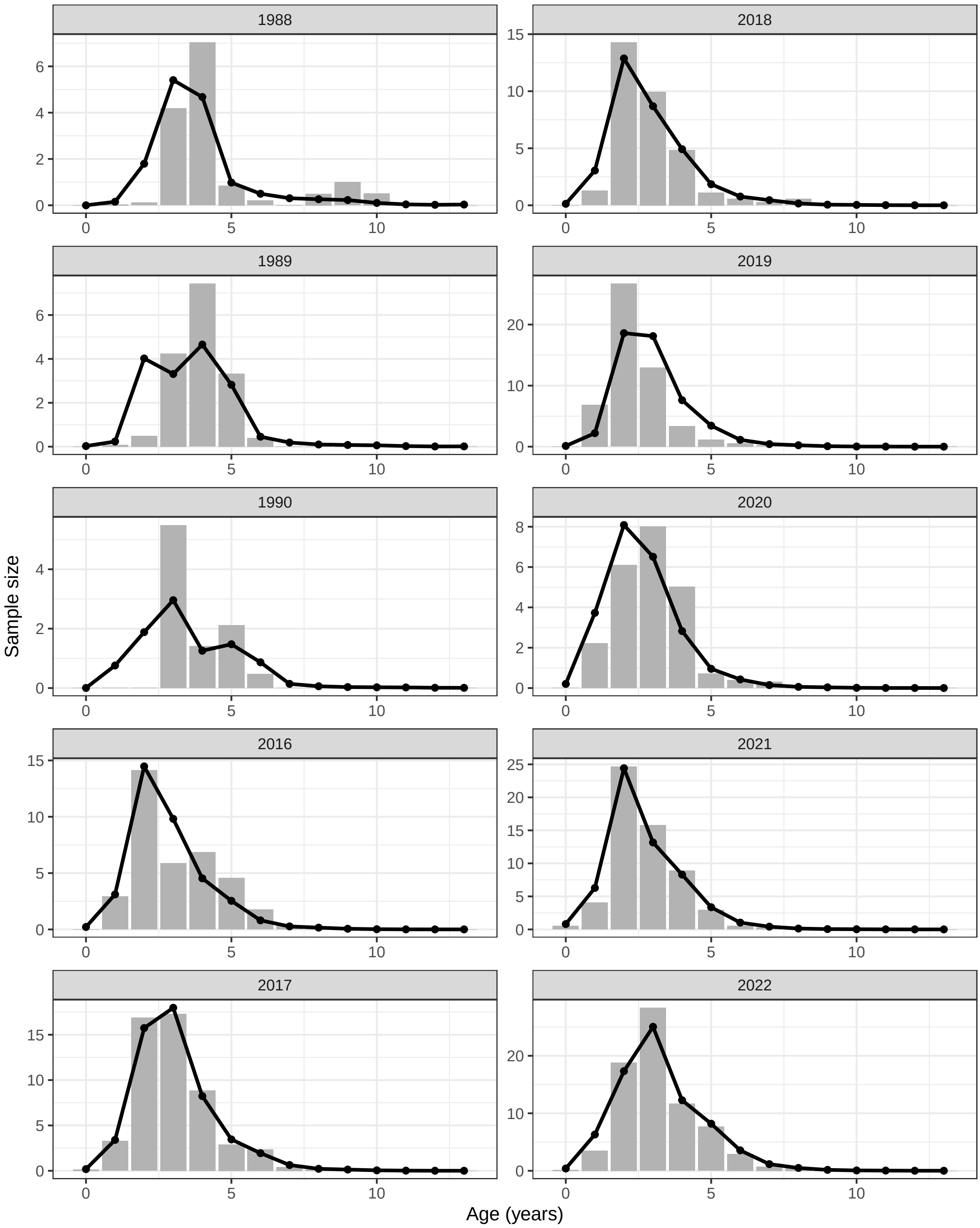

Figure E.40: Scenario 4: Fits to age structures, based on maximum likelihood estimation—grey bars represent input data and black line and points represent model fits

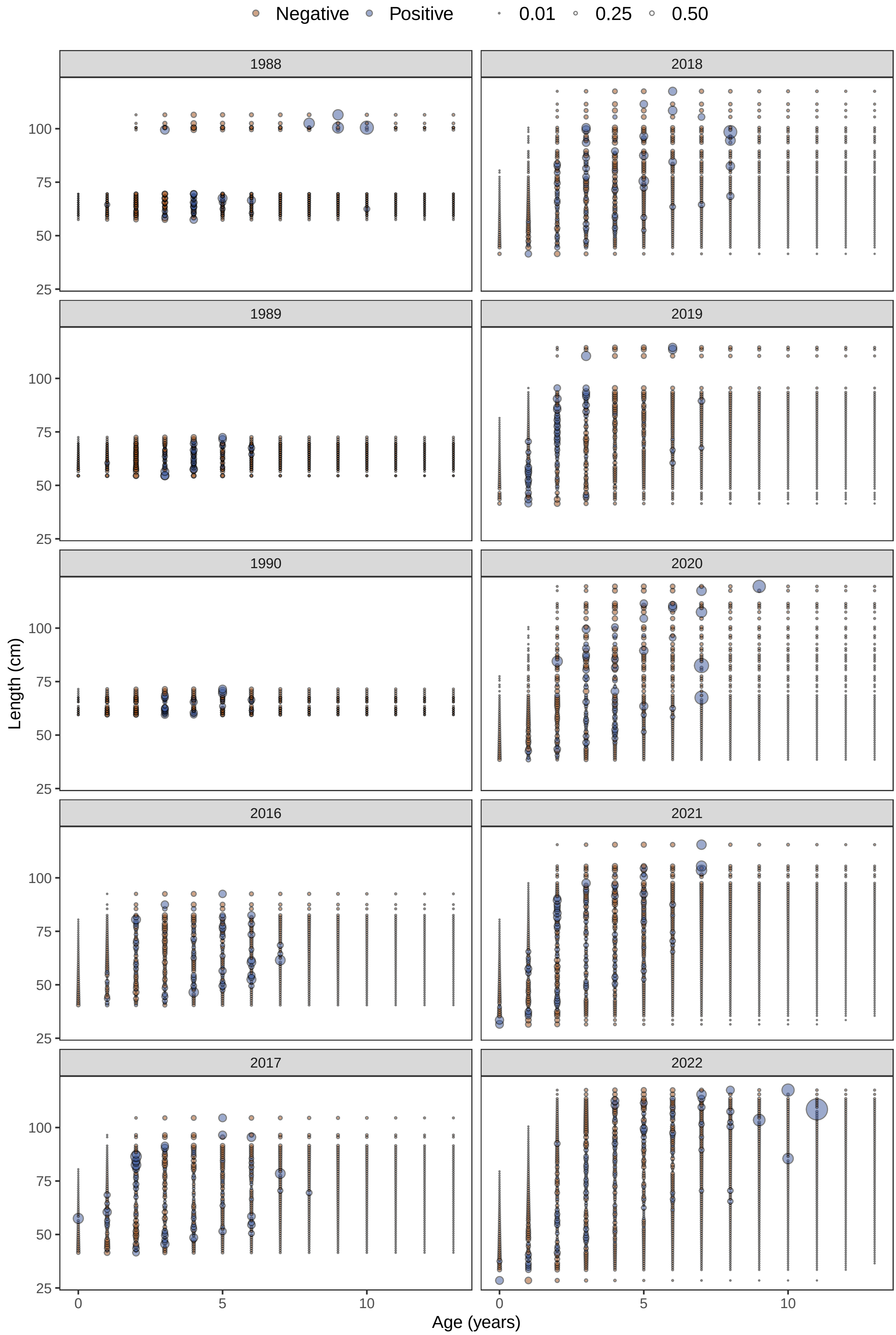

Figure E.41: Scenario 4: Pearson residuals for age-at-length compositions, based on maximum likelihood estimation—circle size represents the magnitude of the Pearson residual

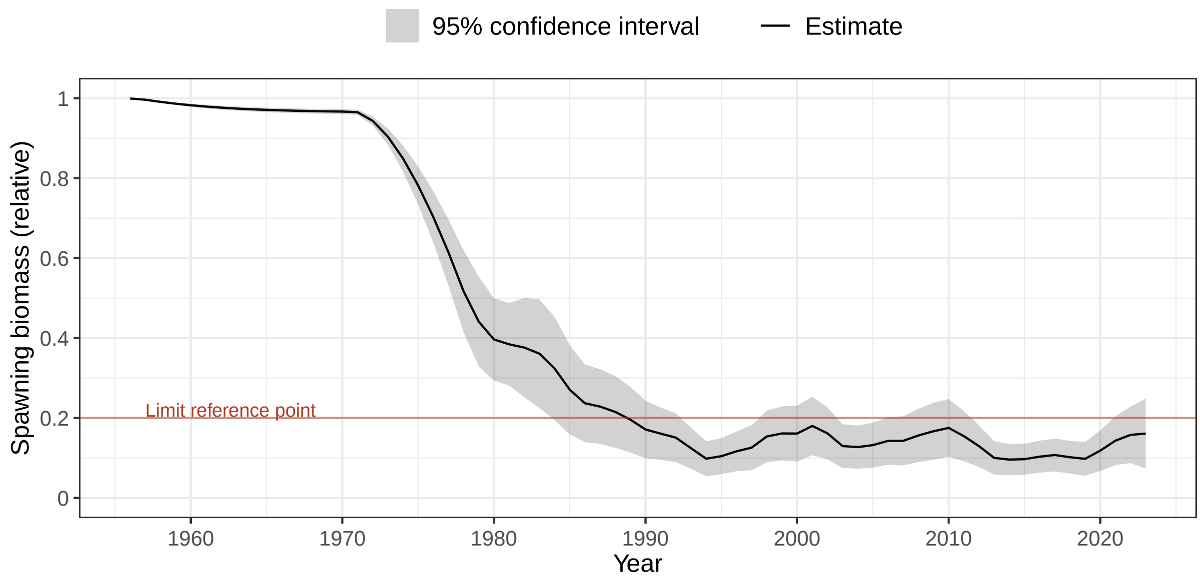

Figure E.42: Scenario 4: Predicted spawning biomass trajectory relative to unfished for king threadfin in the Gulf of Carpentaria, based on maximum likelihood estimation

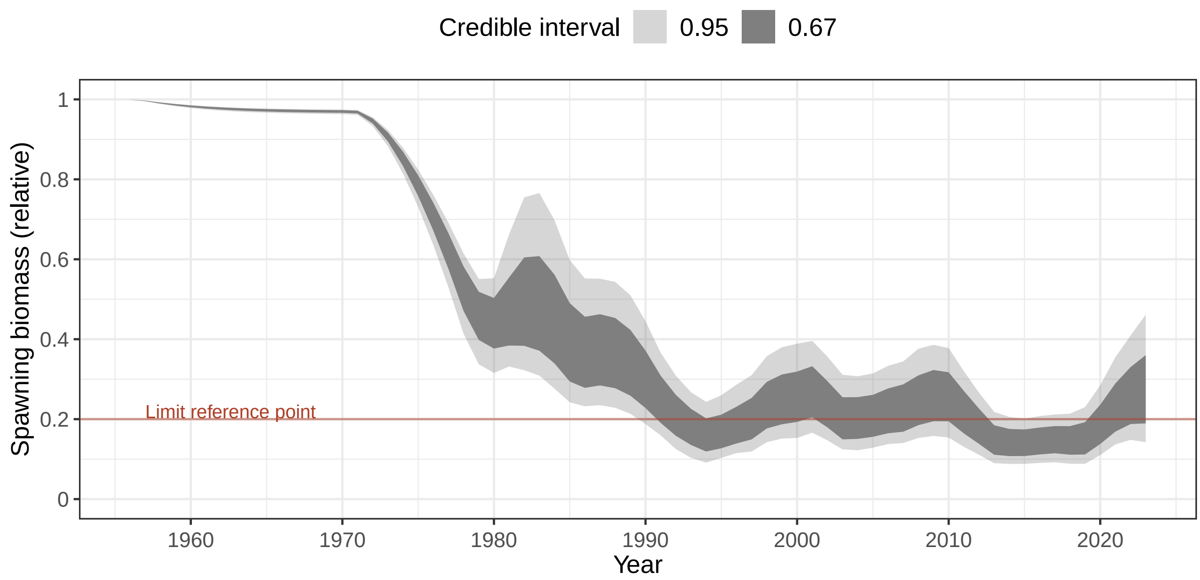

Figure E.43: Scenario 4: Predicted spawning biomass trajectory relative to unfished for king threadfin in the Gulf of Carpentaria, based on MCMC

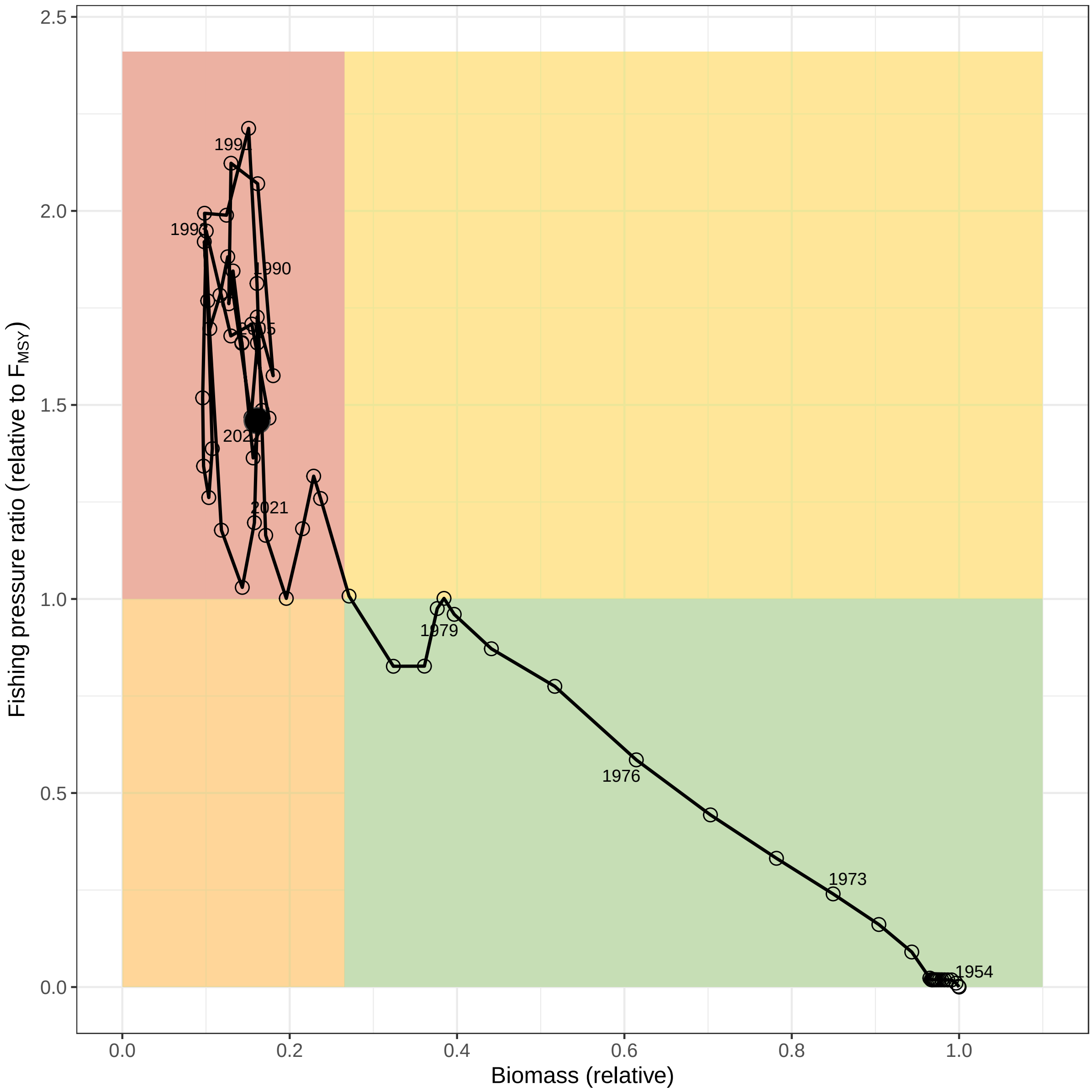

Figure E.44: Scenario 4: Stock status indicator trajectory for king threadfin in the Gulf of Carpentaria, based on maximum likelihood estimation

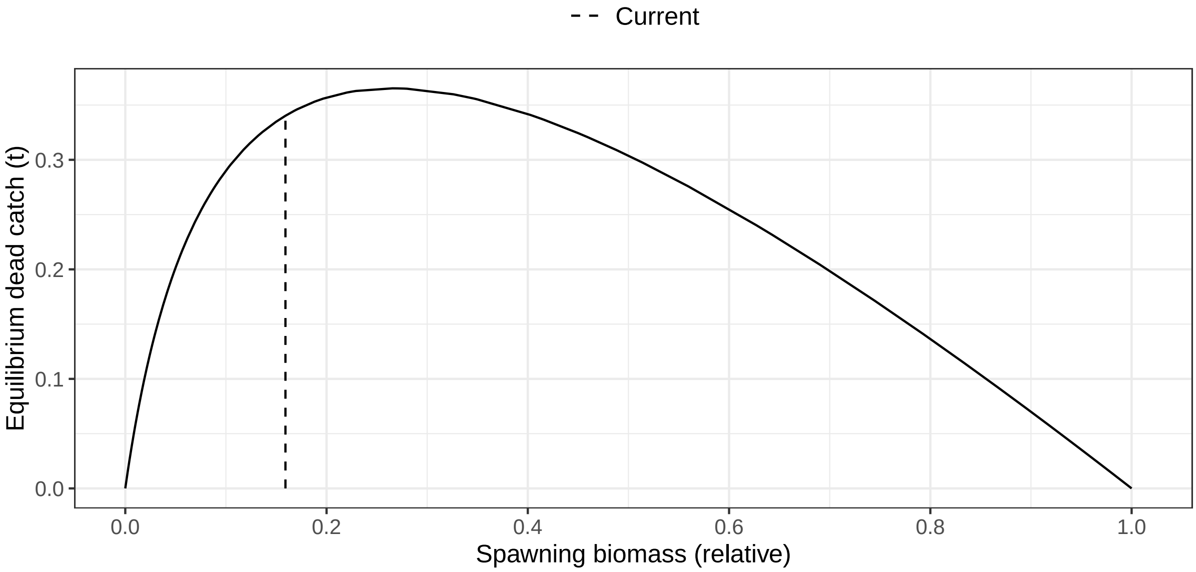

Figure E.45: Scenario 4: Equilibrium dead catch curve for king threadfin in the Gulf of Carpentaria, based on maximum likelihood estimation

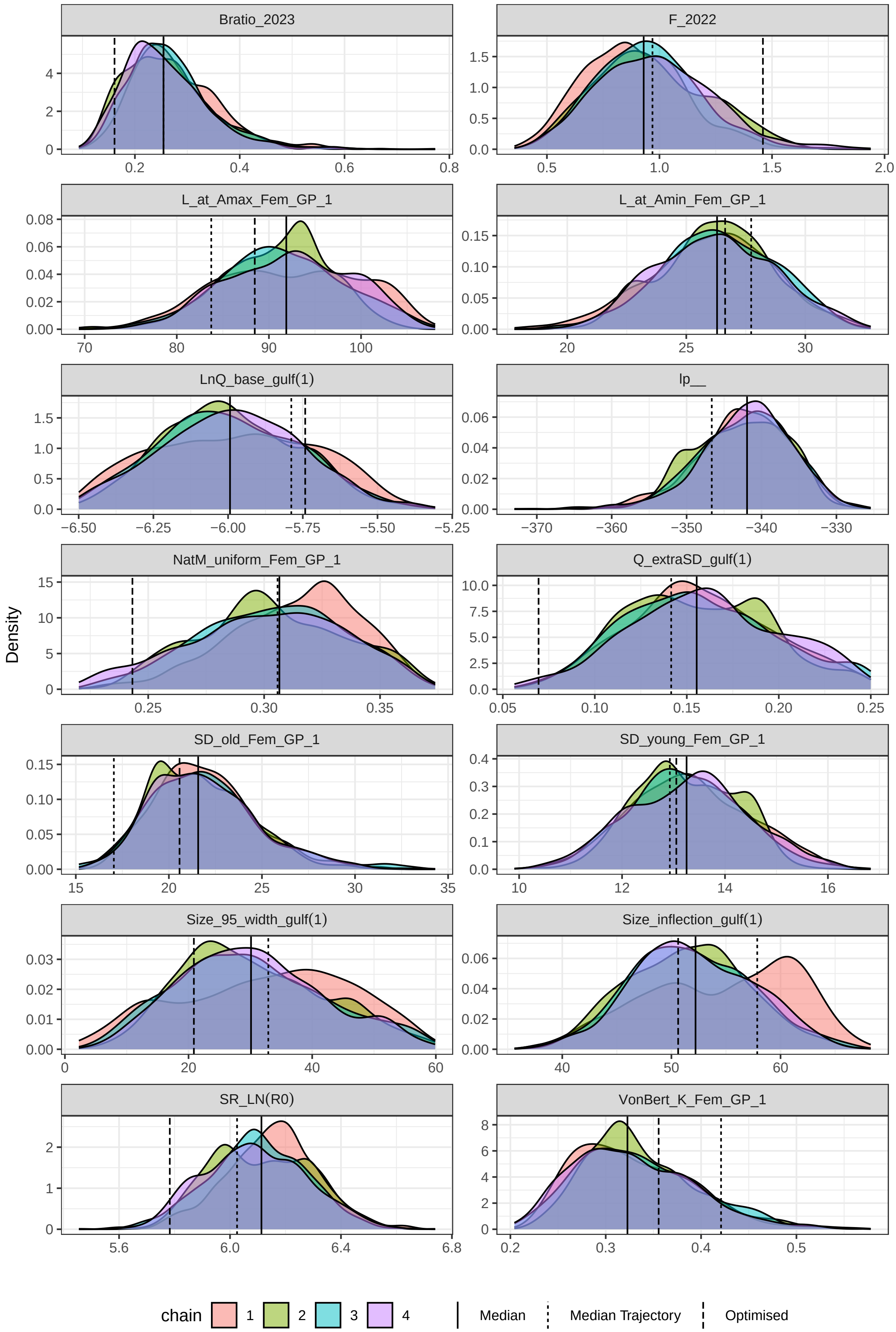

Figure E.46: Scenario 4: Posterior density of MCMC iterations. “Median” line shows median parameter value for MCMC iterations “Optimised” shows the parameter value found from maximum likelihood estimates.

Figure E.47: Scenario 4: Trace plot of MCMC iterations—"Optimised" shows the parameter value found from maximum likelihood estimates

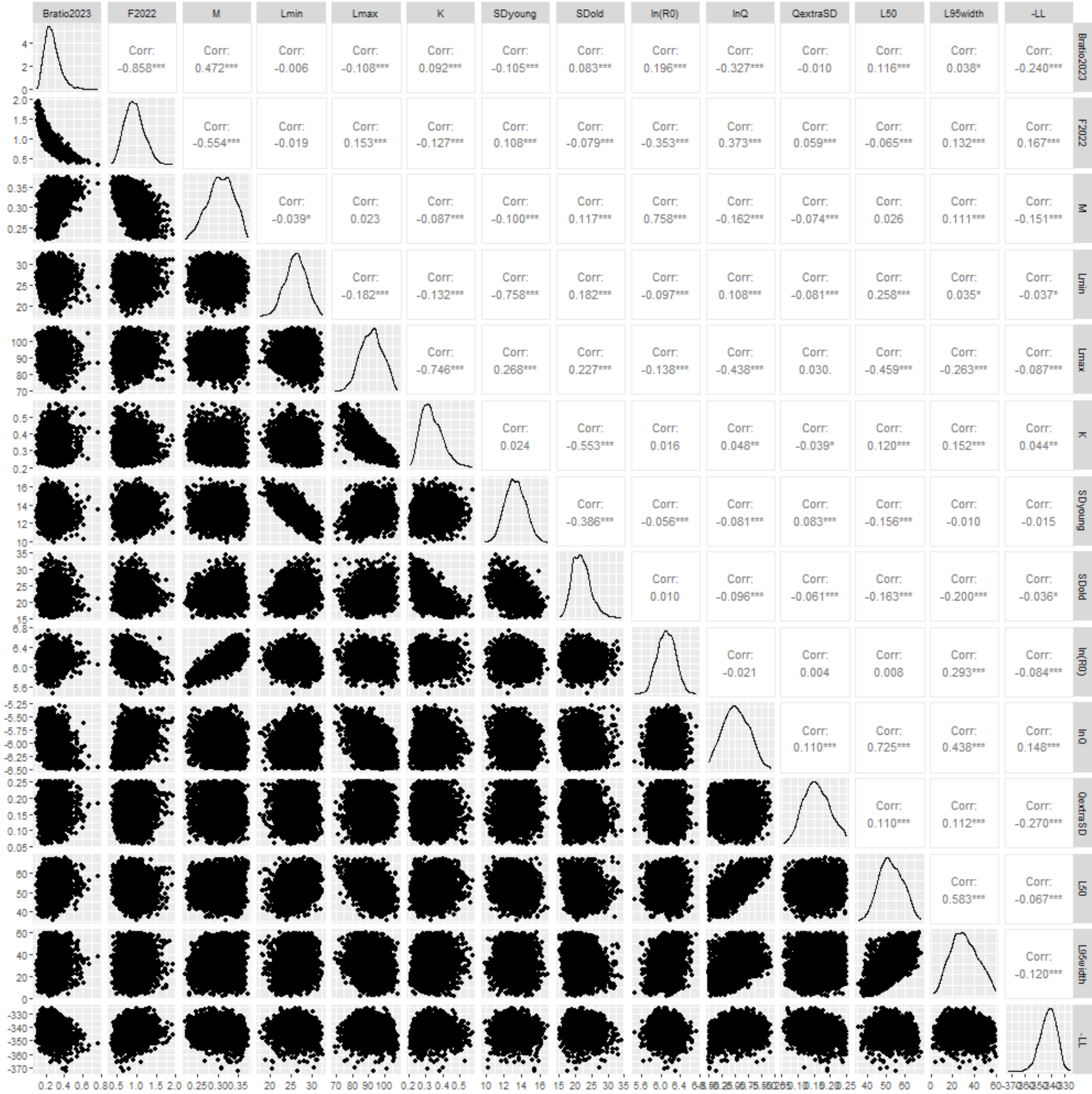

Figure E.48: Scenario 4: Correlation plot of MCMC iterations

E.5 Scenario 5

Parameter	Estimate	Phase	Min	Max	Initial value	Standard deviation
L_{min}	26.91	2	15.00	33.00	20.00	2.49
L_{max}	85.87	2	65.00	110.00	75.00	6.15
K	0.38	3	0.20	0.70	0.40	0.07
$\mathrm{SD}_{\mathrm{young}}$	12.80	3	8.00	18.00	13.00	1.12
$\mathrm{SD}_{\mathrm{old}}$	20.72	3	15.00	35.00	20.00	2.58
$\ln R_0$	6.00	1	5.00	8.00	7.00	0.11
$\ln q$	0.24	5	-5.00	5.00	0.00	0.55
QextraSD	0.08	7	0.00	0.50	0.10	0.03
L_{50}	51.74	4	30.00	70.00	55.00	4.69
$L_{95\mathrm{width}}$	20.28	4	1.00	60.00	25.00	8.02

Table E.9: Stock Synthesis parameter estimates for Scenario 5 population model for king threadfin in the Gulf of Carpentaria, based on maximum likelihood estimation

Symbol	MCMC median	MCMC 2.5%	MCMC 97.5%
M			
L_{min}	27.02	21.69	31.80
L_{max}	87.54	75.97	104.30
K	0.36	0.24	0.52
$\mathrm{SD}_{\mathrm{young}}$	12.95	10.87	15.36
$\mathrm{SD}_{\mathrm{old}}$	21.05	17.16	28.84
$\ln R_0$	6.09	5.87	6.33
$\ln q$	-6.02	-6.48	-5.62
QextraSD	0.17	0.09	0.24
L_{50}	55.59	42.00	64.26
$L_{95\mathrm{width}}$	28.73	5.93	51.49

Table E.10: Stock Synthesis parameter estimates for Scenario 5 population model for king threadfin in the Gulf of Carpentaria, based on MCMC estimation

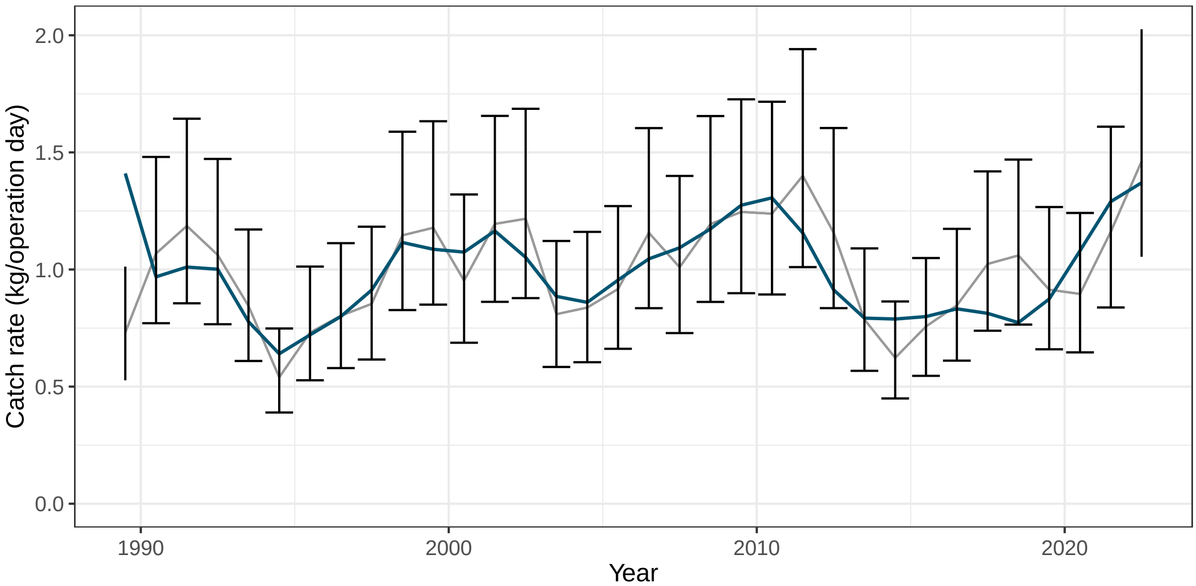

Figure E.49: Scenario 5: Model predictions (blue line) to standardised catch rates for king threadfin in the Gulf of Carpentaria, based on maximum likelihood estimation—grey line and error bars represent the model input and associated uncertainty

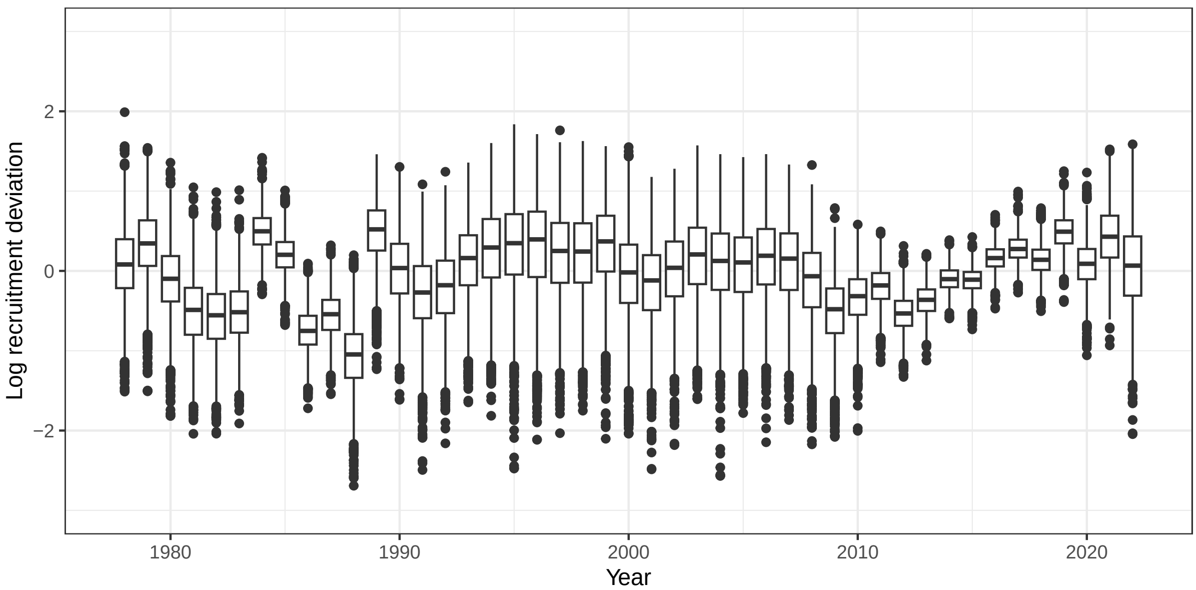

Figure E.50: Scenario 5: Recruitment deviations—whiskers represent 95% credible intervals, boxes represent 50% credible intervals, horizontal bars represent medians, and the points represent outliers

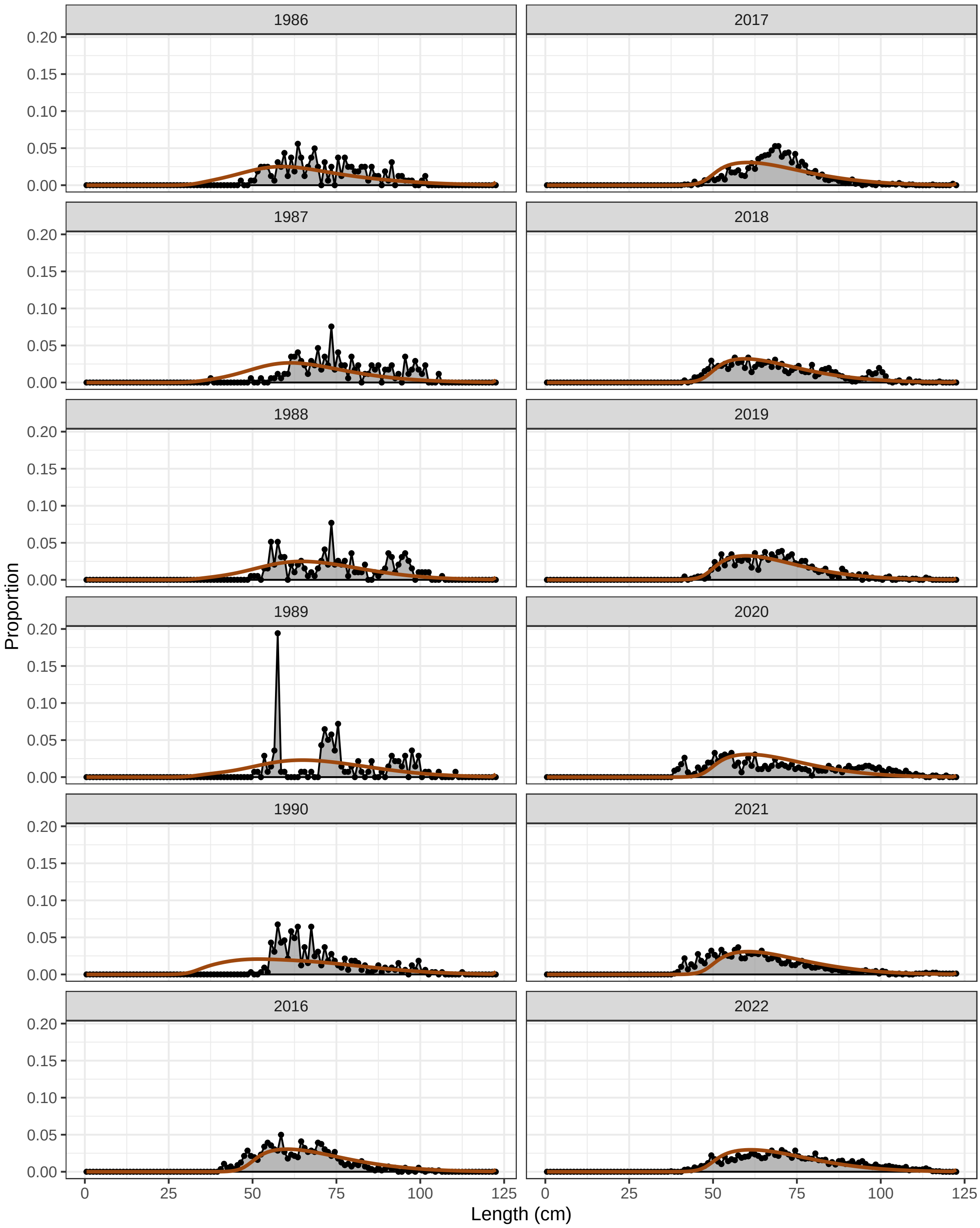

Figure E.51: Scenario 5: Fits to length structures, based on maximum likelihood estimation—the grey area and black line represent data inputs and the red line represents the model fits

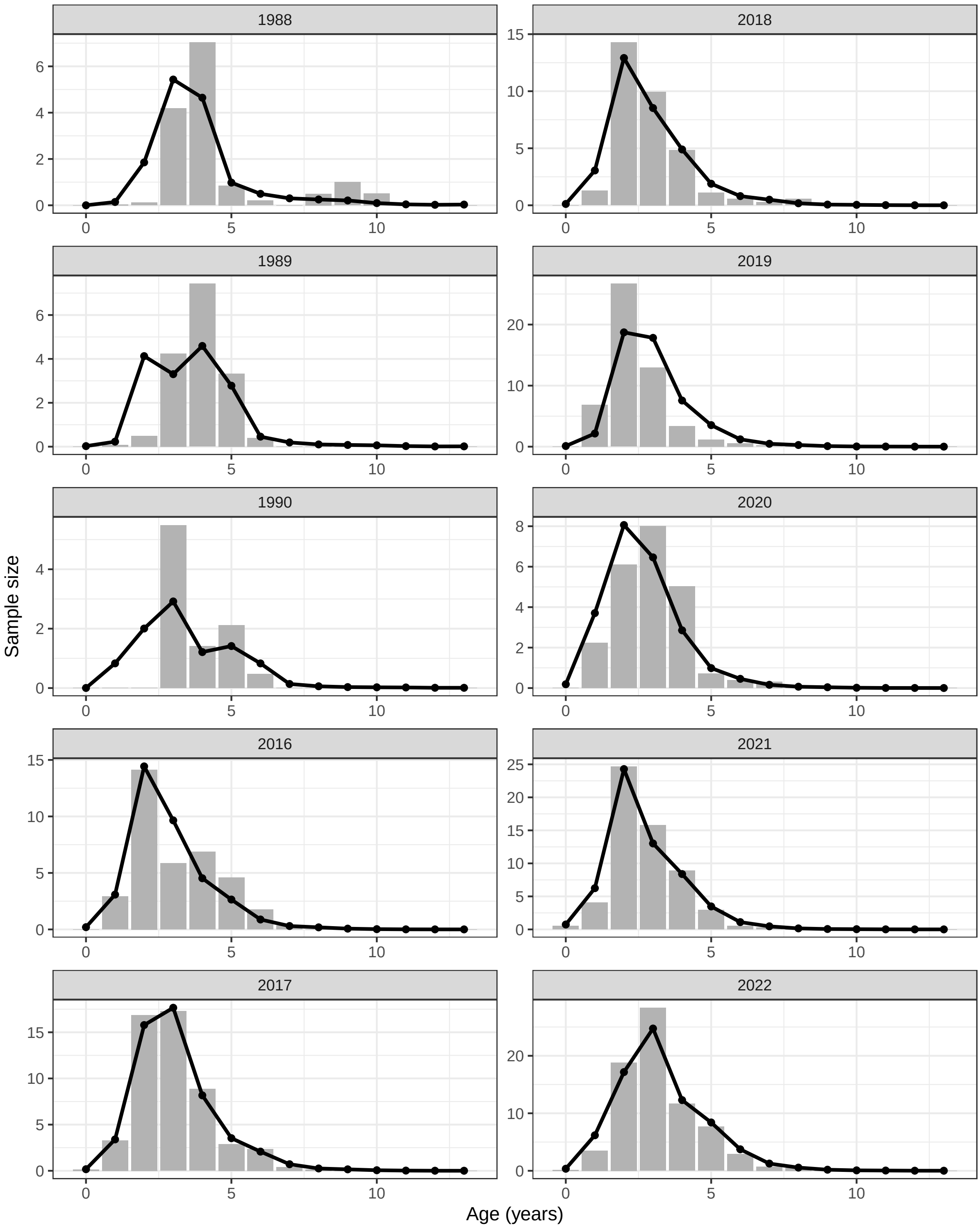

Figure E.52: Scenario 5: Fits to age structures, based on maximum likelihood estimatio—grey bars represent input data and black line and points represent model fitsn

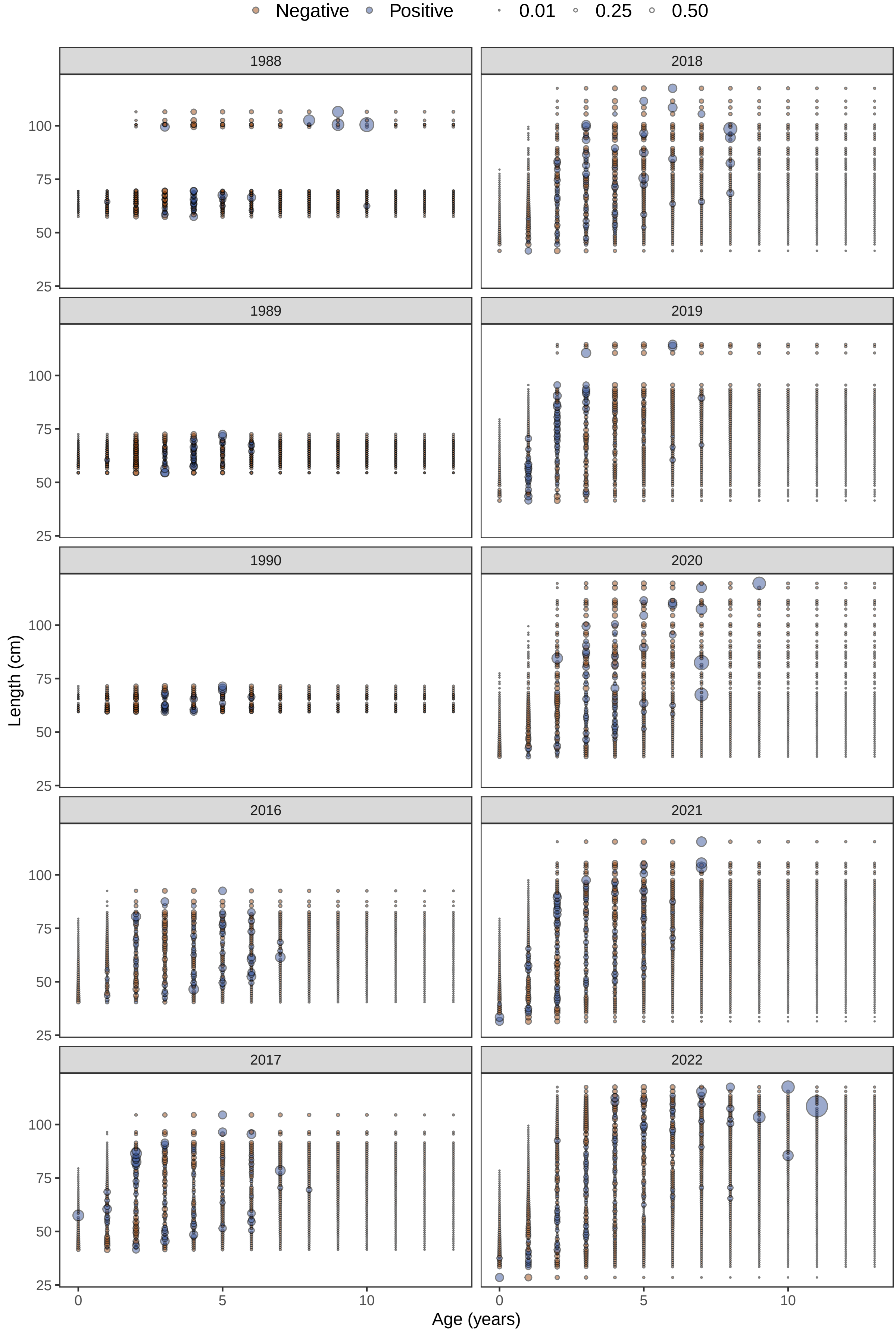

Figure E.53: Scenario 5: Pearson residuals for age-at-length compositions, based on maximum likelihood estimation—circle size represents the magnitude of the Pearson residual

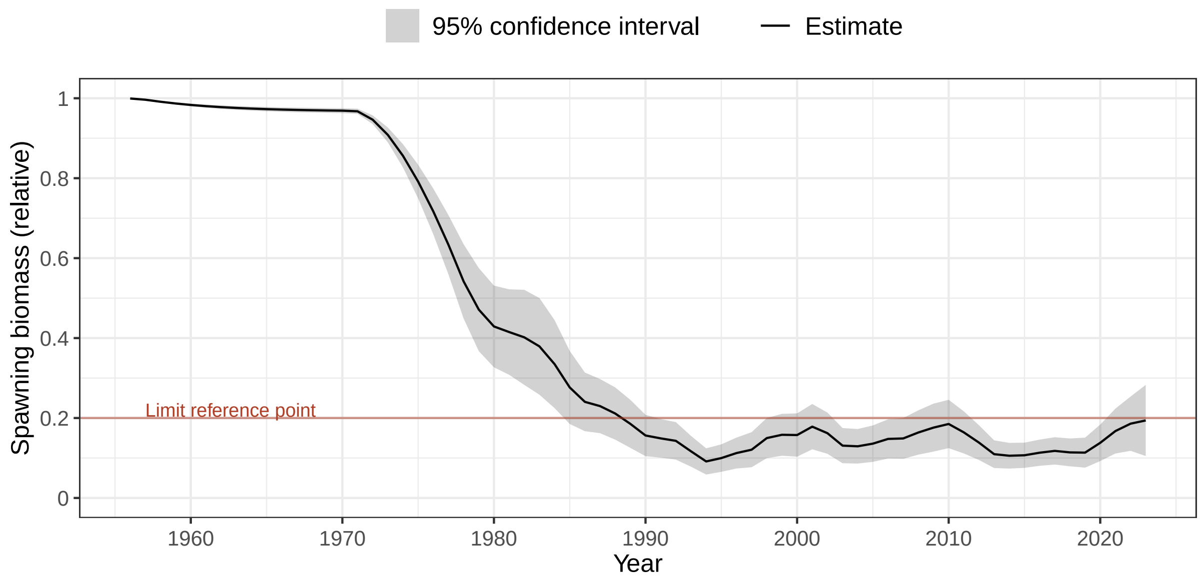

Figure E.54: Scenario 5: Predicted spawning biomass trajectory relative to unfished for king threadfin in the Gulf of Carpentaria, based on maximum likelihood estimation

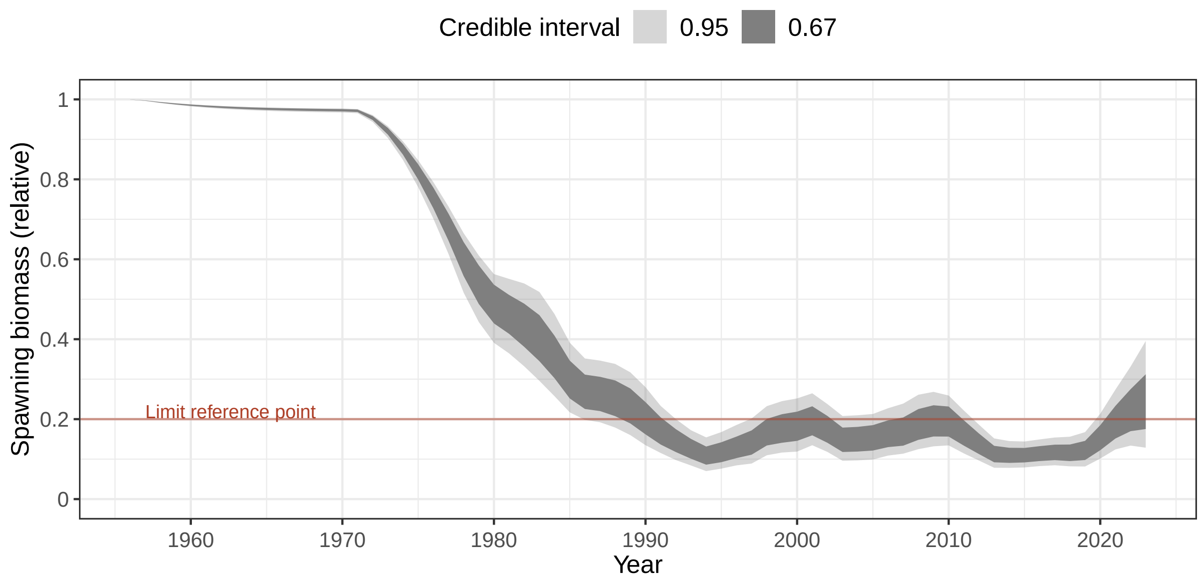

Figure E.55: Scenario 5: Predicted spawning biomass trajectory relative to unfished for king threadfin in the Gulf of Carpentaria, based on MCMC

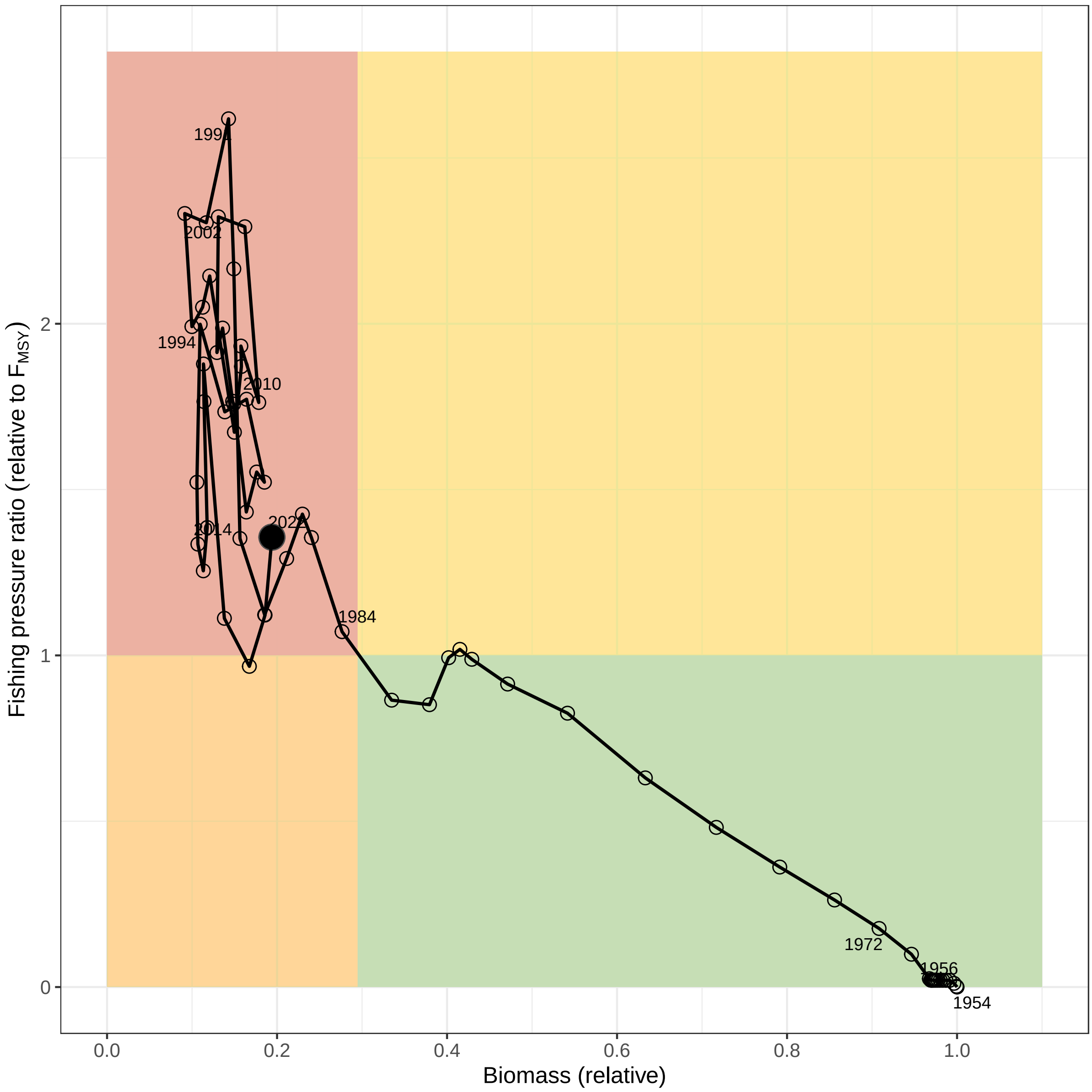

Figure E.56: Scenario 5: Stock status indicator trajectory for king threadfin in the Gulf of Carpentaria, based on maximum likelihood estimation

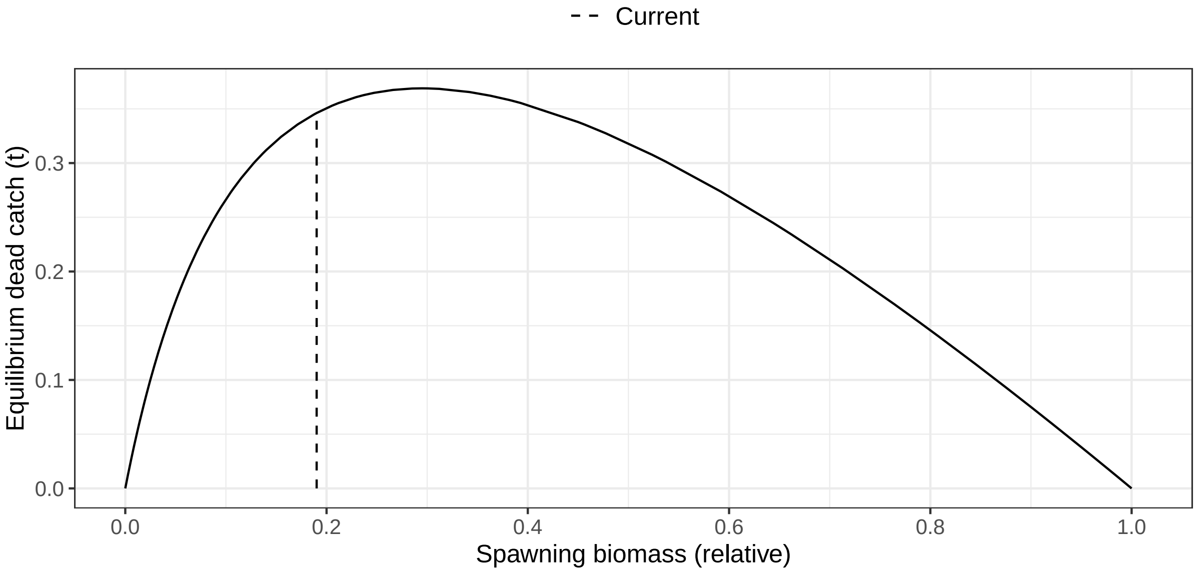

Figure E.57: Scenario 5: Equilibrium dead catch curve for king threadfin in the Gulf of Carpentaria, based on maximum likelihood estimation

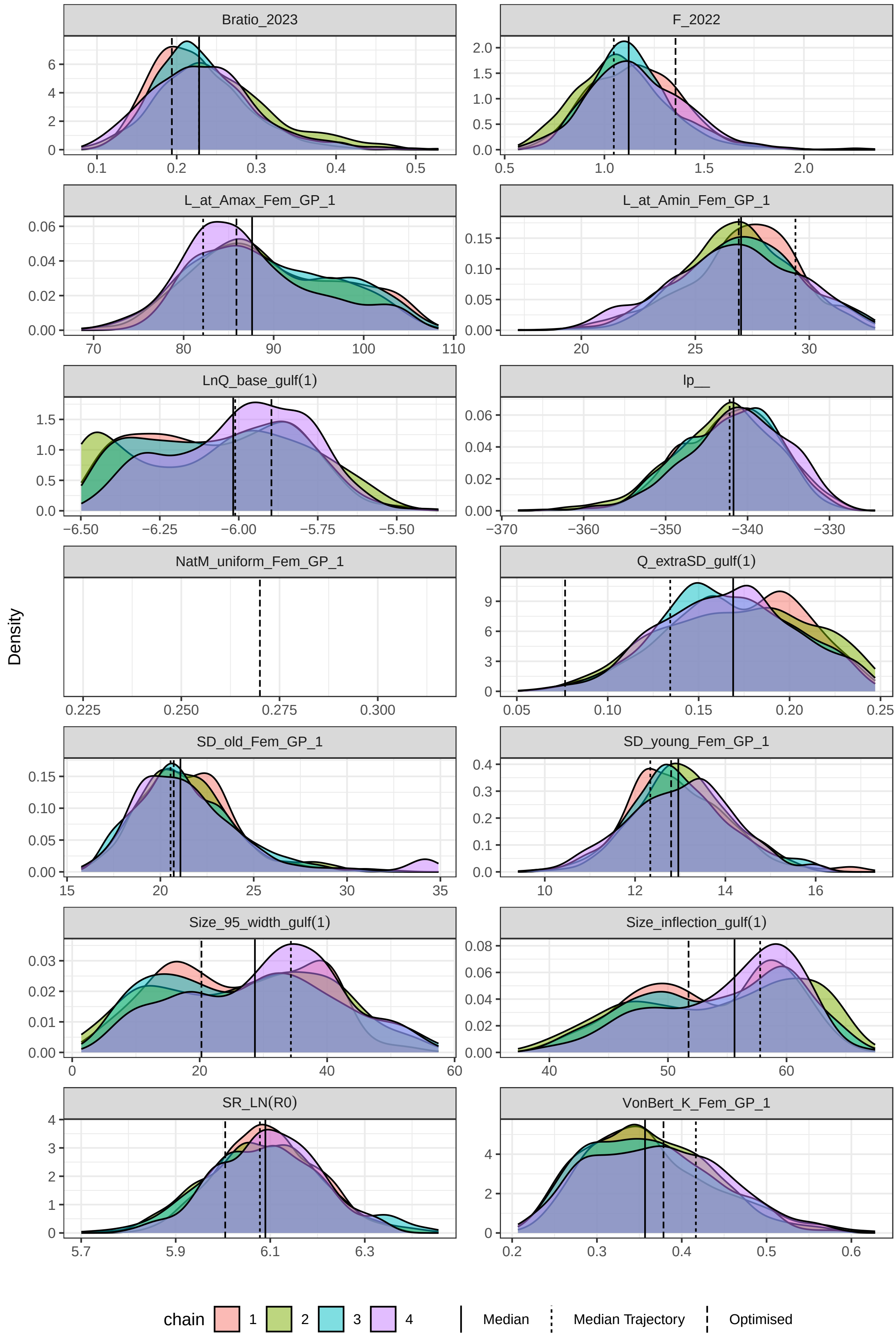

Figure E.58: Scenario 5: Posterior density of MCMC iterations. “Median” line shows median parameter value for MCMC iterations “Optimised” shows the parameter value found from maximum likelihood estimates.

Figure E.59: Scenario 5: Trace plot of MCMC iterations—“Optimised” shows the parameter value found from maximum likelihood estimates

Figure E.60: Scenario 5: Correlation plot of MCMC iterations

E.6 Scenario 6

Parameter	Estimate	Phase	Min	Max	Initial value	Standard deviation
L_{min}	26.71	2	15.00	33.00	20.00	2.50
L_{max}	87.12	2	65.00	110.00	75.00	6.29
K	0.37	3	0.20	0.70	0.40	0.07
$\mathrm{SD}_{\mathrm{young}}$	12.94	3	8.00	18.00	13.00	1.13
$\mathrm{SD}_{\mathrm{old}}$	20.57	3	15.00	35.00	20.00	2.56
$\ln R_0$	6.00	1	5.00	8.00	7.00	0.12
$\ln q$	0.26	5	-5.00	5.00	0.00	0.55
QextraSD	0.07	7	0.00	0.50	0.10	0.03
L_{50}	51.35	4	30.00	70.00	55.00	4.72
$L_{95\mathrm{width}}$	20.89	4	1.00	60.00	25.00	8.55

Table E.11: Stock Synthesis parameter estimates for Scenario 6 population model for king threadfin in the Gulf of Carpentaria, based on maximum likelihood estimation

Symbol	MCMC median	MCMC 2.5%	MCMC 97.5%
M			
L_{min}	26.75	21.67	31.62
L_{max}	90.52	77.48	105.99
K	0.34	0.24	0.50
$\mathrm{SD}_{\mathrm{young}}$	13.12	11.14	15.41
$\mathrm{SD}_{\mathrm{old}}$	21.32	17.31	27.19
$\ln R_0$	6.07	5.84	6.29
$\ln q$	-5.95	-6.37	-5.39
QextraSD	0.15	0.08	0.23
L_{50}	53.82	40.96	64.78
$L_{95\mathrm{width}}$	28.20	5.73	54.32

Table E.12: Stock Synthesis parameter estimates for Scenario 6 population model for king threadfin in the Gulf of Carpentaria, based on MCMC estimation

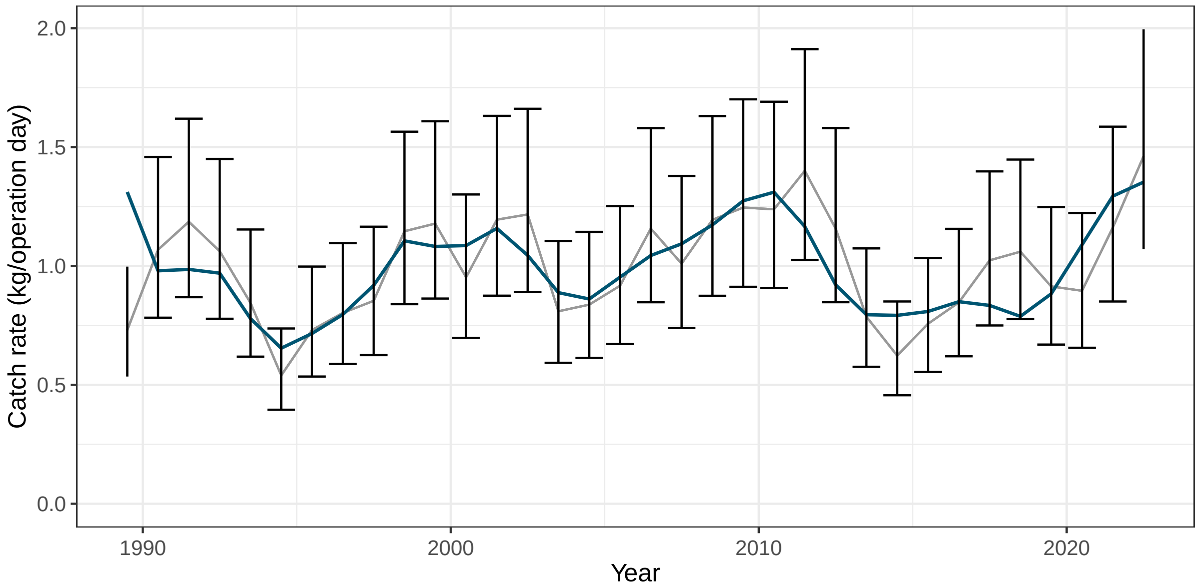

Figure E.61: Scenario 6: Model predictions (blue line) to standardised catch rates for king threadfin in the Gulf of Carpentaria, based on maximum likelihood estimation—grey line and error bars represent the model input and associated uncertainty

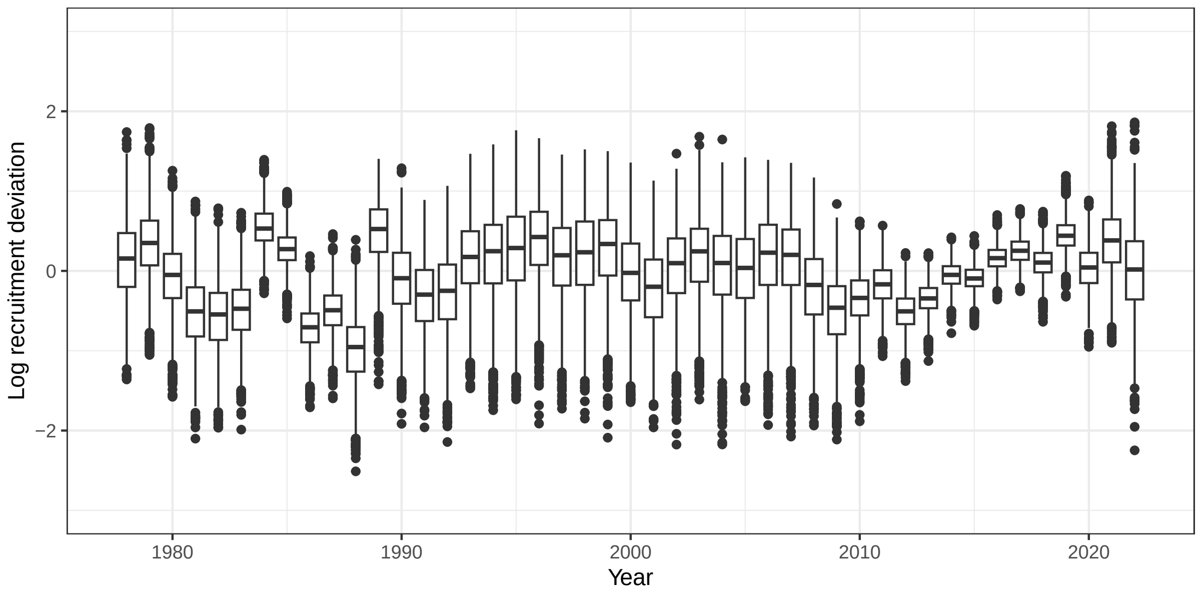

Figure E.62: Scenario 6: Recruitment deviations—whiskers represent 95% credible intervals, boxes represent 50% credible intervals, horizontal bars represent medians, and the points represent outliers

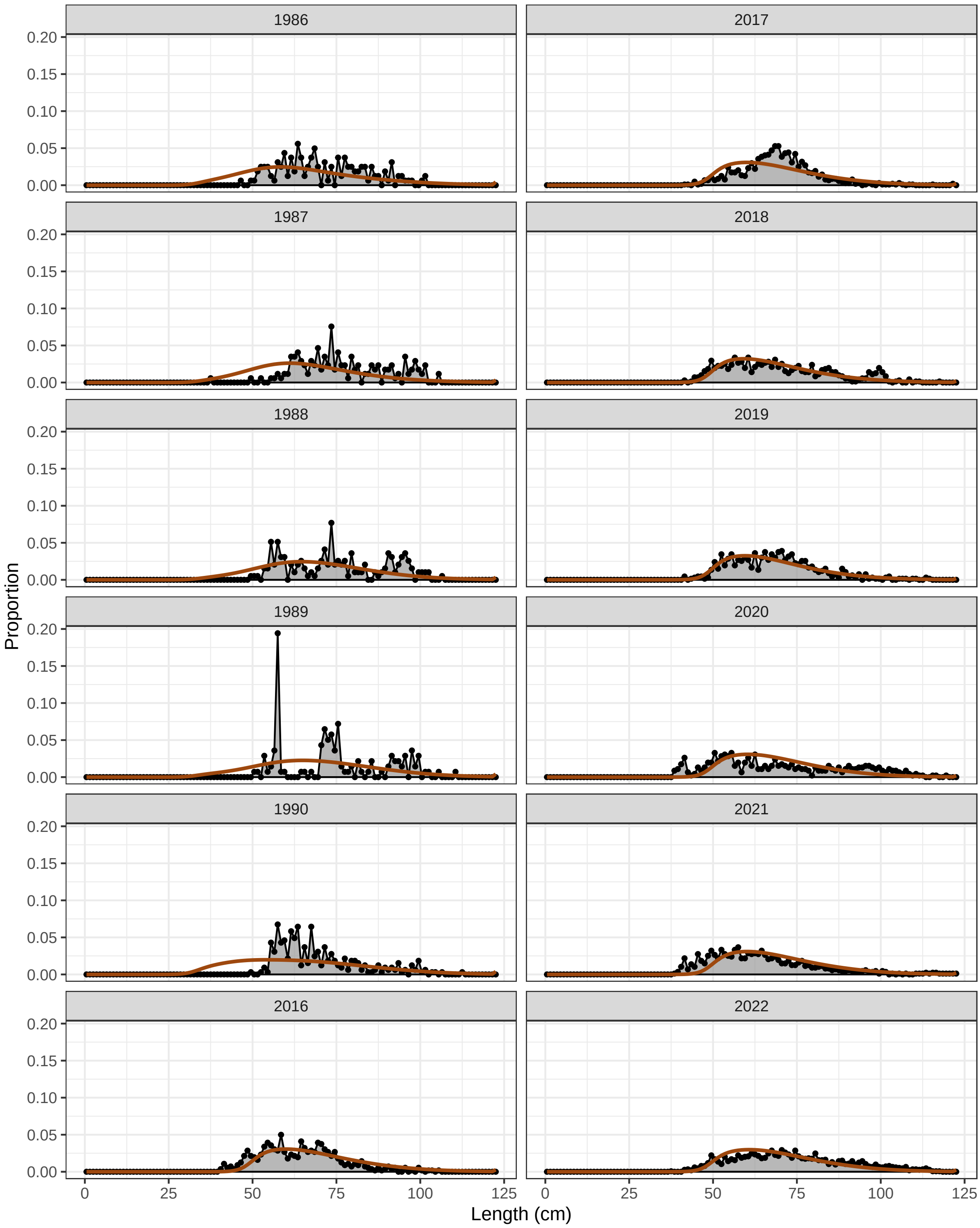

Figure E.63: Scenario 6: Fits to length structures, based on maximum likelihood estimation—the grey area and black line represent data inputs and the red line represents the model fits

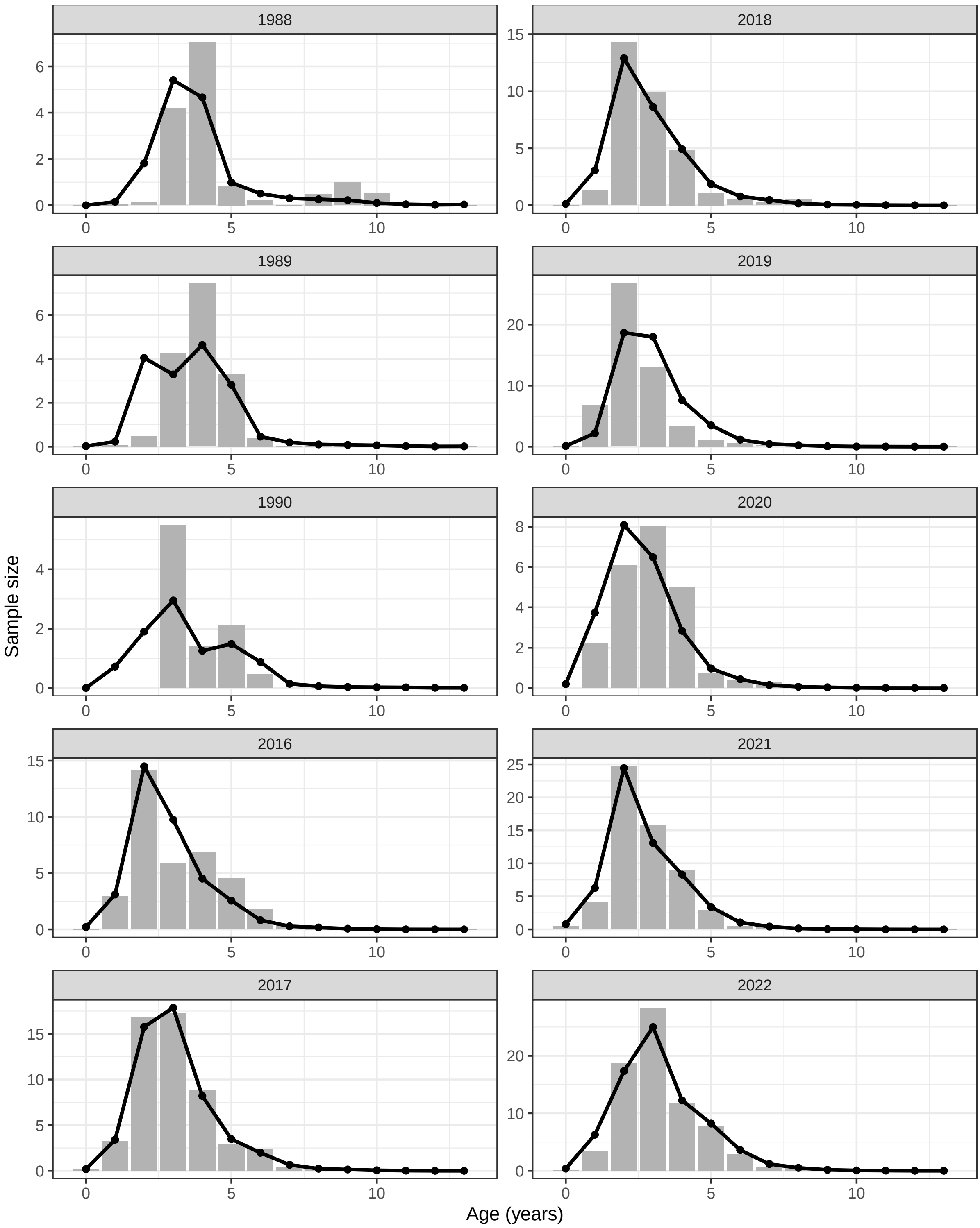

Figure E.64: Scenario 6: Fits to age structures, based on maximum likelihood estimation—grey bars represent input data and black line and points represent model fits

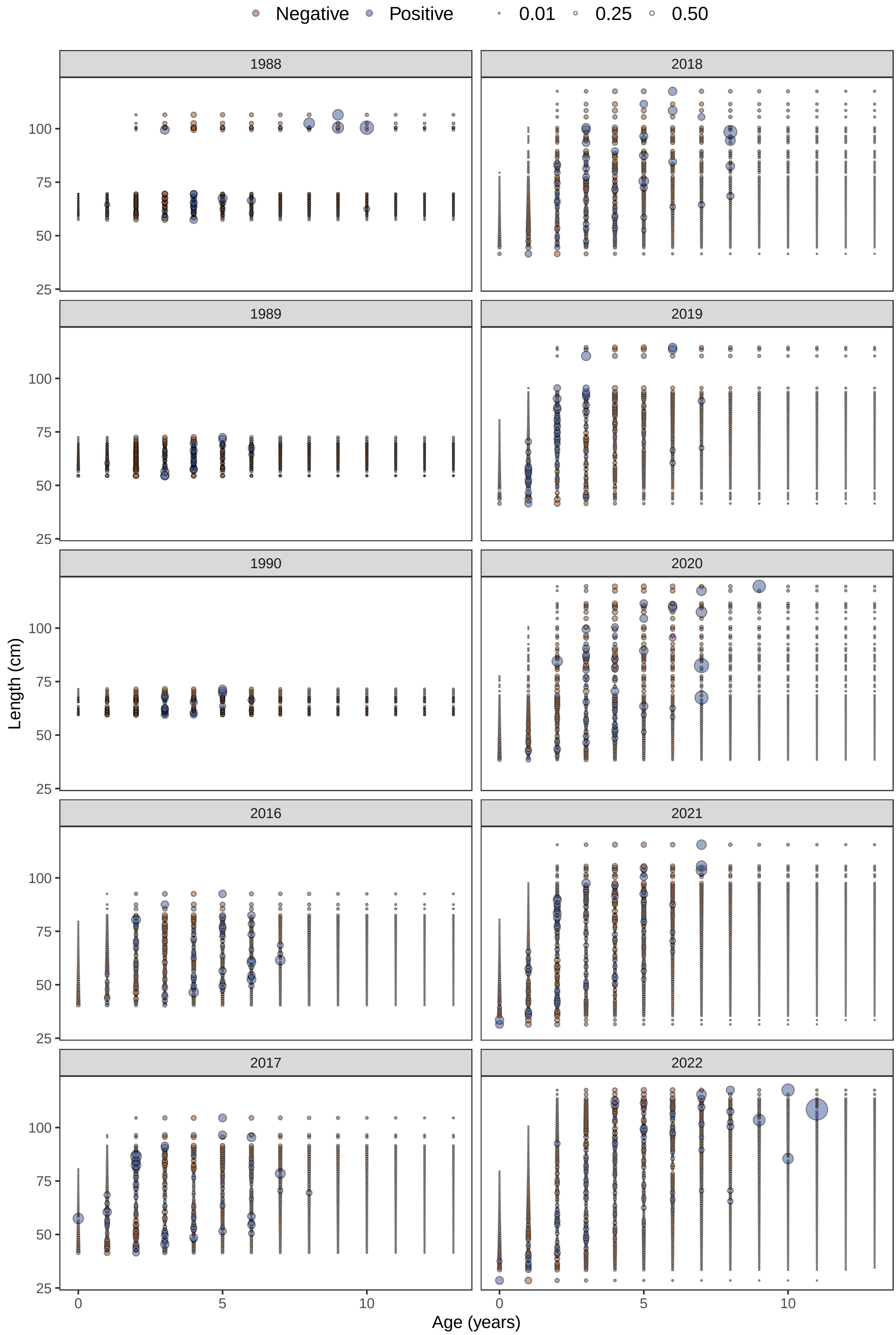

Figure E.65: Scenario 6: Pearson residuals for age-at-length compositions, based on maximum likelihood estimation—circle size represents the magnitude of the Pearson residual

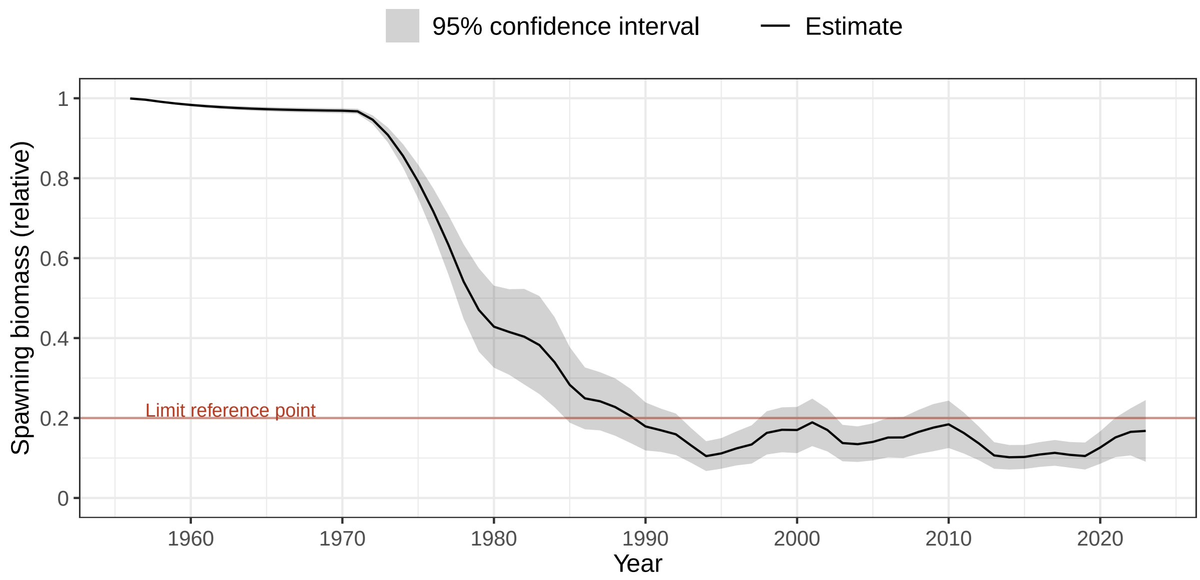

Figure E.66: Scenario 6: Predicted spawning biomass trajectory relative to unfished for king threadfin in the Gulf of Carpentaria, based on maximum likelihood estimation

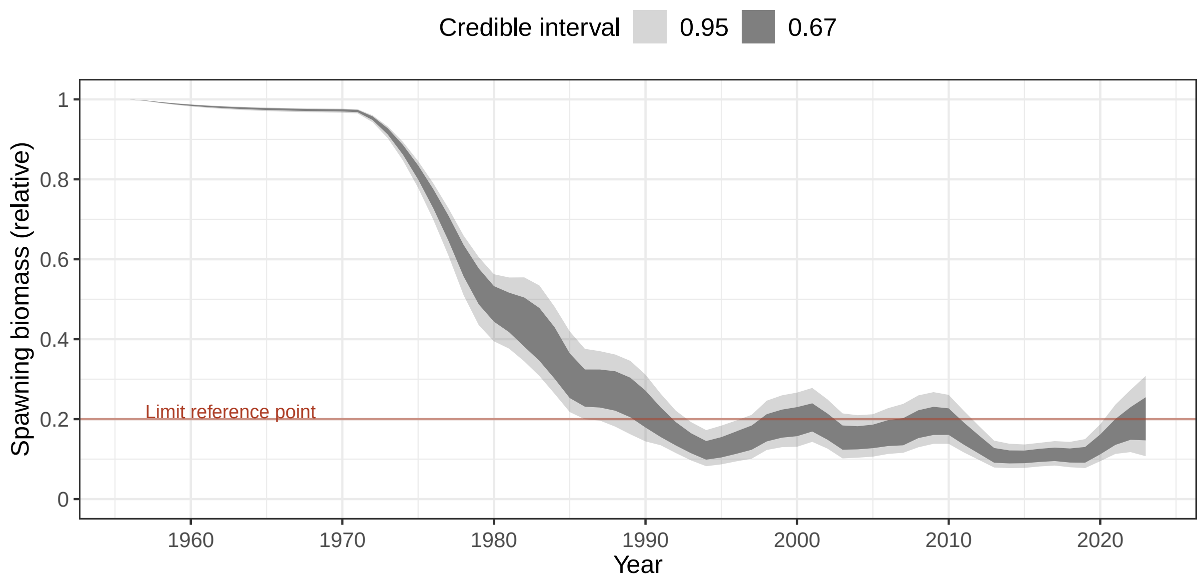

Figure E.67: Scenario 6: Predicted spawning biomass trajectory relative to unfished for king threadfin in the Gulf of Carpentaria, based on MCMC

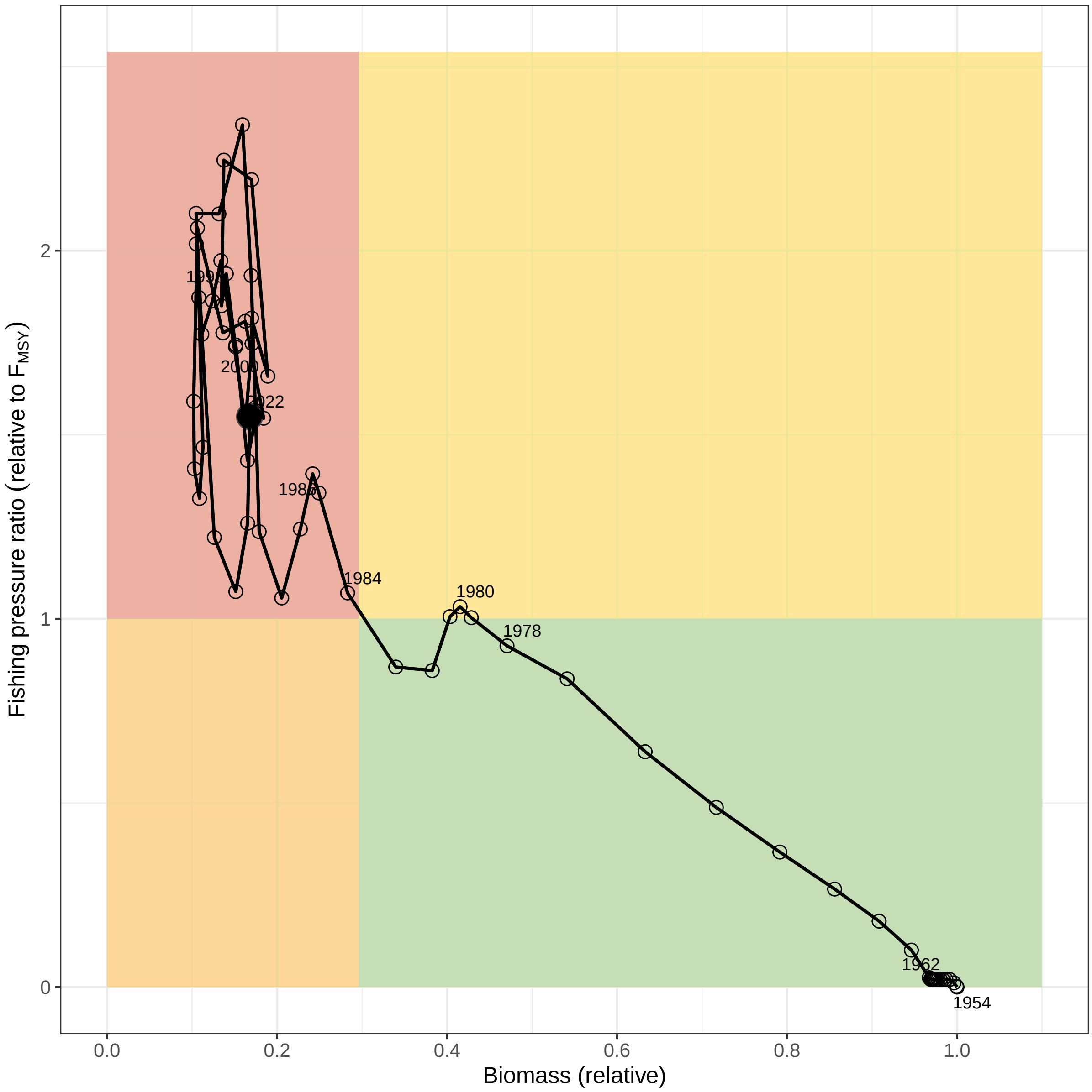

Figure E.68: Scenario 6: Stock status indicator trajectory for king threadfin in the Gulf of Carpentaria, based on maximum likelihood estimation

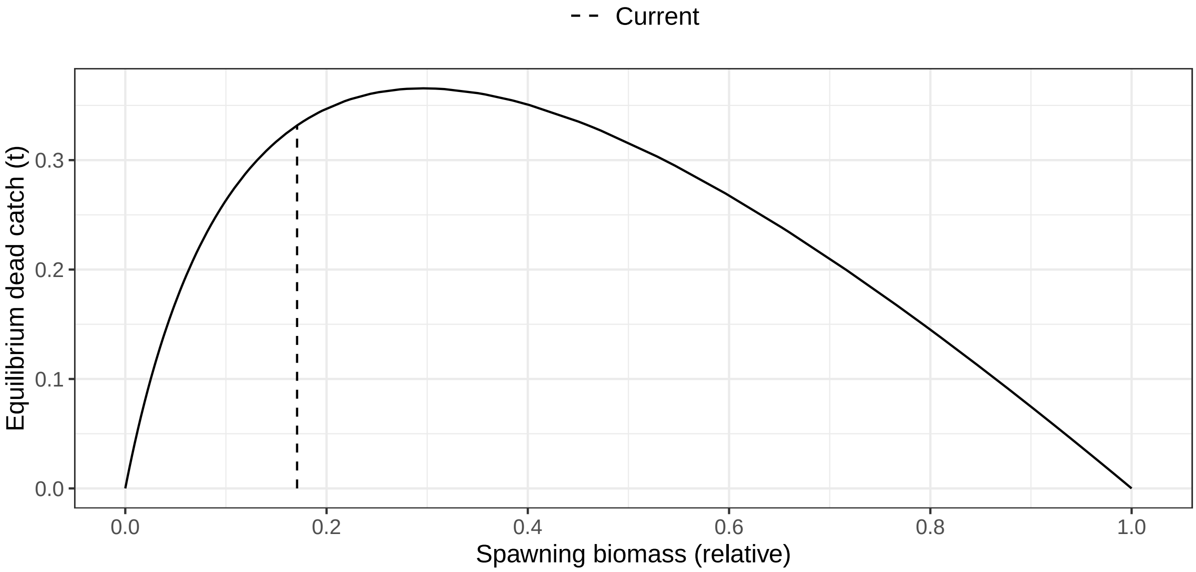

Figure E.69: Scenario 6: Equilibrium dead catch curve for king threadfin in the Gulf of Carpentaria, based on maximum likelihood estimation

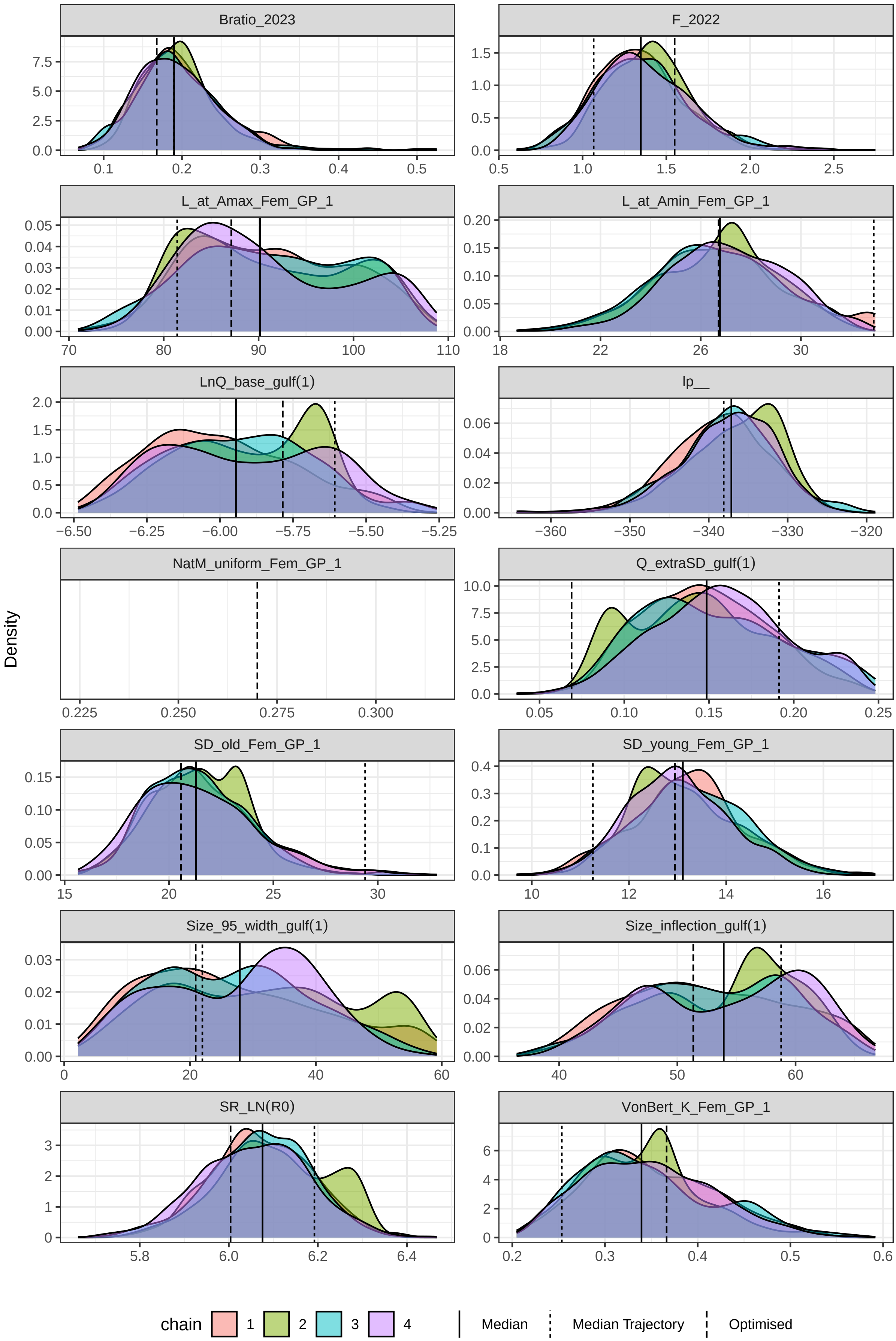

Figure E.70: Scenario 6: Posterior density of MCMC iterations. "Median" line shows median parameter value for MCMC iterations "Optimised" shows the parameter value found from maximum likelihood estimates.

Figure E.71: Scenario 6: Trace plot of MCMC iterations—“Optimised” shows the parameter value found from maximum likelihood estimates

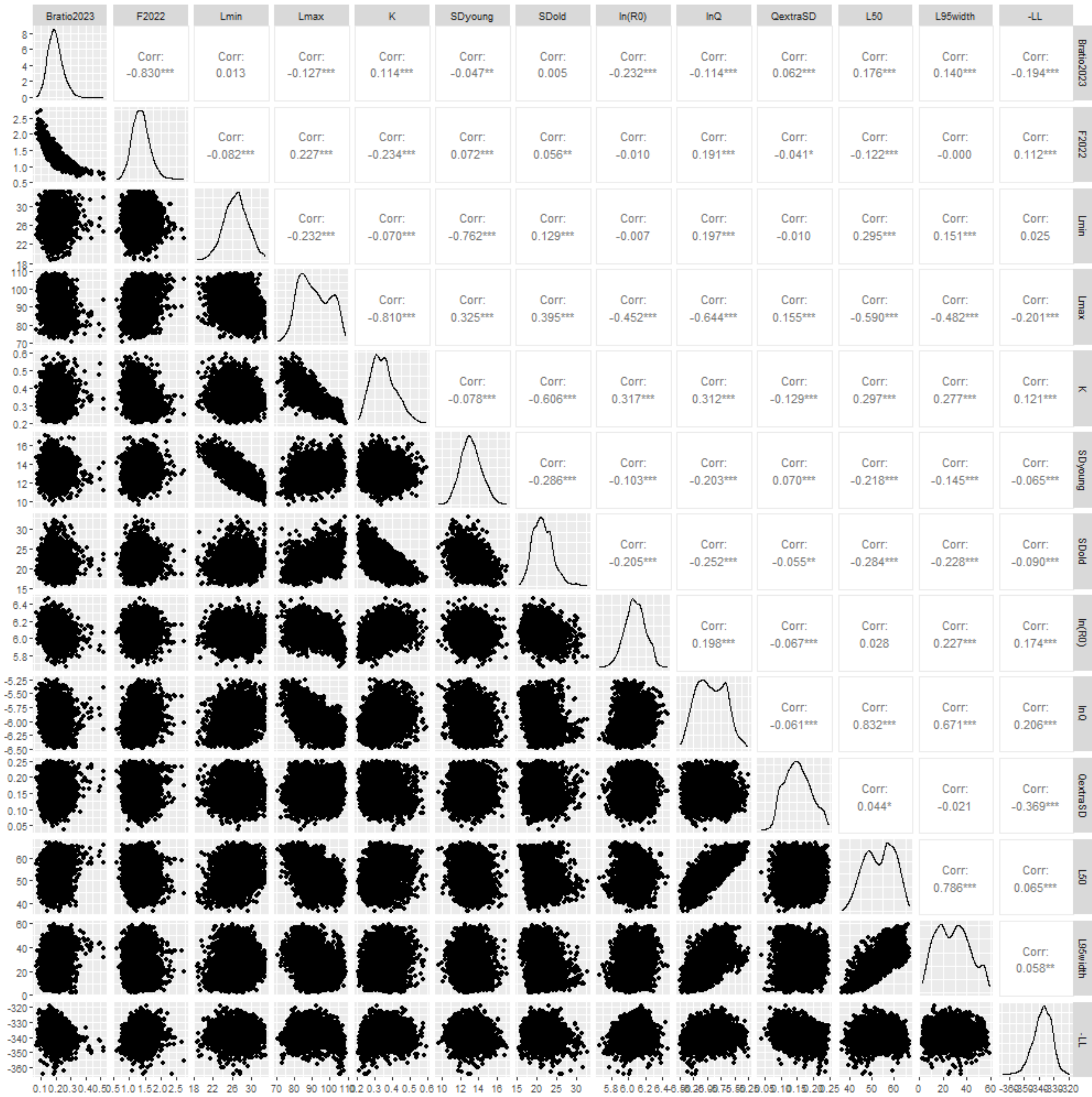

Figure E.72: Scenario 6: Correlation plot of MCMC iterations

E.7 Scenario 7

Parameter	Estimate	Phase	Min	Max	Initial value	Standard deviation
L_{min}	26.57	2	15.00	33.00	20.00	2.50
L_{max}	88.09	2	65.00	110.00	75.00	6.63
K	0.36	3	0.20	0.70	0.40	0.07
$\mathrm{SD}_{\mathrm{young}}$	12.93	3	8.00	18.00	13.00	1.12
$\mathrm{SD}_{\mathrm{old}}$	20.99	3	15.00	35.00	20.00	2.69
$\ln R_0$	5.90	1	5.00	8.00	7.00	0.11
$\ln q$	0.44	5	-5.00	5.00	0.00	0.58
QextraSD	0.08	7	0.00	0.50	0.10	0.03
L_{50}	50.96	4	30.00	70.00	55.00	4.66
$L_{95\mathrm{width}}$	20.69	4	1.00	60.00	25.00	8.72

Table E.13: Stock Synthesis parameter estimates for Scenario 7 population model for king threadfin in the Gulf of Carpentaria, based on maximum likelihood estimation

Symbol	MCMC median	MCMC 2.5%	MCMC 97.5%
M			
L_{min}	26.93	22.05	31.27
L_{max}	87.48	76.87	104.04
K	0.34	0.25	0.51
$\mathrm{SD}_{\mathrm{young}}$	13.00	11.09	15.20
$\mathrm{SD}_{\mathrm{old}}$	21.11	17.46	28.28
$\ln R_0$	6.00	5.78	6.30
$\ln q$	-5.88	-6.41	-5.53
QextraSD	0.17	0.08	0.24
L_{50}	56.96	42.56	64.09
$L_{95\mathrm{width}}$	36.36	7.72	54.94

Table E.14: Stock Synthesis parameter estimates for Scenario 7 population model for king threadfin in the Gulf of Carpentaria, based on MCMC estimation

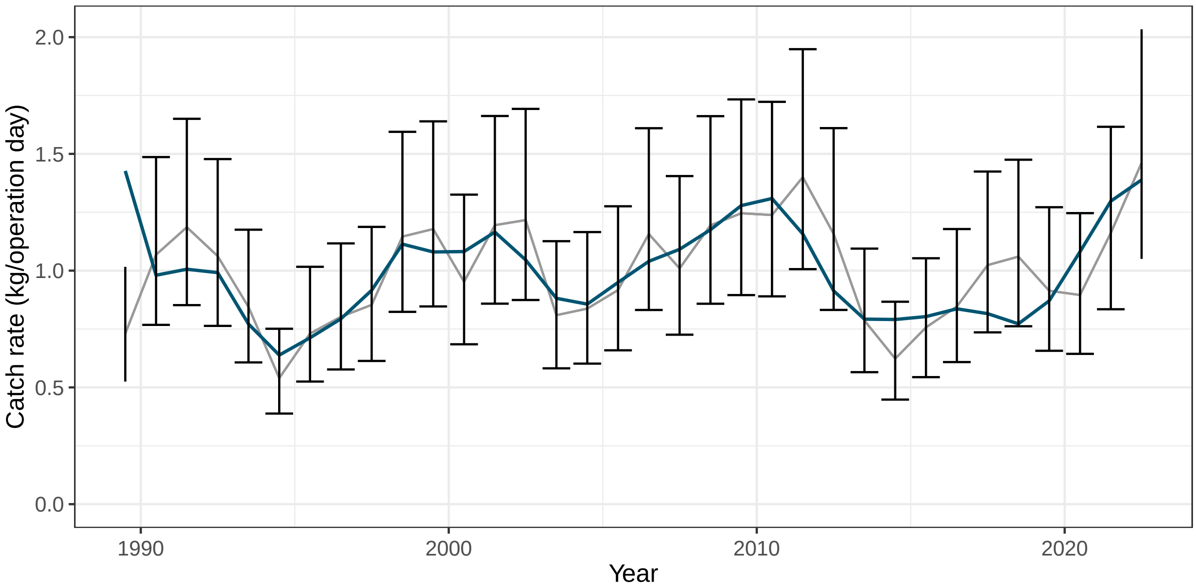

Figure E.73: Scenario 7: Model predictions (blue line) to standardised catch rates for king threadfin in the Gulf of Carpentaria, based on maximum likelihood estimation—grey line and error bars represent the model input and associated uncertainty

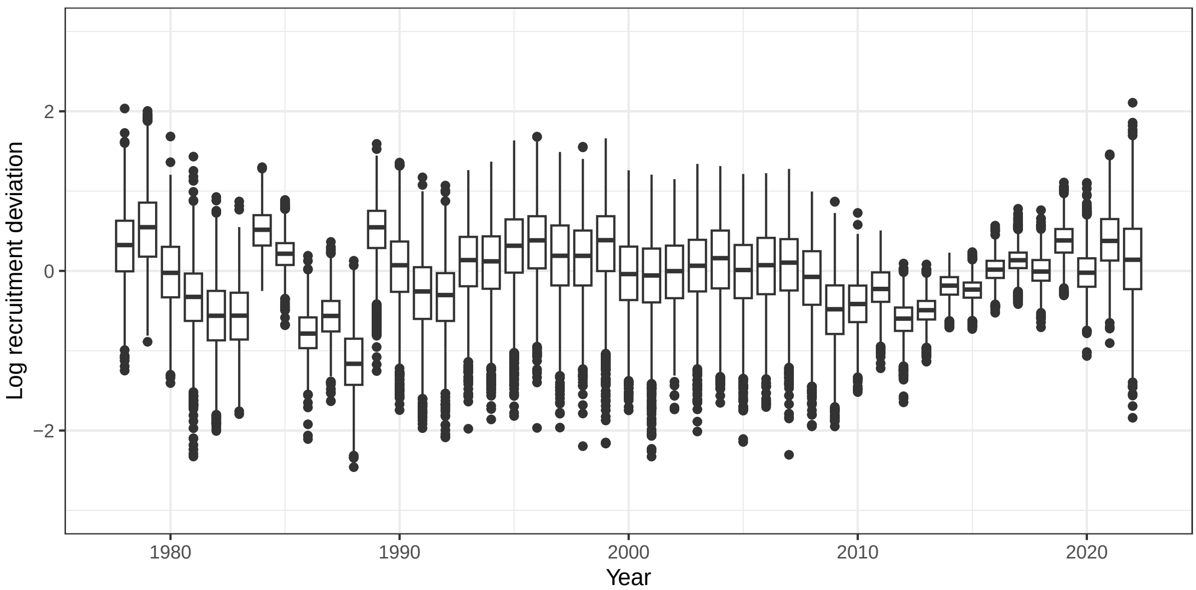

Figure E.74: Scenario 7: Recruitment deviations—whiskers represent 95% credible intervals, boxes represent 50% credible intervals, horizontal bars represent medians, and the points represent outliers

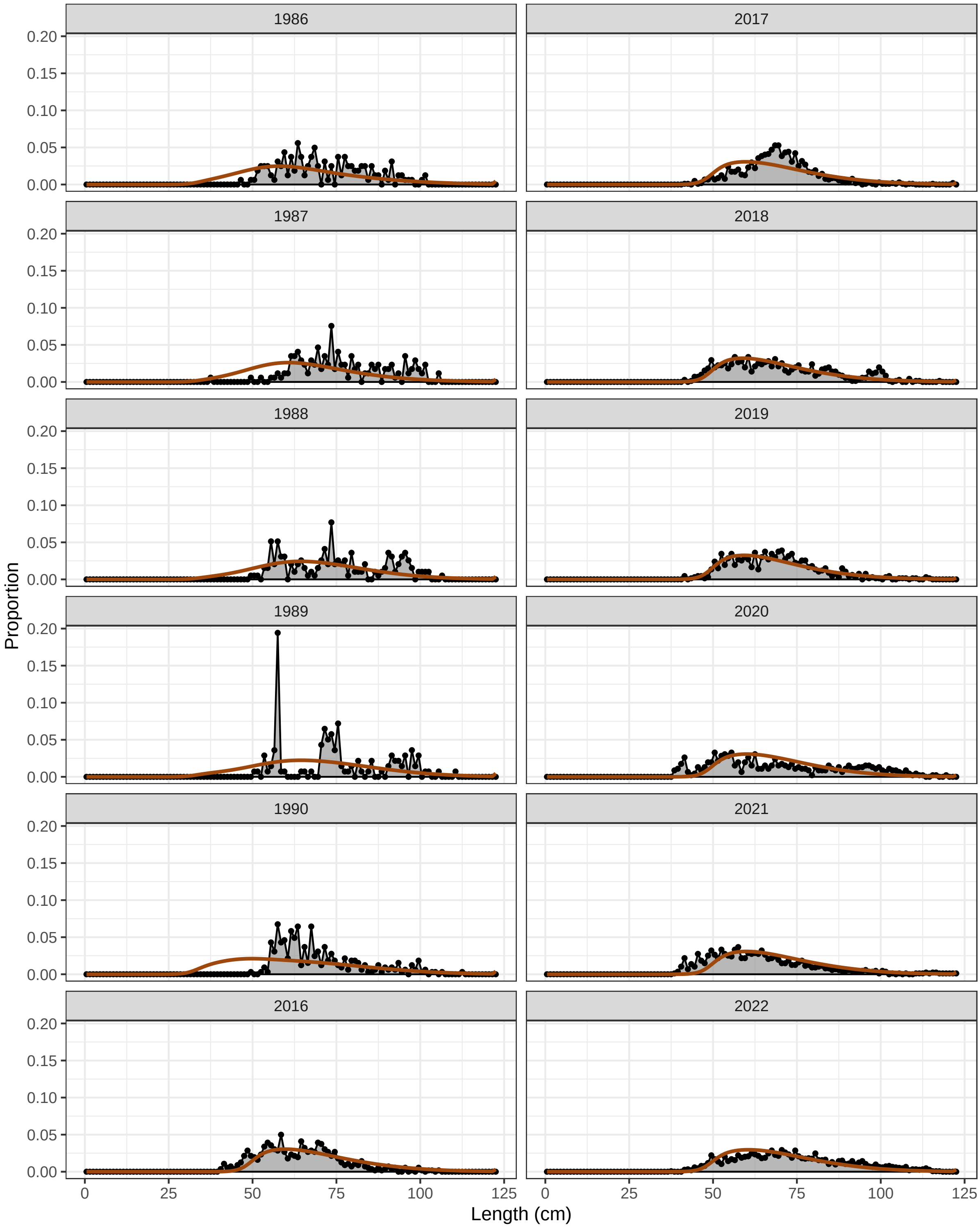

Figure E.75: Scenario 7: Fits to length structures, based on maximum likelihood estimation—the grey area and black line represent data inputs and the red line represents the model fits

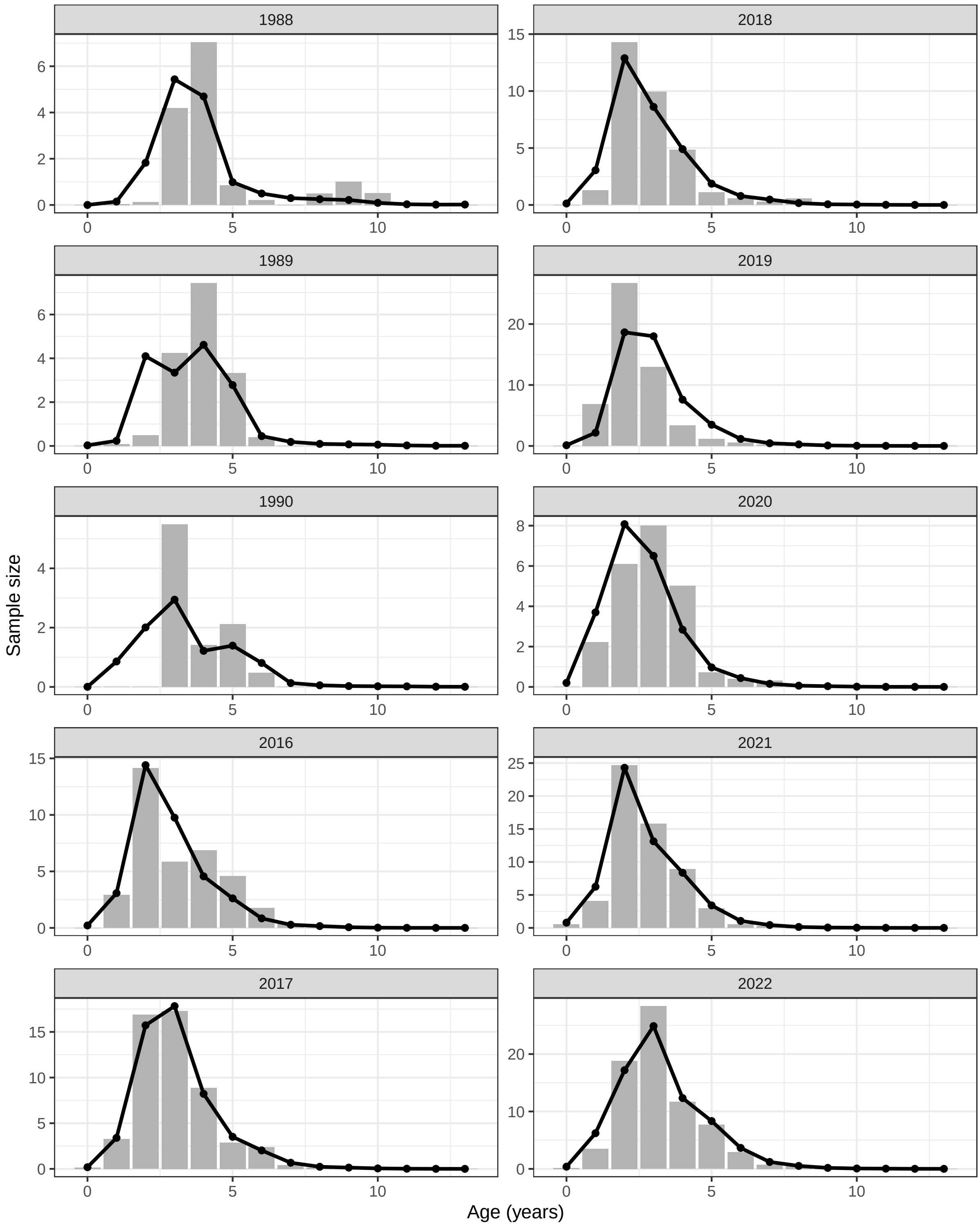

Figure E.76: Scenario 7: Fits to age structures, based on maximum likelihood estimation—grey bars represent input data and black line and points represent model fits

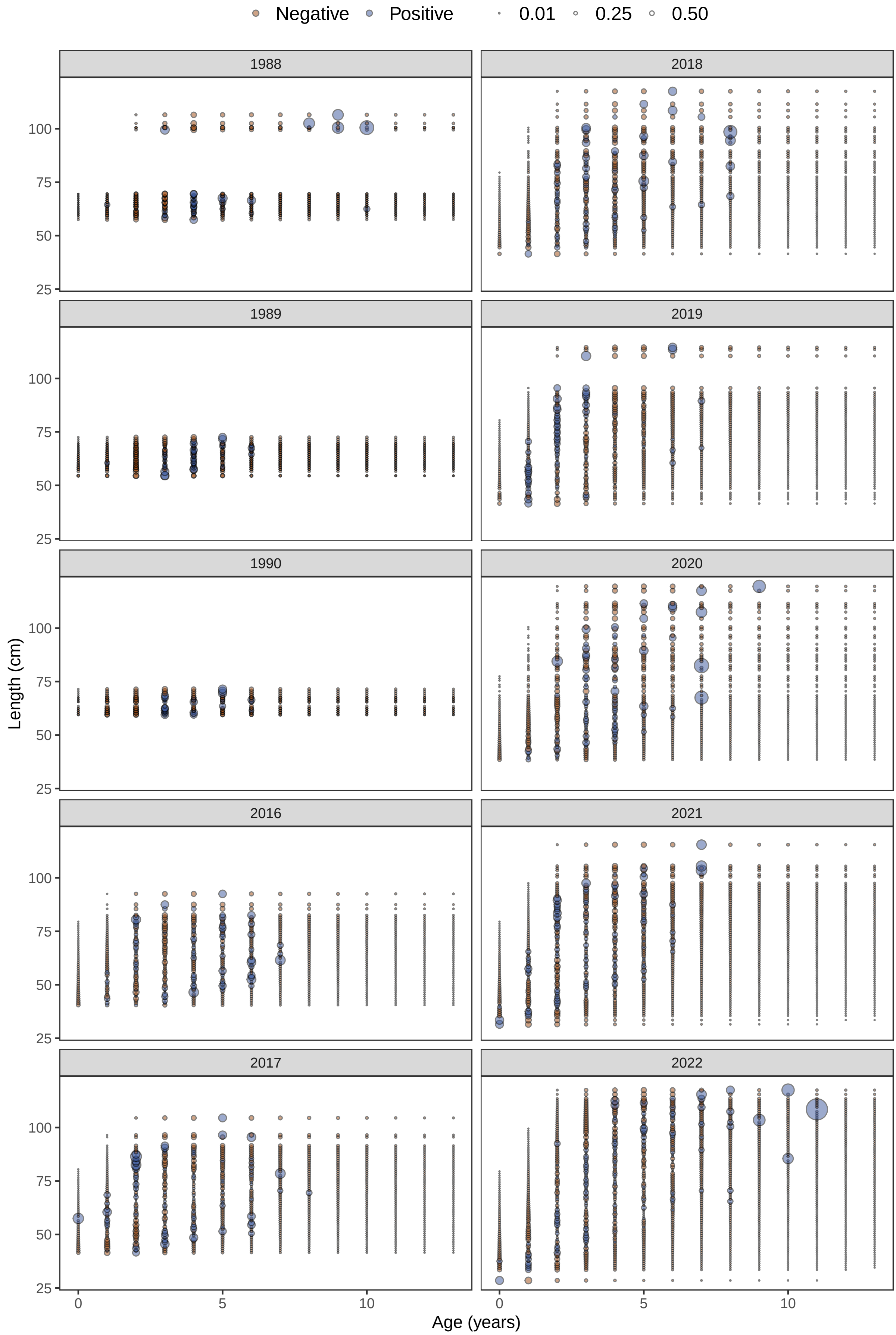

Figure E.77: Scenario 7: Pearson residuals for age-at-length compositions, based on maximum likelihood estimation—circle size represents the magnitude of the Pearson residual

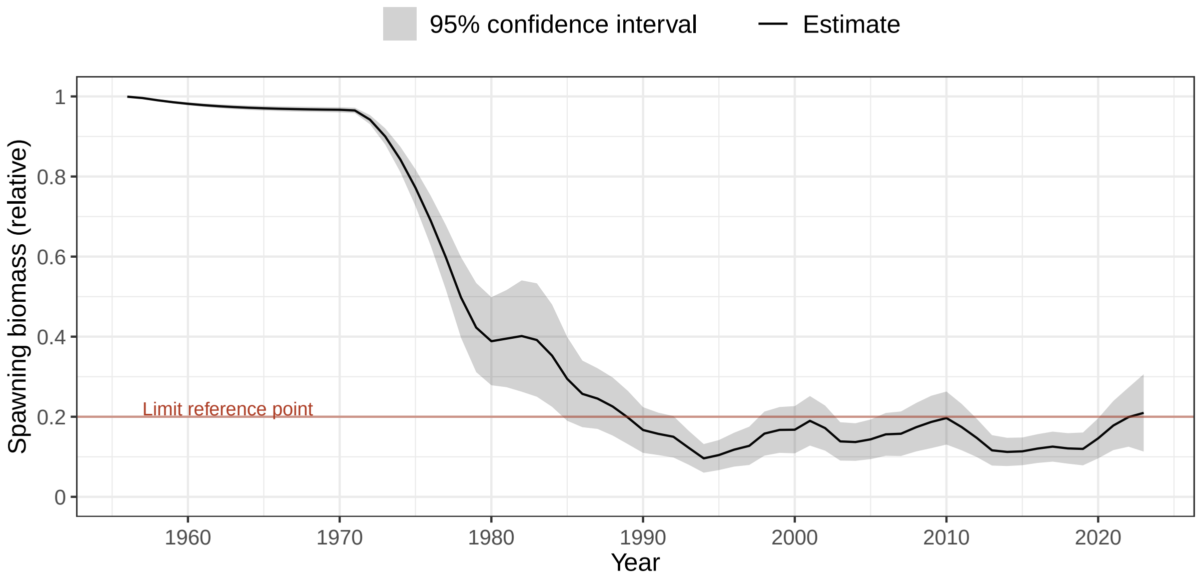

Figure E.78: Scenario 7: Predicted spawning biomass trajectory relative to unfished for king threadfin in the Gulf of Carpentaria, based on maximum likelihood estimation

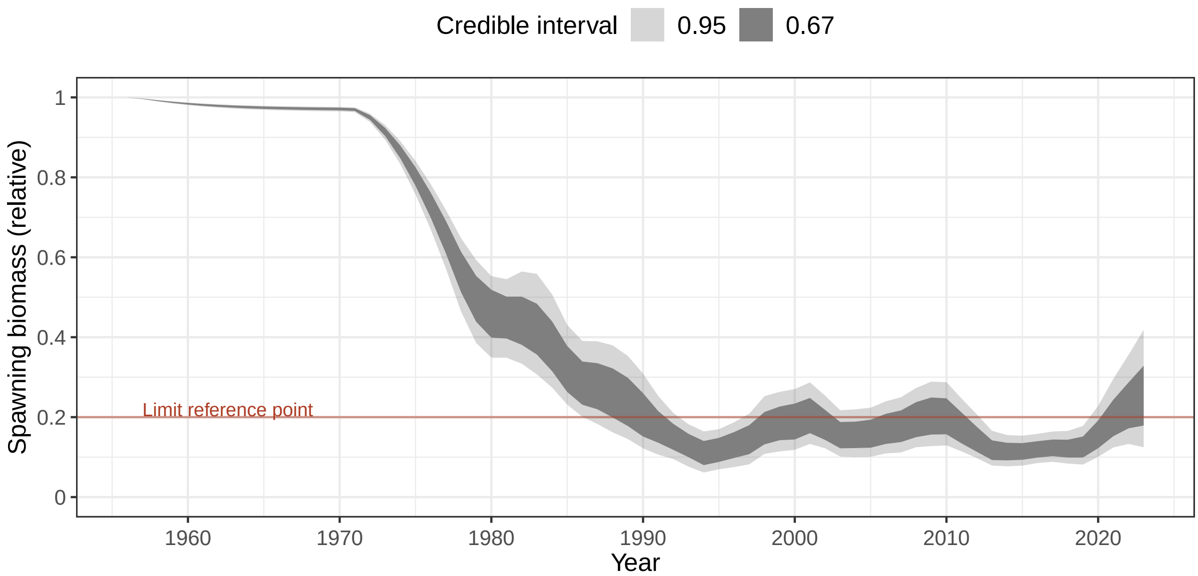

Figure E.79: Scenario 7: Predicted spawning biomass trajectory relative to unfished for king threadfin in the Gulf of Carpentaria, based on MCMC

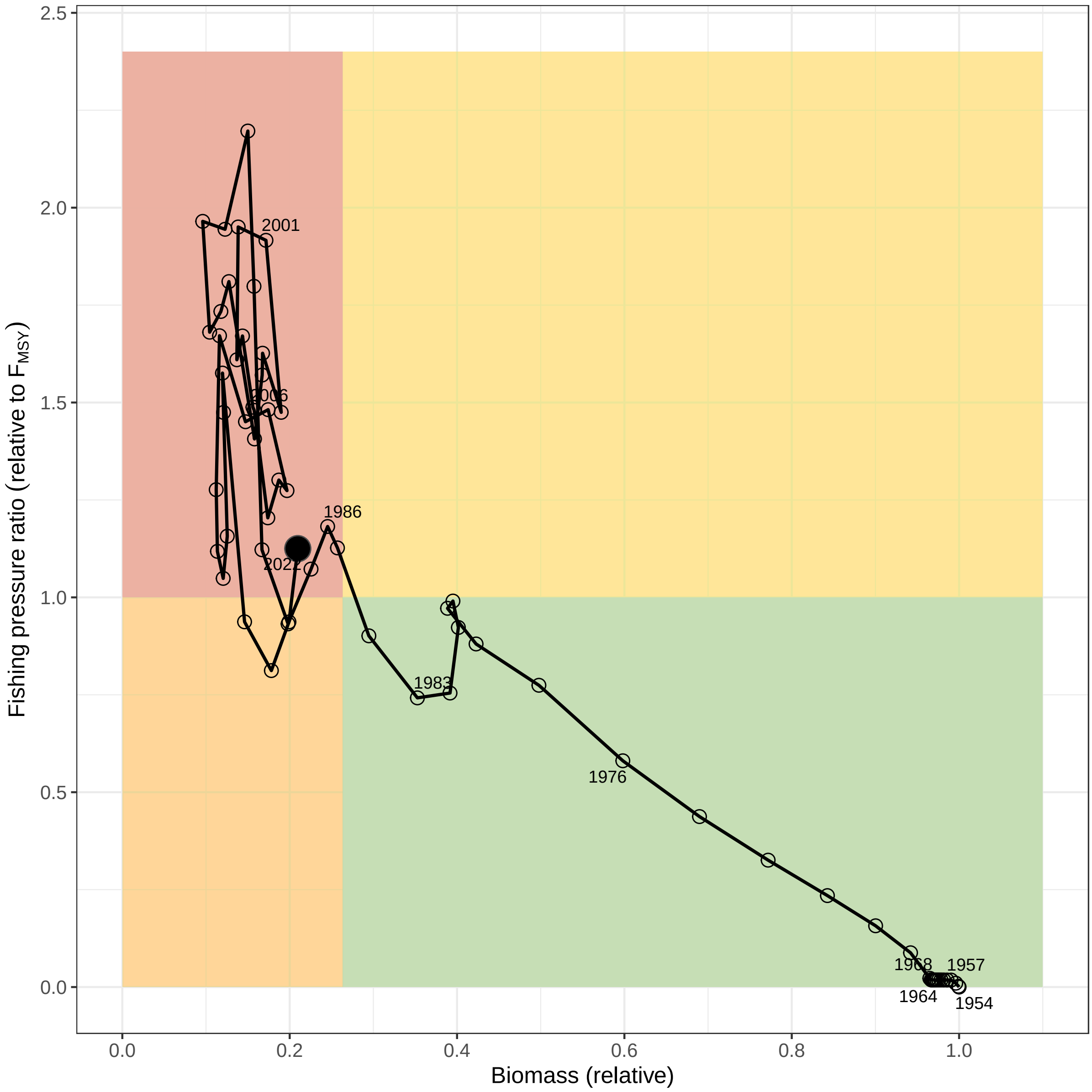

Figure E.80: Scenario 7: Stock status indicator trajectory for king threadfin in the Gulf of Carpentaria, based on maximum likelihood estimation

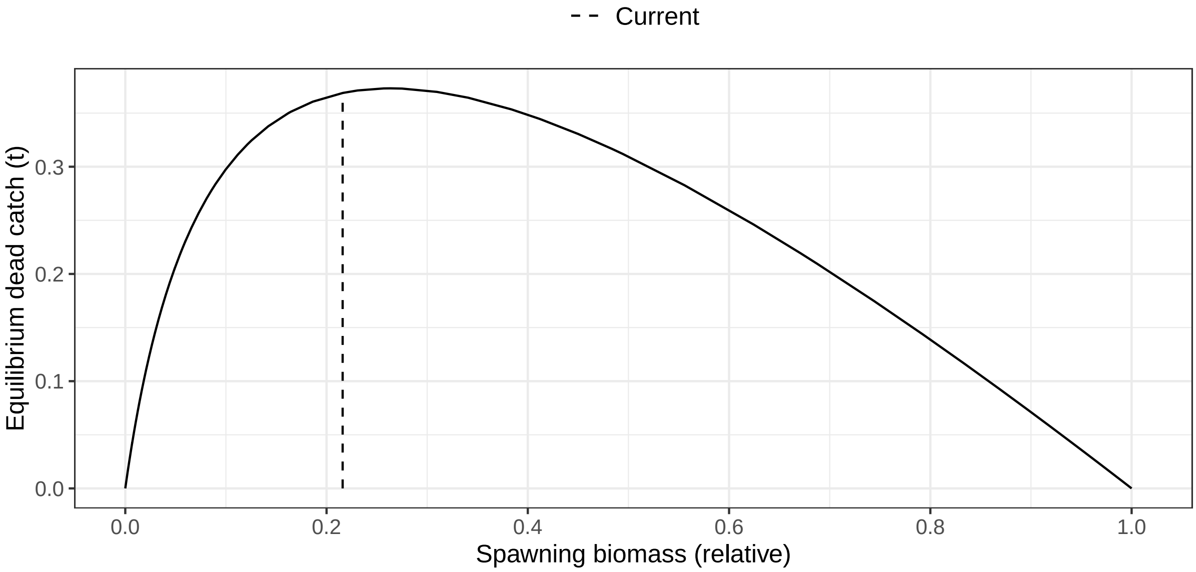

Figure E.81: Scenario 7: Equilibrium dead catch curve for king threadfin in the Gulf of Carpentaria, based on maximum likelihood estimation

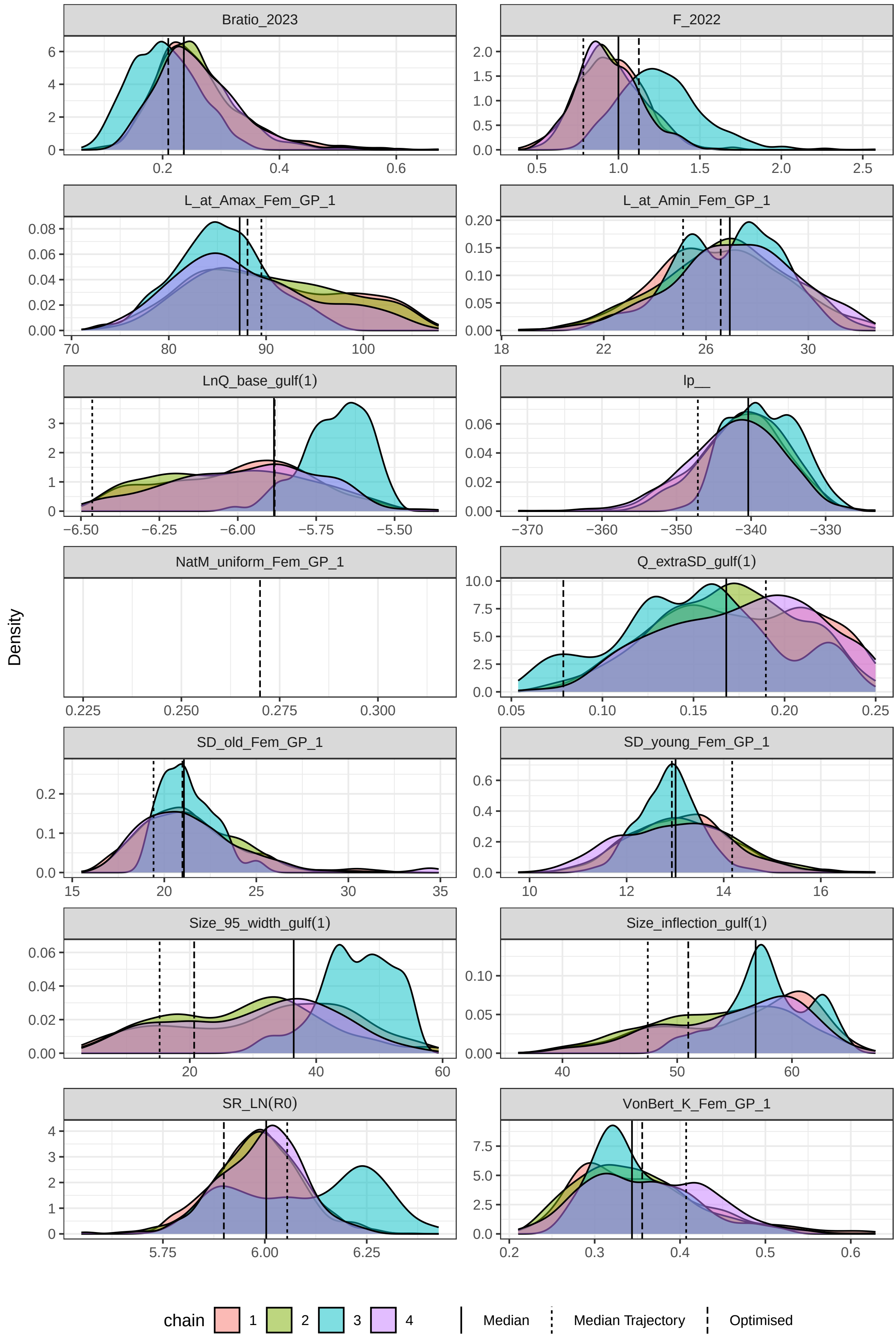

Figure E.82: Scenario 7: Posterior density of MCMC iterations. "Median" line shows median parameter value for MCMC iterations "Optimised" shows the parameter value found from maximum likelihood estimates.

Figure E.83: Scenario 7: Trace plot of MCMC iterations—"Optimised" shows the parameter value found from maximum likelihood estimates

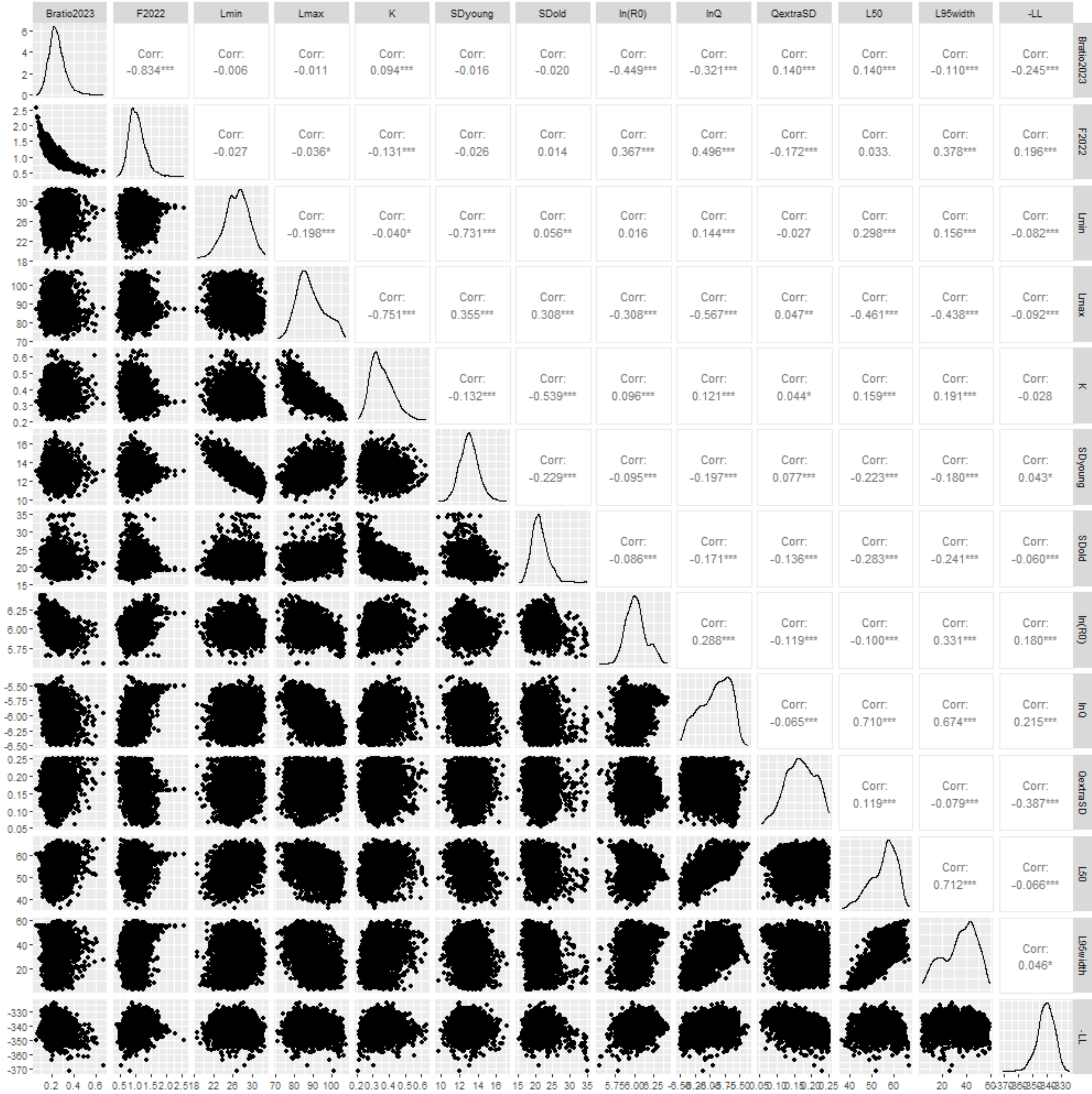

Figure E.84: Scenario 7: Correlation plot of MCMC iterations

E.8 Scenario 8

Parameter	Estimate	Phase	Min	Max	Initial value	Standard deviation
L_{min}	26.40	2	15.00	33.00	20.00	2.51
L_{max}	89.18	2	65.00	110.00	75.00	6.77
K	0.35	3	0.20	0.70	0.40	0.07
$\mathrm{SD}_{\mathrm{young}}$	13.06	3	8.00	18.00	13.00	1.12
$\mathrm{SD}_{\mathrm{old}}$	20.82	3	15.00	35.00	20.00	2.66
$\ln R_0$	5.90	1	5.00	8.00	7.00	0.12
$\ln q$	0.45	5	-5.00	5.00	0.00	0.58
QextraSD	0.07	7	0.00	0.50	0.10	0.03
L_{50}	50.65	4	30.00	70.00	55.00	4.76
$L_{95\mathrm{width}}$	21.58	4	1.00	60.00	25.00	9.48

Table E.15: Stock Synthesis parameter estimates for Scenario 8 population model for king threadfin in the Gulf of Carpentaria, based on maximum likelihood estimation

Symbol	MCMC median	MCMC 2.5%	MCMC 97.5%
M			
L_{min}	26.73	21.62	31.97
L_{max}	91.52	77.52	107.01
K	0.32	0.23	0.50
$\mathrm{SD}_{\mathrm{young}}$	13.21	11.08	15.57
$\mathrm{SD}_{\mathrm{old}}$	21.18	17.16	27.09
$\ln R_0$	5.97	5.74	6.18
$\ln q$	-5.91	-6.40	-5.45
QextraSD	0.15	0.08	0.24
L_{50}	54.57	40.90	64.43
$L_{95\mathrm{width}}$	30.44	4.72	54.18

Table E.16: Stock Synthesis parameter estimates for Scenario 8 population model for king threadfin in the Gulf of Carpentaria, based on MCMC estimation

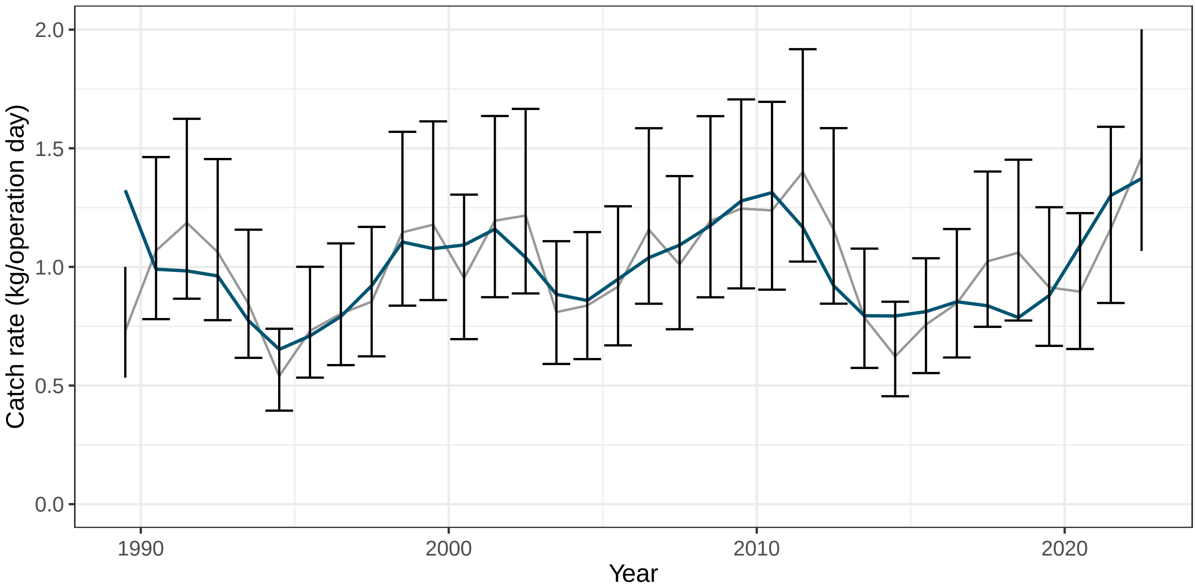

Figure E.85: Scenario 8: Model predictions (blue line) to standardised catch rates for king threadfin in the Gulf of Carpentaria, based on maximum likelihood estimation—grey line and error bars represent the model input and associated uncertainty

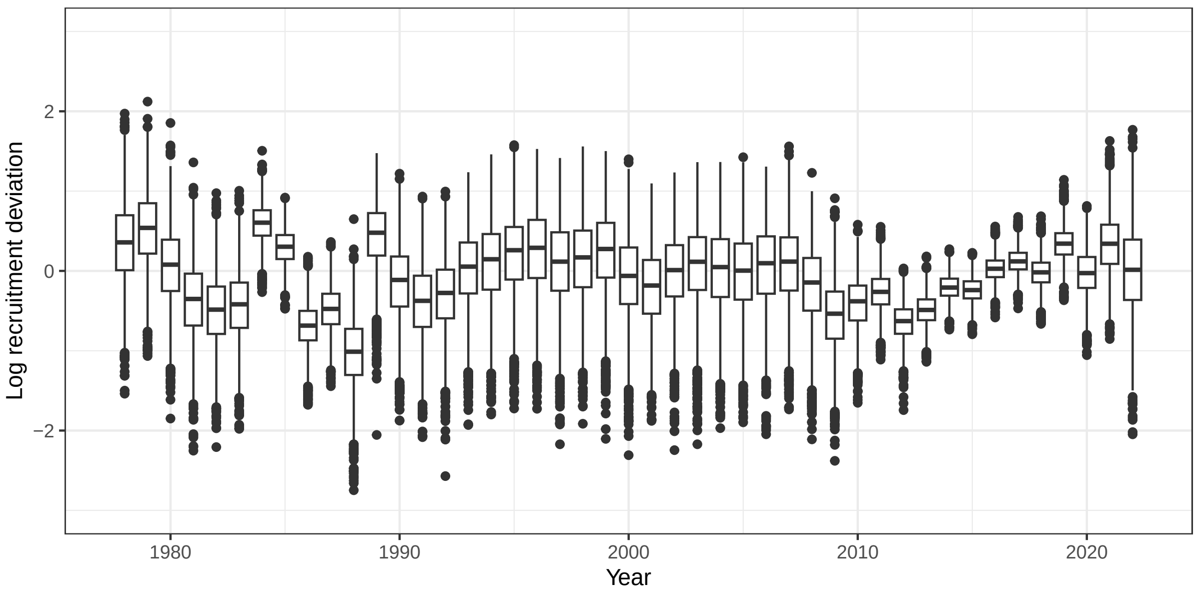

Figure E.86: Scenario 8: Recruitment deviations—whiskers represent 95% credible intervals, boxes represent 50% credible intervals, horizontal bars represent medians, and the points represent outliers

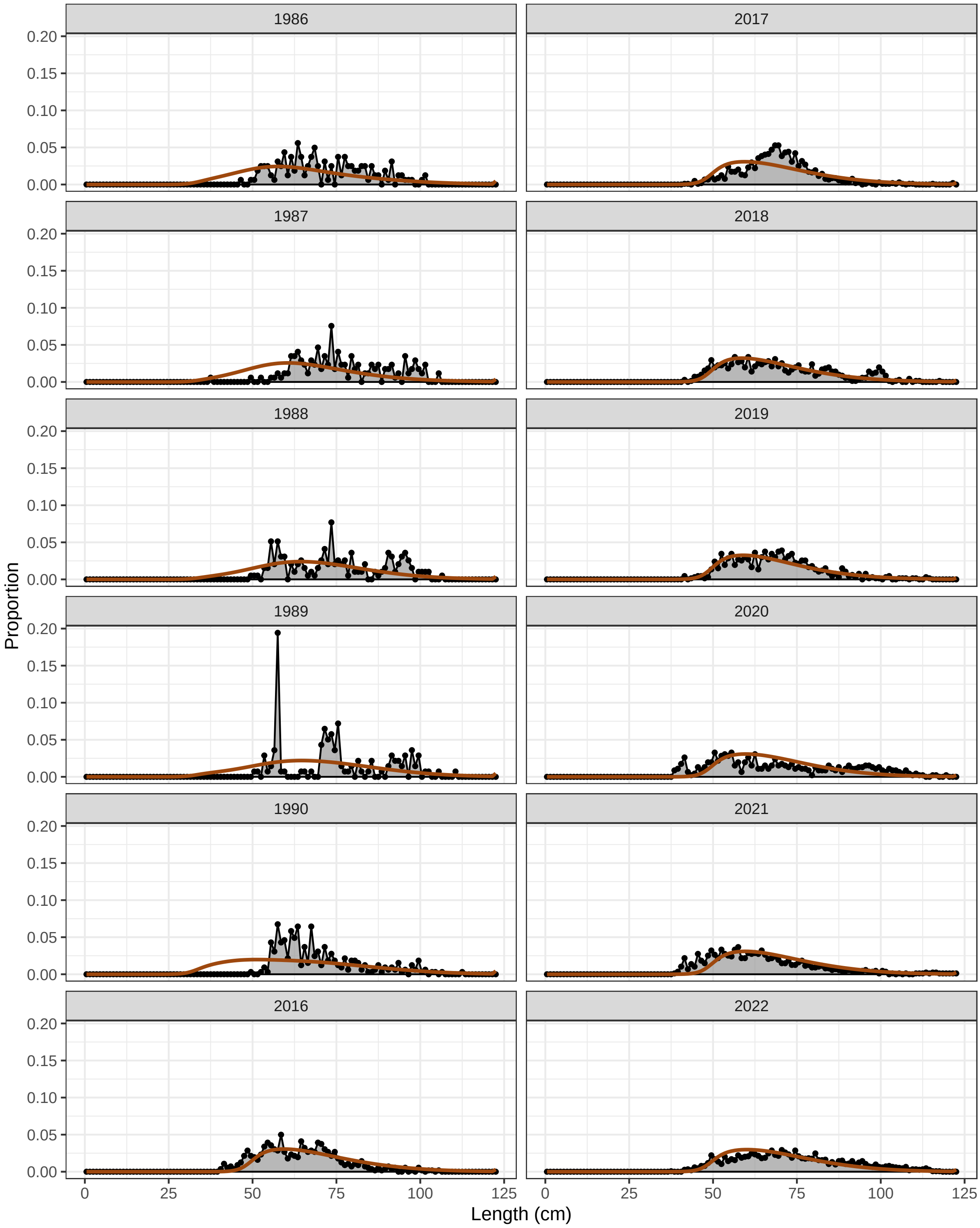

Figure E.87: Scenario 8: Fits to length structures, based on maximum likelihood estimation—the grey area and black line represent data inputs and the red line represents the model fits

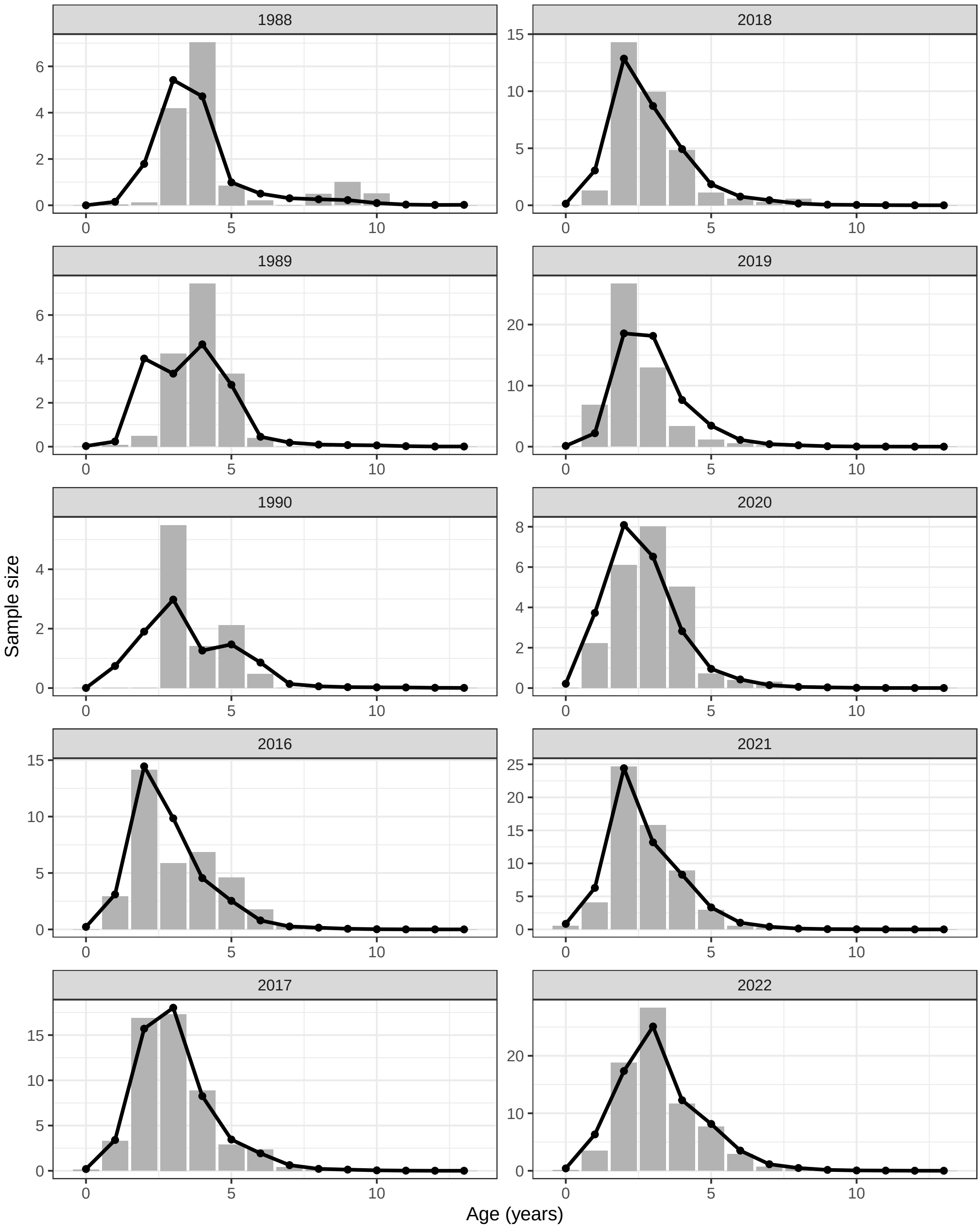

Figure E.88: Scenario 8: Fits to age structures, based on maximum likelihood estimation—grey bars represent input data and black line and points represent model fits

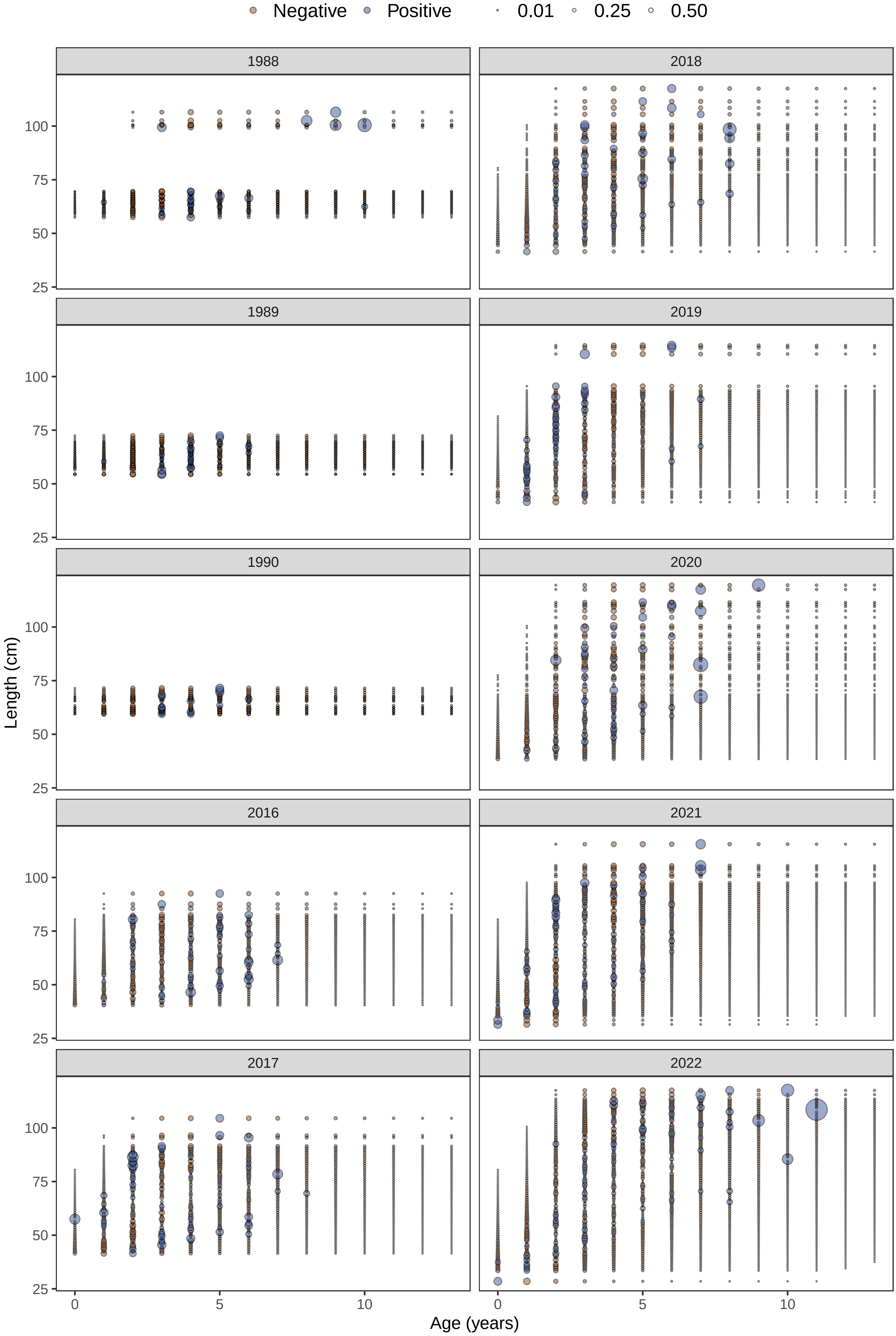

Figure E.89: Scenario 8: Pearson residuals for age-at-length compositions, based on maximum likelihood estimation—circle size represents the magnitude of the Pearson residual

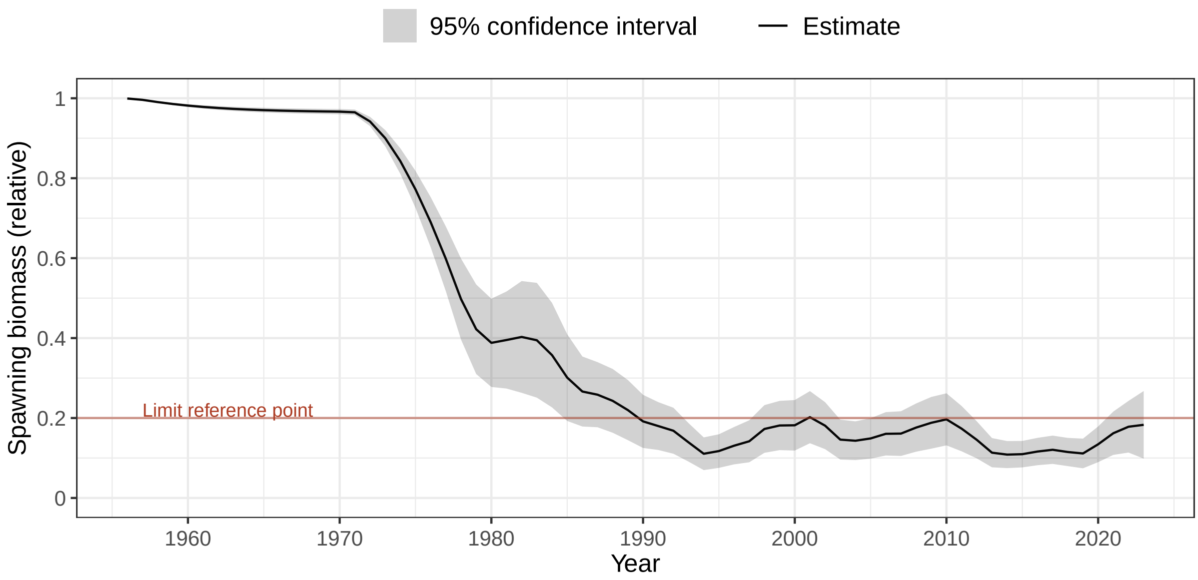

Figure E.90: Scenario 8: Predicted spawning biomass trajectory relative to unfished for king threadfin in the Gulf of Carpentaria, based on maximum likelihood estimation

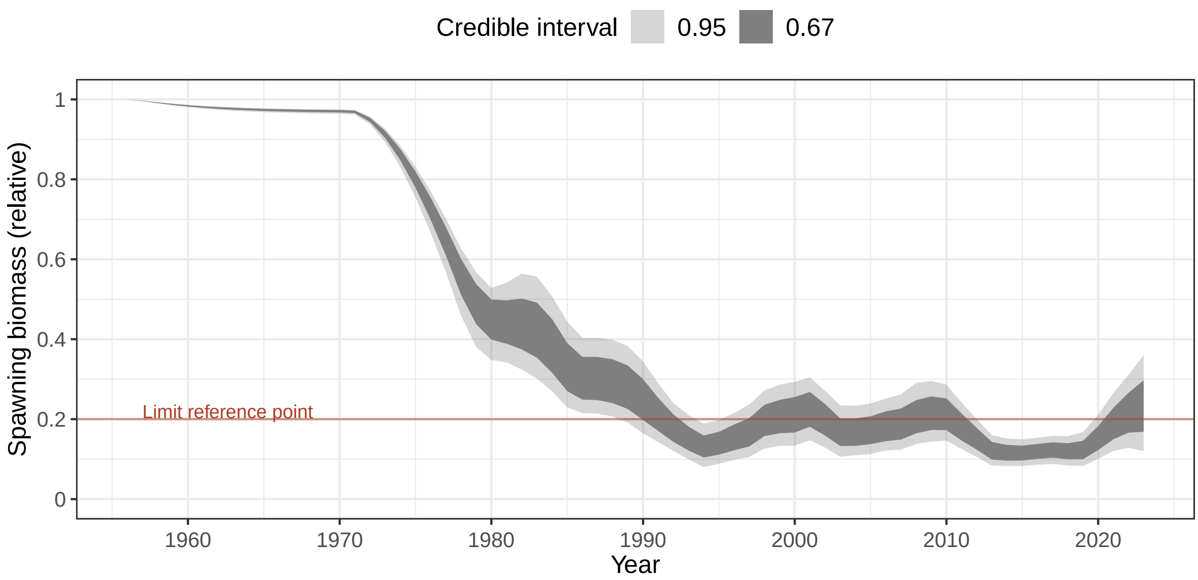

Figure E.91: Scenario 8: Predicted spawning biomass trajectory relative to unfished for king threadfin in the Gulf of Carpentaria, based on MCMC

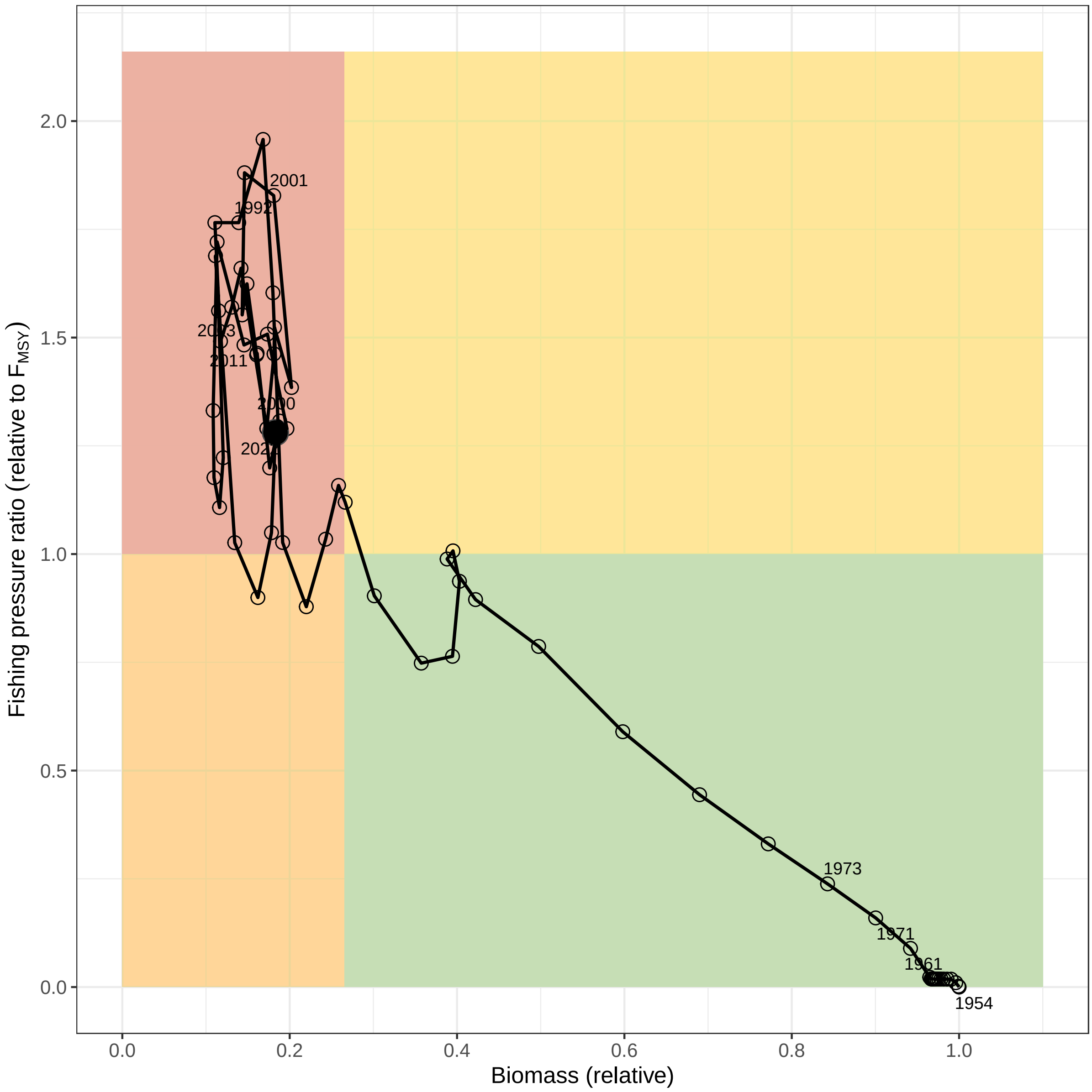

Figure E.92: Scenario 8: Stock status indicator trajectory for king threadfin in the Gulf of Carpentaria, based on maximum likelihood estimation

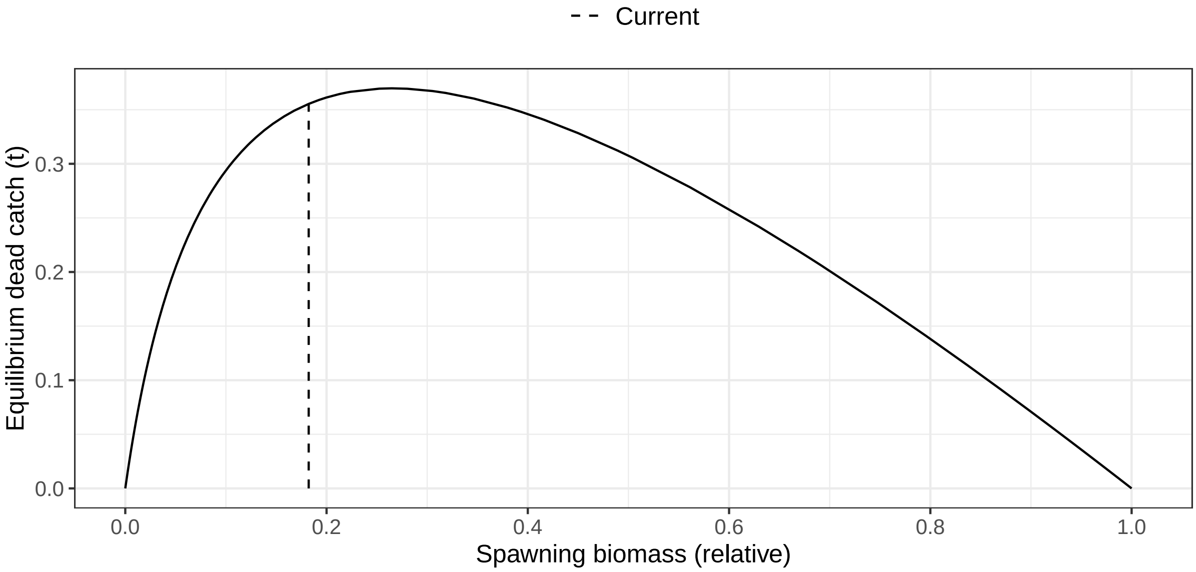

Figure E.93: Scenario 8: Equilibrium dead catch curve for king threadfin in the Gulf of Carpentaria, based on maximum likelihood estimation

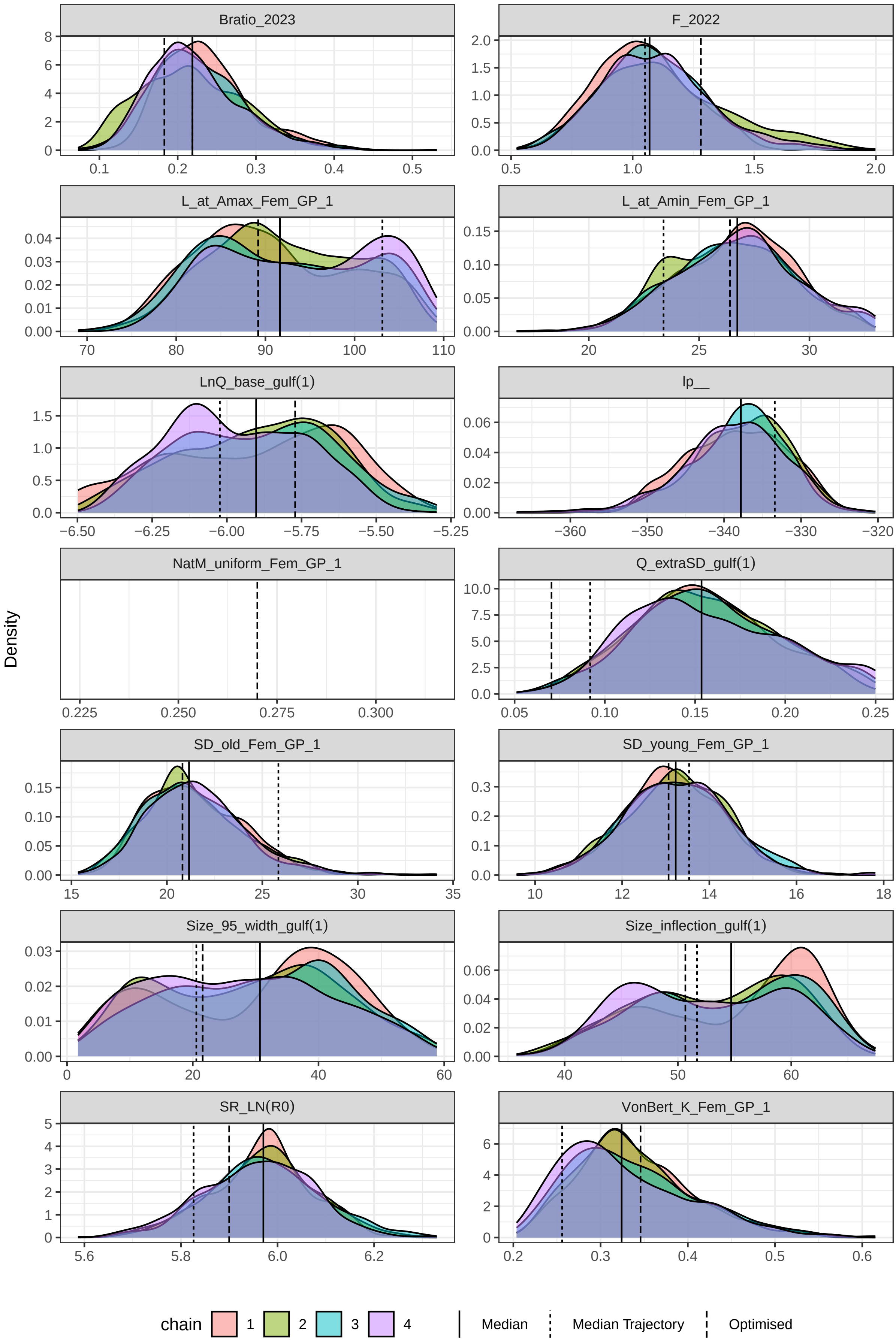

Figure E.94: Scenario 8: Posterior density of MCMC iterations. "Median" line shows median parameter value for MCMC iterations "Optimised" shows the parameter value found from maximum likelihood estimates.

Figure E.95: Scenario 8: Trace plot of MCMC iterations—“Optimised” shows the parameter value found from maximum likelihood estimates

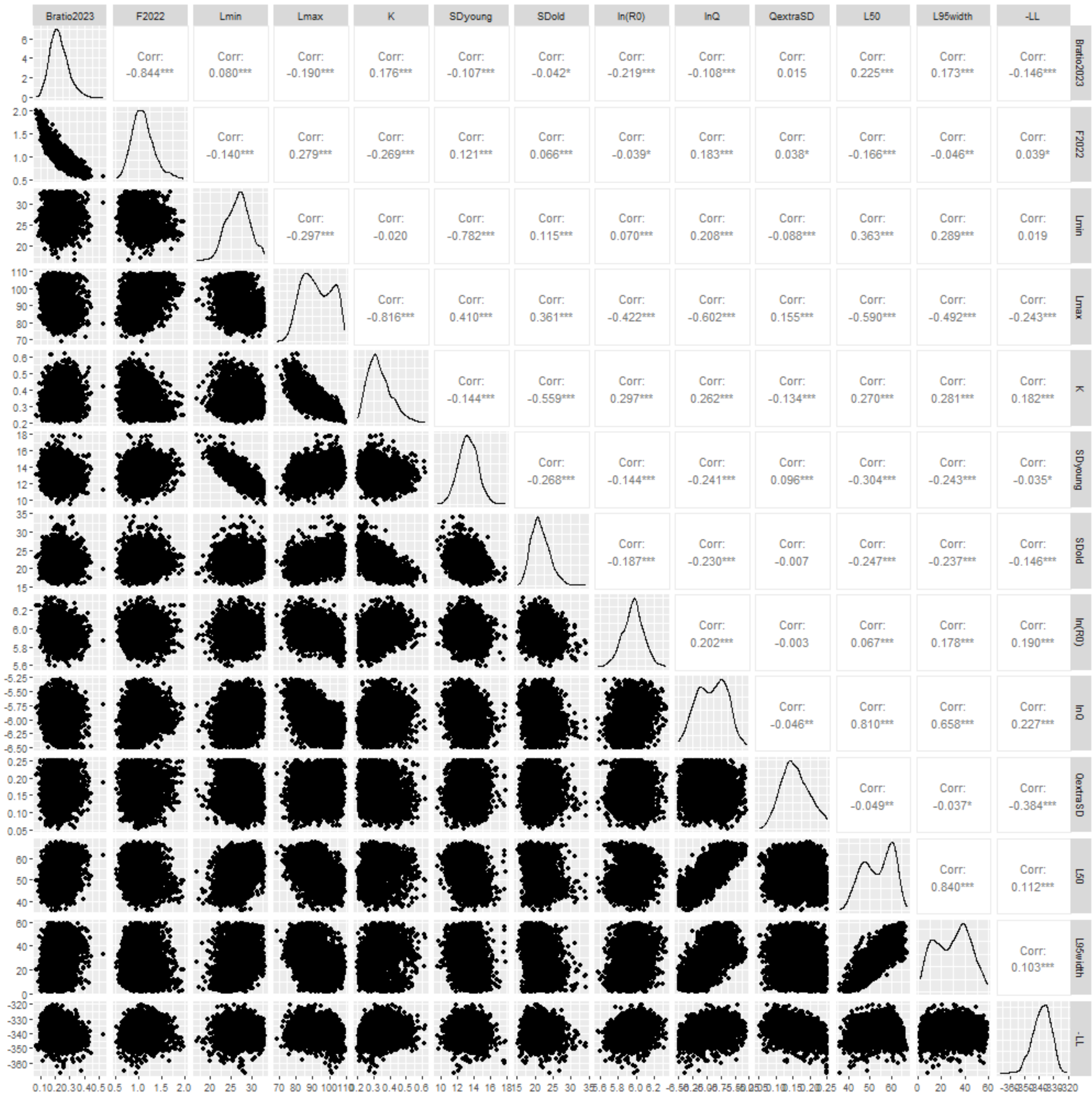

Figure E.96: Scenario 8: Correlation plot of MCMC iterations