Stock assessment of black teatfish (*Holothuria whitmaei*) in Queensland, Australia, with data to June 2025

June 2026

Queensland
Government

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Contents

Executive summary

Introduction

Black teatfish is a target species of the Queensland Sea Cucumber Fishery (QSCF) due to its high value in Asian export markets. The species is distributed in northern waters of Australia on reef flats, shallow reef slopes, tops of lagoon pinnacles and sandy sea grass beds. Although genetic analyses suggest a single biological stock spanning the Great Barrier Reef (GBR), this assessment separates black teatfish into two stocks. The northern and southern zones of the GBR fishery are split at 19 degrees south just north of Townsville.

As an important Tier 1 species under the Harvest Strategy, the stock assessment was required to determine stock biomass levels against agreed target and limit reference points (Fisheries Queensland 2021).

This stock assessment modelling estimated the spawning biomass at the beginning of the 2026 financial year (i.e. 1 July 2025). The term 'biomass' refers to the total weight of a biological population or stock. 'Spawning biomass' refers to the total weight of mature or reproductively capable individuals within the stock. The 'spawning biomass ratio' is the key biomass estimate presented in this stock assessment. This ratio is simply the current spawning biomass as a percentage of the unfished spawning biomass (i.e. the estimated spawning biomass in 1989 for the north stock and 1996 for the south stock). This stock assessment estimated spawning biomass ratios for both stocks at:

North stock: Spawning biomass at the beginning of 2026 was between 45% and 125% of an assumed unfished state in 1989.

South stock: Spawning biomass at the beginning of 2026 was between 73% and 138% of an assumed unfished state in 1996.

Sea cucumbers are broadcast spawners whose recruitment is naturally episodic, so "unfished" biomass fluctuates around a long-term average rather than a fixed level. In an assessment, that average is the 100% unfished reference point, not a ceiling – so for a lightly fished stock, normal recruitment variability and the necessarily wide credible intervals of a data-limited model can return estimates above 100%. Consequently, the unfished model start year should not be read literally as a claim that no fishing occurred before that time, but rather that biomass is assumed to have been indistinguishable from a pre-fishing long-term average.

This is the second stock assessment of black teatfish in Queensland. The previous stock assessment estimated the biomass ratio in 2021 for the whole GBR as 40 – 42% relative to 1877 (Helidoniotis 2021). Several key aspects of this assessment differ from the previous black teatfish assessment:

- Two stocks were modelled rather than a whole GBR stock. This was done to reflect the disparate exploitation histories of the northern and southern zones and make better use of the individual biomass survey estimates (Knuckey and Koopman 2016; Koopman and Knuckey 2021).
- The present assessment was performed using Stock Synthesis whereas the previous assessment was performed using an age-structured surplus production model (ASPM).

- The previous assessment considered historical catches and modelled the population between 1877 and 2021. The present assessment did not include these historical catches (see detailed discussion of this in Section 4.3.2) and modelled the north stock between 1989 and 2026 and the south stock between 1996 and 2026.
- The previous stock assessment included estimates of biomass from 1996 – 1999. These were sourced from Skewes et al. (2014) who determined them from the surveys conducted by Benzie and Uthicke (2003). The present assessment only considered the biomass estimate for 1999 presented in Uthicke (2004) which is based on the same survey information. Scenarios that included these estimates were not included in the ensemble model. This is discussed in detail in Section 4.3.1.

Methods

The assessment used Stock Synthesis to construct a single-sex age-structured model with an annual time step, fitted to standardised catch rates, length composition data and estimates of biomass from fishery independent surveys. The model incorporated data from Queensland east coast waters spanning the period 1989–2025, collected from the commercial sector and fishery independent surveys. A full listing of all data inputs and sources is given in Table 2.1, with a description of each in Section 2.1.

Although genetic analyses suggest a single biological stock spanning the GBR, this assessment separates black teatfish into two stocks. The north and south stocks were split at 19 degrees south just north of Townsville. The spatial division of stocks was primarily for data availability, survey coverage, and fishery dynamics. This stratification allowed for separate modelling of regions with distinct data inputs; however, it should be recognised as an assessment stratification rather than a confirmed population boundary.

All assessment inputs and outputs are referenced on a financial year basis, where ‘2025’ means July 2024–June 2025.

This assessment used an ensemble approach to combine the outcomes from a suite of ten models for the north and south stocks. The previous stock assessment used outputs from a single ‘base case’ model chosen from the suite of models based on a consensus of the opinions of experts in the project team. The ensemble approach, used here, allocated equal weighting to each of the models and combined their outputs. This reduced reliance on using confidence intervals from choosing a single ‘most likely’ model among the suite of realistic models. The ensemble definitions were:

North stock: Seven scenarios were chosen from combinations of three values of natural mortality (0.2, 0.44 and 0.6 yr^{-1}), two values of recruitment variability (log standard deviations 0.3 and 0.4), three growth profiles (moderate, slower and faster growth) and no shrinkage adjustment applied to the length frequency data.

South stock: Ten scenarios were selected from three values of steepness (0.3, 0.5 and 0.7), three values of natural mortality (fixed as above), three values of recruitment variability (log standard deviations 0.3, 0.4 and 0.6), three growth profiles (as above) and no shrinkage adjustment applied to the length frequency data.

The scenarios are described in Section 2.9.6, where each scenario was run using a Markov chain Monte Carlo framework (MCMC), for 250 000 iterations per scenario.

This report also includes discussion on the influence of the exploratory scenarios which were not included in the ensemble. These scenario results are retained for comparison in Appendix D.

Historical pre-1940 catch and 1990, 1999 and 2016 survey data were excluded due to inconsistency with recent stock trends, as their inclusion led to unrealistic overestimates and masked the documented depletion and recovery since the 1990s.

Results

Biomass

North stock: The results of this assessment (Table 1 and Figure 1) indicate that at the start of 2026, the biomass was estimated to be between 45% and 125% of an assumed unfished state in 1989.

We also report the probability of the estimated 2026 biomass ratio falling into four categories—below 20%, between 20% and 40%, between 40% and 60%, and above 60%.

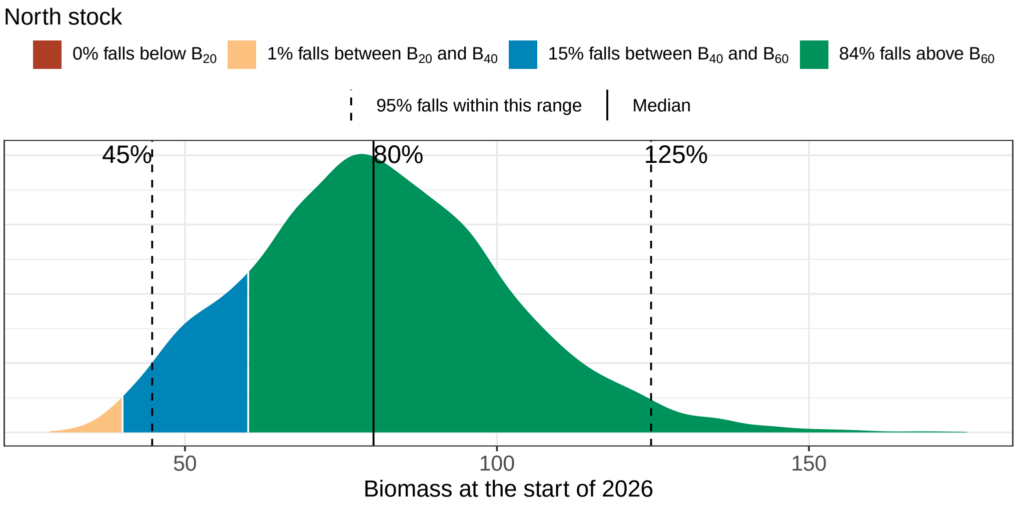

Figure 1: Probability distribution of the biomass ratio at the beginning of 2026 across the full ensemble of scenarios with the credible interval and probability of biomass falling into the four categories indicated for black teatfish in the north zone in Queensland

Table 1: Stock status indicators for black teatfish North stock

Indicator	Value
Biomass ratio (relative to unfished)	
Range (95% credible interval)	45–125%
Median	80%
Probability below 20%	0%
Probability between 20% and 40%	1%
Probability between 40% and 60%	15%
Probability above 60%	84%
Fishing pressure ratio (relative to F_{60})	
Range (95% credible interval)	0.25–1.04
Probability exceeds F_{B60}	4%

The biomass trajectory (Figure 2) follows the anecdotal history of the fishery. The biomass declined sharply between 1990 and 2000, dropping below the limit reference point by 1997 after excessive catches in those years. Following the fishery's closure in the financial year 2000 (October 1999), the stock began to slowly recover and rose above the limit reference point in 2011. The stock then rose above the target reference point in 2020, which corresponds to the fishery's reopening in July 2019 (2020 financial year).

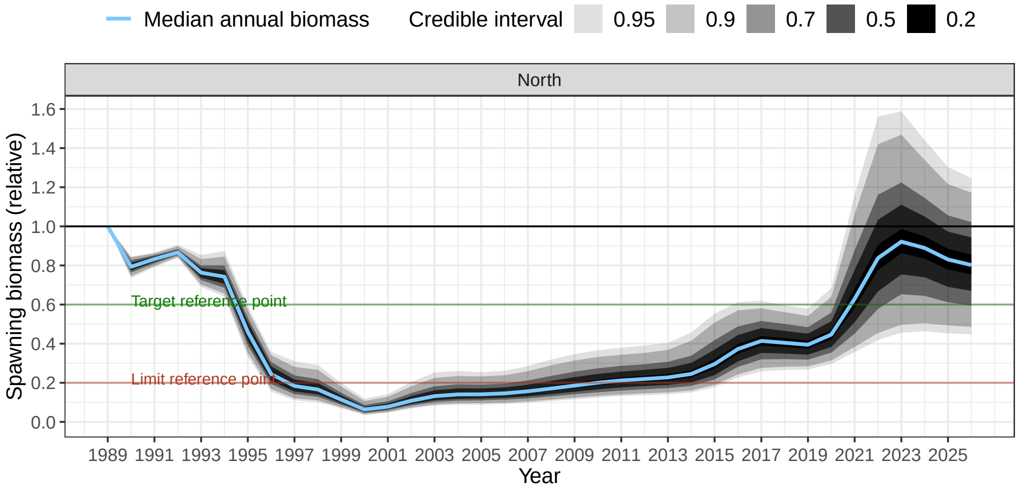

Figure 2: Estimated spawning biomass trajectory relative to unfished for black teatfish in the north stock, from MCMC ensemble scenarios

South stock: The results of this assessment (Table 2 and Figure 3) indicate that at the start of 2026, the biomass was estimated to be between 73% and 138% of an assumed unfished state in 1996.

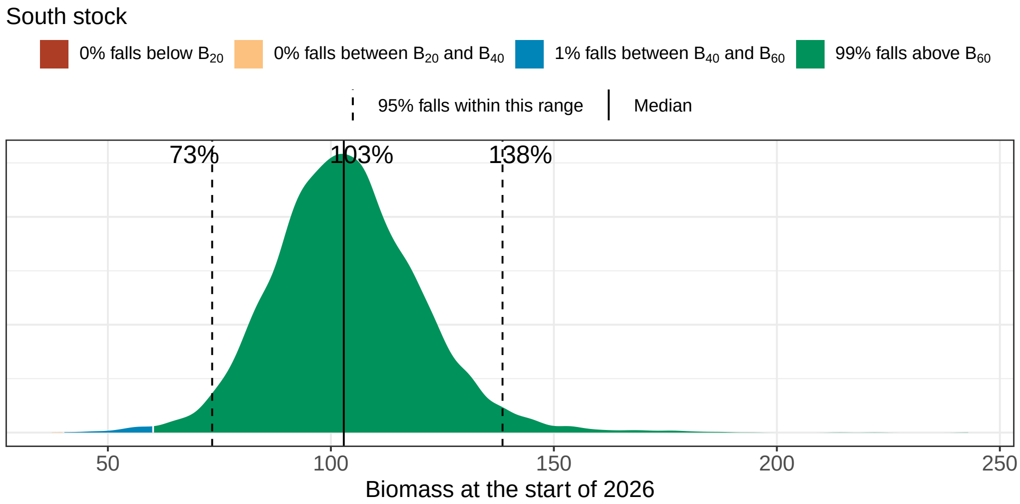

Figure 3: Probability distribution of the biomass ratio at the beginning of 2026 across the full ensemble of scenarios with the credible interval and probability of biomass falling into the four categories indicated for black teatfish in the south zone in Queensland

Table 2: Stock status indicators for black teatfish South stock

Indicator	Value
Biomass ratio (relative to unfished)	
Range (95% credible interval)	73–138%
Median	103%
Probability below 20%	0%
Probability between 20% and 40%	0%
Probability between 40% and 60%	1%
Probability above 60%	99%
Fishing pressure ratio (relative to F_{60})	
Range (95% credible interval)	0.03–0.2
Probability exceeds F_{B60}	0%

The biomass trajectory (Figure 4) indicates that the stock is lightly fished and is unlikely to be below the target biomass reference point of 60%.

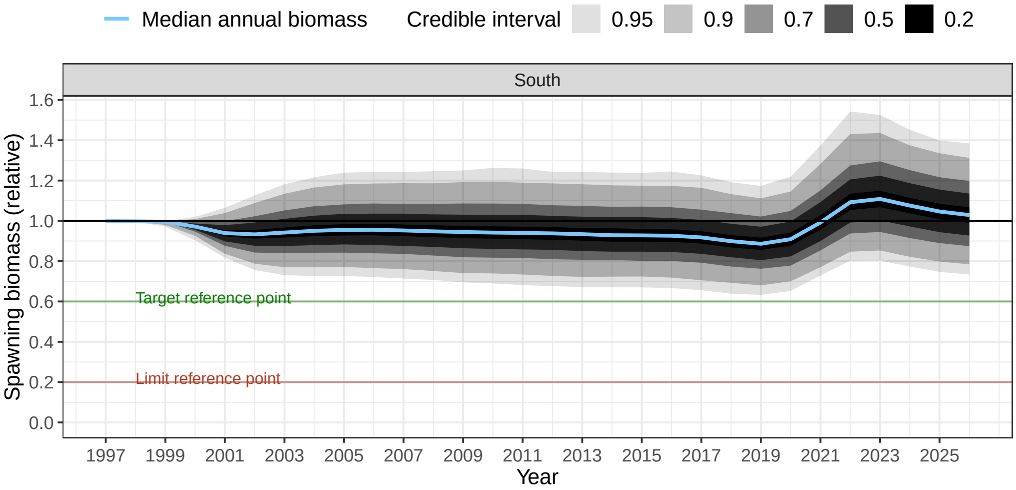

Figure 4: Estimated spawning biomass trajectory relative to unfished for black teatfish in the south stock, from MCMC ensemble scenarios

Catch

North stock Over the last five years, 2020 to 2025, total retained catch averaged 25 t per year.

South stock: Over the last five years, 2020 to 2025, total retained catch averaged 30 t per year.

These combined catches were lower than catches of 190 t (whole weight) prior to the fishery's closure in 2000 (Figure 5).

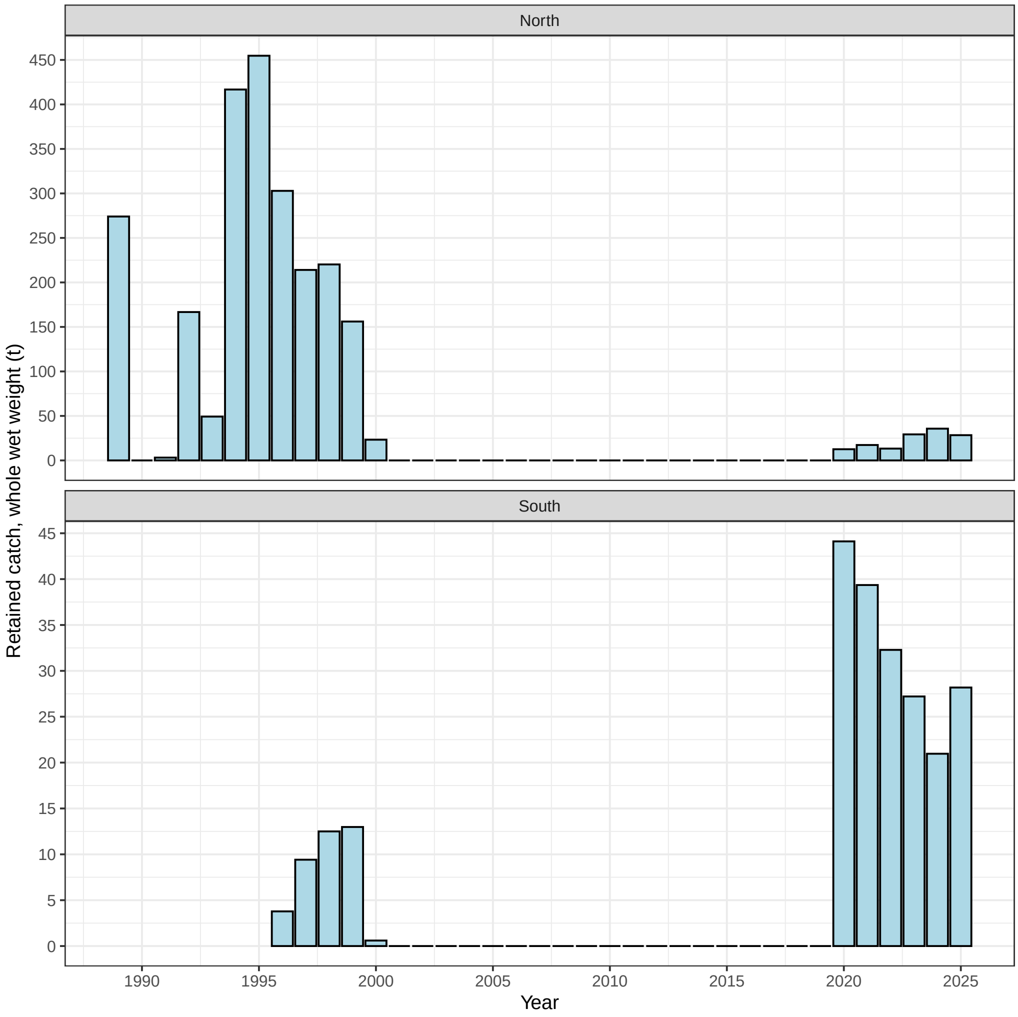

Figure 5: Estimated retained catch between 1989 and 2025 for black teatfish in the north and south stocks. Note that there are no discards of black teatfish

Catch rates

Catch rates (CPUE) from the commercial sectors were standardised, using statistical methods, to estimate an annual index of abundance of black teatfish through time (Figure 6). The response variable for the commercial catch rates model was based on kilograms of black teatfish caught per daily fishing operation.

North stock: The commercial catch rate model included terms for year, number of fishers, latitude band, wind speed and an identifier for the fishing operator.

South stock: The commercial catch rate model included terms for year, number of fishers, latitude band and wind speed.

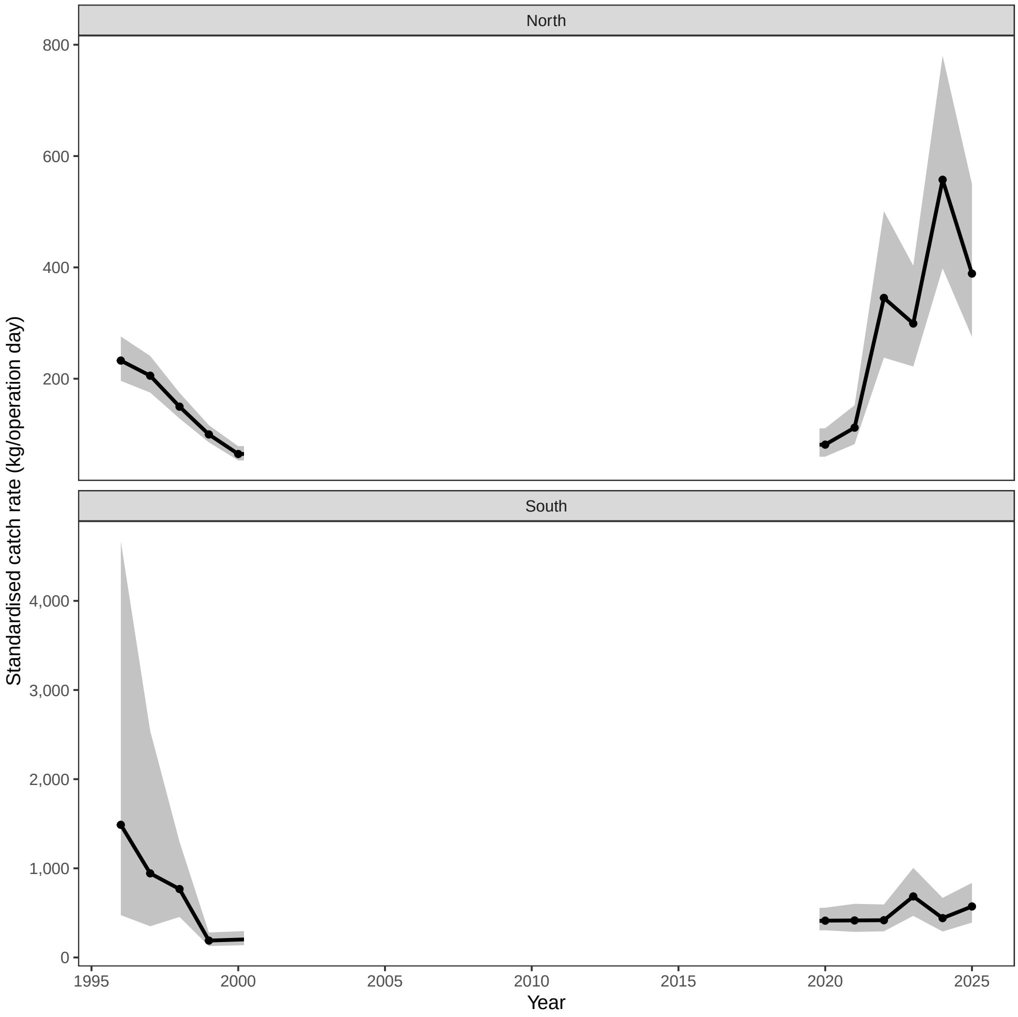

Figure 6: Annual standardised catch rates for Queensland black teatfish in the north and south stocks

Key model influences

The key influences on the stock assessments were the limited and indirect nature of the available data and the strong reliance on model assumptions. In particular, the results were most affected by assumptions about catch rates being proportional to abundance, natural mortality, recruitment patterns and deviations, and the stock–recruit relationship (steepness). Recent increases in the north stock appeared to be driven largely by strong post-2020 catch rate signals and estimated recruitment pulses, which may overstate recovery. Because of this, the most recent biomass surveys provide the strongest and most defensible evidence of the standing stock size.

Previous biomass estimate for 1999 and an estimate of virgin biomass for north stock: The inclusion of both of these biomass estimates produced depletion estimates in 2000 (when the fishery closed) that were substantially higher than the base case scenario of 6%. These estimates were inconsistent with the perceived state of the fishery in 2000 that ultimately led to its closure.

Greater recruitment variability in the north stock: Greater recruitment variability produced stock status estimates that were above the base case. However, remaining scenarios that pre-specified lower population productivity and recruitment variability all estimated a similar stock status to the base case.

Recommendations to improve future assessments

A comprehensive list of recommendations for future work have been made in Section 4.5. At a glance, these are summarised below:

- **Fine scale spatial information of fishing activities:** The Fisheries Queensland vessel monitoring system (VMS) is in operation in the fishery, and has recently been extended to tender vessels and thus could be used to measure fishing effort on a spatial scale. These advances in data collection would undoubtedly provide valuable effort information for future assessments.
- **The biomass estimates and length compositions:** Survey biomass estimates provide empirical estimates of population density and size when combined with retained catch over the same period. Additional years of length compositions attained from biomass surveys are required to infer size selectivity for fishery management and catch evaluations.
- **Life history and biological information:** This information is incomplete for sea cucumber species and research should be undertaken to fill in the gaps in missing biological data to better inform the model on population biology.

Conclusion

This stock assessment was commissioned to establish the status of the Queensland east coast black teatfish stock. This stock assessment benefited from incorporating recommendations from recent Queensland stock assessments and reviews, expanding the advisory team, and adding new data sources to address knowledge gaps. These factors all contributed to an improved model-based assessment.

The black teatfish (BTF) assessments indicate that the stocks were not below the 20% limit reference point and likely above 60%, but exact stock status estimates were uncertain due to data limitations and strong dependence on model assumptions. In particular, model outputs were sensitive to assumptions about catch rate representing abundance, natural mortality, and recruitment patterns. Recent predicted increases in the north stock were based on catch rates and may overstate the extent and rate of recovery.

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We would like to thank industry members who engaged in this project and provided feedback on important fishery dynamics: Chauncey Hammond (Seafresh Australia), Anthony Hart (Tasmanian Seafoods), Anton Krsinich (Tasmanian Seafoods), Ben Cochrane and Rhys Bennett. We would like to thank Dr Matt Koopman and Dr Ian Knuckey from Fishwell who conducted the biomass surveys and provided constructive scientific critiques and discussions throughout the project. We also thank Timothy Skewes who provided valuable advice on sea cucumber biology that guided decision making. Support, input and advice to this assessment was provided by the following Fisheries Queensland scientists and staff: Michelle Winning, Christelle Legrand, Elisabeth Manning and Lauren Jubb. We thank Alise Fox for providing the cover art. Lastly, we thank Alise Fox, Mai Tanimoto and Robyn Lovett for developing the 'SSAND' R package that was used throughout this report.

This project was commissioned by the Queensland Department of Primary Industries.

Glossary

ASPM	Age-structured surplus production model
BBZ	Burrowing blackfish zone
BDM	Bêche-de-mer
B_{20}	The biomass that is 20% of unfished biomass.
B_{40}	The biomass that is 40% of unfished biomass.
B_{60}	The biomass that is 60% of unfished biomass.
CI	Confidence interval or credible interval if from Markov chain Monte Carlo
CITES	Convention on International Trade in Endangered Species of Wild Fauna and Flora
CPUE	Catch per unit effort
DPI	Department of Primary Industries
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)
F_{60}	The fishing pressure that can be applied while keeping the fish stock at 60% of unfished biomass. Also written as F_{B60}
GBR	Great Barrier Reef
GBRMP	Great Barrier Reef Marine Park
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
MSE	Management strategy evaluation
MSY	Maximum sustainable yield
PNG	Papua New Guinea
QSCF	Queensland Sea Cucumber Fishery
RAP	Representative Areas Program of the GBRMP
RHA	Rotational Harvest Arrangement
SS	Stock Synthesis software for fishery stock assessment
Stock	A distinct population that breeds only within itself (rough definition)
TAC	Total allowable catch
Unfished biomass (100%)	The expected average biomass of a stock in the absence of fishing, around which natural variation occurs due to processes such as recruitment and natural mortality. Without fishing, unfished biomass moves up and down around 100% due to recruitment variability. Unfished biomass can also be called virgin biomass

1 Introduction

Black teatfish (*Holothuria whitmaei*) is a species of sea cucumber from the family Holothuriidae. The species is distributed in northern waters of Australia and are generally found between 0 – 20 metres water-depth on reef flats, shallow reef slopes, tops of lagoon pinnacles and sandy sea grass beds (Uthicke 2004).

There is one genetic stock of black teatfish on the Great Barrier Reef (GBR), despite the GBR extending at least 1,300 km (Benzie and Uthicke 2003). Genetic connectivity is likely maintained through 'stepping stone' mechanisms (Benzie and Uthicke 2003; Ceccarelli et al. 2013). In the past few years, there has been new research into black teatfish biology (McSpadden et al. 2024). Black teatfish have an average length of 27.38 cm and average whole weight of 1.8 kg (McSpadden et al. 2024). Growth of black teatfish is understood to be slow (Benzie and Uthicke 2003; Uthicke et al. 2004b). However, length-at-age estimates have yet to be published for black teatfish because, like many sea cucumber species, age estimates from wild populations are extremely difficult to obtain. Estimates of black teatfish longevity are uncertain, with previous modelling testing 5–10 years (Skewes et al. 2014), while earlier research suggests lifespans may extend to several decades (Uthicke et al. 2004b).

Length-at-maturity is estimated to be 26 cm (Conand 1989) and broadcast spawning typically occurs from April to June (Conand 1993; Shiell and Uthicke 2006). Fertilised eggs quickly develop into larvae, which have a planktonic duration of around 2–4 weeks (Tanita et al. 2023; Burgy and Purcell 2024). Black teatfish have high fecundity, although larval survival and the success of recruitment is variable. In general, research studies provide little information about the productivity of sea cucumbers (FAO 2022), but observations have noted slow recovery rates of stock from over fishing on the Great Barrier Reef (Uthicke 2004).

The Queensland Sea Cucumber Fishery (QSCF) is a commercial fishery where divers use hand collection, with underwater breathing apparatus to collect various sea cucumber species. The hand collection method is highly selective, resulting in negligible discards and minimal risk to non-target species. There is negligible recreational or Indigenous catches. The fishery extends from the tip of Cape York to the southern limit of Tin Can Bay. Management arrangements involve a range of input and output controls including catch limits, effort limits and vessel entry limitations, and rotational fishing that consist of spatial-yearly closures (Table 1.1). In 2004, a three-year rotational harvest arrangement (RHA) was introduced in the fishery to distribute the catches spatially over time (Fisheries Queensland 2021). The fishery area within the Great Barrier Reef Marine Park (GBRMP) and the Coral Sea are divided into 158 zones. 52 (year 1 and year 3) and 54 (year 2) zones are made available per annum and a maximum of 18 days diving is allowed per zone, per annum (Fisheries Queensland 2021). The fishery has a limited number of licences and limits to the number of divers in the water at one time. Black teatfish in the QSCF have a minimum legal size (MLS) of 30 cm. In June 2021 black teatfish were identified as Tier 1 species in the harvest strategy requiring formal assessment of the stock depletion levels relative to target and limit reference points (Fisheries Queensland 2021).

Table 1.1: Management measures applied to black teatfish in Queensland waters

Date	Fishery management measure
1988	Compulsory commercial catch logbook reporting commenced
1991	Introduction of quota
1995	Introduction of logbook version BD01; number and weight required; fishery entry limited to existing licence holders
1997	Total allowable commercial catch (TACC) of 500 t for all sea cucumber species with only 380 t allocated to licence holders; Minimum legal size of 15 cm for all sea cucumber species (Benzie and Uthicke 2003)
1998	Total allowable commercial catch of black teatfish set to 188 t (Skewes 2024)
October 1999	Total allowable commercial catch of black teatfish set to 0 t
July 2000	Introduction of logbook version BD02; reports numbers of sea cucumbers
July 2004	Representative Areas Program (RAP), comprehensive rezoning of the whole Great Barrier Reef protecting a total of approximately 33% of the fishable habitat in the GBRMP; Memorandum of Understanding implemented voluntary Rotational Zoning Scheme to distribute effort across the fishery area; Fishery split into North and South zones at 19° S
July 2006	Introduction of logbook version BD03; only numbers of sea cucumbers required (weights recorded on buyer return logbook)
November 2008	Performance management system implemented
July 2009	Fishers to report RHA zone and burrowing blackfish zone (BBZ)
November 2013	Introduction of logbook version BD04; reports weights instead of number of sea cucumbers
July 2014	North and South zoning removed (Skewes 2024)
2016	Zone 1 biomass survey report estimated black teatfish stocks exceeded 70% of unfished biomass
July 2019	Black teatfish fishery reopened. Total allowable commercial catch of black teatfish set to 30 t
August 2020	Listed on CITES Appendix II: “not necessarily now threatened with extinction but... may become so unless trade is closely controlled” (CITES 2024)
September 2020	Granted export approval for 12 months, until 30 September 2021 (Anonymous 2020)
June 2021	Queensland Sea Cucumber Fishery harvest strategy: 2021–2026 released; Recreational no-take of black teatfish
November 2021	Granted export approval for three years, until 30 November 2024 (Anonymous 2021)
September 2021	Introduction of logbook version BD05; reports estimated weights and number of containers
November 2024	Positive (conditional) non-detriment finding (DCCEEW 2024)

As a result of the 0 t black teatfish TAC, from 2000 onwards, the QSCF diversified its catches, targeting species such as white teatfish (*Holothuria fuscogilva*) and prickly redfish (*Thelenota ananas*) (Skewes et al. 2014; Wickens et al. 2024). Subsequent management of the fishery was developed to avoid overfishing other species which included the implementation of the RHA, species specific TACs or catch triggers and conservative size limits (McShane and Knuckey 2022; Wickens et al. 2024). There have also been numerous biomass surveys undertaken for various species which have been used as the basis for past stock assessments. Two of these surveys have occurred for black teatfish in 2016 (Knuckey and Koopman 2016) and 2021 (Koopman and Knuckey 2021) in the northern and southern zones of the fishery, respectively. The first survey undertaken in 2016, demonstrated that densities had recovered above 70% of pre-closure levels (as required in the harvest strategy (Fisheries Queensland 2021)) and subsequently fishing for black teatfish recommenced in July 2019 with a TAC of 30 t processed weight (Figure 1.1). This TAC was set at a harvest fraction equivalent to 0.5% of the surveyed biomass.

Sea cucumbers are processed at sea using a number of product forms that are species dependent, with 'salted' being the main product form for black teatfish. Therefore, management measures often refer to the product form or a conversion to gutted weight for setting catch limits. Catches in different product form weights are often referred to in the literature and are often ambiguous. In this report, catches have been converted to, and are presented as, whole wet weight. However, catches referred to in a management context, and presented in Figure 1.1, refer to salted weight.

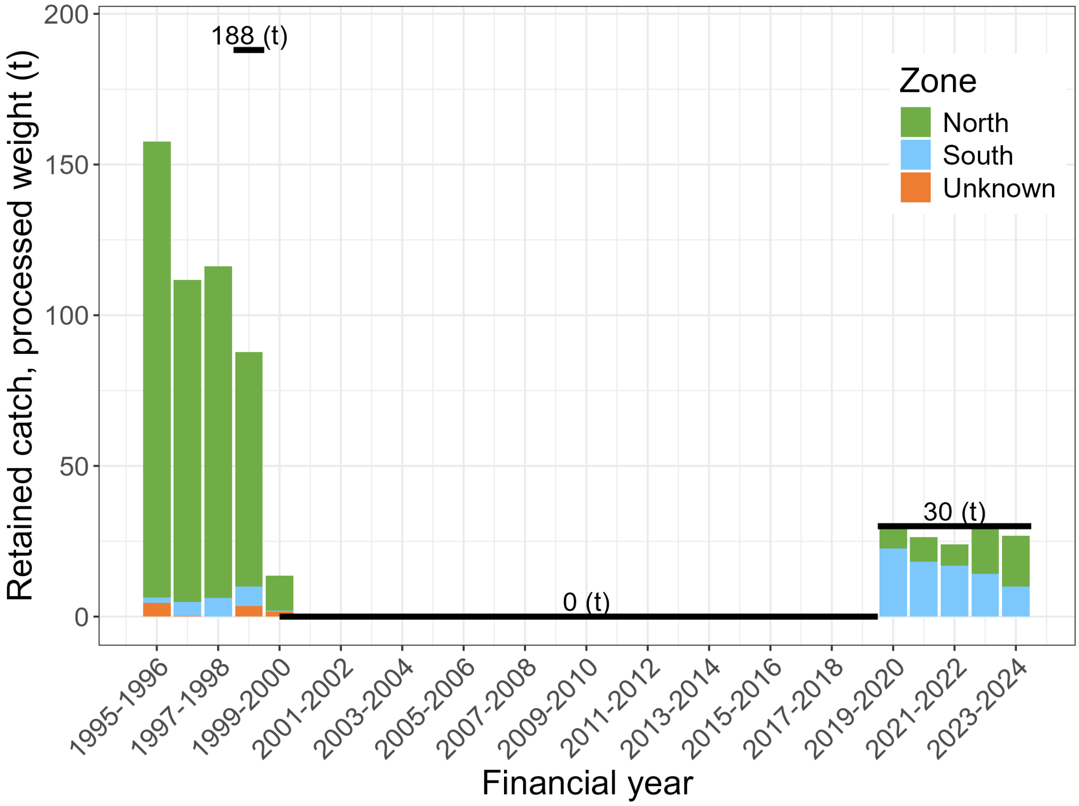

Figure 1.1: Changes in total allowable catch (TAC) of landed black teatfish reported in fishing logbooks from 1995-1996 to 2023-2024. Catches from the north and south stocks are shown by the green and blue bars, respectively. Catches from records with no location information are shown as orange bars. All catches are shown as processed weight and the corresponding TACs through time are shown as the black horizontal lines.

Although genetic analyses suggest a single biological stock spanning the GBR, this assessment separates black teatfish into two stocks. The northern and southern zones of the GBR fishery, split at 19 degrees south just north of Townsville, have had dissimilar exploitation histories, amplifying the different spatial roles in reproductive connectivity and productivity. Prior to the fishery closure in October 1999, black teatfish were harvested almost exclusively from the northern zone, but since the fishery re-opening in July 2019, catches have been larger in the southern zone (Figure 1.1). Therefore, this assessment modelled the black teatfish as a north and south stock using this spatial scale, in order to effectively model their differing exploitation histories and account for localised depletion in the northern zone. The assessment uses financial year data (July 1 to June 30 each year) up to the end of June 2025 to provide estimates of relative biomass that support harvest control rules specified in the harvest strategy (Fisheries Queensland 2021).

As an important Tier 1 species under the HS, a stock assessment is required to determine stock depletion levels against agreed target and limit reference points (Fisheries Queensland 2021). Here a stock assessment was performed using an integrated age structured model developed using Stock Synthesis (Methot and Wetzel 2013), which has been effectively applied for other sea cucumber stock assessments on the GBR (Smart et al. 2024a; Smart et al. 2024b).

2 Methods

2.1 Data sources

Data sources included in this assessment (Table 2.1) were used to determine catch rates (CPUE), length compositions, biomass estimates, and annual harvests. The assessment period began in 1989 for the north stock and 1996 for the south stock, up until 2025 inclusive.

Table 2.1: Data inputs for the assessment

Data	Years	Source	References
Reported catches	1989–1995	Scientific literature	Uthicke (2004)
Commercial logbook	1996–2025	Compulsory commercial logbook database (CFISH)	
Buyer returns	2001–2025	Compulsory commercial logbook database (CFISH)	
Biomass survey	1999–2001	Stock size of bêche-de-mer, recruitment patterns and gene flow in black teatfish, and recovery of over-fished black teatfish stock on the Great Barrier Reef	Benzie and Uthicke (2003)
Biomass survey	2016	Survey to estimate the biomass and recovery of black teatfish (Holothuria whitmaei) in Zone 1 of the Queensland Sea Cucumber Fishery (East Coast)	Knuckey and Koopman (2016)
Biomass survey	2021	Biomass survey of black teatfish in Zone 2 of the Queensland Sea Cucumber Fishery (East Coast)	Koopman and Knuckey (2021)

2.2 Stock identification information

Black teatfish (*Holothuria whitmaei*) distribution extends from the northern waters of Western Australia east to southern China and Hawaii and south to Elizabeth reef in the Tasman Sea (Uthicke 2004). *Holothuria whitmaei* was formally distinguished from the black teatfish found in the Indian Ocean (*Holothuria nobilis*) through mtDNA sequencing in 2004 (Uthicke et al. 2004a). The Pacific Ocean black teatfish is entirely black as an adult whereas the Indian Ocean black teatfish has white ventro-lateral dots (Uthicke 2004). Prior to 2004, literature often confused the scientific names so species descriptions and location are used to identify the true species.

A study of holothurians in New Caledonia (Conand 1989) significantly informs the current knowledge of black teatfish biology. At the time of the study, the Indian and Pacific black teatfish were undifferentiated so the former name, *Holothuria nobilis*, was used for the species we now call *Holothuria whitmaei*. It is obvious that Conand was studying the same species present on the Great Barrier Reef because the *Holothuria whitmaei* distribution extends to New Caledonia. The same applies to the black teatfish biomass survey report from 2003 (Benzie and Uthicke 2003).

2.3 Regions

In 2004, a rotational harvest arrangement (RHA) was introduced in the fishery to distribute catch and effort spatially. The fishery area within the GBRMP and the Coral Sea are divided into 158 zones: 52 (year 1 and year 3) and 54 (year 2) zones (Figure 2.1) are made available per annum and a maximum of 18 days diving is allowed per zone, per annum (Fisheries Queensland 2021). The fishery has also been divided into zone 1 (north of $19^\circ\ S$ latitude) and zone 2 (south of $19^\circ\ S$ latitude) which have been used in management through time as a way of further spreading sea cucumber catches across the fishery.

Black teatfish have had spatially variable exploitation in the past, with almost all of the harvest and overfishing occurring the north zone. Accordingly, two assessment units (referred to as 'stocks' henceforth) have been used in this stock assessment with the existing zones 1 and 2 used to demarcate them. The biomass surveys conducted in 2016 and 2021 occurred in each of these zones, further facilitating this separation (Knuckey and Koopman 2016; Koopman and Knuckey 2021).

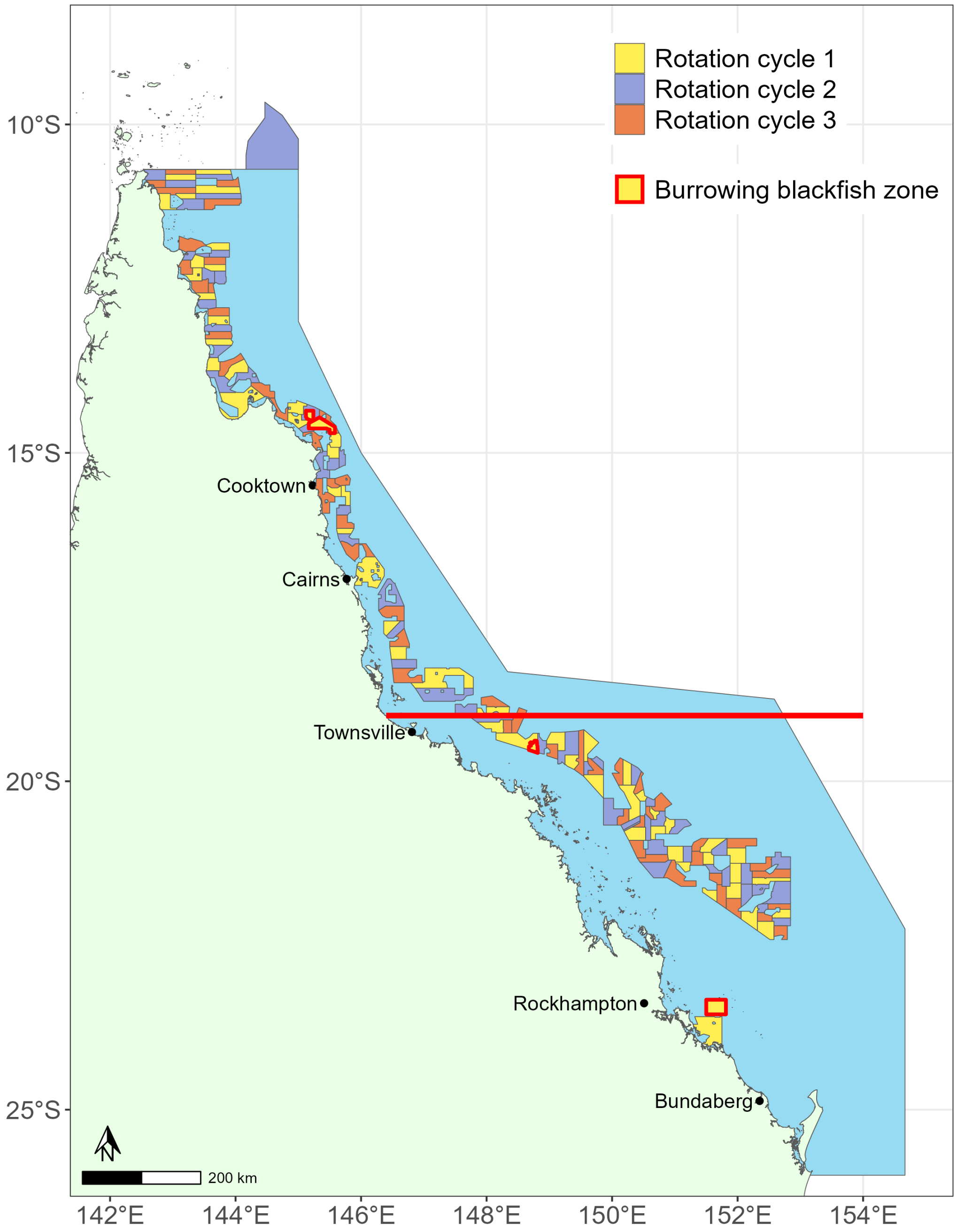

Figure 2.1: Map of the QSCF RHA. The north and south zones are separated at the red line at $19^\circ\ S$ latitude

2.4 Retained catch estimates

2.4.1 Commercial

2.4.1.1 Modern (1996 onwards)

Harvest estimates from 1996 to 2025 fishing years were reconstructed from the logbook and buyer return data. Logbook records that provided catch in numbers rather than weight were converted to weight using the average weight of an individual of the species in the specified product form. The average processed weight of an individual was determined from logbook records where both weight and number were recorded. The average weight of a black teatfish, calculated from the commercial logbooks, was 0.92 kg for both ‘salted’ and ‘whole dead’ product forms. Black teatfish in the Queensland Sea Cucumber Fishery were reported as whole dead from 1995 to 1999 but salted from 2019 onwards. However, available evidence suggests that black teatfish have been landed as salted product in all years and these early catches have been incorrectly recorded as ’whole dead’. The most important information comes from industry members, who highlighted that all sea cucumbers are processed at sea before catches are recorded and that this applies to black teatfish catches landed prior to the closure in 2000. Therefore, salted weight was converted to live weight with the conversion ratio of 0.529 from Murphy et al. (2021) and Purcell et al. (2009a). Whole dead weight was assumed to be equivalent to live weight.

Logbook catches were scaled so that the total catch matched buyer returns for each year. Buyer returns do not include information on BDM zone so statewide harvest levels were used for this scaling. The scaling resulted in a catch weight increase of 3%, 10%, 19%, 4%, and 7% in 2019, 2020, 2021, 2022 and 2024 and a catch weight decrease of 5% in 2023 for all black teatfish records.

2.4.1.2 Historical (pre–1996)

Black teatfish catches have a long history that pre-dates modern day logbook records, extending back to the 1880s (Saville-Kent 1893). Large catches were estimated to have occurred from 1900 – 1945 (Uthicke 2004), before a 40-year period where no fishing occurred. These historical catch estimates were included in the previous black teatfish stock assessment (Helidoniotis 2021). However, a recent review by Skewes (2024) has highlighted large uncertainties in these values, suggesting that they are likely overestimated. Given this uncertainty, and the 40-year period of no fishing, these historical catches were not included in the current stock assessment. The importance of this decision is discussed in Section 4.3.2. Available evidence suggests that these catches only occurred in the northern GBR and can be attributed to the north stock.

Fishing records exist for the modern QSCF from 1989 – 1995 that are not recorded in the Fisheries Queensland CFISH database. These were sourced from Uthicke (2004) and included in the stock assessment for the north stock, as this was the area where fishing occurred in this period.

A complete series of estimated catch (1880–2025) for the north stock is provided in Figure 2.2. This includes catches reported in logbooks and buyer return forms (1996 onwards) and values sourced for the literature (Saville-Kent 1893; Uthicke 2004).

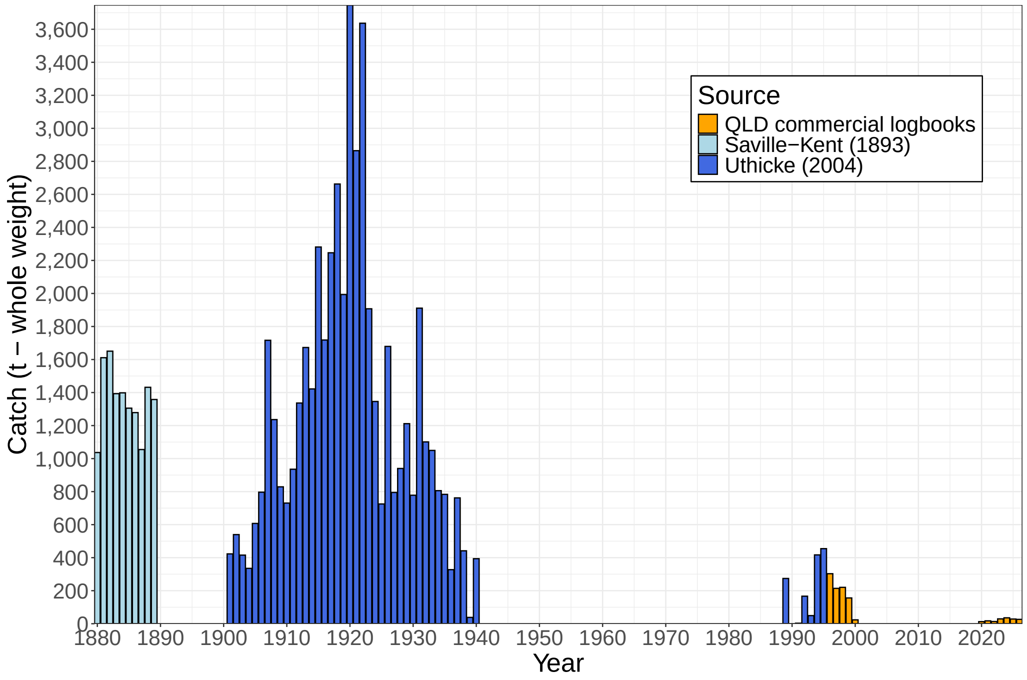

Figure 2.2: Historical harvest levels reported for the north stock of black teatfish from multiple sources.

2.4.2 Recreational

There is no information available on recreational nor charter boat catches. However, these catches are considered negligible with the recreational and charter sectors allocated a combined 1% of the statewide harvest for all sea cucumber species (Fisheries Queensland 2021).

2.4.3 Indigenous

The traditional fishing rights of Aboriginal peoples and Torres Strait Islanders are protected under legislation and accordingly there is no defined allocation or estimates of take (Fisheries Queensland 2021).

2.5 Standardised indices of abundance

Queensland commercial logbook records of retained black teatfish per day were used as an index of black teatfish abundance.

2.5.1 Data preparation

Bêche-de-mer daily logbook records were filtered to include data that are representative of the black teatfish fishery and provide sufficient coverage of model covariates. Daily records were filtered by including operators in the top 95% by total catch, excluding records with zero black teatfish and excluding records with no spatial information or incorrect spatial information. The filtered data was then cleaned to account for changing logbook field names, logbook field instructions, aggregate spatial information to a coarser scale and add trip meta-data. Number of crew substituted number of fishers, hours were redesigned to capture the average hours per fisher, latitude was aggregated into latitude bands and the cumulative number of days spent in each BDM zone was added.

2.5.2 Model design

Catch per unit effort (CPUE) was modelled with a generalised linear model (GLM) with a gamma error distribution and log link function. Whole, wet weight was used as the response variable and explanatory covariates aimed to remove the effects of variable catchability and density. Catch per unit effort was modelled using non-zero records only because black teatfish are a highly targeted species and targeted effort was not identifiable from logbook data.

Black teatfish have significantly different exploitation histories in the northern and southern zones of the fishery. Therefore, these areas were modelled separately. After filtering, there were 2,763 daily records in the northern zone and 476 records in the southern zone. Due to the limited data, the models were susceptible to overfitting so few covariates could be included in the models. This was particularly true for the south stock GLM. The key covariates to account for in the standardisation process were location, operator, and the number of fishers.

The form of the northern zone GLM was:

$$\text{Kilograms} \sim \text{Year} + \text{Operator} + \text{NumberOfFishers} + \text{LatitudeBand} + \text{WindSpeed}. \tag{2.1}$$

The form of the southern zone GLM was:

$$\text{Kilograms} \sim \text{Year} + \text{NumberOfFishers} + \text{LatitudeBand} + \text{WindSpeed}. \tag{2.2}$$

For the GLM, year, operator, and latitude band (at one degree of latitude) were factors and the number of fishers and wind speed were numeric. Several other variables (such as depth and month) were explored but were not included in the final set of covariates as they as were either collinear with other variables or did not improve model performance. Latitude bands at one degree intervals were used to include a spatial variable in the GLMs rather than BDM zone or fishing grid. This was necessary as the RHA prevents fishing from occurring annually at the BDM zone level, creating temporal discontinuity for this variable. While fishing grids include several BDM zones (some of which will be open to fishing in any given year), the limited number of fishing events meant that fishing grids were not always fished annually either. Therefore, latitude band was the best spatial variable to apply given that the QSCF is a relatively small fishery (in terms of catch and effort) that is spread over a large area.

Model performance and diagnostics were assessed using the ‘performance‘ R package. These are presented in Appendix A.

2.6 Biomass surveys

Black teatfish in the Queensland sea cucumber fishery have been surveyed on three occasions. The first survey was completed during the fishery closure in 1999 in the northern zone. The second survey, also in the northern zone, was completed in 2015 and influenced the reopening of the fishery in July 2019. As this survey occurred in October 2015, it occurs in the 2016 financial year and is referred to as the 2016 survey from this point onwards. The third survey was conducted in the southern zone in 2021 as fishing effort extended south. All three surveys were criticised for high variability in density estimates and uncertainty of the total habitat areas used for extrapolation (Anonymous 2020; Anonymous 2021; Skewes 2024; Anonymous 2022).

Estimates of surveyed biomass considered in the stock assessment models are presented in Table 2.2

2.6.1 North (1999)

FRDC project 1998/133 aimed to provide an estimate of standing stock of bêche-de-mer off the east coast of Queensland (Benzie and Uthicke 2003). The survey was conducted on 72 reefs between 12^o S and 22^o S but only reefs North of 19^o S were considered for the biomass estimate results. The survey was restricted to mid shelf and outer shelf reefs on the reef flat area with $<$ 60% sand cover as this was identified as black teatfish habitat. Using GIS coverage, the total habitat area for black teatfish in the Northern zone of the GBR was estimated to be 224,241 hectares.

The study focused on comparing open and closed reefs to gain insight into depletion caused by fishing. In 1999, the average density on open reefs was 5.52 individuals per hectare and the average density on closed reefs was 20.88 individuals per hectare. The fishery was closed in October 1999 (or financial year 2000) and the survey was repeated at 23 of the original reefs. Of the 23 resampled reefs, 4 reefs exhibited an increasing or stable density trend in 2000 and 2001. Most reefs showed a decrease in 2000 and an increase in 2001 or vice versa.

Uthicke et al. (2004b) produced a gutted weight biomass estimate for the northern zone of 2,518 (t) which included the fished and protected areas of the fishery (167,431 hectares and 56,810 hectares, respectively). It was estimated that without fishing, the virgin biomass of black teatfish would have been 5,585 (t) gutted weight, suggesting a reduction to 2,518 (t) gutted weight from unfished biomass (Uthicke et al. 2004b). This result suggests a relative biomass estimate of 45 % in 1999 in fished areas. Attempts were made to include these estimates of virgin biomass and biomass in 1999 (converted to whole weight) in the north stock assessment as well as the more recent 2016 survey. However, these attempts were unsuccessful and are presented and discussed in Section 3.2.5.

2.6.2 North (2016)

In October and November of 2015, Fishwell Consulting completed a black teatfish survey in the northern zone (Knuckey and Koopman 2016). The survey was restricted to exposed mid shelf and outer barrier reefs between 12^o S and 19^o S. Transects were generated only within the “reef top buffer” - an area of 200 m width a distance of 50 m from the exposed reef edge. Skewes et al. (2010) identified the reef top buffer as an area likely to contain high quantities of black teatfish.

Knuckey and Koopman (2016) estimated a similar mean gutted weight to Benzie and Uthicke (2003) at 1.152 kg and a mean whole weight of 1.82 kg. The mean densities in exposed mid shelf reefs were 12.45 and 13.51 for open and closed zones, respectively. The mean densities in outer barrier reefs were 23.57 and 27.03 for open and closed zones, respectively. The biomass estimates from the survey were only extrapolated out to ”reef top buffer” habitats on exposed mid shelf reefs and outer barrier reefs. The total buffer area used for the biomass estimate was 18,365 hectares. The resulting biomass estimate for the northern area was 599 (t) whole (i.e, live wet weight) biomass which includes areas open and closed to fishing.

2.6.3 South (2021)

When the fishery re-opened in July 2019, a significant portion of the black teatfish effort was concentrated in the southern zone. In April 2021, Fishwell Consulting conducted a new survey with consideration of different black teatfish habitat preferences due to a greater tidal range (Koopman and Knuckey 2021). Industry asserted that black teatfish preferred deeper reef slopes in the southern zone, so the survey was stratified across six bio-regional strata as identified in Kerrigan et al. (2010): coral sea swains northern reefs, hard line reefs, strong tidal mid shelf reefs, strong tidal outer shelf reefs, swains mid reefs and swains outer reefs. Since the southern zone of the fishery had such a short exploitation history, the survey did not consider open and closed reef areas for comparison.

The mean weight of black teatfish on hard line reefs and strong tidal mid shelf reefs were significantly different to those from the other four strata. The mean weight used for biomass calculations was 2.103 kg for hard line and strong tidal mid shelf reefs and 1.469 kg for the other four strata. Black teatfish densities ranged from 19.04 individuals per hectare in the deep coral sea swains northern reefs to 3.73 individuals per hectare in the deep swains outer reefs (excluding strata with no teatfish observed).

The total area extrapolated was 496,900 hectares and the total biomass was 6,327 (t).

Table 2.2: Biomass estimates used as stock assessment inputs. Note that biomass estimates for Uthicke et al. (2004b) have a larger extrapolated area than Knuckey and Koopman (2016) for the north stock and are not directly comparable.

Years	Biomass (whole weight)	Source	Stock
1990 (Virgin)	8,823 (t)	Uthicke et al. (2004b)	north
1999	3,978 (t)	Uthicke et al. (2004b)	north
2016	599 (t)	Knuckey and Koopman (2016)	north
2021	6,327 (t)	Koopman and Knuckey (2021)	south

2.7 Biological relationships

2.7.1 Growth curves

Parameters for the von Bertalanffy growth curve, including standard deviations about the mean length for both old and young fish, were pre-specified within the models (Table 2.3). As growth parameters for black teatfish are unknown, assumed parameters were applied based on the biology of the species (Figure 2.3). These values were sensitivity tested with three different sets of growth assumptions included in the ensemble model.

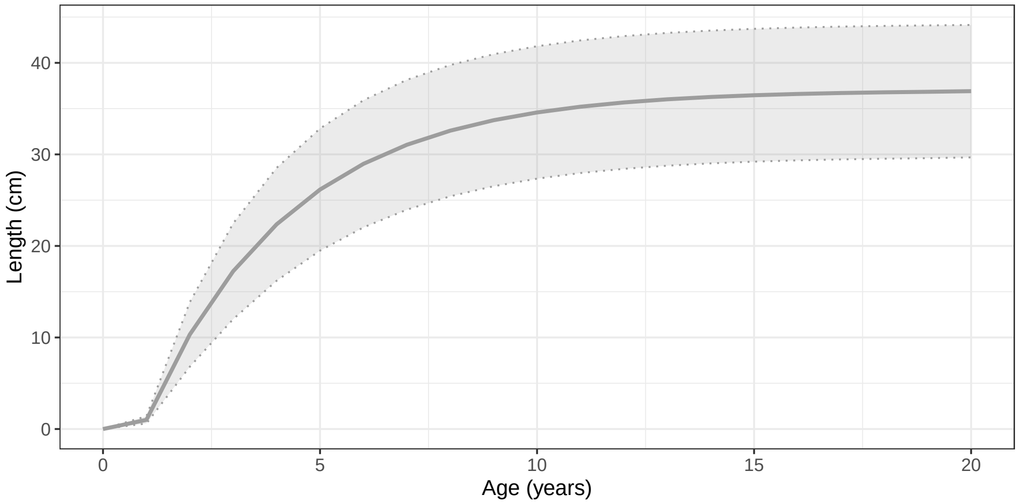

Figure 2.3: Pre-specified growth of black teatfish (95% confidence intervals) for both stocks

2.7.2 Maturity and fecundity

Conand (1989) found that black teatfish mature at a relatively large size, with 50% of animals mature by 26 cm or 800 g total weight. Conand (1989) provides a maturity curve for black teatfish in panel A of Figure 84 which indicates that about 95% of animals are mature by approximately 900 g open weight. Open weight was measured after mid-dorsal incision to remove water from inside the animal. Purcell et al. (2009b) revised Conand (1989) and found that 90% of individuals are mature at 1.135 kg whole weight. In this stock assessment, the length at which 95% of animals are mature was set to 32.4 cm derived by converting the open weight of 900 g to total length using 2.3 from Table 23, Conand (1989):

$$W_{\text{open}} = \exp(-5.8) \cdot L^{2.18} \tag{2.3}$$

where W_{open} is the open weight (g) and L is the total length (mm).

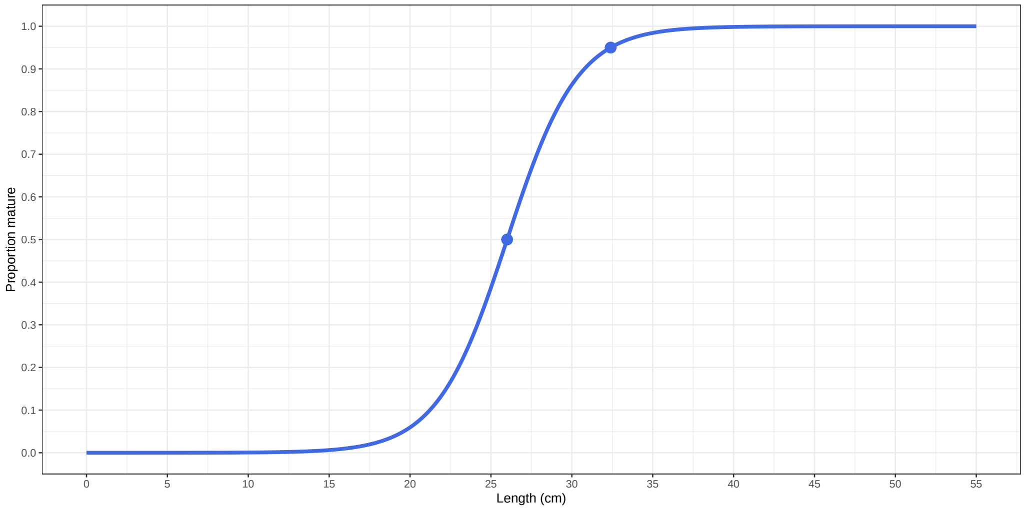

Figure 2.4: Length-at-maturity for black teatfish. The maturity ogive specified in stock synthesis is shown as the blue curve with L_{50} and L_{95} parameters.

2.7.3 Weight and length

The weight-length relationship used in this stock assessment was estimated from data collected during the 2016 biomass survey (Knuckey and Koopman 2016). A linear model was fit to weight and length data on a log(10) scale and then re-converted to natural space using a bias correction factor (Ogle 2015), resulting in the following equation:

$$W_L = W_\alpha \times L^{W_\beta} \tag{2.4}$$

where W_L is average weight (kg) at total length L (cm), W_α = 0.0471 and W_β = 1.14695.

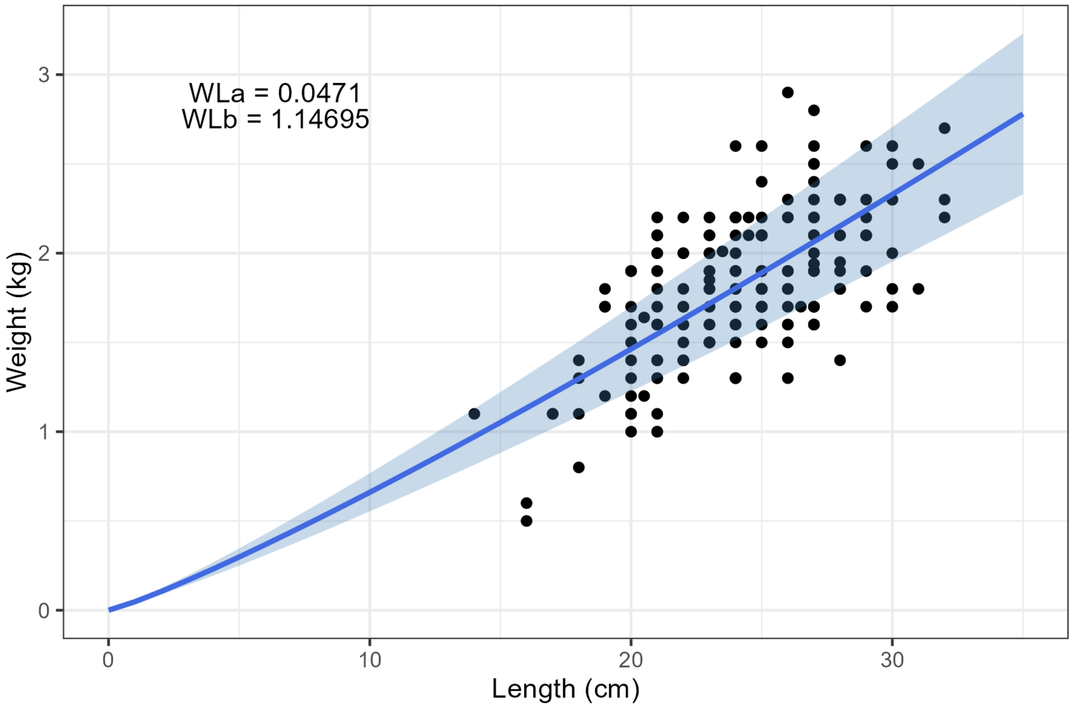

Figure 2.5: Weight-length relationship for black teatfish

2.8 Length data

Some limited length data were available from the 2016 (Knuckey and Koopman 2016) and 2021 surveys (Koopman and Knuckey 2021) which were input to the Stock Synthesis model in two-cm length bins. No age data were available. Sea cucumbers can truncate and elongate their lengths, potentially biasing length compositions. As all measurements collected were ex-situ rather than on the seafloor, it was likely that some degree of shrinkage occurred. To account for this, a 10% increase in length was applied to all measurements. This corresponds with the same adjustment applied for black teatfish in the Torres Strait (Murphy et al. 2024) and is a plausible correction factor based on comparisons of in-situ and ex-situ measurements for other Holothuria species (Djenidi et al. 2024).

In the stock assessment, the length composition informs the selectivity of the survey fleet which is then mirrored to the commercial fleets above their respective MLS (15 cm prior to 2008 and 30 cm following this).

2.9 Population model

2.9.1 Description

A single-sex population dynamic model was fitted to the data to determine the number of black teatfish in each year and each age group using the software package Stock Synthesis (SS). A full technical description of SS is given in Methot et al. (2021).

The model used three fleets: two for the commercial fishery (split either side of an MLS change in 2008) which provided catch and an index of abundance, and one for the biomass surveys which provided an index of abundance and length composition data, but not catches. The commercial fleet was split at this year as the change in MLS would cause changes in the selectivity, catchability and the abundance index. The separate treatment of these two periods is an appropriate and simple method for factoring this management implication into the population model.

2.9.2 Model assumptions

The main assumptions of the Stock Synthesis model were:

- The fishery began at virgin levels in 1989 for the north stock and 1996 for the south stock
- Sub-populations within the fishery are not broadly reproductively isolated.
- The instantaneous natural mortality rate does not depend on length, age, year or sex.
- CPUE was proportional to abundance.
- There was a 50/50 sex ratio.
- The proportion of mature sea cucumbers depends on length and not age.
- The proportion of sea cucumbers vulnerable to fishing depends on length and not age.
- Growth occurs according to the von Bertalanffy growth curve.

2.9.3 Model parameters

A variety of parameters were included in the Stock Synthesis model, with some of these fixed at pre-specified values and others estimated or mirrored. Uniform priors were used unless stated otherwise. Parameter values, their treatment (pre-specified, mirrored or estimated) and their description are available in Table 2.3.

The natural logarithm of unfished recruitment ($ln(R_0)$) was estimated within the Stock Synthesis model. Beverton-Holt stock recruitment steepness (h) was fixed at a pre-specified value. Steepness is a metric relating to the productivity of the stock. Specifically, h refers to the fraction of recruitment from a virgin population that is obtained when the population is at 20% of virgin spawning biomass (Lee et al. 2012). For the base case, h was pre-specified to the (natural scale) initial value of 0.3, based on prior knowledge that sea cucumber species often have low biological productivity and the recovery of overfished populations is often slow (Uthicke et al. 2004b). Alternate values of h were included in sensitivity testing (details in Section 2.9.6).

Natural mortality (M) was pre-specified in the model as 0.44 yr^{-1} as per Skewes et al. (2014). Alternate values of M were included in sensitivity testing (details in Section 2.9.6) and in a likelihood profile analysis (Appendix C.1).

Logistic length-based selectivity parameters were estimated in the model for the recent biomass surveys. The selectivity of the commercial fleet was mirrored to the survey selectivity for lengths above the MLS. This was justified as the surveys were undertaken by sea cucumber fishers and therefore the selectivity would match that of the fishery above the MLS. Lengths below the MLS had a commercial selectivity of zero. This approach has been used in previous sea cucumber stock assessments that are conditioned on similar survey data (Smart et al. 2024a; Smart et al. 2024b).

Recruitment deviations were estimated from the first year that CPUE was fit to for each stock, until 2024. Recruitment variation (σ_R) was pre-specified as 0.3 which was selected as it prevented over-fitting to catch rate indices and maintained a relative biomass trajectory that did not unreasonably exceed the unfished biomass levels. This was examined through Stock Synthesis diagnostic plots from the *r4ss* package (Taylor et al. 2021) such as the dynamic B_0 figure. Recruitment deviations improved fits to length composition data and abundance indices as annual variability in recruitment allowed for changes in the population on shorter time-scales than fishing mortality alone. Alternate values of σ_R were included in sensitivity testing (details in Section 2.9.6).

Table 2.3: Parameters included in the population model

Symbol	Description	Treatment	Value
M	Natural mortality	Pre-specified	0.44 (yr^{-1})
a_0	Length-at-age-zero	Pre-specified	0
L_∞	Asymptotic length	Pre-specified	37 cm
K	Von Bertalanffy growth coefficient	Pre-specified	0.3 (yr^{-1})
$\mathrm{SD}_{\mathrm{young}}$	Standard deviation of length at minimum age	Pre-specified	0.2
$\mathrm{SD}_{\mathrm{old}}$	Standard deviation of length at maximum age	Pre-specified	0.1
h	Steepness	Pre-specified	0.3
$\ln R_0$	Log of number of recruits when unfished	Estimated	
σ_R	Recruitment variability	Pre-specified	0.3
$\ln q$	Log of catchability	Estimated for each fleet	
L_{50}	Length at 50% selectivity (cm)	Pre-specified	26 cm
L_{95}	Length at 95% selectivity (cm)	Pre-specified	32 cm
W_α	Weight-length relationship	Pre-specified	0.0471
W_β	Weight-length relationship	Pre-specified	1.14695
recdev	Recruitment deviations between 1995 and 2024	Estimated	

2.9.4 Parameter estimation

Markov chain Monte Carlo (MCMC) was performed on all scenarios using 250,000 iterations with a thinning of 250 to investigate the posterior parameter distributions. Convergence of the MCMC was monitored using the potential scale reduction factor ($\hat{R}$) (Brooks and Gelman 1998) and visual examination of the posterior densities, trace plots and correlation plots for each scenario (see Appendix D). Success was determined for values $0.99 < \hat{R} < 1.01$ (Gelman et al. 2013) and overlapping posterior density. MCMC results were used to report biomass estimates with associated uncertainty.

As this report uses both MCMC and MLE it is important to distinguish how uncertainty is reported in both situations. The Bayesian term ‘credible interval’ reflects that there is a 95 percent probability that the parameter or quantity is within that interval, conditional on the data and the model. Alternatively, maximum likelihood methods use the frequentist term ‘confidence interval’ to describe the interval in which the parameter or quantity would be within for 95 percent of the possible realisations of error. Confusingly, both are condensed to the acronym ‘CI’ but should be distinguishable by context.

2.9.5 Model weighting

No formal model weightings were applied to the stock assessment model as the data-limited nature of the assessment prevents methods such as Francis weightings (Francis 2011) from being applied.

2.9.6 Sensitivity tests

As with any stock assessment model, several modelling decisions and/or assumptions must be made when insufficient information is available. The consequences of these decisions were tested through sensitivity analyses where the Stock Synthesis model was re-run using alternative conditions. These sensitivity analyses offer transparency into these decision making processes and demonstrate the impact that they have on the final model results. Here, a number of additional model runs were undertaken to determine each model's sensitivity to pre-specified parameters, assumptions and model inputs. The sensitivities, and notations used to denote variations were as follows:

- **Steepness (*h*):** As the base case steepness was pre-specified at a low level (0.3), two higher values were tested as alternatives:
  - "Mid": 0.5
  - "High": 0.7

- **Recruitment variability (σ_R):** Two higher alternatives to σ_R were examined to test the models sensitivity to this parameter.
  - "Mid": 0.4
  - "Higher": 0.6

- **Natural mortality (*M*):** Natural mortality was pre-specified in the models as 0.44 yr^{-1} as per Skewes et al. (2014). This was determined in Skewes et al. (2014) from Hoenig's method using a maximum age of 10 years (Hoenig 1983).
  The alternative values tested were:
  - "Low": 0.2 yr^{-1}
  - "Higher": 0.6 yr^{-1}

- **Growth:** As previously described in Section 2.7.1, no growth information has been published on black teatfish from any region. Therefore, assumed and pre-specified von Bertalanffy growth parameters were used to approximate growth. The influence of these assumed parameters was tested by providing alternative von Bertalanffy growth parameters (L_∞ and k) that result in faster or slower growth:
  - "Slow": L_∞ = 37 cm; k = 0.1 yr^{-1}; a_0 = 0
  - "Fast": L_∞ = 45 cm; k = 0.2 yr^{-1}; a_0 = 0

- **Shrinkage adjustment:** Length measurements collected by Knuckey and Koopman (2016) and Koopman and Knuckey (2021) were taken from animals brought to the surface due to dive logistics. Therefore, there was a possibility that these sea cucumbers could have shrunk in length as a response to this. An adjustment was made so that lengths were increased by 10%, as per Murphy et al. (2024). As a sensitivity analysis, this adjustment was removed.

- **Additional biomass surveys:** Biomass estimates for the north stock were available from Uthicke et al. (2004b) for 1999 and virgin conditions. Two additional scenarios were applied that included these biomass estimates as well as the 2016 estimate (Knuckey and Koopman 2016). No length compositions are available from these surveys so the selectivity estimated from length data collected in 2016 was applied to these surveys as well. As there is a spatial misalignment between-surveys, the 2016 survey was scaled up to 2,593 t across the full northern zone, to represent that this survey accounted for only 23% of the dry reef area
  - "Historical survey estimate included": Biomass estimates from 1999 and 2016 included.
  - "Historical survey and virgin biomass estimates included": Biomass estimates from 1999 and 2016 included as well as a virgin biomass estimate applied for 1990.

In total, twelve model runs were undertaken to determine the model's sensitivity to different parameter values and assumptions (Table 2.4). Detailed outputs of each scenario are presented in Appendix D.

Table 2.4: Scenario configuration for sensitivity analyses

Scenario number	Zone	Scenario Name	Steepness	Natural Mortality	Shrinkage	Growth	SigmaR	Biomass surveys included
1	both	Base Case	0.30	0.44	0.10	moderate	0.30	Recent
2	both	Steepness = 0.5	0.50	0.44	0.10	moderate	0.30	Recent
3	both	Steepness = 0.7	0.70	0.44	0.10	moderate	0.30	Recent
4	both	Natural mortality = 0.2	0.30	0.20	0.10	moderate	0.30	Recent
5	both	Natural mortality = 0.6	0.30	0.60	0.10	moderate	0.30	Recent
6	both	No shrinkage applied	0.30	0.44	0.00	moderate	0.30	Recent
7	both	Faster growth profile	0.30	0.44	0.10	fast	0.30	Recent
8	both	Slower growth profile	0.30	0.44	0.10	slow	0.30	Recent
9	both	SigmaR = 0.4	0.30	0.44	0.10	moderate	0.40	Recent
10	both	SigmaR = 0.6	0.30	0.44	0.10	moderate	0.60	Recent
11	north	Historical survey and virgin biomass estimates included	0.30	0.44	0.10	moderate	0.30	2016, 1999 and virgin biomass estimate
12	north	Historical survey estimate included	0.30	0.44	0.10	moderate	0.30	2016 and 1999

2.9.7 Ensemble

This assessment used an ensemble approach to combine the outcomes from a suite of ten models for the north and south stocks. The previous stock assessment used outputs from a single 'base case' model chosen from the suite of models based on a consensus of the opinions of experts in the project team. The ensemble approach, used here, allocated equal weighting to each of the models and combined their outputs. This reduced reliance on using confidence intervals from choosing a single 'most likely' model among the suite of realistic models.

For the north stock, seven of the sensitivity scenarios listed in Section 2.9.6 were included in the ensemble approach with an equal weighting. Scenarios eleven and twelve, which included historical biomass estimates, were not included in the ensemble as these biomass estimates were determined to be inconsistent with the 2016 biomass estimate, and the established history of the fishery. This is discussed in detail in Section 4.3.1. Scenarios 2, 3 and 10 were also removed from the final ensemble as these scenarios included values of h or σ_R that estimated a population productivity that was deemed too high for the species.

For the south stock, all sensitivity scenarios listed in Section 2.9.6 were included in the ensemble approach with an equal weighting. While a base case model is still identified with the default set of parameters applied, this model is only used to show fits to the data (Section 3.2.2) and describe the model performance in the diagnostics (Appendix C.1) which cannot be applied to a complete ensemble. Within the ensemble, this base case model has the same weighting as all other scenarios.

3 Results

3.1 Model inputs

3.1.1 Data availability

Model inputs are described for black teatfish from the north and south stock. Model outputs in this section relate to Scenario 1 as a reference scenario (as defined in Table 2.4). Results from all scenarios are presented in Appendix D.

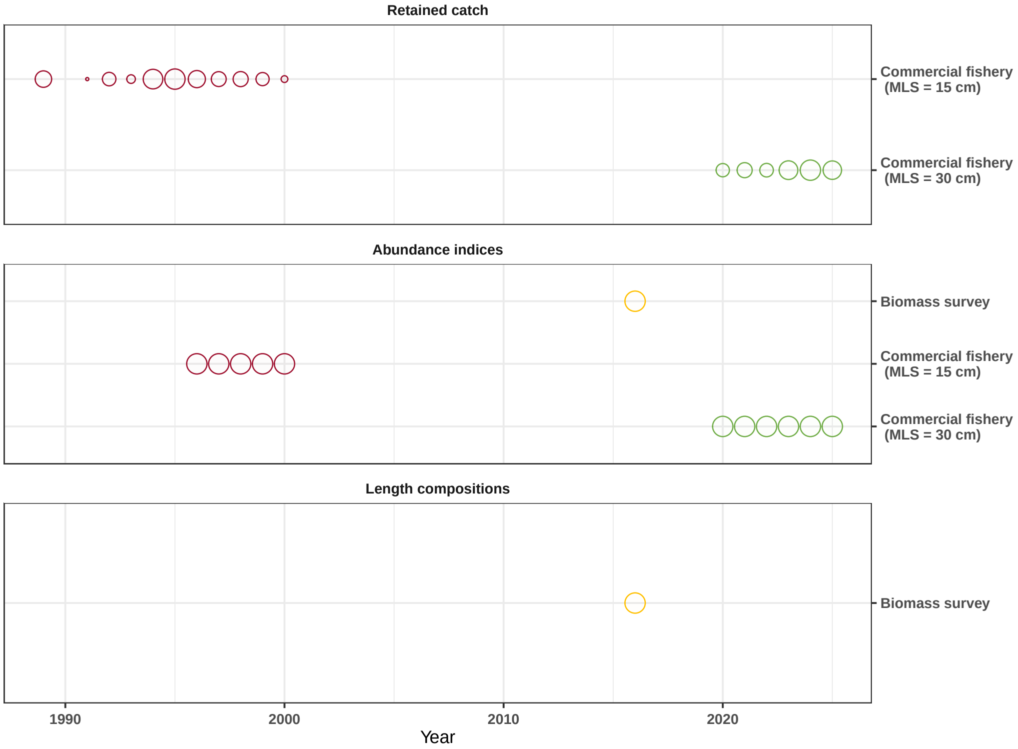

Figure 3.1: Data presence by year for each category of data type for the north stock

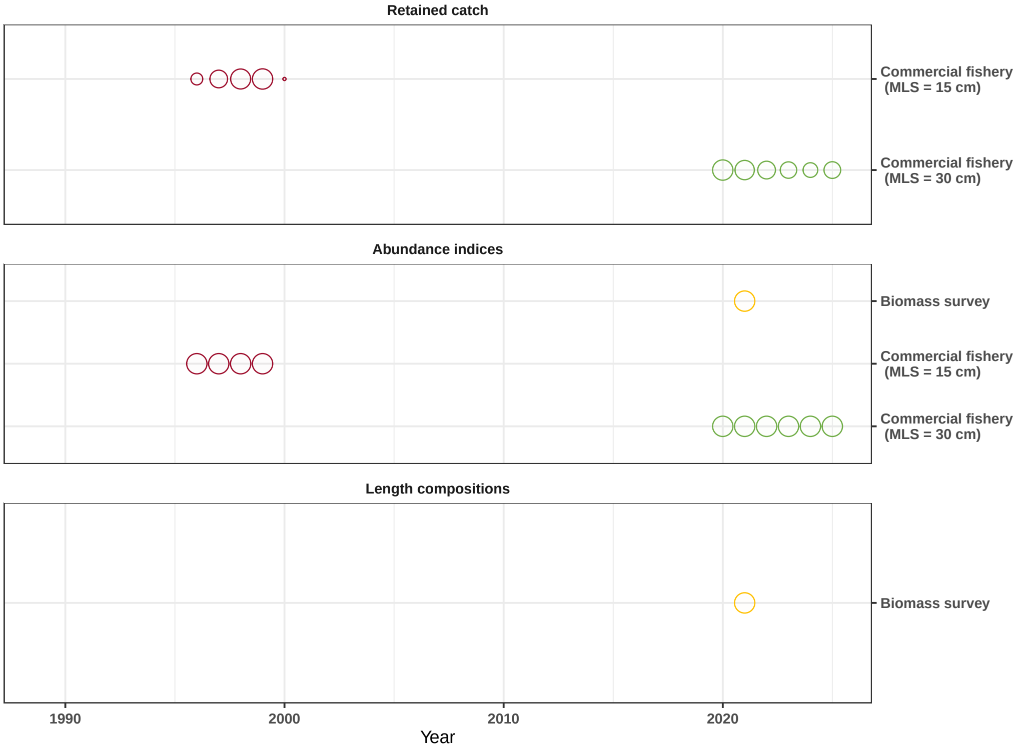

Figure 3.2: Data presence by year for each category of data type for the south stock

3.1.2 Retained catch estimates

Catches for black teatfish in the QSCF started in 1989 for the north stock and quickly climbed to over 450 t, before falling away steeply to 23 t in the 2000 when the fishery was closed partway through the fishing season (Figure 3.3). During this same period, catches were far smaller for the south stock, peaking at 13 t in 1999. As catches dropped for the north stock between 1996 and 1999, they appear to increase for the south stock during this same period (Figure 3.3).

Since the fishery re-opened in July 2019, catches have been larger for the south stock (mean of 30 t) than the north stock (mean of 25 t) (Figure 3.3). These catches are about ten times lower than the catches of the 1990s; current catches are constrained by a 30 t TAC (processed weight).

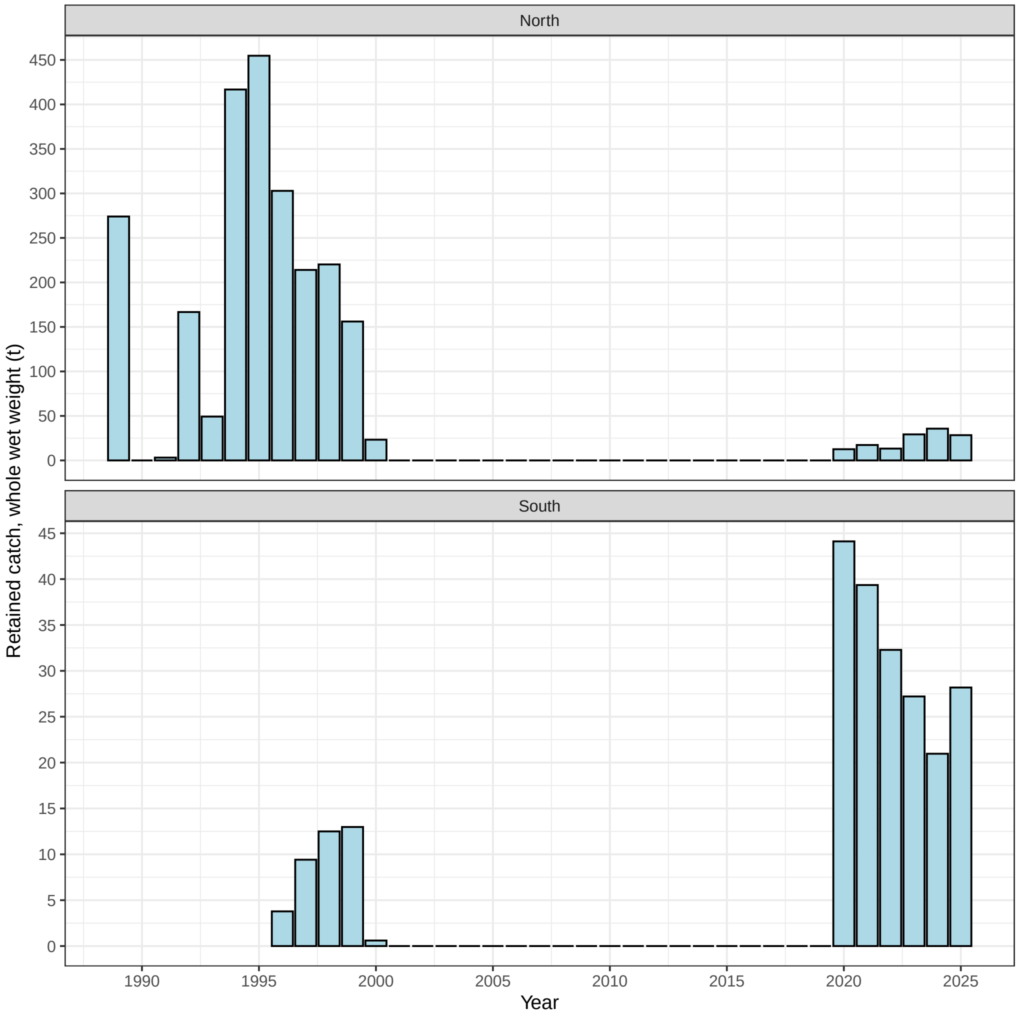

Figure 3.3: Estimated retained catch for each stock between 1989 and 2025

3.1.3 Standardised indices of abundance

The standardised CPUE for the north stock shows a clear declining trend from 1995–2000, demonstrating the stock's decline during this period (Figure 3.4). While a similar decline occurred for the south stock, this is based on a very low number of fishing events, as demonstrated by the large error estimates (Figure 3.4). When the fishery re-opened in July 2019, a relatively stable CPUE occurred for the south stock, while an increasing CPUE was estimated for the north stock (Figure 3.4).

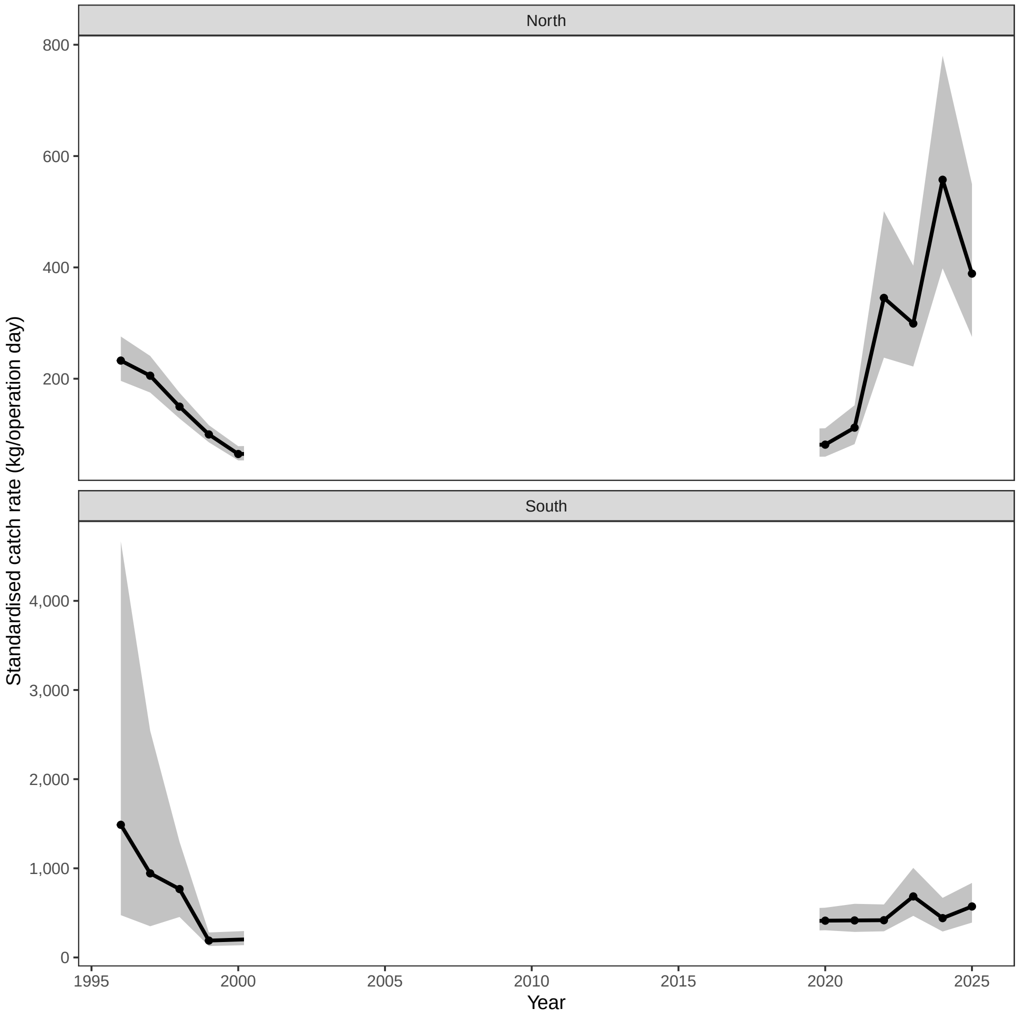

Figure 3.4: Annual standardised catch rates

3.1.4 Length composition

Length structures from the 2016 (Knuckey and Koopman 2016) and 2021 (Koopman and Knuckey 2021) surveys are presented in (Figure 3.5). The majority of measured individuals were below the MLS of 30 cm (Figure 3.5).

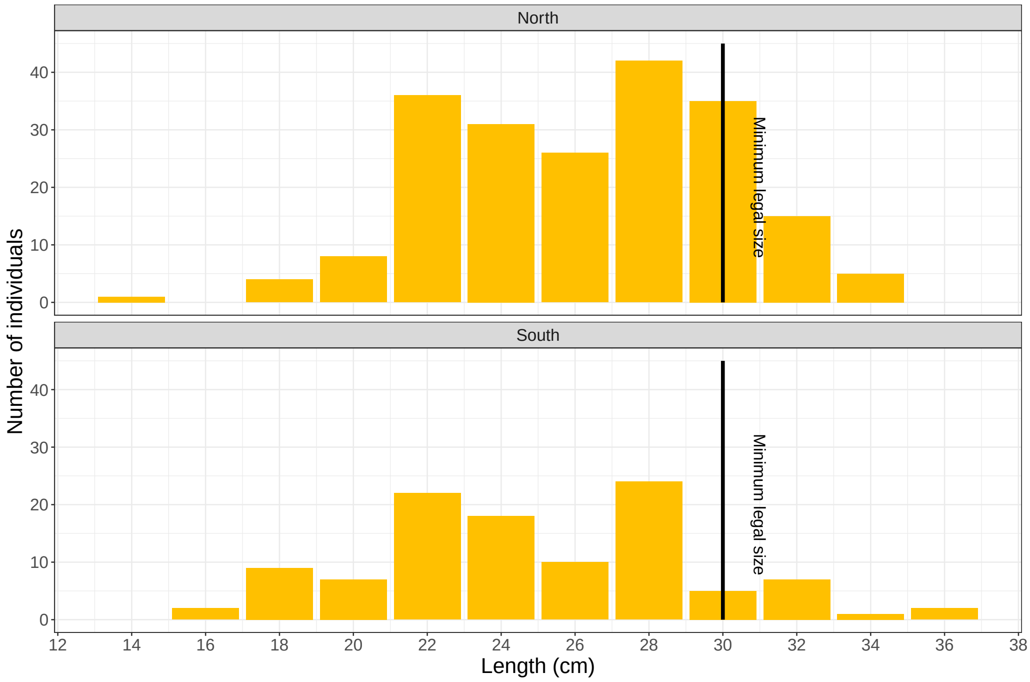

Figure 3.5: Length composition from 2016 north stock biomass survey (Knuckey and Koopman 2016) and 2021 south stock biomass survey (Koopman and Knuckey 2021). A shrinkage rate of 10% has been applied to all length classes.

3.2 Model outputs

3.2.1 Model parameters

Parameter estimates across the ensemble (see Table 2.4) are listed in Tables 3.1 and 3.2. The full list of estimated parameters is given for each scenario in Appendices D.

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

Symbol	MCMC median	MCMC 2.5%	MCMC 97.5%
SR_LN(R0)	7	5.6	7.9
SSB_Virgin	738.3	500.5	1338.4
SSB_2026	601.22	381.7	968.83
Bratio_2026	0.8	0.4	1.2
LnQ_base_Old_catches(2)	-0.3	-0.8	0.2
LnQ_base_Recent_catches(3)	0.04	-0.6	0.79
Size_inflection_Recent_survey_absolute(1)	21.3	18.3	22.9
Size_95%width_Recent_survey_absolute(1)	3.6	2.1	5.6

Table 3.2: Summary of parameter estimates for the south stock from the ensembled scenarios. MCMC Median is median parameter value from robust MCMC scenarios. MCMC 2.5% and 97.5% indicates 95% credible interval.

Symbol	MCMC median	MCMC 2.5%	MCMC 97.5%
SR_LN(R0)	8.5	6.6	9.9
SSB_Virgin	3481.4	1934.7	6065.6
SSB_2026	3562.61	2017.46	6097.62
Bratio_2026	1	0.7	1.4
LnQ_base_Old_catches(2)	-2.7	-3.3	-2
LnQ_base_Recent_catches(3)	-1.16	-1.92	-0.54
Size_inflection_Recent_survey_absolute(1)	18.8	16.1	21.9
Size_95%width_Recent_survey_absolute(1)	3.3	0.6	6.6

3.2.2 Model fits

3.2.2.1 CPUE fits

A close fit to CPUE was achieved for the north stock between 1996 and 2000, tracking the populations decline during this period (Figure 3.6). From 2020 onwards, the fit to CPUE for the north stock was adequate and followed the increasing trend, although it underfit the final model year (Figure 3.6).

A poorer fit to the CPUE was achieved for the south stock, as the estimated CPUE was very flat (Figure 3.6). This reflects the relatively light exploitation of this stock and the wider standard errors that occur from 1996 to 1999 for the standardised CPUE (Figure 3.6).

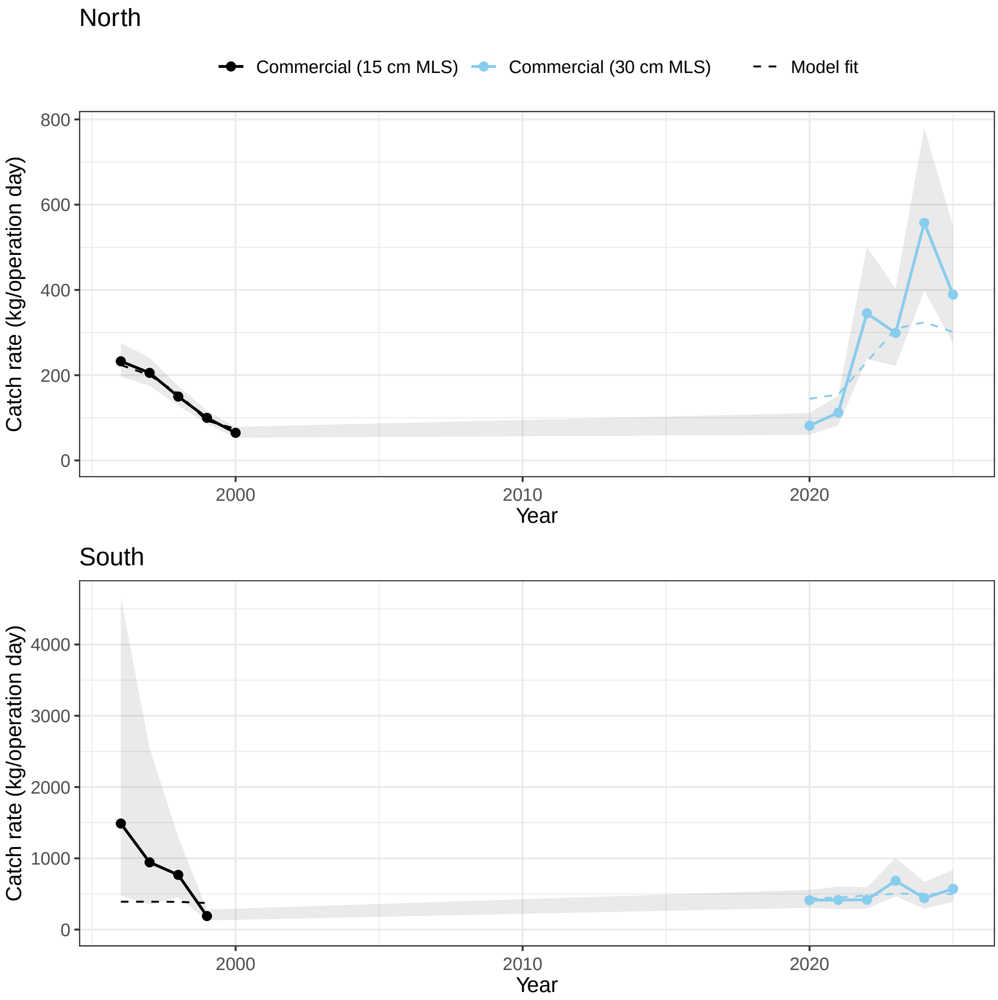

Figure 3.6: Model fit to catch rates for the base case models

3.2.2.2 Biomass survey fits

An exact fit to the surveyed biomass occurred for the south stock, while the north stock was under fit by approximately 200 t (Figure 3.7). However, this fit was still within the confidence intervals of the 2016 survey estimate, demonstrating that it remains appropriate (Figure 3.7).

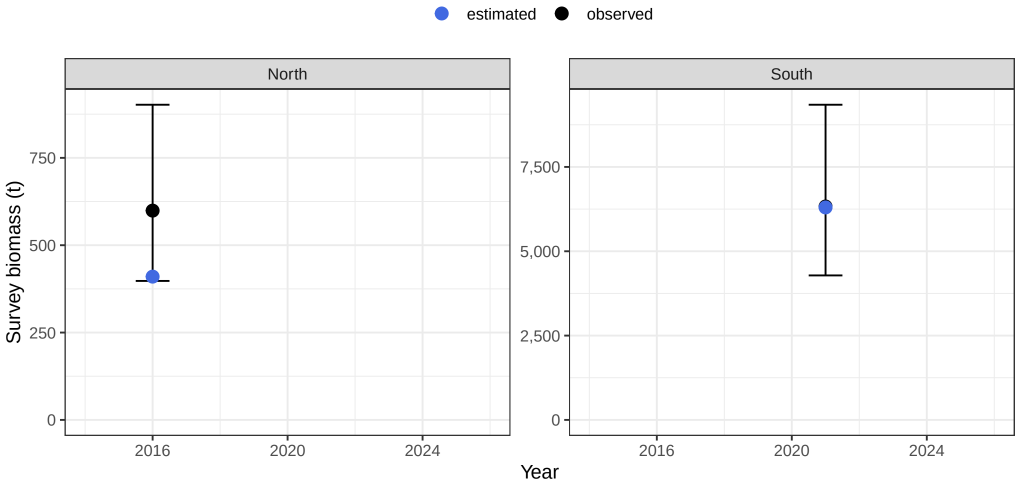

Figure 3.7: Model fit to survey biomass estimate for the base case models.

3.2.2.3 Length composition fits

Adequate fits to the length compositions occurred for both stocks (Figure 3.8). The length composition data had several pronounced peaks, caused by low sample sizes and the shrinkage scaling that was applied (Figure 3.8). If necessary, this can be addressed through increasing the bin size from 2 to 5 cm. However, this is a wider range than is ideal for a species of this size. The fit of these length composition smooths out these peaks (Figure 3.8), avoiding the need to adjust the input data through larger bin sizes.

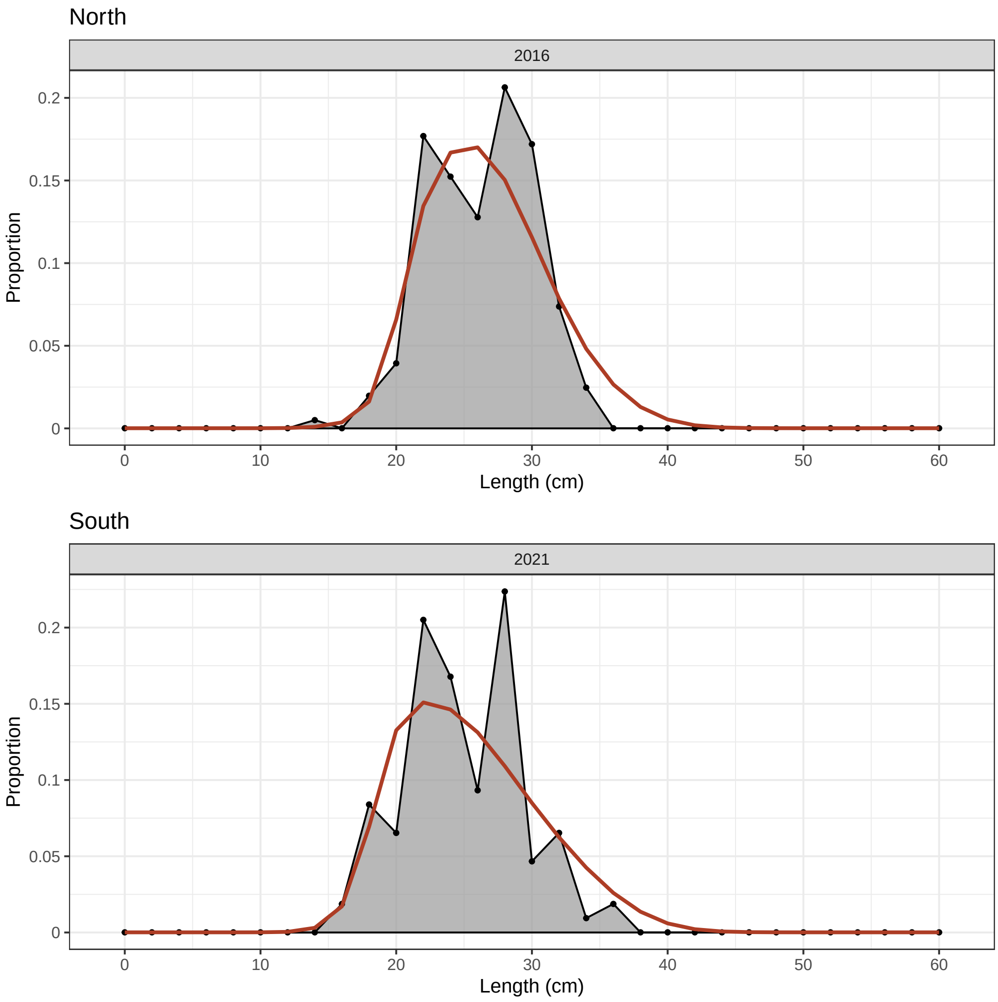

Figure 3.8: Model fit to length composition for the base case model.

3.2.3 Selectivity

The resulting selectivity functions (Figure 3.9) represent the relative proportion of black teatfish of a given length that can be caught by the commercial fleet or included in the biomass surveys (ranging from zero to 100%). Only the selectivity curve for the biomass survey is estimated for each stock, with commercial selectivity mirrored to these estimates above the MLS. The MLS in the QSCF was increased in 2008 (while the fishery was closed) from 15 cm to 30 cm. Therefore, the selectivity of the commercial fleet before the closure was close to the selectivity estimated by the surveys and thus only the commercial selectivity is displayed in the graph in Figure 3.9. The survey selectivity was very similar for both stocks (light blue line in Figure 3.9).

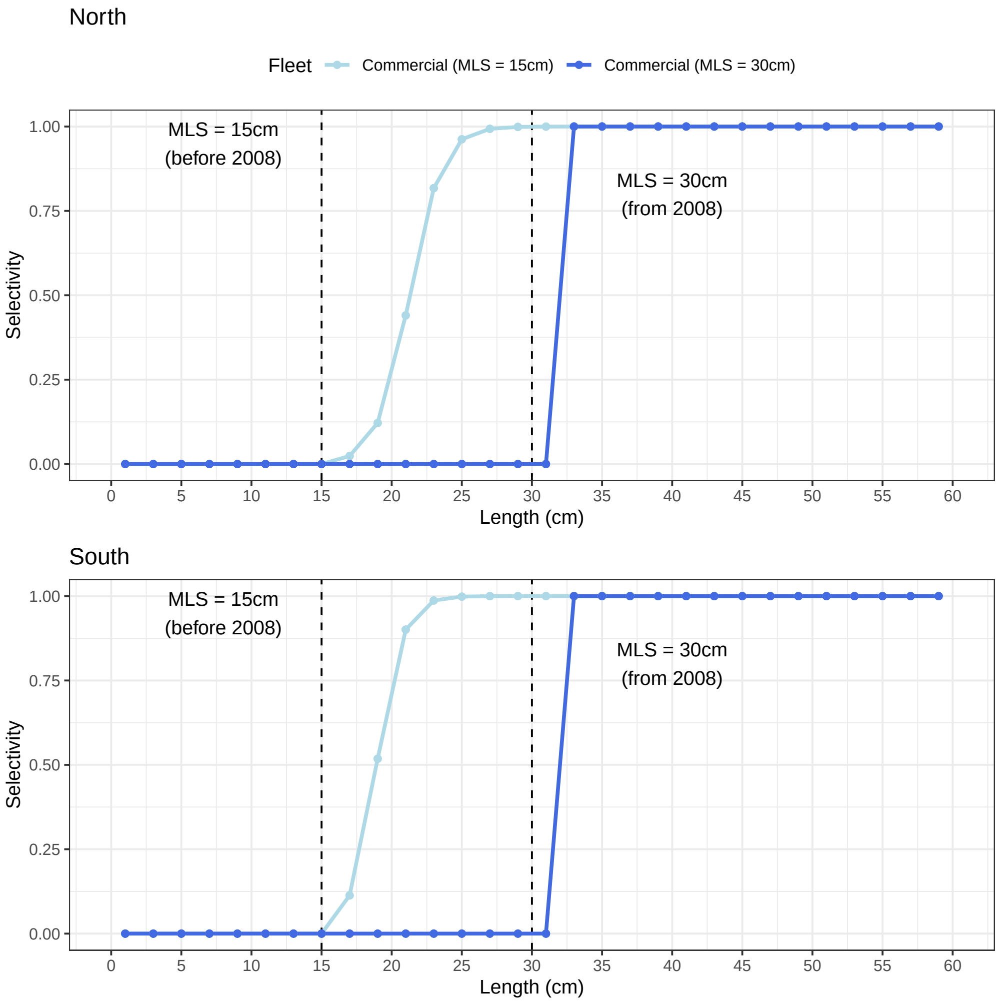

Figure 3.9: Model estimated length-based selectivity for the base case model—the dashed line shows the minimum legal size before and after 2008. The selectivity of the commercial fleet before the closure was close to the selectivity estimated by the surveys and thus the biomass survey selectivity is not shown

3.2.4 Spawning biomass estimates

3.2.4.1 North stock

The relative spawning biomass from the ensemble model for the north stock at the beginning of 2026 was between 45% and 125% of an assumed unfished state in 1989 (Figure 3.10).

Seven model scenarios were included in the ensemble model for the north stock (Table 2.4), covering a range of modelling assumptions and sensitivity tests. Relative biomass trajectories for all scenarios are presented in Figure 3.11. In general, all scenarios followed a similar trend to the base case scenario (Figure 3.11). Four scenarios estimated a relative spawning biomass in 2026 above the base case model, and therefore there was a large level of uncertainty in some years of the ensemble model. These included scenarios where h or σ_R were higher than the default used in the base case (Figure 3.11). The remaining scenarios (including those that used alternative growth profiles) estimated a relative spawning biomass similar to the base case (Figure 3.11). The most pessimistic scenario applied an M of 0.2 yr^{-1} which estimated the relative spawning biomass at approximately 50% in 2026 (Figure 3.11).

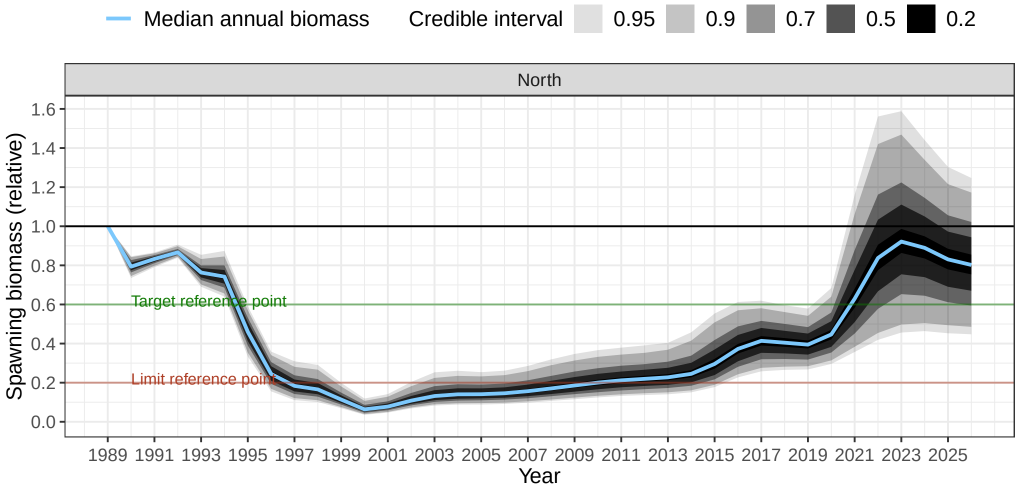

Figure 3.10: Estimated spawning biomass trajectory relative to unfished for black teatfish in the north stock, from MCMC ensemble scenarios

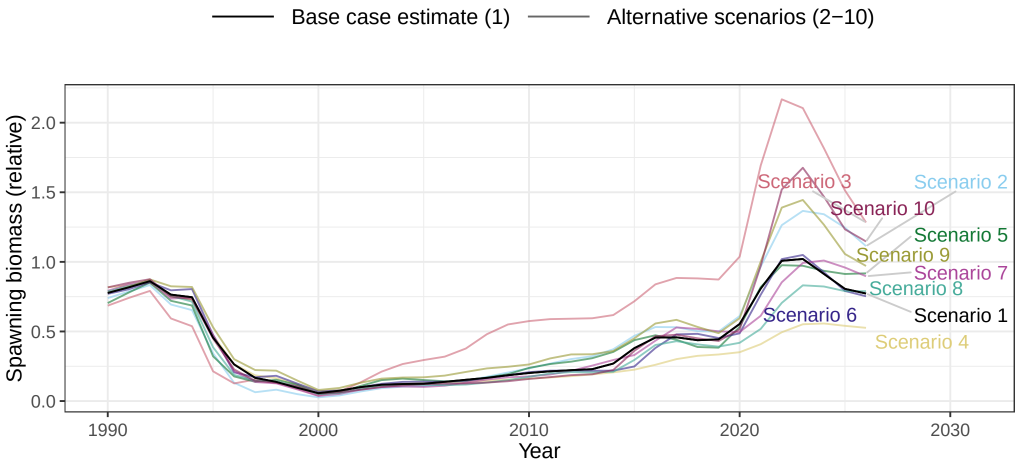

Figure 3.11: Estimated spawning biomass trajectory relative to unfished levels for black teatfish in north stock from 1989 to 2026 for all scenarios.

Table 3.3: Summary of model outcomes for all scenarios. $B_{2026}\%$ is the most likely biomass at the start of 2026 relative to unfished in 1989, with the 95% confidence interval for maximum likelihood estimatations and 95% credible interval for MCMC estimations

Scenario	**MLE**			**MCMC**		
	$B_{2026}\%$	$B_{2026,lower}\%$	$B_{2026,upper}\%$	$B_{2026}\%$	$B_{2026,lower}\%$	$B_{2026,upper}\%$
1	0.66	0.46	0.85	0.77	0.52	1.07
2	1.15	0.93	1.37	1.11	0.87	1.42
3	1.32	1.07	1.58	1.28	1.01	1.59
4	0.43	0.28	0.59	0.53	0.38	0.75
5	0.79	0.57	1.02	0.92	0.64	1.26
6	0.64	0.43	0.84	0.75	0.52	1.06
7	0.74	0.53	0.95	0.90	0.62	1.26
8	0.64	0.45	0.84	0.79	0.54	1.10
9	0.82	0.53	1.11	0.97	0.62	1.46
10	1.01	0.57	1.44	1.15	0.67	1.94
11	1.38	1.12	1.65	1.19	0.87	1.56
12	1.35	1.09	1.62	1.23	0.93	1.65

The posterior distribution of the ensemble model estimated that relative spawning biomass at the beginning of 2026 had an 84% probability of being above 60%, a 15% probability of being between 40 and 60%, a 1% probability of being between 20 and 40%, and a 0% probability of being below 20% (Figure 3.12; Table 3.4).

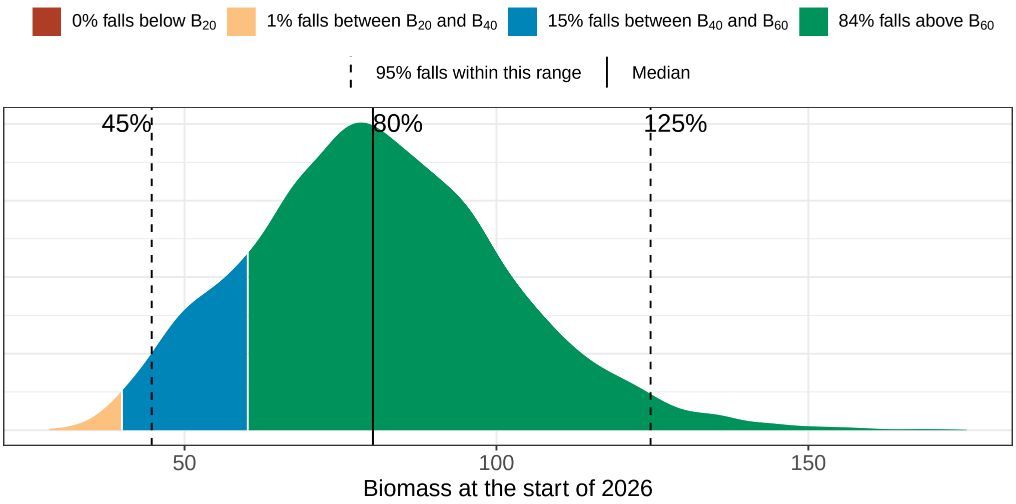

Figure 3.12: Probability distribution of the biomass ratio at the beginning of 2026 across the full ensemble of scenarios with the credible interval and probability of biomass falling into the four categories indicated

Table 3.4: Stock status indicators for black teatfish North stock

Indicator	Value
Biomass ratio (relative to unfished)	
Range (95% credible interval)	45–125%
Median	80%
Probability below 20%	0%
Probability between 20% and 40%	1%
Probability between 40% and 60%	15%
Probability above 60%	84%
Fishing pressure ratio (relative to F_{60})	
Range (95% credible interval)	0.25–1.04
Probability exceeds F_{B60}	4%

The relative spawning biomass trajectory of the north stock follows the anecdotal history of the fishery (Figure 3.10). The spawning biomass declined sharply between 1990 and 2000, dropping below the limit reference point by 1997 after excessive catches in those years. Following the fishery's closure in 2000, the stock began to slowly recover and rose above the limit reference point in 2011 (Figure 3.10). The stock then rose above the target reference point in 2020, which corresponds to the fishery's re-opening. The stock has continued to increase since then, as catches have been ten times lower than those that caused the population declines in the 1990s (Figure 3.3; 3.10). The virgin spawning biomass was estimated as 738 t and the spawning biomass at the beginning of 2026 was estimated as 601 t (Figure 3.13).

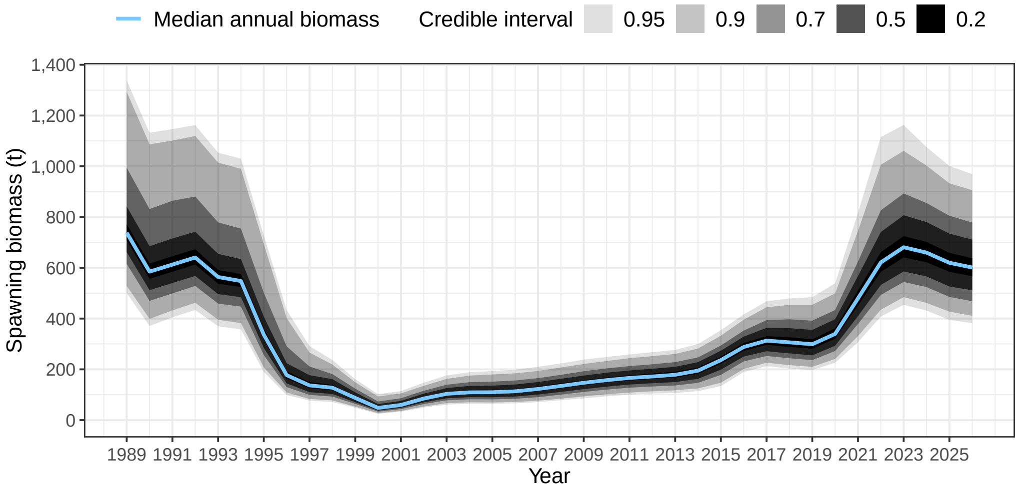

Figure 3.13: Estimated absolute spawning biomass for black teatfish in north stock, from MCMC ensemble scenarios

3.2.4.2 South stock

The relative spawning biomass from the ensemble model for the south stock at the beginning of 2026 was between 73% and 138% of an assumed unfished state in 1996 (Figure 3.14). Ten model scenarios were included in the ensemble model for the south stock (Table 2.4), covering a range of modelling assumptions and sensitivity tests. Relative biomass trajectories for all scenarios are presented in Figure

3.15. In general, all scenarios followed a similar trend to the base case scenario and indicated that the stock is lightly fished and close to virgin levels in 2026 (Figure 3.15).

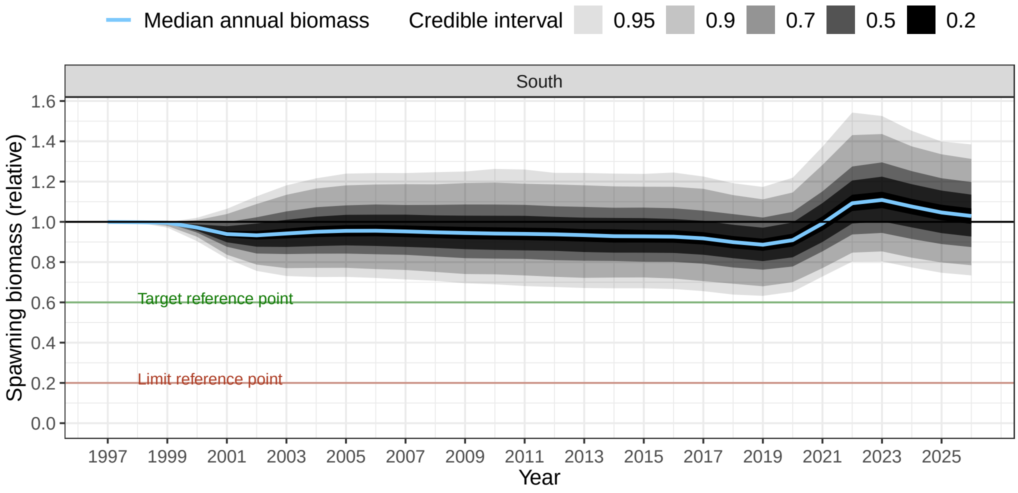

Figure 3.14: Estimated spawning biomass trajectory relative to unfished for black teatfish in the south stock, from MCMC ensemble scenarios

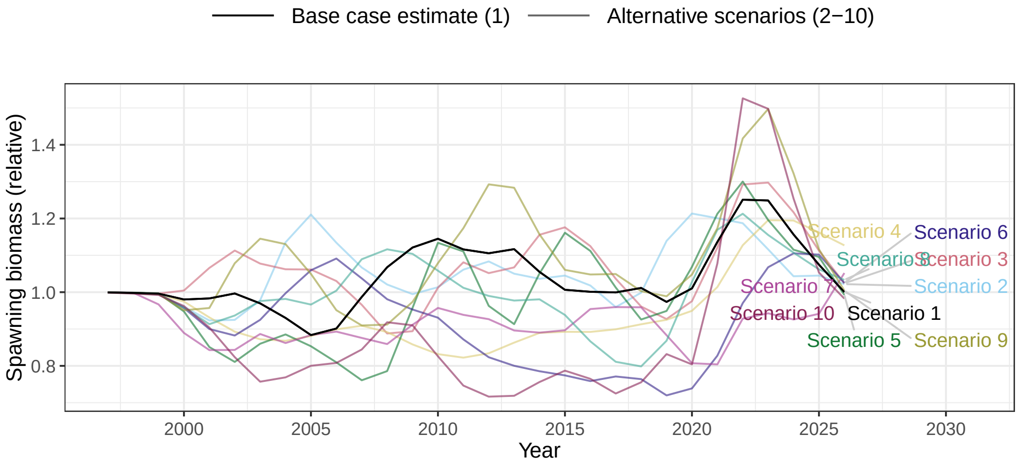

Figure 3.15: Estimated spawning biomass trajectory relative to unfished levels for black teatfish in the south stock from 1989 to 2026 for all scenarios.

Table 3.5: Summary of model outcomes for all scenarios. $B_{2026}\%$ is the most likely biomass at the start of 2026 relative to unfished in 1996, with the 95% confidence interval for maximum likelihood estimatations and 95% credible interval for MCMC estimations

Scenario	**MLE**			**MCMC**		
	$B_{2026}\%$	$B_{2026,lower}\%$	$B_{2026,upper}\%$	$B_{2026}\%$	$B_{2026,lower}\%$	$B_{2026,upper}\%$
1	1.03	0.87	1.18	1.00	0.76	1.31
2	1.04	0.86	1.22	1.02	0.82	1.28
3	1.04	0.86	1.23	1.02	0.83	1.26
4	1.09	0.98	1.21	1.13	0.92	1.39
5	1.03	0.83	1.22	0.99	0.73	1.34
6	1.05	0.89	1.20	1.02	0.79	1.34
7	1.08	0.91	1.26	1.05	0.78	1.39
8	1.04	0.90	1.19	1.03	0.80	1.32
9	1.05	0.84	1.26	1.00	0.69	1.44
10	1.07	0.76	1.39	0.98	0.56	1.72

The posterior distribution of the ensemble model estimated that relative spawning biomass at the beginning of 2026 had an 99% probability of being above 60%, a 1% probability of being between 40 and 60%, a 0% probability of being between 20 and 40%, and a 0% probability of being below 20% (Figure 3.16; Table 3.6).

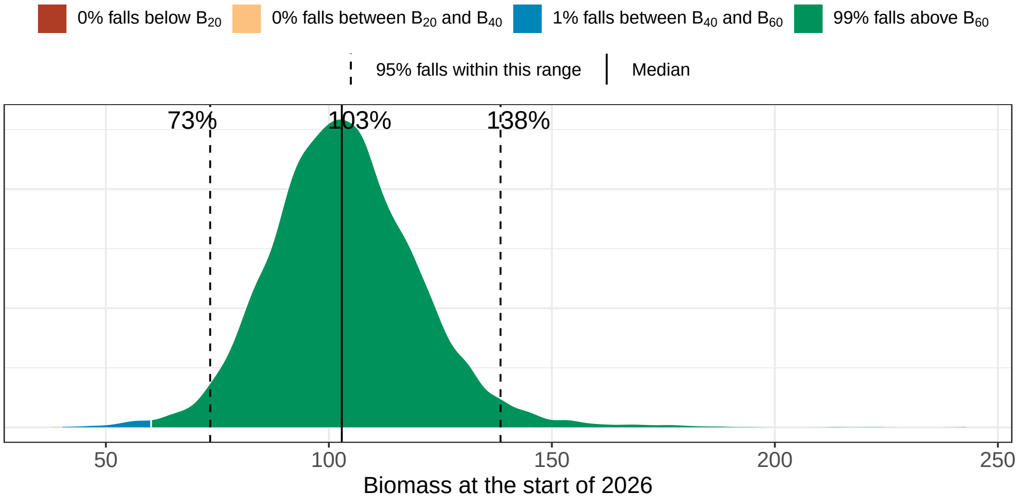

Figure 3.16: Probability distribution of the biomass ratio at the beginning of 2026 across the full ensemble of scenarios with the credible interval and probability of biomass falling into the four categories indicated

Table 3.6: Stock status indicators for black teatfish South stock

Indicator	Value
Biomass ratio (relative to unfished)	
Range (95% credible interval)	73–138%
Median	103%
Probability below 20%	0%
Probability between 20% and 40%	0%
Probability between 40% and 60%	1%
Probability above 60%	99%
Fishing pressure ratio (relative to F_{60})	
Range (95% credible interval)	0.03–0.2
Probability exceeds F_{B60}	0%

The relative spawning biomass trajectory of the south stock also follows the anecdotal history of the fishery (Figure 3.14). Catches have been low in comparison to the north stock, which was heavily fished in the 1990s (Figure 3.3). The survey estimates of biomass were far higher than that of the north stock (Table 2.2), indicating that this stock is the larger of the two and has had lower levels of exploitation. Accordingly, the stock assessment model estimates the stock to be lightly fished and that spawning biomass has been close to virgin levels for the past 30 years (Figure 3.14). The virgin spawning biomass was estimated as 3,481 t and the spawning biomass at the beginning of 2026 was estimated as 3,563 t indicating the light exploitation that has occurred on this stock comparatively to the north stock (Figures 3.13; 3.17).

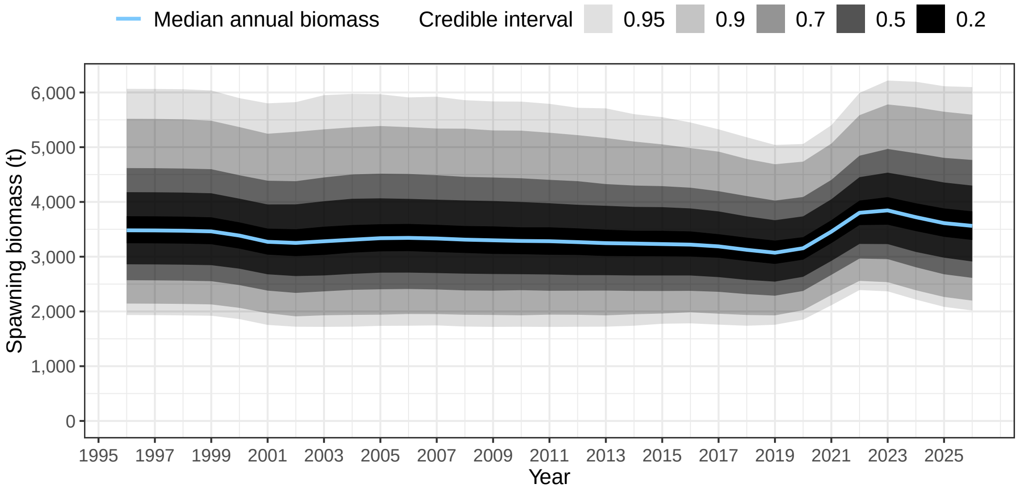

Figure 3.17: Estimated absolute spawning biomass for black teatfish in the south stock, from MCMC ensemble scenarios

3.2.5 Additional biomass surveys included

Scenario 11 and 12 explored the inclusion of a previous biomass estimate for 1999 and an estimate of virgin biomass that were available from Uthicke et al. (2004b) for the north stock. The estimated selectivity from the 2016 survey (Knuckey and Koopman 2016) was also applied to these estimates as no additional length data was available to estimate this separately. The inclusion of both of these biomass estimates produced depletion estimates in 2000 (when the fishery closed) that were substantially higher than the base case scenario (Figure 3.18). The base case scenario estimated that the stock reached 6% of relative spawning biomass in 2000, consistent with the sharp declines in CPUE during this period that led to the fishery's closure. Conversely, Scenarios 11 and 12 estimated a relative spawning biomass in 2001 of 56% and 55%, respectively. Given that these estimates are close to the biomass target reference point for the stock, they are inconsistent with the perceived state of the fishery in 2000 that ultimately led to its closure.

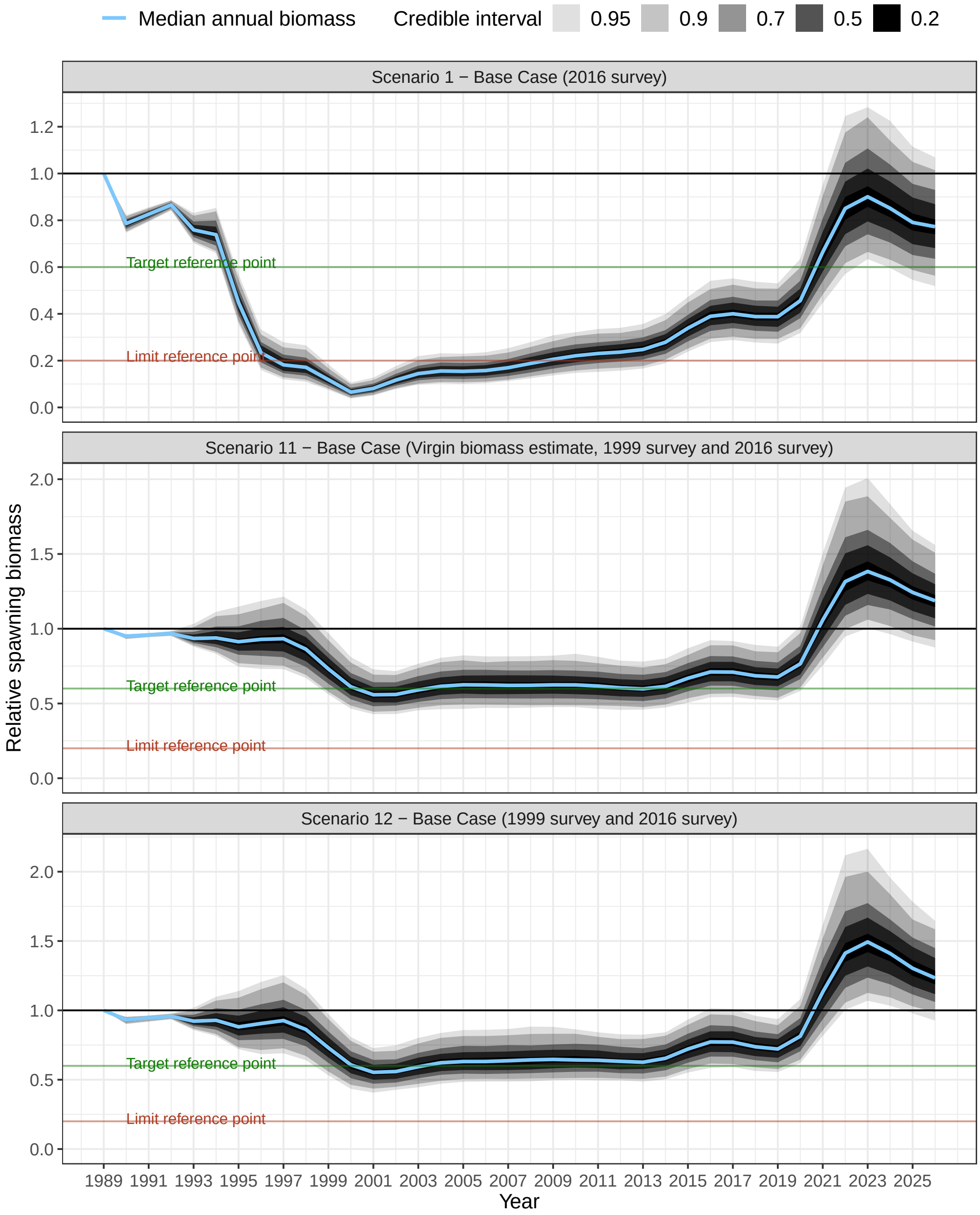

Figure 3.18: Estimated spawning biomass trajectory relative to unfished for Scenarios 1, 11 and 12 from MCMC model runs.

This result is driven by the 1999 biomass estimate, which was larger than the biomass estimate from 2016 (Figure 3.19). This was contrary to evidence demonstrating that the stock was depleted in 2000, and that no catches had occurred between the two surveys, and therefore the biomass in 2016 should be the higher estimate. Consequently, the Stock Synthesis model needed to underestimate the 1990 and 1999 estimates, while overestimating the 2016 estimate in order to fit to a combination of these surveys in Scenarios 11 and 12 (Figure 3.19).

Given that this early survey result is inconsistent with the perceived state of the stock that led to its closure, these estimates were not considered suitable to include in the stock assessment and these scenarios were not included in the ensemble. The inclusion of only the 2016 estimate provides both a more conservative stock assessment outcome, and a better approximation to the anecdotal history of the fishery – that heavy overfishing occurred in the 1990s leading to the stock declining below the biomass limit reference point of 20%.

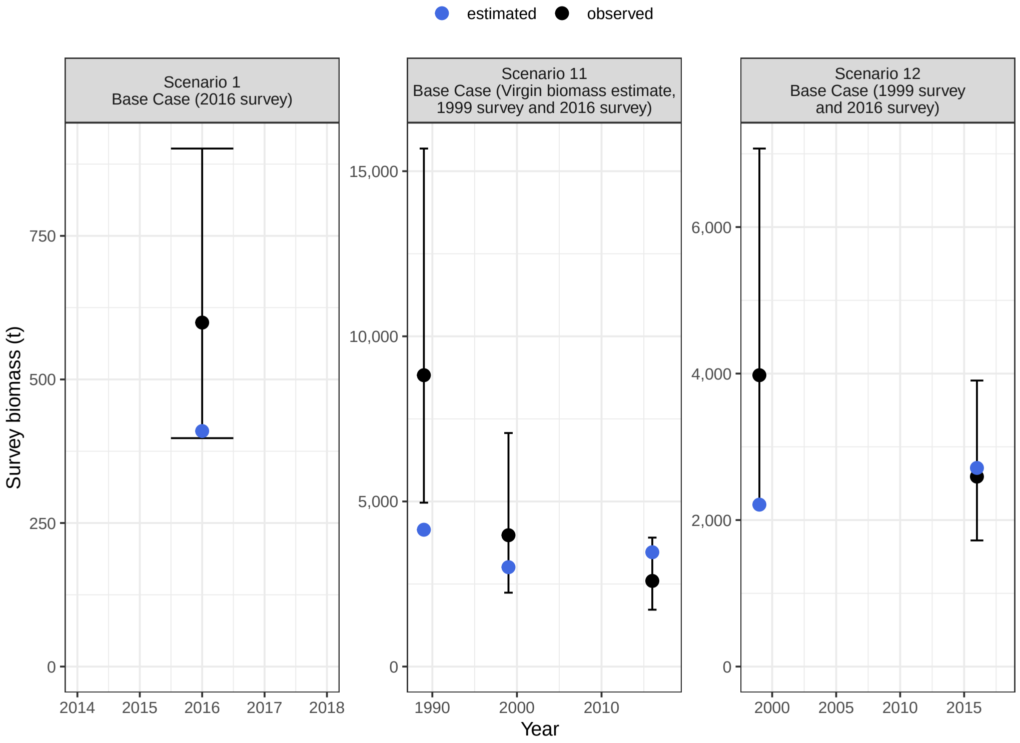

Figure 3.19: Model fits to surveyed biomass in 1999 and 2016 as well as a virgin biomass estimate from the 1999 survey.

4 Discussion

4.1 Stock status

Stock status for the north stock at the beginning of 2026 was estimated to be between 45% and 125% (95% credible interval over the MCMC ensemble). The probability that the biomass was below 20% in 2026 was estimated to be 0%. The biomass trajectory indicates that biomass declined below 20% of unfished spawning biomass in 2000, but recovered during the fishery's 20 year closure. Recent catches have maintained the population above the target biomass reference point.

Stock status for the south stock at the beginning of 2026 was estimated to be between 73% and 138% (95% credible interval over the MCMC ensemble). The probability that the biomass was below 20% at this time was estimated to be 0%. The biomass trajectory indicates that this is a lightly exploited stock that has never declined below the target biomass reference point.

4.2 Performance of the population model

4.2.1 Scenarios

Twelve model scenarios were included for the north stock that accounted for uncertainty in key parameters such as h, σ_R and M as well as uncertainty in growth, application of a shrinkage correction for lengths, and additional biomass estimates from earlier surveys (Uthicke 2004). Seven of these scenarios were included in the ensemble model, and account for the wider variability in stock status in 2026. Scenarios that used parameters allowing for greater recruitment variability (i.e., h and σ_R) produced stock status estimates that were above the base case. However, remaining scenarios that pre-specified lower population productivity and recruitment variability all estimated a similar stock status to the base case. This included scenarios with alternative assumptions on growth parameters, which demonstrated that the north stock model was not sensitive to these inputs. Only one scenario (M of 0.2 yr^{-1}) yielded a notably more pessimistic stock status than the base case but this was still above 50% unfished biomass in 2026. This value of M was also well below values considered in previous literature (Skewes et al. 2014). These seven scenarios were included in a final model ensemble to fully account for uncertainty in these parameters. This leads to a wide variation in stock status, but still demonstrates that there is an 84% probability of the stock being above the 60% biomass target reference point. The two scenarios that examined the inclusion of additional biomass surveys were not included in the ensemble and are discussed in detail in Section 4.3.1.

Ten model scenarios were included for the south stock and provided consistent stock statuses. The consistency between scenarios was driven by the models being conditioned on the large biomass estimate from the 2021 survey (Koopman and Knuckey 2021) and the relatively low levels of catch. Therefore, all scenarios estimated a stock that has been lightly exploited.

4.2.2 Previous stock assessment

This is the second stock assessment undertaken for black teatfish on the GBR, with the previous assessment undertaken in 2021 (Helidoniotis 2021). Several substantial updates have been made between this assessment and the previous one:

- Two stocks were modelled rather than a whole GBR stock. This was done to reflect the disparate exploitation histories of the northern and southern zones and make better use of the individual biomass survey estimates (Knuckey and Koopman 2016; Koopman and Knuckey 2021).
- The present assessment was performed using Stock Synthesis whereas the previous assessment was performed using an age-structured surplus production model (ASPM).
- The previous assessment considered historical catches and modelled the population between 1877 and 2021. The present assessment did not include these historical catches (see detailed discussion of this in Section 4.3.2) and modelled the north stock between 1989 and 2026 and the south stock between 1996 and 2026.
- The previous stock assessment included estimates of biomass from 1996 – 1999. These were sourced from Skewes et al. (2014) who determined them from the surveys conducted by Benzie and Uthicke (2003). The present assessment only considered the biomass estimate for 1999 presented in Uthicke (2004) which is based on the same survey information. Scenarios that included these estimates were not included in the ensemble model. This is discussed in detail in Section 4.3.1.

The previous assessment estimated stock status in 2021 for the whole GBR as 40 – 42 % relative to 1877 (Helidoniotis 2021). However, the well documented stock decline that occurred in the late 1990's and led to the fisheries closure was not evident in the biomass trajectory. There are a number of reasons why this could have occurred, but the most likely reason was the inclusion of the historical catch reconstructions undertaken by Uthicke (2004). These estimates show a peak yield of 5,500 t gutted weight during World War I — close to twenty times the peak catch of ~450 t whole wet weight from the 1990s. This caused the stock assessment to estimate a large virgin biomass and a higher level of stock productivity than was realistic. Consequently, the model estimated that catches in the 1990's were sustainable, given that the stock had previously been harvested at much larger levels in the past. However, the available evidence strongly indicates that overfishing in the 1990's did occur and that the fishery closure was justified.

These catch reconstructions prior to 1990 (Uthicke 2004) are highly uncertain, as detailed by Skewes (2024) and discussed in Section 4.3.2. Therefore, they were not included in the present assessment for the north stock. This represents the most consequential update between black teatfish stock assessments as the well documented stock decline of the 1990's is now captured in the model outputs of the present assessment.

4.3 Key considerations

4.3.1 Previous biomass estimates

The black teatfish south stock had a single biomass estimate available which, given its light exploitation history, essentially represents a virgin biomass level. This was supported by the ensemble model, which estimated a relative spawning biomass in 2026 of between 73% and 138% of unfished.

Several biomass estimates were available for the north stock, each carefully considered during this assessment. The first estimate, available for 1999, was produced by Uthicke (2004) based on wide-scale surveys undertaken over 1998 – 2001 (Benzie and Uthicke 2003). This estimate represents the north stock size in 1999 following its decline, and was 2,518 t gutted weight, equivalent to 3,978 t whole wet weight. At the time of the survey, this was used to estimate a stock depletion to 45% of unfished biomass, implying a pre-depletion biomass of 5,585 t gutted weight (8,823 t whole wet weight). The northern zone survey undertaken in 2016 estimated a biomass of 599 t whole wet weight across an area that represented the main fishing grounds prior to the fishery closure (Knuckey and Koopman

2016), some of which are now closed as part of the representative areas program (RAP) implemented in 2004. As this accounted for an estimated 23% of the dry reef area, it scales to 2,593 t across the full northern zone.

These two values create an immediate discrepancy: the biomass estimate following the stock's depletion is higher than the estimate following a 17-year closure during which the stock should have recovered. Three noteworthy points help explain this. First, the surveys undertaken by Benzie and Uthicke (2003) were not designed to estimate absolute biomass. Rather, they were designed to examine differences in black teatfish density between areas open and closed to fishing, a purpose they were well suited to (Knuckey and Koopman 2016; Koopman and Knuckey 2021). As a result, these data are less reliable when scaled into absolute biomass estimates for use in a stock assessment than the random stratified surveys conducted by Knuckey and Koopman (2016).

Second, these biomass estimates encompass both open and closed fishing areas (Uthicke 2004). For use in a stock assessment model, it would be preferable to separate these spatial areas to account for different levels of exploitation. The results of Benzie and Uthicke (2003) indicate that black teatfish densities were 75% lower in open areas compared to closed areas, reflecting substantial depletion in fished zones. When included as a single biomass estimate in the stock assessment model, however, this depletion signal is not reproduced, and the model instead estimated a relative spawning biomass of 55% in 2001 (Scenario 12). The 1999 estimate therefore likely overestimates population size in the fished areas to which catch and CPUE data relate, creating conflicts within the stock assessment model. While the 2016 survey also covers some areas now closed to fishing, it is considered more representative of the available black teatfish population in the northern zone. Separating the 2016 survey into open and closed fishing zones was considered but deemed unnecessary, as the survey was already treated as a conservative biomass estimate. Notably, the ensemble model under fit this biomass input regardless, approximating the biomass estimated for open areas only (~400 t).

Third, black teatfish densities on the outer barrier reef surveyed in 2016 exceeded 20 individuals per hectare (Knuckey and Koopman 2016), consistent with the densities documented on closed reefs by Benzie and Uthicke (2003), indicating a degree of stock recovery to unfished density levels. While the 1999 survey was designed to compare densities between open and closed areas, the scaling of these results to an absolute biomass estimate was undertaken after the fact rather than as a primary survey objective. In contrast, the 2016 survey was explicitly designed with biomass estimation as its main purpose. Given that both surveys recorded similar densities on closed or lightly fished reefs, but that the 2016 survey was purpose built for biomass estimation, it is the more reliable estimate for inclusion in the stock assessment.

The conflicts between these estimates became apparent during model exploration (Section 3.2.5), where scenarios attempted to incorporate all estimates into a single stock assessment. This required compromises that were not optimal, including further upscaling the 2016 estimate to the full dry reef habitat and assuming consistent selectivity across surveys due to the absence of length data from 1999. This resulted in poor model fits, biomass estimates lower than the 1999 survey value, and relative spawning biomass trajectories that failed to reflect the documented stock history, showing little to no depletion between 1999 and 2001.

Although the 1999 surveys were valuable in characterising the state of the north stock and supporting the fishery closure, these estimates were ultimately not suitable for inclusion in the stock assessment model. There was considerable evidence that absolute biomass could not be accurately determined from these surveys in a way that would reliably inform the assessment. The most likely scenario was that the 1999 survey overestimated biomass, and therefore omitting these survey estimates from the stock assessment was the most risk averse decision. Omitting them produced relative spawning biomass results that better reflect the well documented history of the north stock's decline, and yielded more conservative and risk averse outcomes for management.

4.3.2 Historical exploitation of north stock

The long-term exploitation history of black teatfish is both fascinating and uncertain. Sea cucumber fishing in Queensland following European settlement can be traced back to the early 1800s through a series of anecdotal records (see Skewes (2024) national report for a detailed account). Export information is available from the 1880s onward, representing the first data that can be used to characterise sea cucumber catches in Queensland, the Torres Strait, and Papua New Guinea (PNG) (Saville-Kent 1893). Fishing continued through the first half of the 20th century before ceasing altogether by the 1950s. The most comprehensive catch estimates from this period were assembled by Uthicke (2004), who estimated that catches peaked at 5,500 t gutted weight during World War I — close to twenty times the peak catch of 450 t whole wet weight for black teatfish recorded by the QSCF from 1990 to 1999. Most if not all of this catch occurred in the northern zone of the fishery (Knuckey and Koopman 2016). As fishing occurred through hand collection on reef flats and breath-held diving, high-value shallow-water species such as black teatfish and prickly redfish (*Thelenota ananas*) are suspected to have constituted much of this catch (Uthicke 2004). Therefore, these historical catches have been considered in past stock assessments for both species (Smart et al. 2024b; Helidoniotis 2021).

Since these assessments were undertaken, a detailed review of these estimates by Skewes (2024) provided important context for how these data should have been treated in assessments. Both Skewes (2024) and Uthicke (2004) noted that considerable assumptions were required to scale export data to catch estimates. The value of the catch in Australian pounds — the only reliable data available — was first converted to dry weight to estimate a tonnage of product for each year, then converted to gutted weight using a further conversion factor. Both conversions carry significant uncertainty; Skewes (2024) notes that applying a different, yet still defensible, average price per kg would change catch estimates by 50%. Furthermore, these estimates cannot be disaggregated between Queensland, the Torres Strait, and PNG (Uthicke 2004), adding another source of uncertainty even if most of the catch likely originated from Queensland. Species composition was also unknown and has previously been assumed to be predominantly black teatfish (Helidoniotis 2021). Skewes (2024) instead proposed that species were likely serially depleted, meaning catches in earlier years would have had different compositions to later years, when more economically valuable species such as black teatfish would already have been fished down.

It is therefore likely that historical catches of black teatfish were substantial and far exceeded those of the modern QSCF (Skewes 2024), but may have been considerably less than those estimated by Uthicke (2004). However, given the uncertainty in these estimates, they cannot be reliably included in the catch series of a stock assessment model. Given that no sea cucumber fishing occurred for more than 40 years, it is appropriate given the biology and population growth rates to treat 1989 as the baseline for this assessment and relate virgin stock size back to this year.

The historical catch series was included in the previous black teatfish stock assessment (Helidoniotis 2021), with a notable consequence: despite substantial evidence to the contrary, little to no reduction in biomass was estimated from 1990 to 1999. This occurred because including the earlier period of substantially higher catches forces the model to estimate a population carrying capacity large enough to sustain catches of that magnitude. A 40-year period with catches orders of magnitude higher than those documented in logbooks in the early 1990s therefore caused the model to estimate a virgin biomass in excess of 15,000 t, which is why the modelled biomass showed negligible decline during the 1990s despite catches peaking at 450 t (Helidoniotis 2021).

Constraining the current assessment to 1989–2025 provides a more conservative estimate of population productivity and better accounts for the risk associated with a stock that has been demonstrably depleted at least once — and possibly twice, considering the historical catch record (Skewes 2024). The virgin biomass estimated from the ensemble model was 738 t (501 t – 1338 t). Consequently, catches from 1990 to 1999 produce an estimated decline in stock biomass consistent with the qualitative stock history of black teatfish in the northern zone.

4.4 Unmodelled influences

4.4.1 Stock structure assumptions

Previous research has recommended that Queensland sea cucumber populations be considered as sub-populations that contribute to a larger meta-population (Wolfe and Byrne 2022). While ideal, this was not possible at a reef scale with the current data and information available for species caught in the QSCF, including black teatfish. From the information available, it is likely that black teatfish populations are reasonably well mixed and could be considered as a single population on the GBR (Skewes 2024). However, this assessment considered two stocks as management units in the fishery, separated at 19° S for the northern and southern zones. This was done because differing exploitation histories have occurred between these zones, which required separate stock assessment models to adequately represent the differing changes to the populations over time (Friedman et al. 2011). This was supported by a separate survey occurring for each zone (Knuckey and Koopman 2016; Koopman and Knuckey 2021) and allowed these stocks to be separated in the models. Ideally, a finer scale stock assessment would benefit species that could have reef level meta-population dynamics. However, while this scale cannot be accounted for in the stock assessment due to the large data demands, it has been considered through MSE (Skewes et al. 2014; Wickens et al. 2024) and is addressed in the current fishery management arrangements. The RHA is a key management measure implemented in the QSCF and its main goal is to maintain high sea cucumber densities across the GBR and minimise the possibility of localised depletion. Therefore, the risk associated with considering a broad stock structure for black teatfish is reduced by considering finer scale populations in management. Despite this, it will remain important to gain an improved understanding of recruitment dynamics and stock structure for black teatfish and other species in the QSCF.

4.4.2 Marine park zoning

The closed areas of the GBRMP are difficult to incorporate into stock assessments as no fishery dependent data are available from these areas. However, information on population size within green zones is available from biomass surveys conducted in the northern and southern zones (Knuckey and Koopman 2016; Koopman and Knuckey 2021) and was included in the stock assessment models. For the south stock, given its light exploitation history, conditioning the model on the available biomass estimate produces a stock assessment that effectively encompasses both green and blue zones of the GBRMP, although these are not distinguished within the model. The 2021 survey (Koopman and Knuckey 2021) covers a broader proportion of total reef area than the 2016 northern zone survey (Knuckey and Koopman 2016) and given that catches have been small and stock depletion minimal, the south stock assessment therefore provides results representative of the whole population. For the north stock, the biomass estimate represents the area that was open to fishing prior to the RAP implementation in 2004 (Knuckey and Koopman 2016), meaning the north stock model represents an area that was historically open to fishing but now includes areas closed as green zones.

Spatial models capable of accounting for green and blue zones separately cannot be implemented due to data limitations, as catch and CPUE data are only available from areas where fishing occurred. While the stock assessment models do not differentiate between open and closed areas, the management implications of marine park zoning have been considered through management strategy evaluation (Skewes et al. 2014; Wickens et al. 2024) and are therefore accounted for in the fishery's management framework.

4.4.3 Environmental/climatic influences

Environmental variables such as heat, wind, cyclones and rainfall could be drivers of sea cucumber abundance which were not included as variables in the stock assessment model as environmental parameters. Data on daily wind speed was the only exception to this. These variables will have an influence on natural mortality and recruitment success and could explain variability in abundance indices if appropriately included in analyses. Furthermore, climate change impacts on the GBR are expected to increasingly affect marine populations (Rogers et al. 2017; Welch et al. 2014) and it is unlikely that sea cucumbers will be immune to these impacts.

4.4.4 Multi-species dynamics

The QSCF is a multi-species fishery that collects up to twenty-two species (Fisheries Queensland 2021) which can pose complications if targeting is not accurately accounted for in catch rate standardisation (Hoyle et al. 2024). Multi-species fisheries can also have their dynamics driven by market forces such as changing species values. This can impact catches if market opportunities cause fishers to target other species. Therefore, trends in catches can be more related to fishery economic decision making than stock status. This increases the importance of stock assessments in fisheries such as the QSCF as unexplained catch declines have been interpreted as issues with stock status and serial species depletion (Eriksson and Byrne 2015; Wolfe and Byrne 2022).

4.5 Recommendations

4.5.1 Stock assessment

The greatest improvement that could be made to the black teatfish stock assessments would be to consider finer scale population dynamics that match the reef-level demographics that occur for sea cucumbers. However, this is a difficult challenge to overcome as spatial stock assessments with multiple spatial areas require substantially more data than non-spatial equivalents. Given the data-limited nature of sea cucumber fisheries, and especially the black teatfish fishery given its history, the amount of data required to truly represent their complex population structures may be unachievable. Therefore, use of data-limited stock assessments, such as this one, paired with cautious and conservative management arrangements as demonstrated by Skewes et al. (2014) and Wickens et al. (2024) remains the most appropriate and risk-averse approach for the QSCF.

4.5.2 Monitoring

- **Fine scale spatial information of fishing activities.** This can be particularly valuable in dive fisheries where catch rates can be highly hyperstable. Fisher hour expresses effort as a unit of time only, while space use can be a more appropriate or complementary unit of effort (Mundy 2012). As dive area increases to account for reduced densities then catch rates decline, providing more information to stock assessments. Dive logger and GPS technology has been trialed in abalone fisheries and is now in operation in several Australian jurisdictions (Mundy 2012). They can also only provide indices of abundance once they have been in use long enough to create a sufficient time series. The Fisheries Queensland vessel monitoring system (VMS) is in operation in the QSCF, and has recently been extended to tender vessels and thus could be used to measure fishing effort on a spatial scale. These advances in data collection would undoubtedly provide valuable effort information for future assessments.

- **The biomass estimates and length compositions.** These were vital inputs to this assessment. These biomass estimates essentially anchor the stock assessment model to an accurate absolute biomass level with the relative biomass trajectory estimated from the remaining model inputs. This indicates the importance of this information, not only for these assessments, but also for any other sea cucumber species in the QSCF that may be assessed in the future. While a single estimate of biomass is clearly valuable to these stock assessment models, multiple estimates that create a time series will add further value. Currently, selectivity is estimated from a single year of length frequency data and there will be some bias introduced depending on how much recent recruitment has influenced population length structure at the time of the survey. Additional years of length compositions attained from biomass surveys will reduce this bias. Furthermore, a time series of biomass estimates will provide empirical estimates of population productivity when combined with retained catch over the same period. This will occur as the biomass trajectory between surveys can be better quantified and the model can consider the relative contribution of catch (removals) and recruitment (additions) to the population that would cause this trend. Stock assessments that have been built using long time series of absolute abundance from surveys have benefited greatly from this and have been able to estimate productivity parameters (such as M) which are rarely attempted in other assessments (Grammer et al. 2021). Therefore, while substantial benefits to this assessment have been realised through the availability of a single survey estimate, there remains opportunity for additional surveys to provide additional benefits.

4.5.3 Research

Life history and biological information is often missing or incomplete for sea cucumber species (Friedman et al. 2011; Purcell et al. 2013). Incomplete life history information was overcome in this assessment by sensitivity testing the model to assumed biological parameters and including these scenarios in the ensemble model. However, this is not a long-term substitute for missing biological data, and these information gaps need to be filled. Therefore, collecting growth information should be a research priority for black teatfish.

4.6 Conclusions

This stock assessment was commissioned to establish the status of Queensland black teatfish and inform the management of the QSCF. For the north stock, biomass was estimated to be between 45% and 125% at the beginning of 2026, relative to an assumed unfished state in 1989. This interval was generated over an ensemble of seven scenarios. For the south stock, biomass was estimated to be between 73% and 138% at the beginning of 2026, relative to an assumed unfished state in 1996. This interval was generated over an ensemble of ten scenarios.

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A Diagnostics for standardised indices of abundance

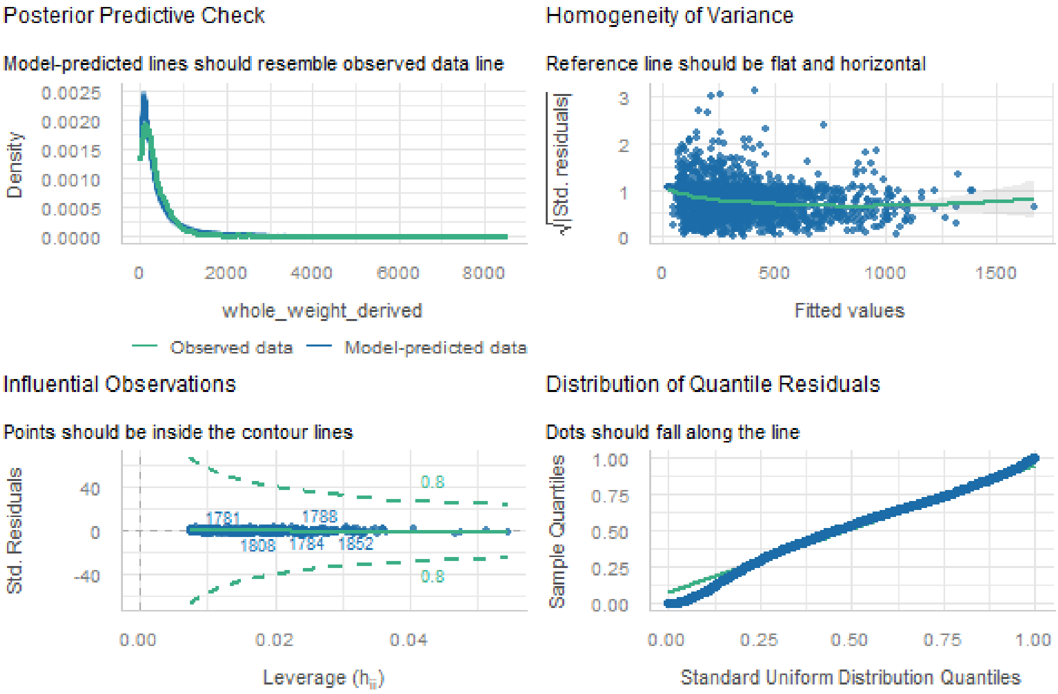

Figure A.1: Northern zone GLM diagnostics

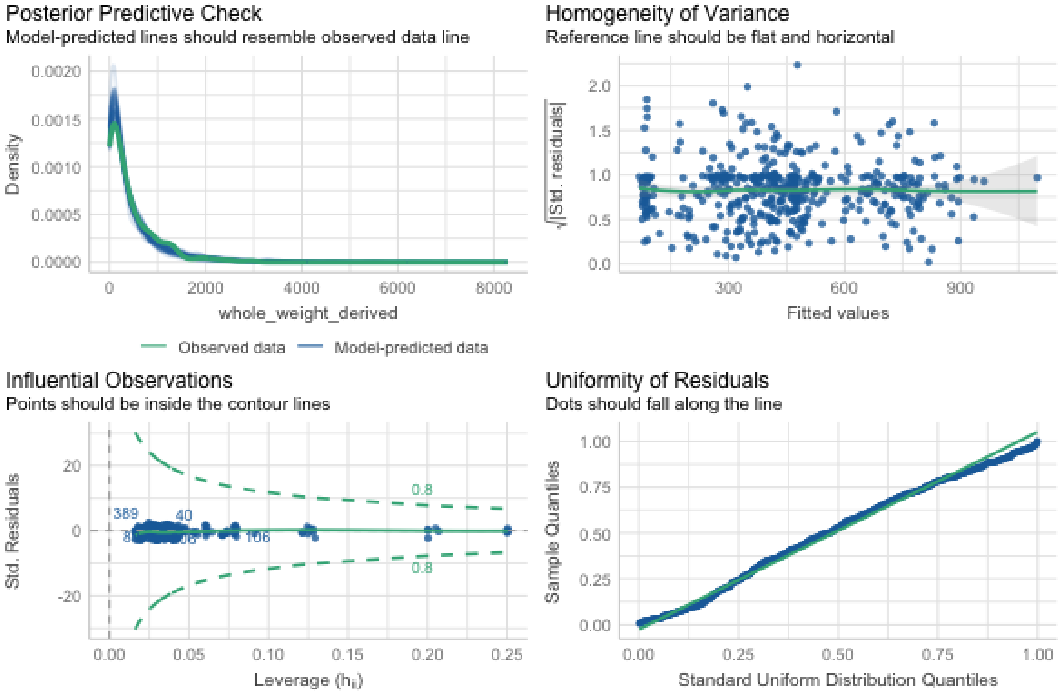

Figure A.2: Southern zone GLM diagnostics

B Model inputs

B.1 Biological data

B.1.1 Weight and length

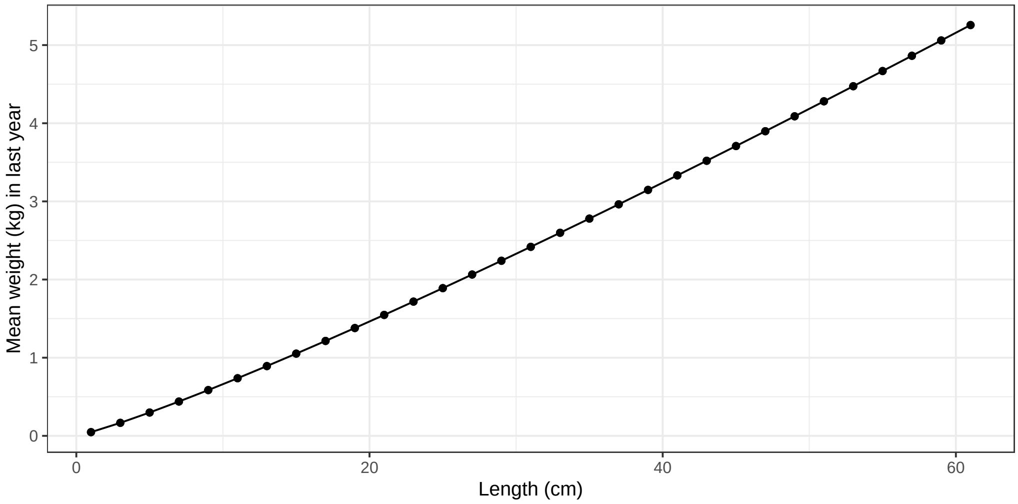

Figure B.1: Weight–length relationship for black teatfish in Queensland

B.1.2 Fecundity and maturity

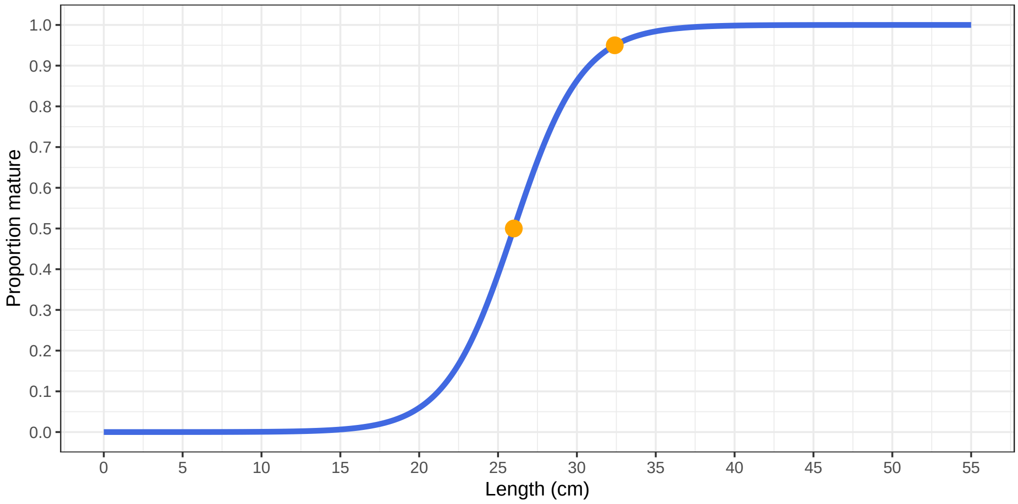

Figure B.2: Length-at-maturity. Orange points show the length-at-50% maturity and 95% maturity.

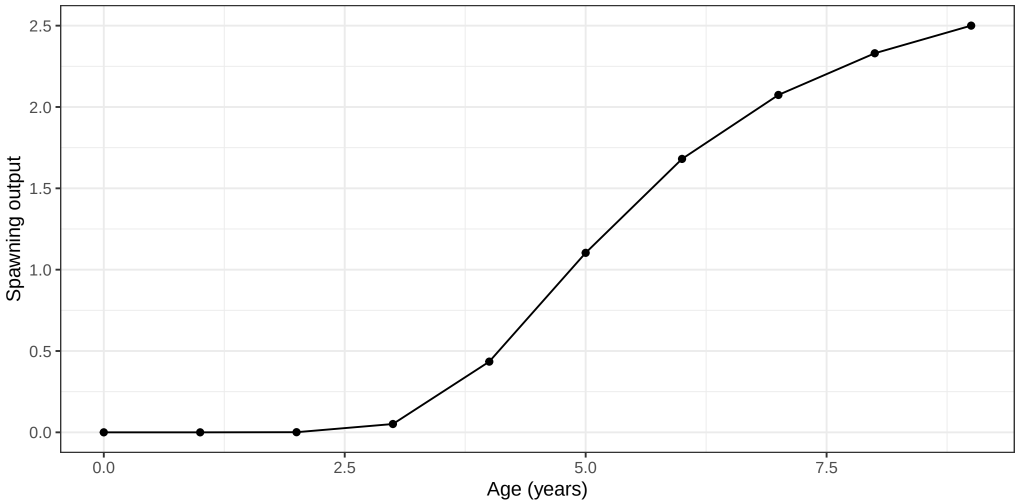

Figure B.3: Spawning output (maturity multiplied by fecundity) at age for black teatfish in Queensland

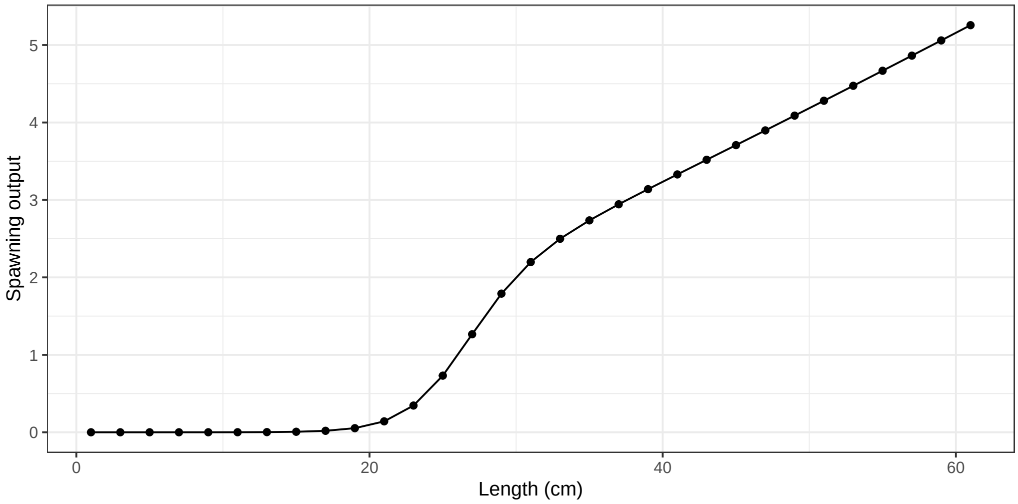

Figure B.4: Spawning output (maturity multiplied by fecundity) at length for black teatfish in Queensland

C Model outputs

C.1 MLE diagnostics

C.1.1 Likelihood profile

Likelihood profile on $\ln(R_0)$, steepness and natural mortality was conducted on the base case scenario as reference.

C.1.1.1 North stock

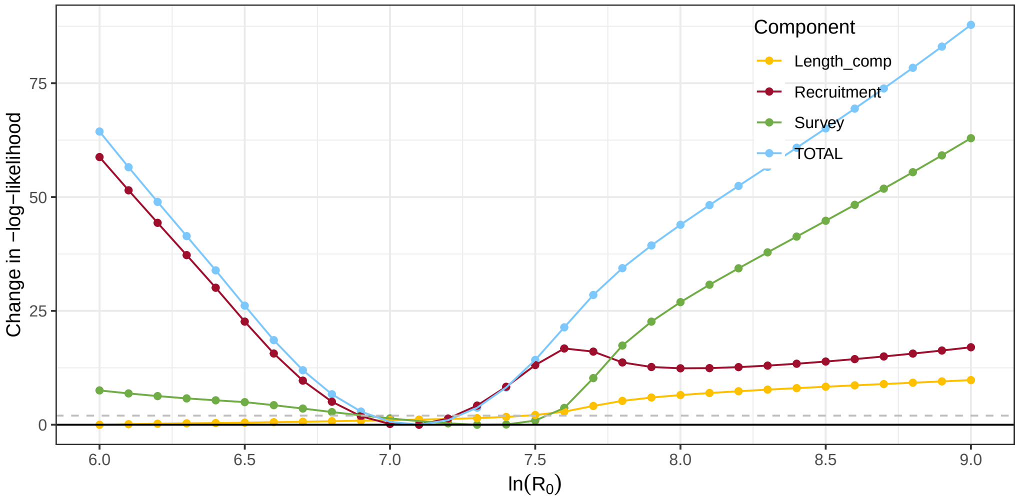

Figure C.1: Likelihood profile for $\ln(R_0)$. Dashed grey line shows the cut-off for a difference of 1.98 likelihood points. Values within this range are considered to have equal model support.

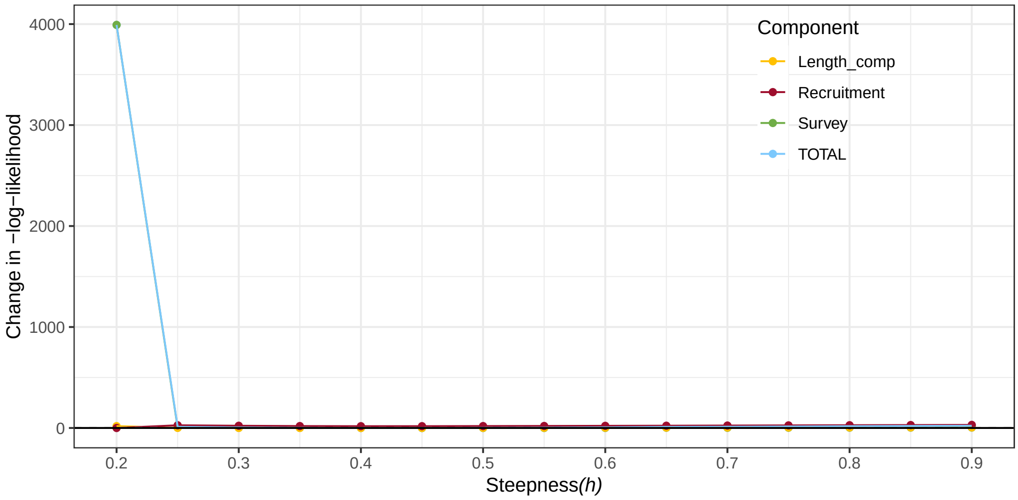

Figure C.2: Likelihood profile for steepness (h). Dashed grey line shows the cut-off for a difference of 1.98 likelihood points. Values within this range are considered to have equal model support.

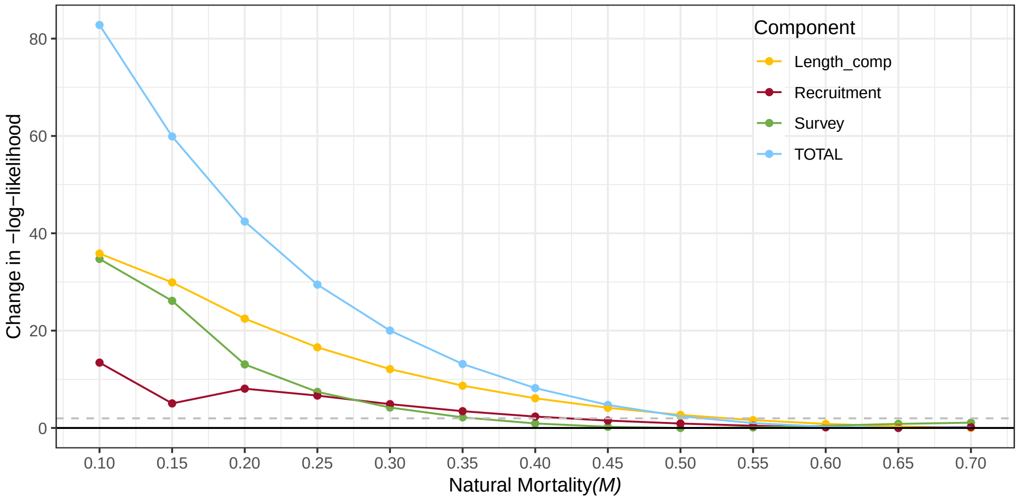

Figure C.3: Likelihood profile for natural mortality (M). Dashed grey line shows the cut-off for a difference of 1.98 likelihood points. Values within this range are considered to have equal model support.

C.1.1.2 South stock

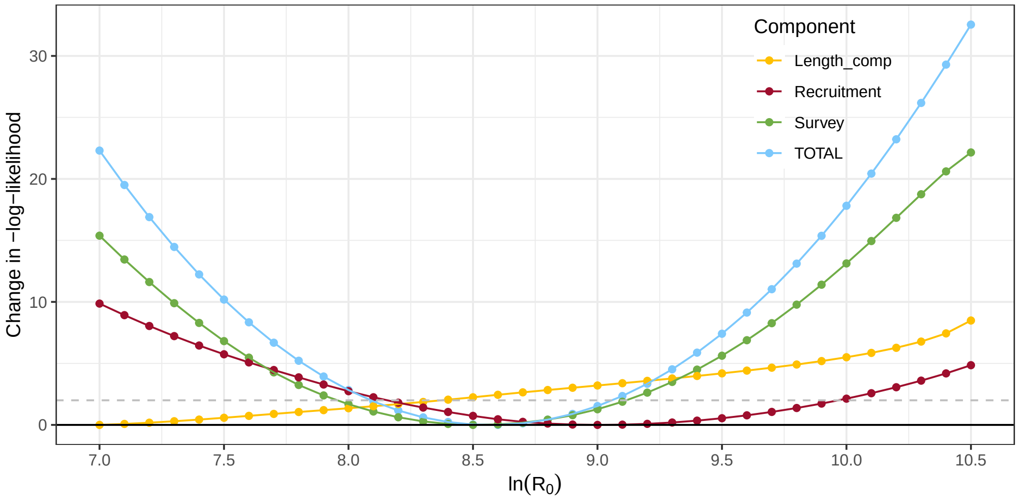

Figure C.4: Likelihood profile for $\ln(R_0)$. Dashed grey line shows the cut-off for a difference of 1.98 likelihood points. Values within this range are considered to have equal model support.

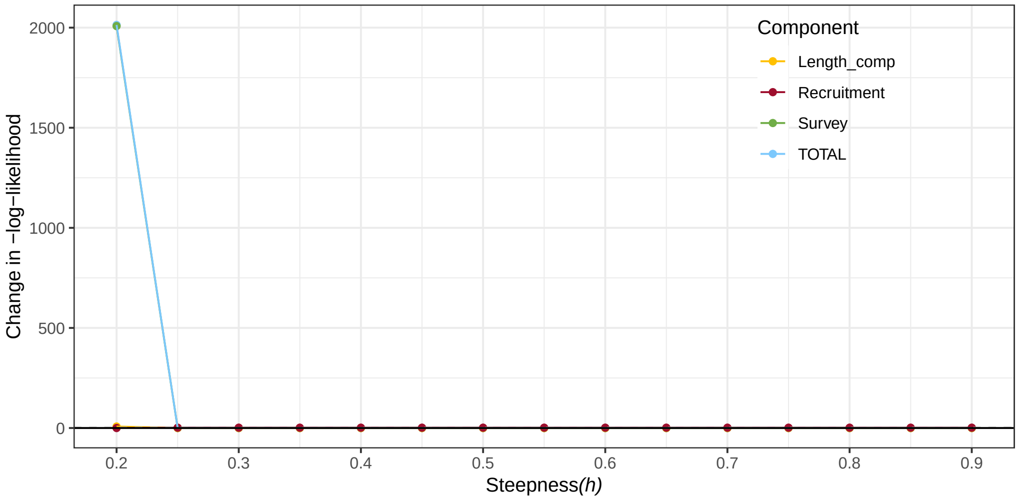

Figure C.5: Likelihood profile for steepness (h). Dashed grey line shows the cut-off for a difference of 1.98 likelihood points. Values within this range are considered to have equal model support.

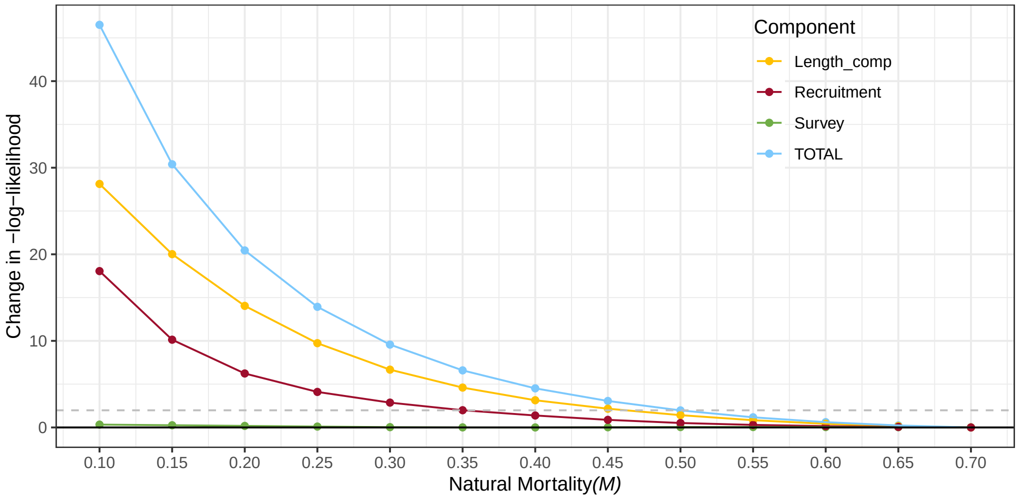

Figure C.6: Likelihood profile for natural mortality (M). Dashed grey line shows the cut-off for a difference of 1.98 likelihood points. Values within this range are considered to have equal model support.

C.2 Other outputs

C.2.1 Stock-recruit curve

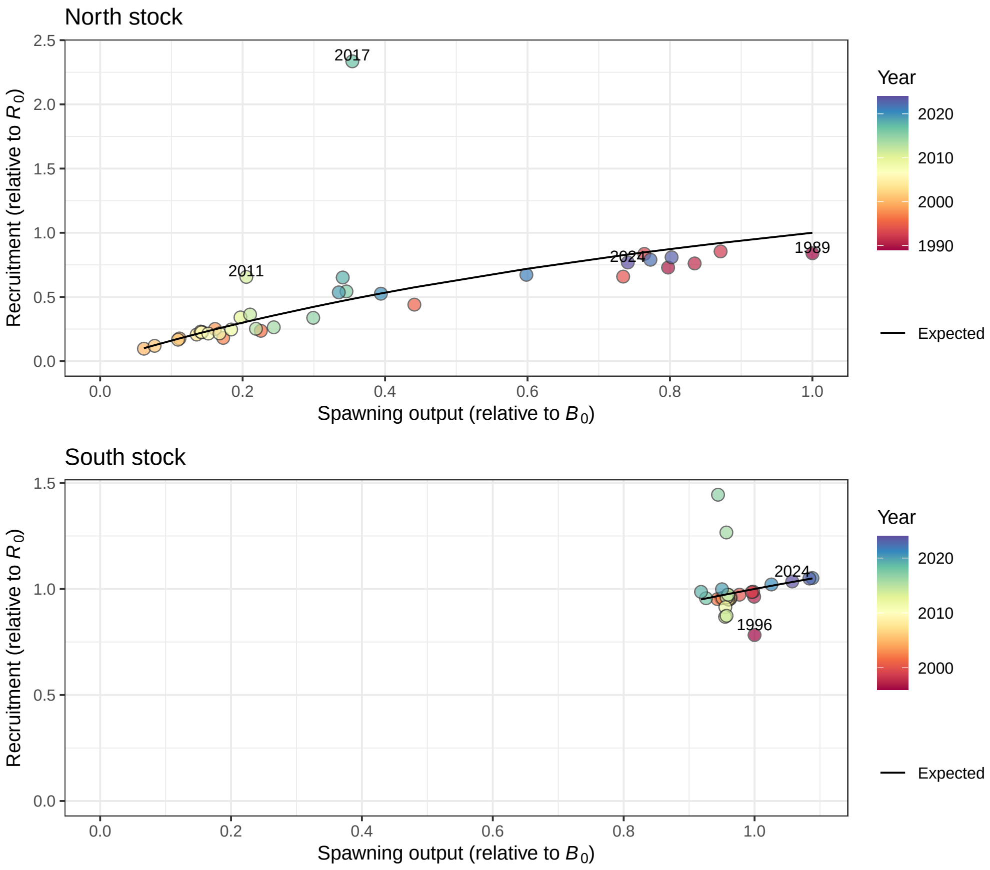

Figure C.7: Stock-recruitment curve based on the base case scenarios. Point colors indicate year, with warmer colors indicating earlier years and cooler colors in showing later years

C.2.2 Fishing mortality

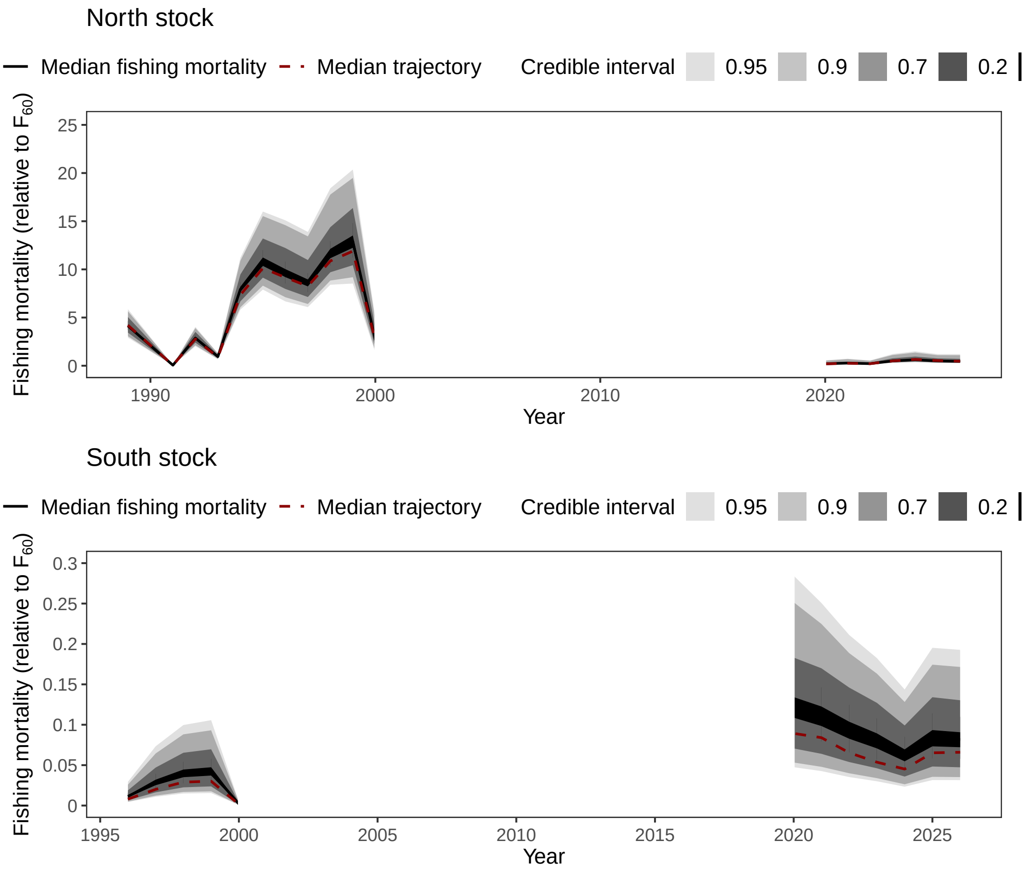

Figure C.8: Time series of fishing mortality ratio (F/F_{60}) from the ensemble model

C.2.3 Recruitment deviations

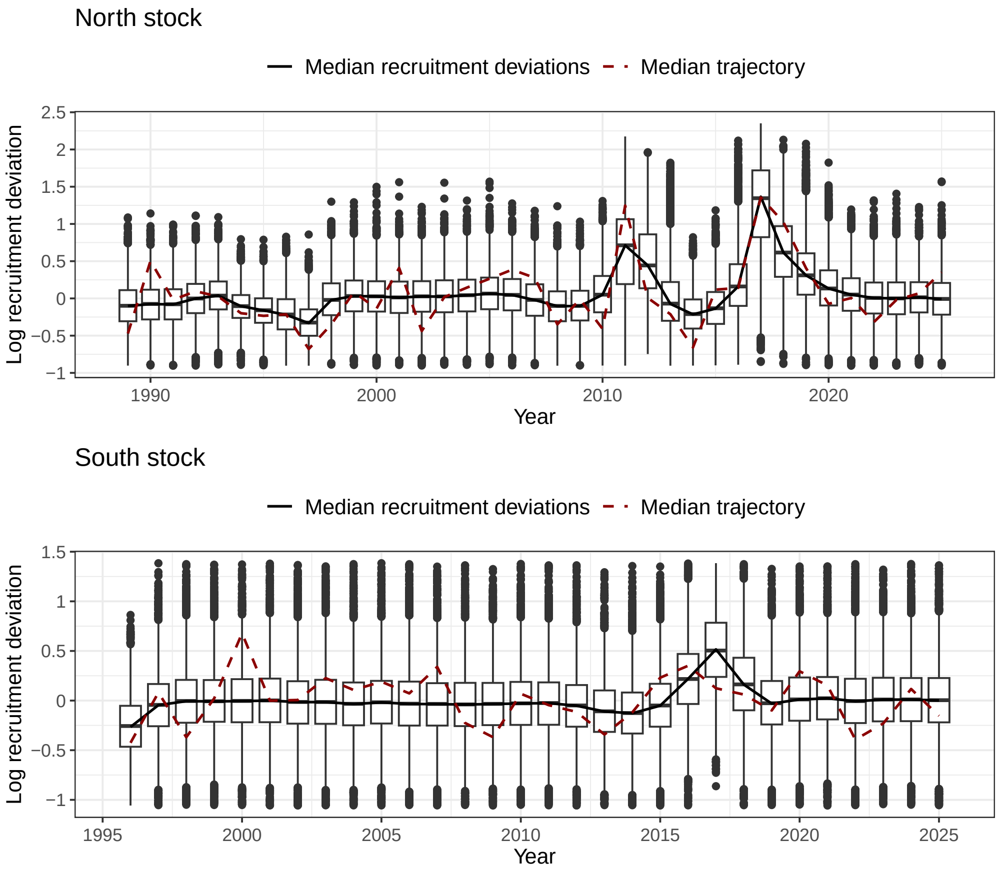

Figure C.9: Recruitment deviations from the ensemble model—whiskers represent 95% credible intervals, boxes represent 50% credible intervals, horizontal bars represent medians, and the points represent outliers

C.2.4 Sensitivity: parameter estimates and derived quantities

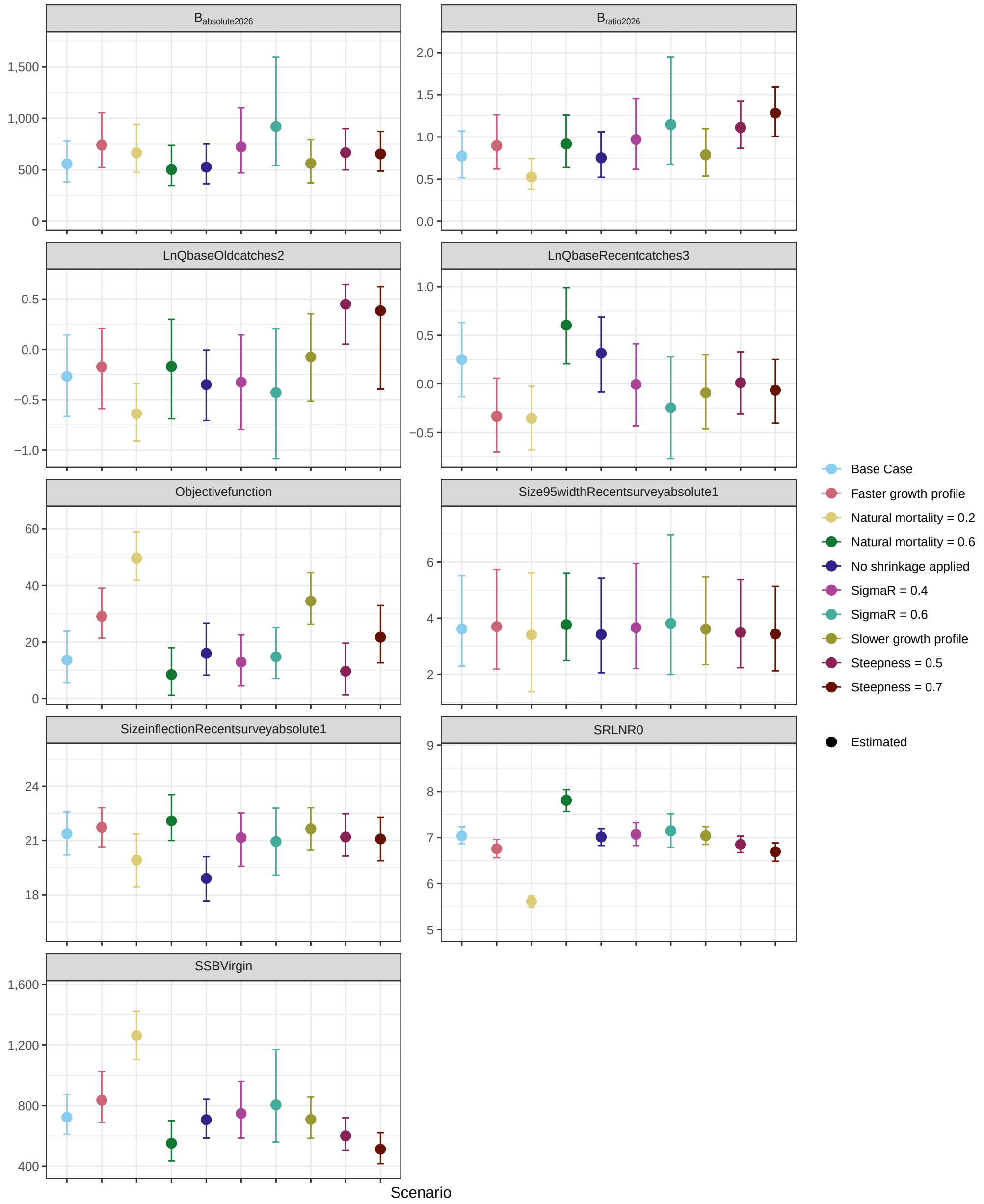

Figure C.10: Comparison of parameter estimates and derived quantities among the Twelve scenarios included in the ensemble model for the North stock

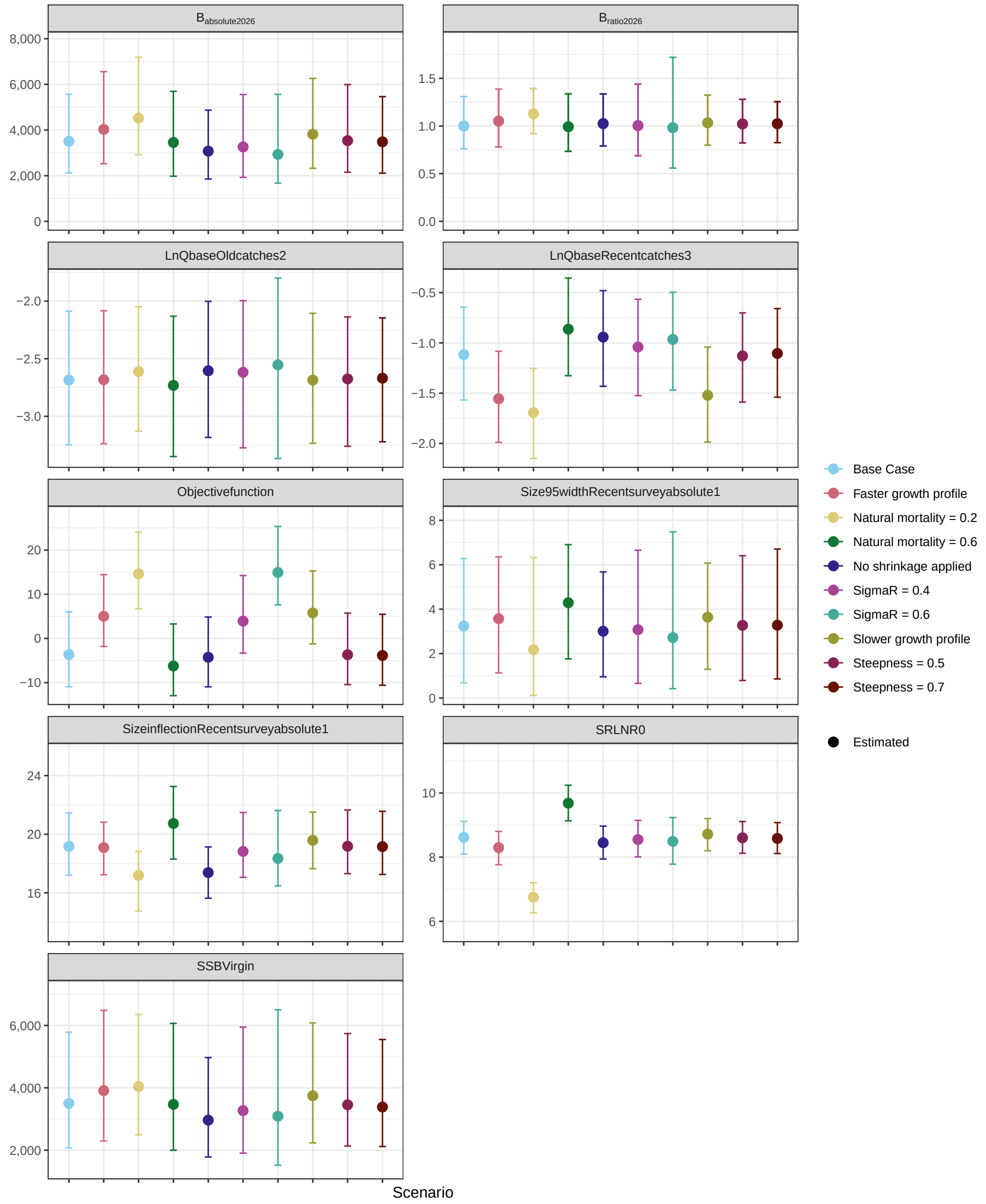

Figure C.11: Comparison of parameter estimates and derived quantities among the Twelve scenarios included in the ensemble model for the South stock

D Detailed model outputs

D.1 North stock

D.1.1 Base Case

This section presents results for the Base Case scenario.

Table D.1: Summary of parameter estimates for black teatfish the Base Case scenario. MCMC Median is median parameter value from robust MCMC scenarios. MCMC 2.5% and 97.5% indicates 95% credible interval.

Symbol	MCMC median	MCMC 2.5%	MCMC 97.5%
SR_LN(R0)	7	6.9	7.2
SSB_Virgin	723.2	610.6	874.1
SSB_2026	559.24	383.55	779.54
Bratio_2026	0.8	0.5	1.1
LnQ_base_Old_catches(2)	-0.3	-0.7	0.1
LnQ_base_Recent_catches(3)	0.25	-0.13	0.63
Size_inflection_Recent_survey_absolute(1)	21.4	20.2	22.6
Size_95%width_Recent_survey_absolute(1)	3.6	2.3	5.5

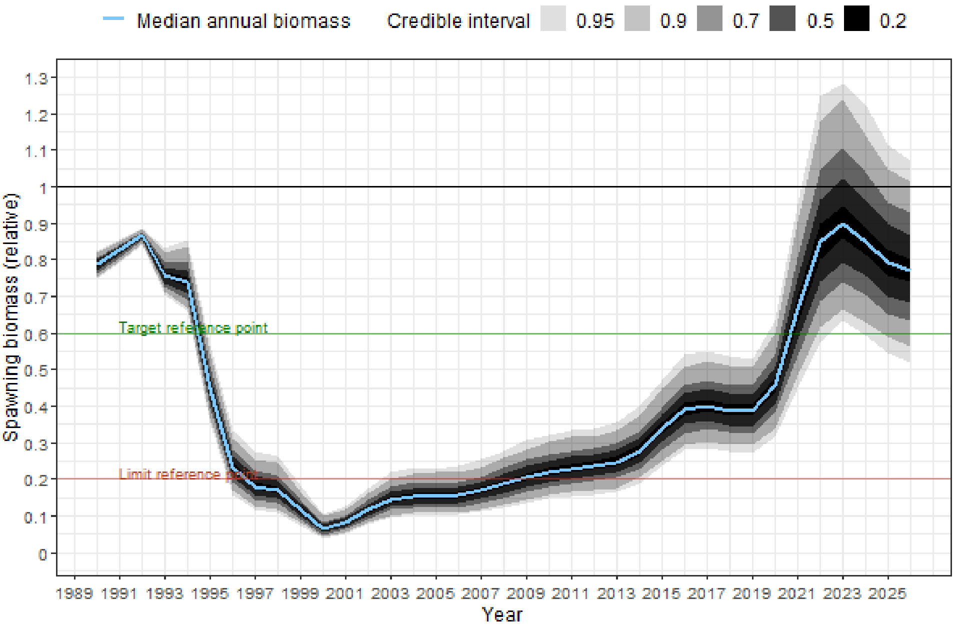

Figure D.1: Relative spawning biomass for the Base Case scenario

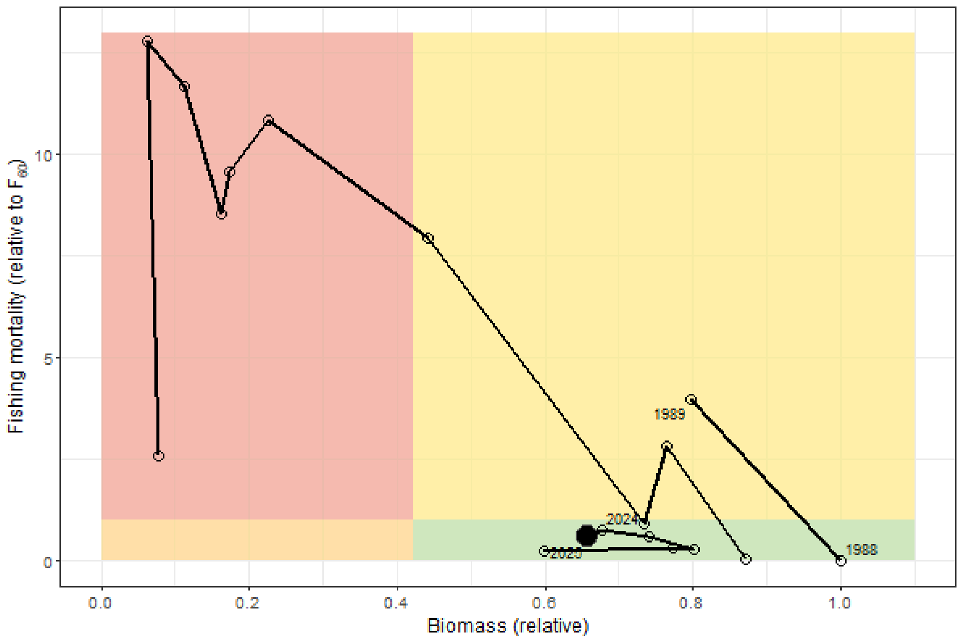

Figure D.2: Phase plot for the Base Case scenario

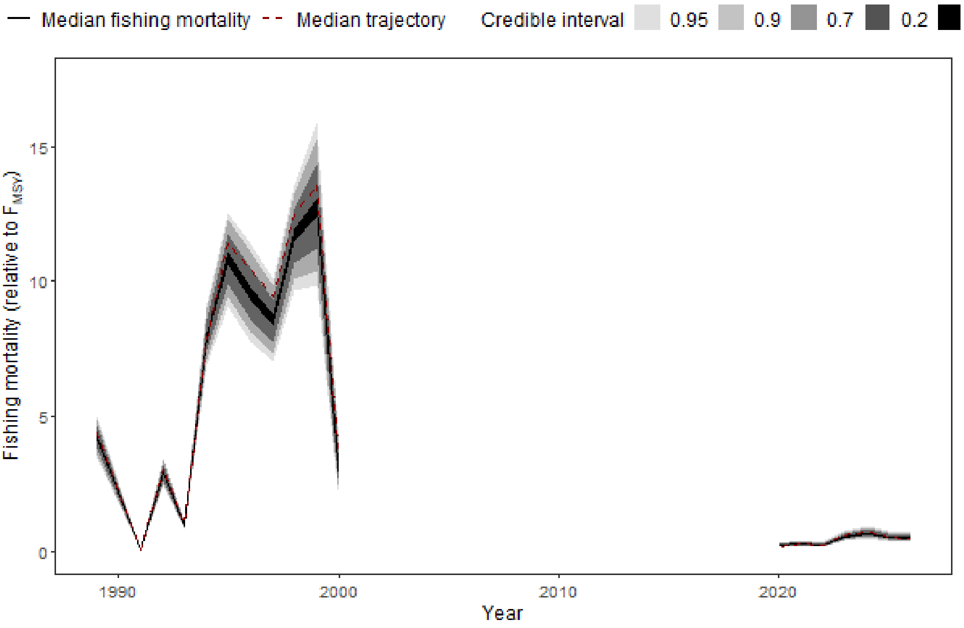

Figure D.3: Fishing mortality for the Base Case scenario

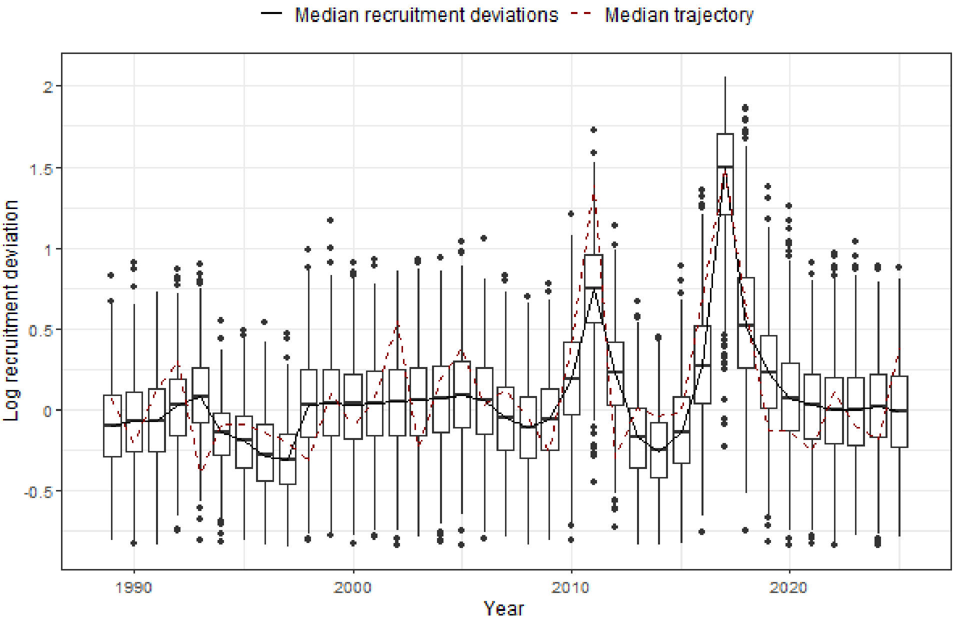

Figure D.4: Recruitment deviations for the Base Case scenario

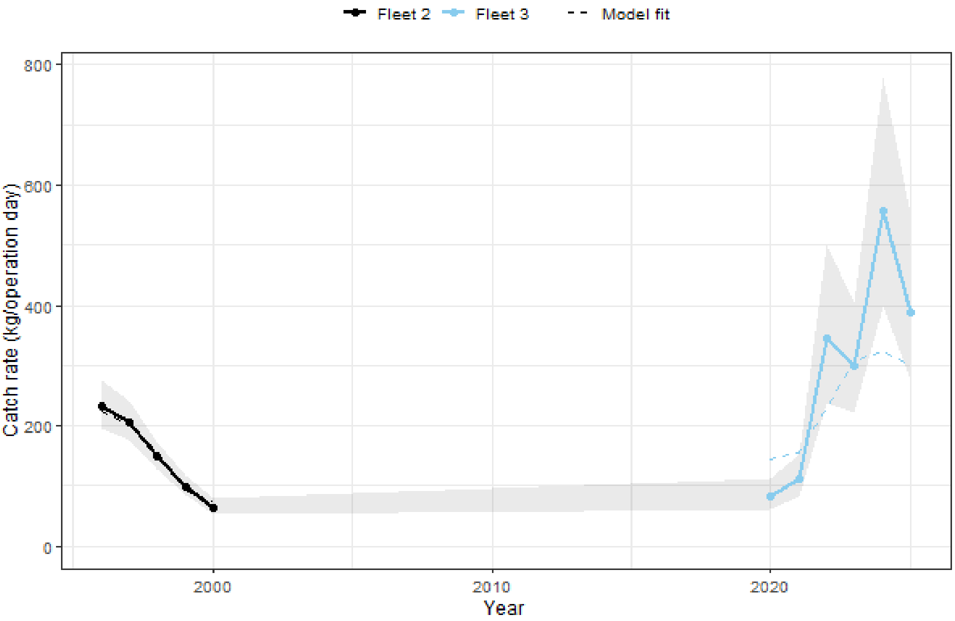

Figure D.5: CPUE fit for the Base Case scenario

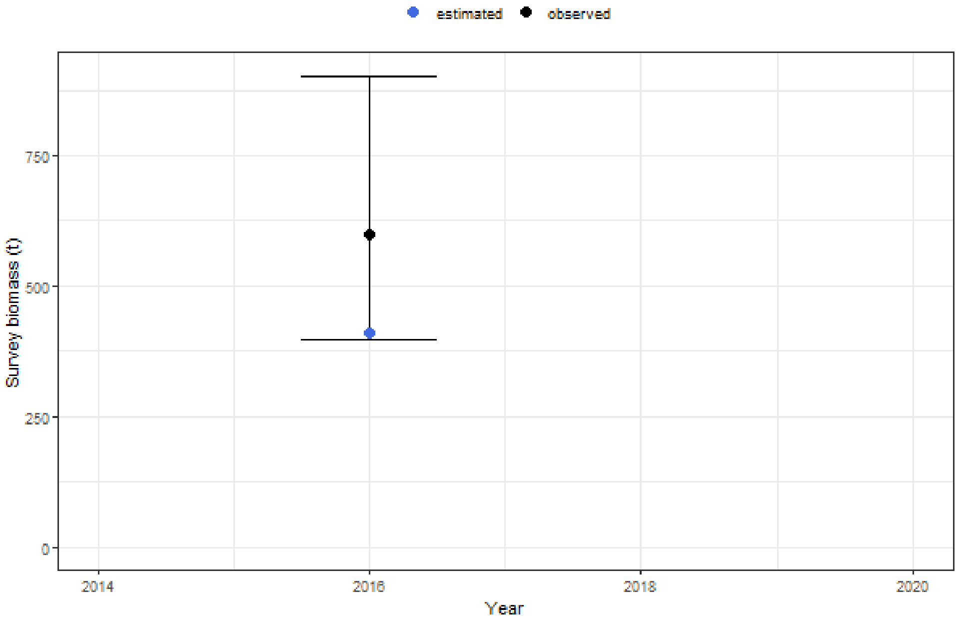

Figure D.6: Surveyed biomass fit for the Base Case scenario

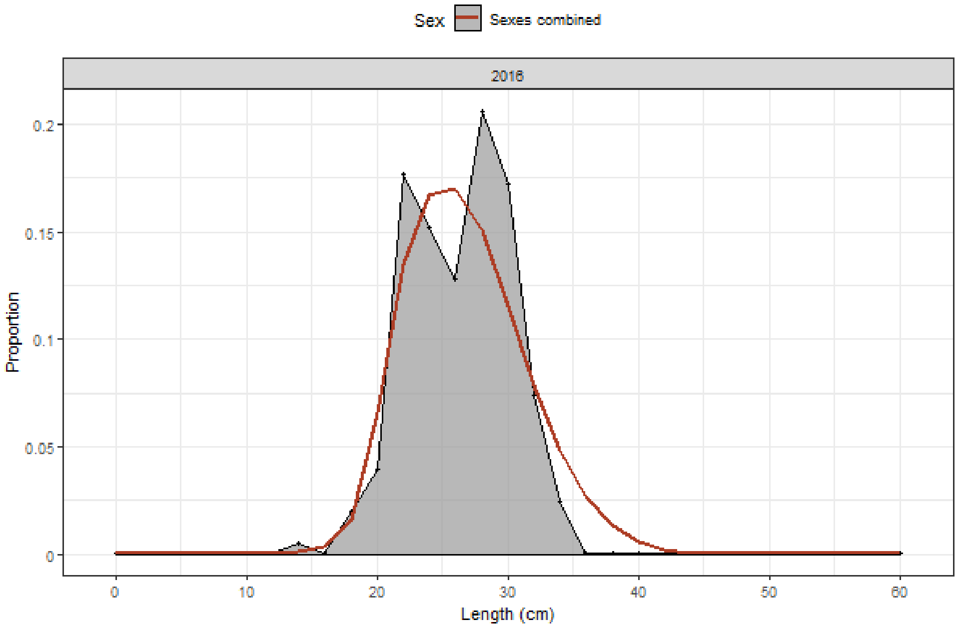

Figure D.7: Length composition fit for the Base Case scenario

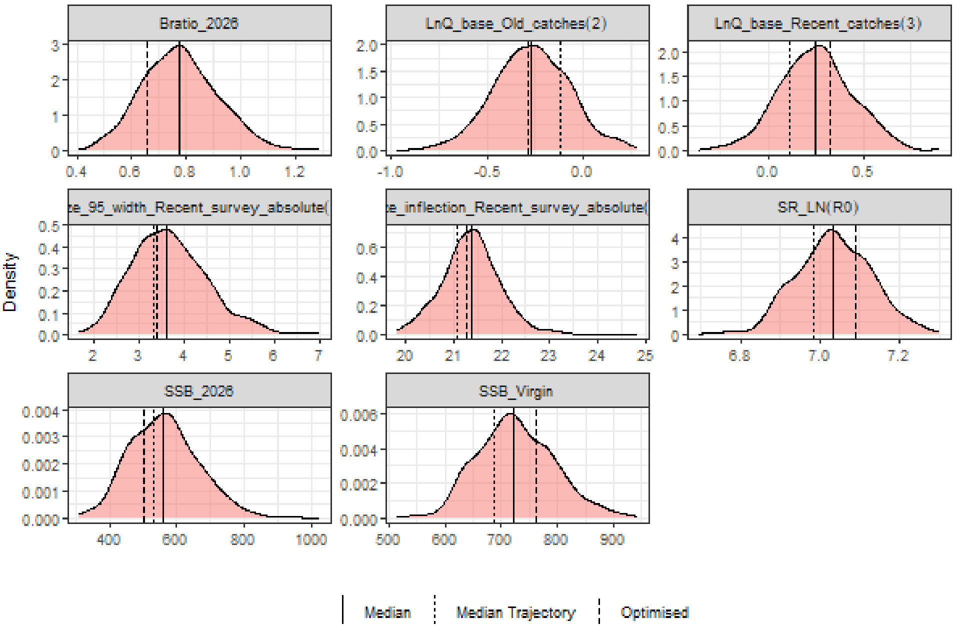

Figure D.8: MCMC parameter posterior densities for the Base Case scenario

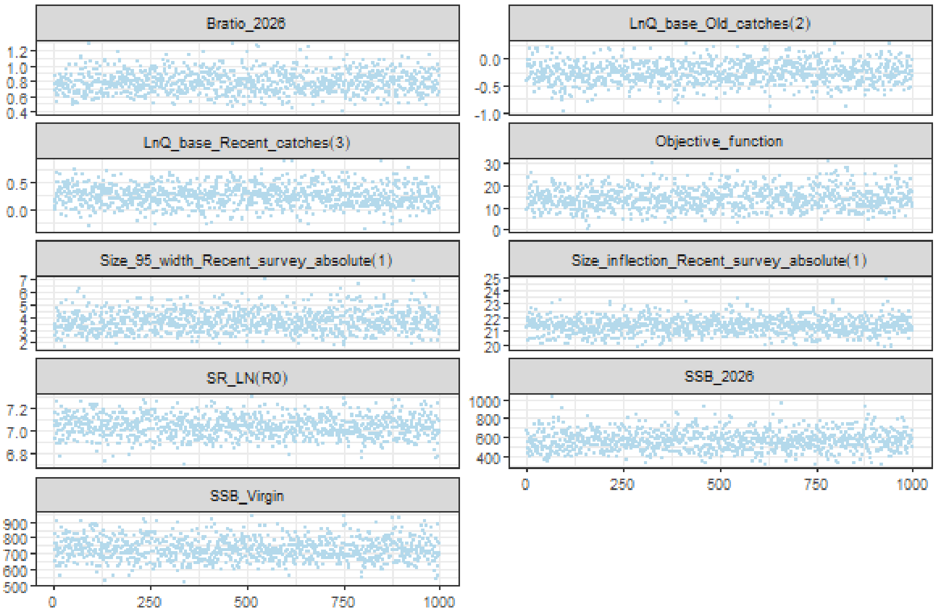

Figure D.9: MCMC trace plots for the Base Case scenario

D.1.2 Steepness = 0.5

This section presents results for the Steepness = 0.5 scenario.

Table D.2: Summary of parameter estimates for black teatfish the Steepness = 0.5 scenario. MCMC Median is median parameter value from robust MCMC scenarios. MCMC 2.5% and 97.5% indicates 95% credible interval.

Symbol	MCMC median	MCMC 2.5%	MCMC 97.5%
SR_LN(R0)	6.8	6.7	7
SSB_Virgin	600.4	503	719.9
SSB_2026	667.52	500.32	900.83
Bratio_2026	1.1	0.9	1.4
LnQ_base_Old_catches(2)	0.4	0.1	0.6
LnQ_base_Recent_catches(3)	0.01	-0.31	0.33
Size_inflection_Recent_survey_absolute(1)	21.2	20.1	22.5
Size_95%width_Recent_survey_absolute(1)	3.5	2.2	5.4

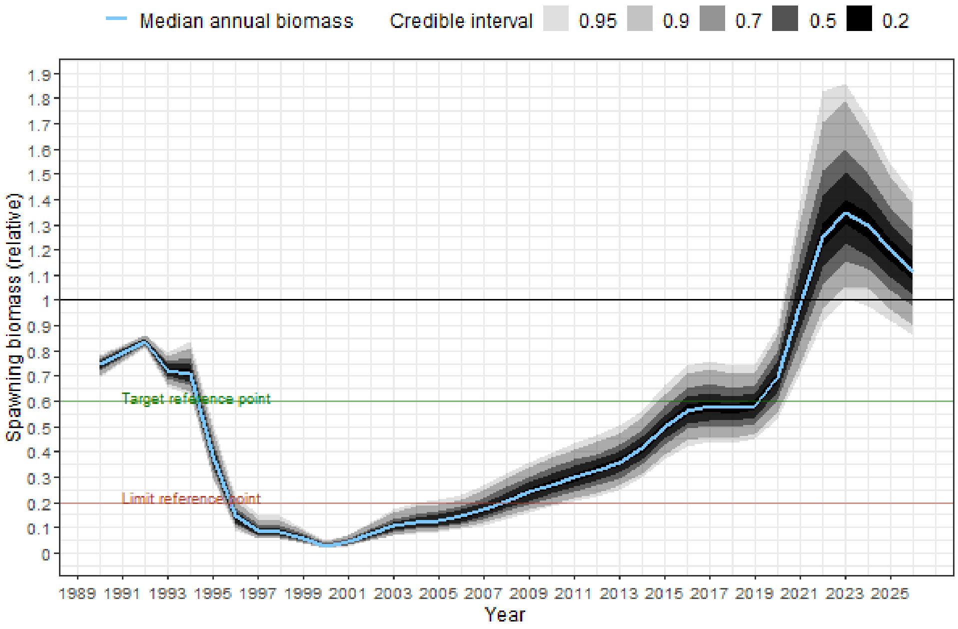

Figure D.10: Relative spawning biomass for the Steepness = 0.5 scenario

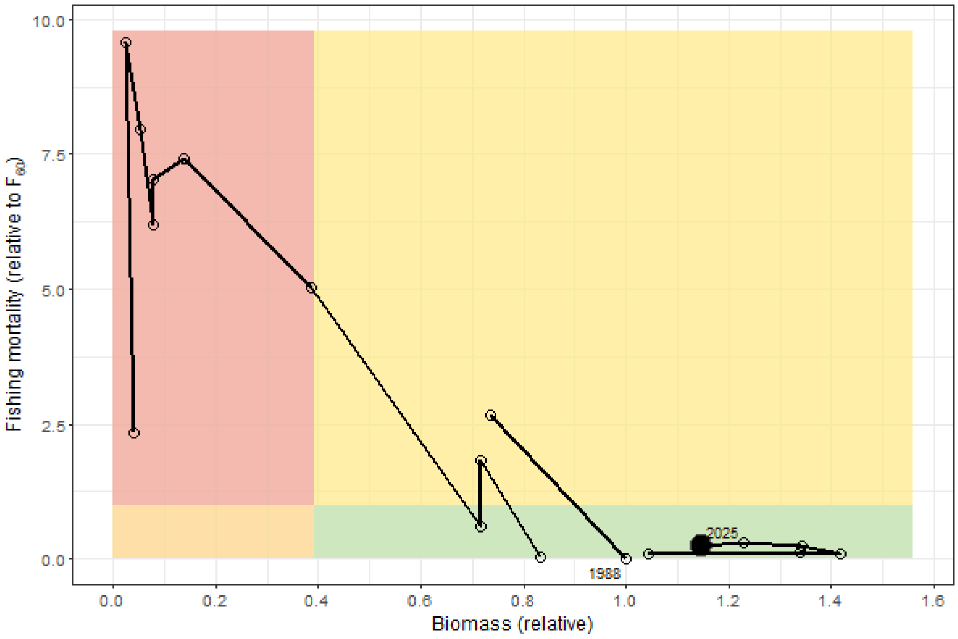

Figure D.11: Phase plot for the Steepness = 0.5 scenario

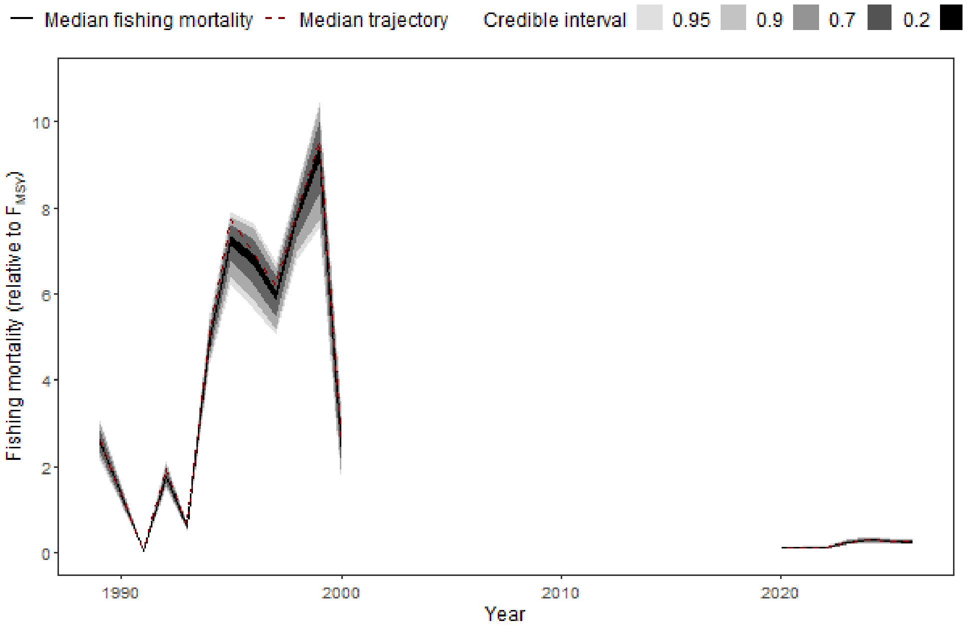

Figure D.12: Fishing mortality for the Steepness = 0.5 scenario

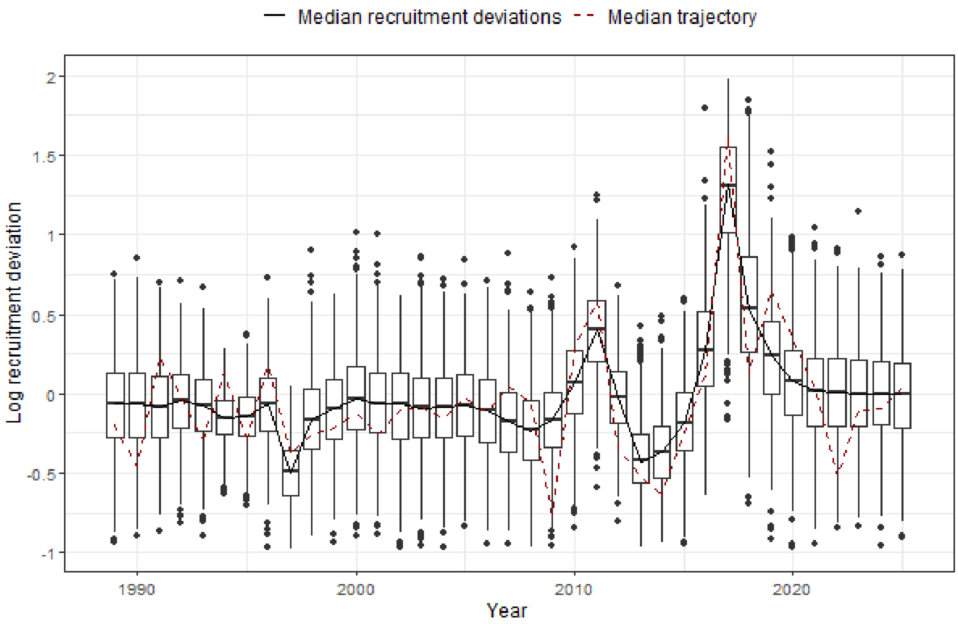

Figure D.13: Recruitment deviations for the Steepness = 0.5 scenario

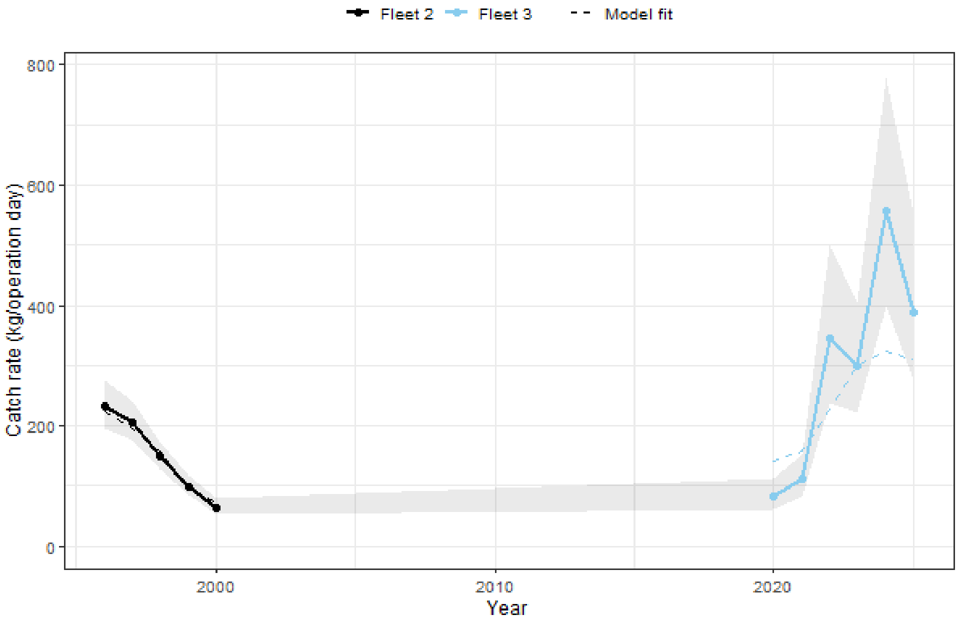

Figure D.14: CPUE fit for the Steepness = 0.5 scenario

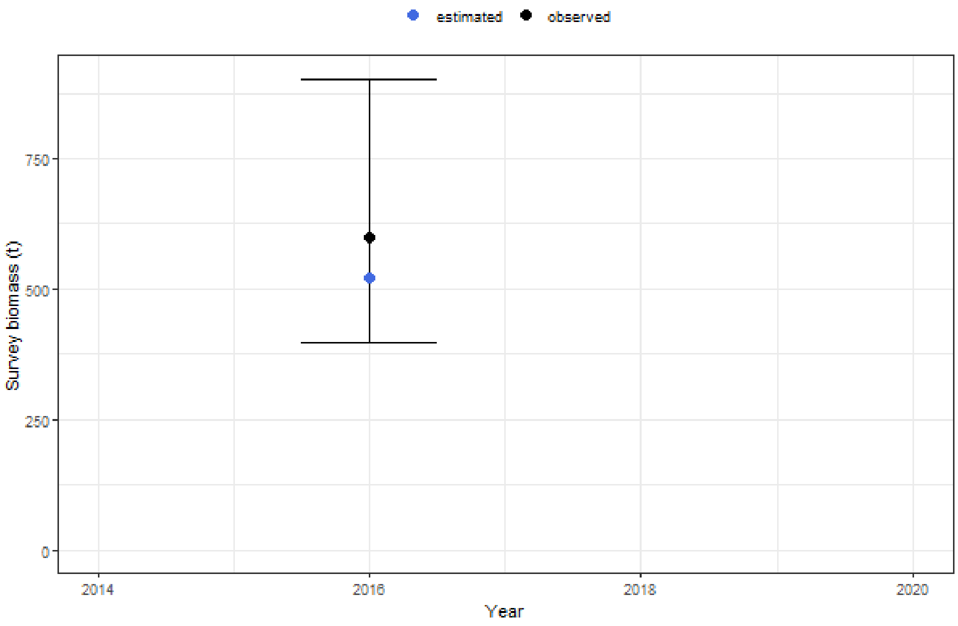

Figure D.15: Surveyed biomass fit for the Steepness = 0.5 scenario

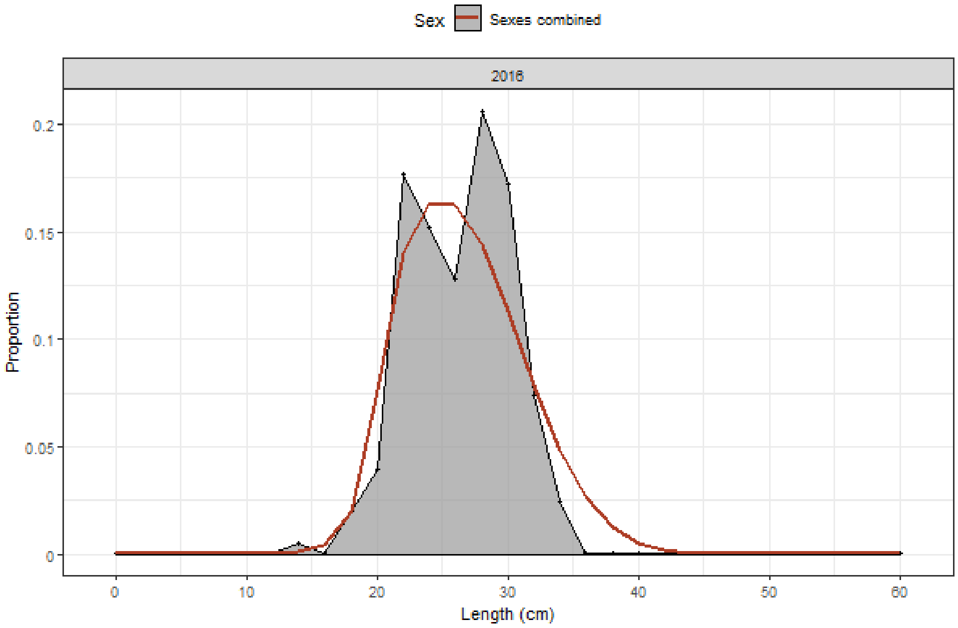

Figure D.16: Length composition fit for the Steepness = 0.5 scenario

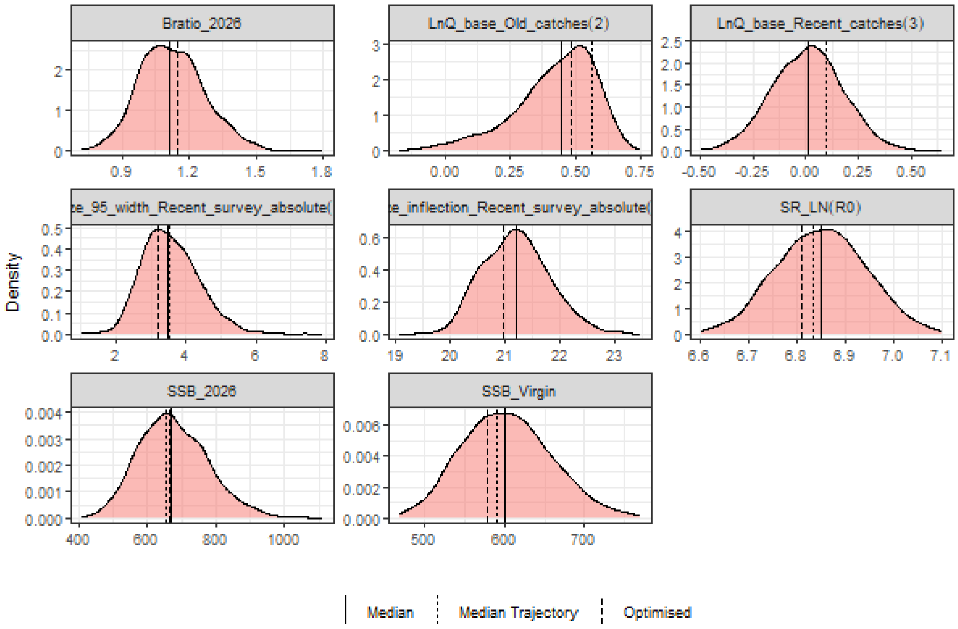

Figure D.17: MCMC parameter posterior densities for the Steepness = 0.5 scenario

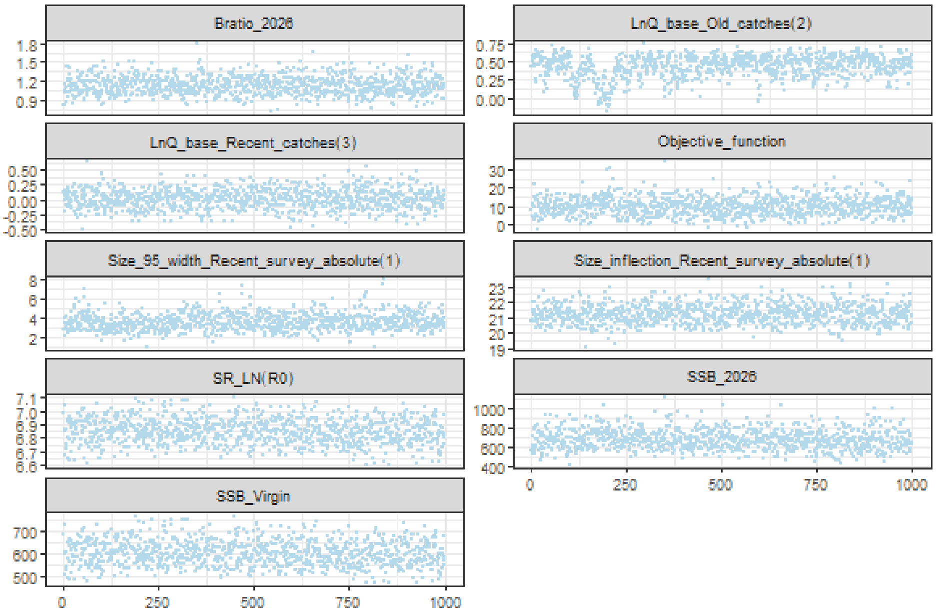

Figure D.18: MCMC trace plots for the Steepness = 0.5 scenario

D.1.3 Steepness = 0.7

This section presents results for the Steepness = 0.7 scenario.

Table D.3: Summary of parameter estimates for black teatfish the Steepness = 0.7 scenario. MCMC Median is median parameter value from robust MCMC scenarios. MCMC 2.5% and 97.5% indicates 95% credible interval.

Symbol	MCMC median	MCMC 2.5%	MCMC 97.5%
SR_LN(R0)	6.7	6.5	6.9
SSB_Virgin	512.4	416.6	620.6
SSB_2026	654.72	488.28	873.53
Bratio_2026	1.3	1	1.6
LnQ_base_Old_catches(2)	0.4	-0.4	0.6
LnQ_base_Recent_catches(3)	-0.07	-0.41	0.25
Size_inflection_Recent_survey_absolute(1)	21.1	19.9	22.3
Size_95%width_Recent_survey_absolute(1)	3.4	2.1	5.1

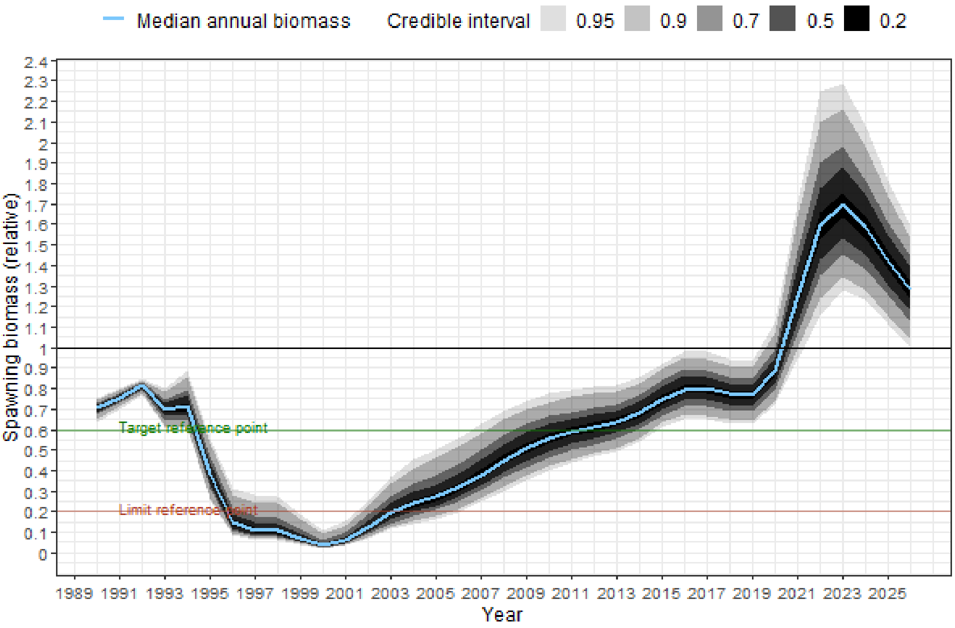

Figure D.19: Relative spawning biomass for the Steepness = 0.7 scenario

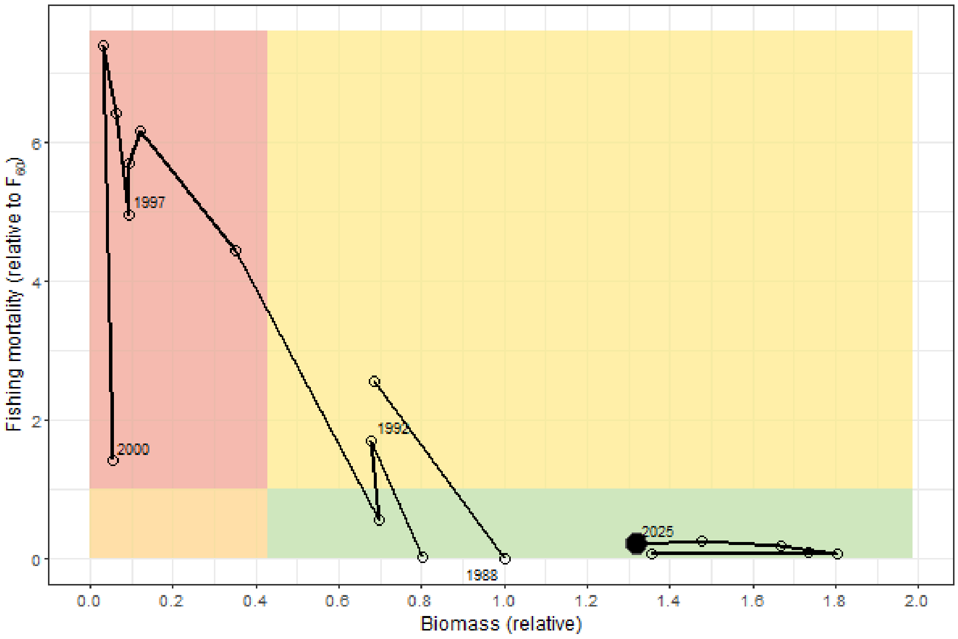

Figure D.20: Phase plot for the Steepness = 0.7 scenario

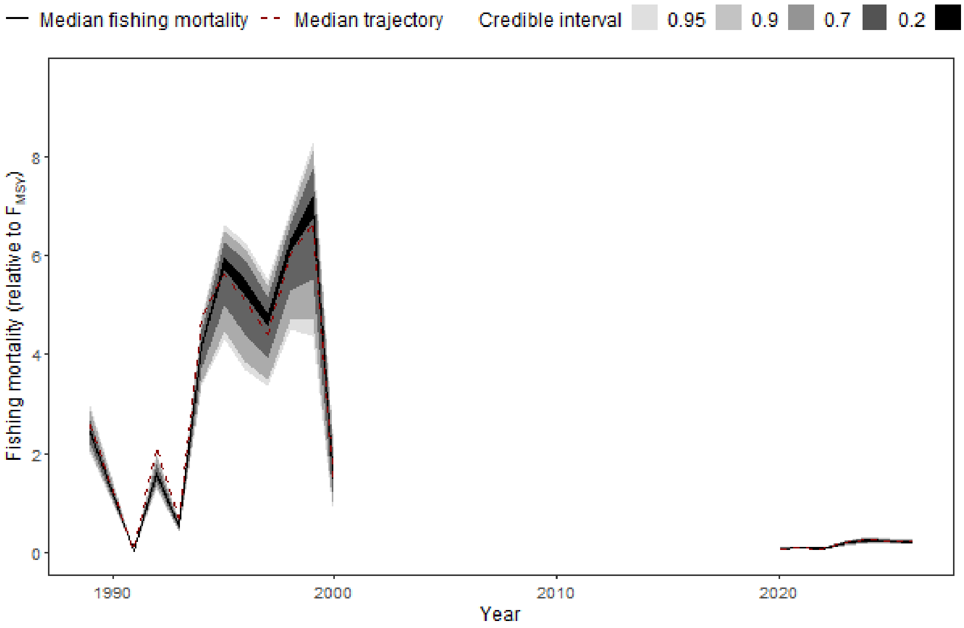

Figure D.21: Fishing mortality for the Steepness = 0.7 scenario

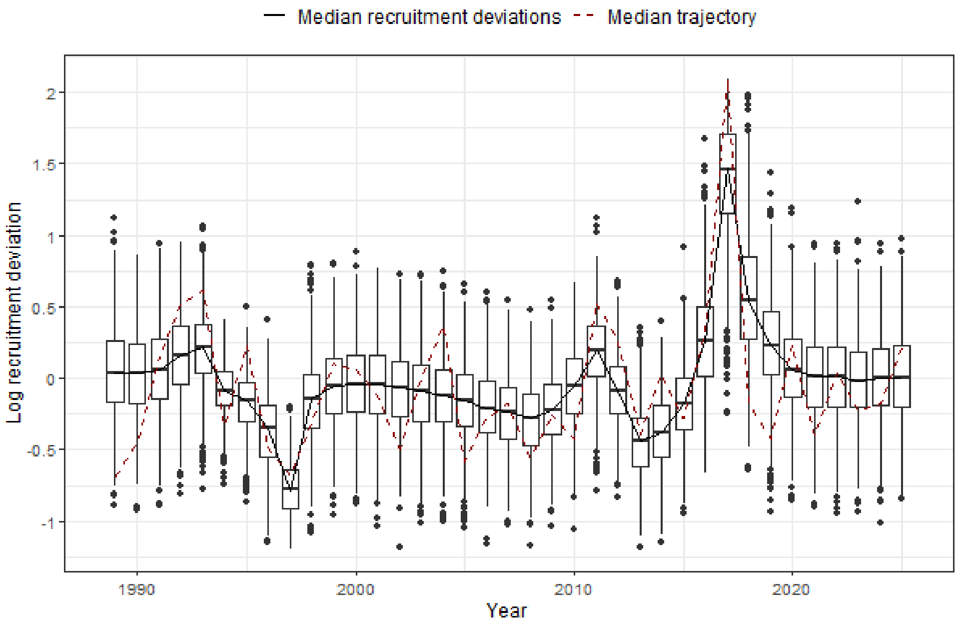

Figure D.22: Recruitment deviations for the Steepness = 0.7 scenario

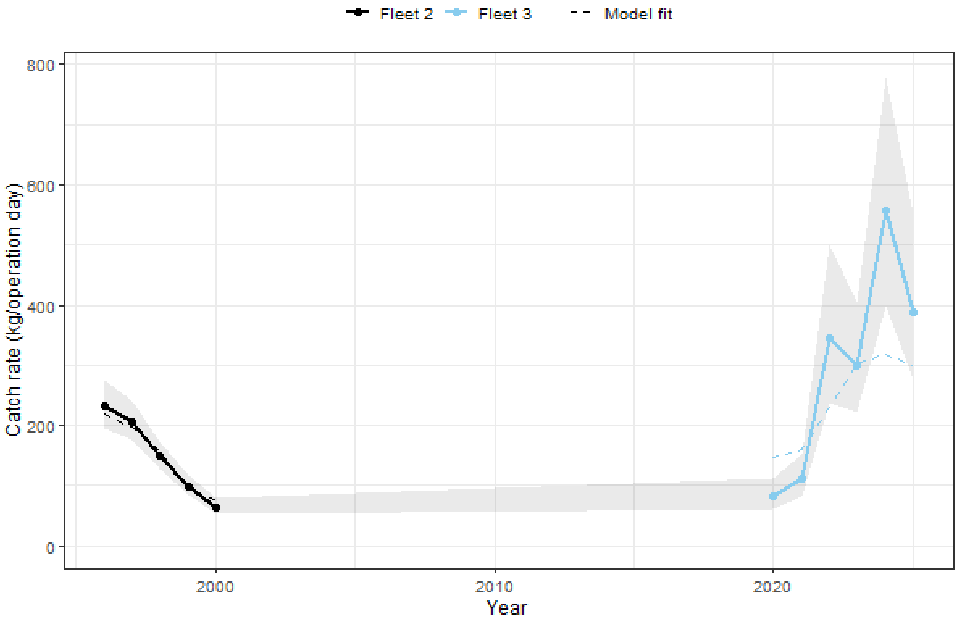

Figure D.23: CPUE fit for the Steepness = 0.7 scenario

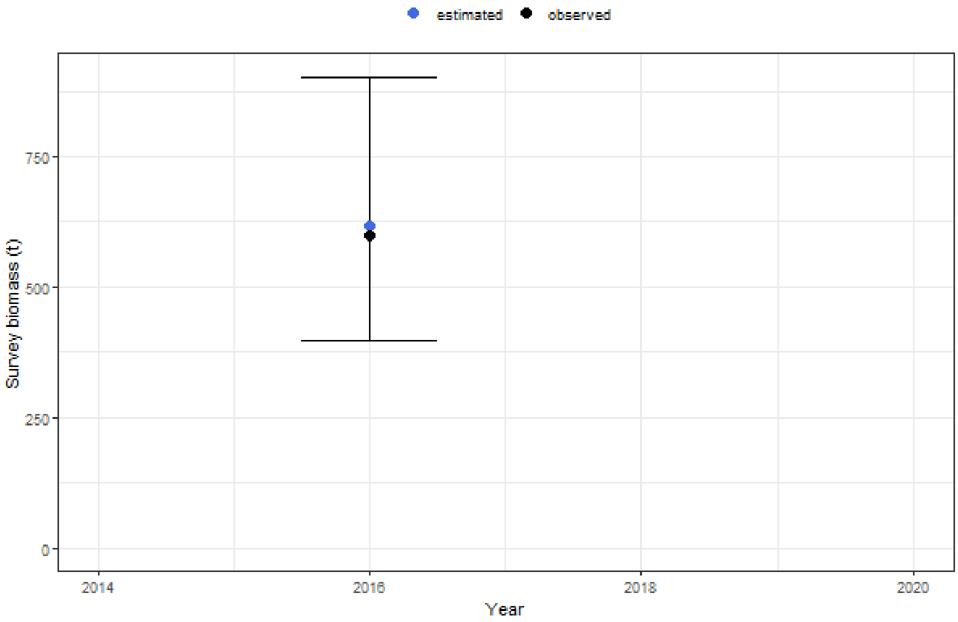

Figure D.24: Surveyed biomass fit for the Steepness = 0.7 scenario

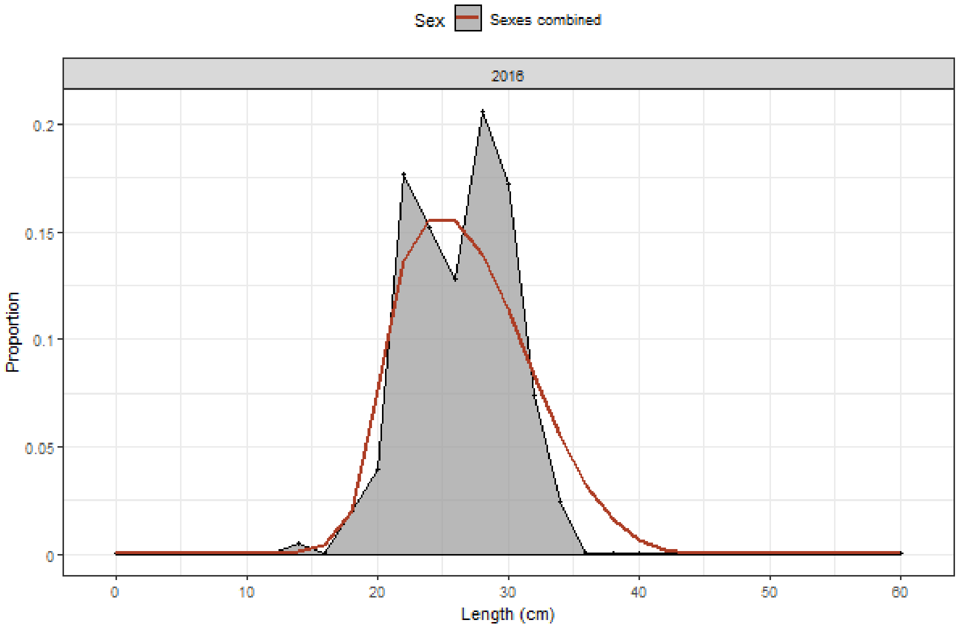

Figure D.25: Length composition fit for the Steepness = 0.7 scenario

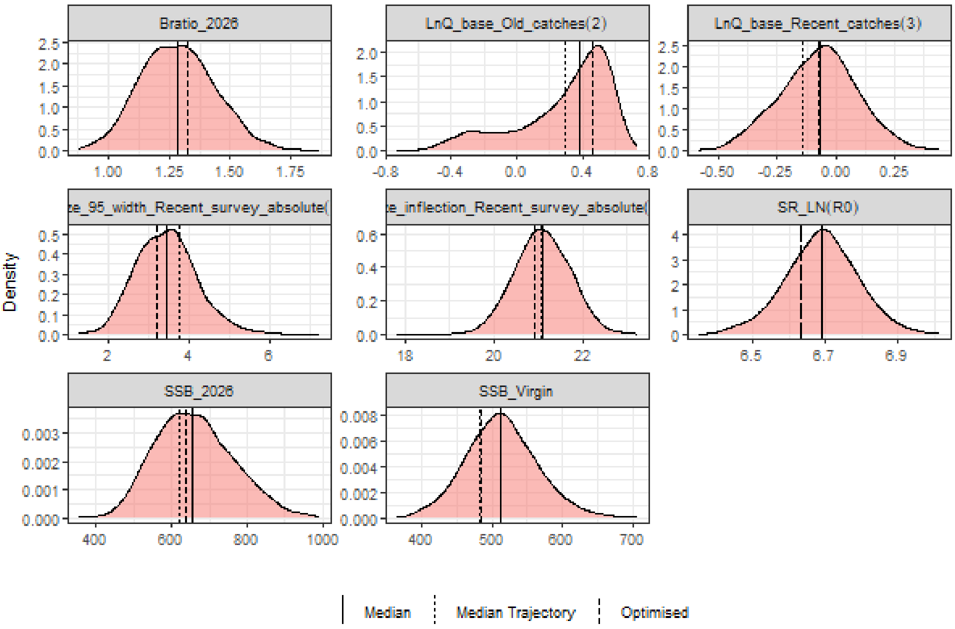

Figure D.26: MCMC parameter posterior densities for the Steepness = 0.7 scenario

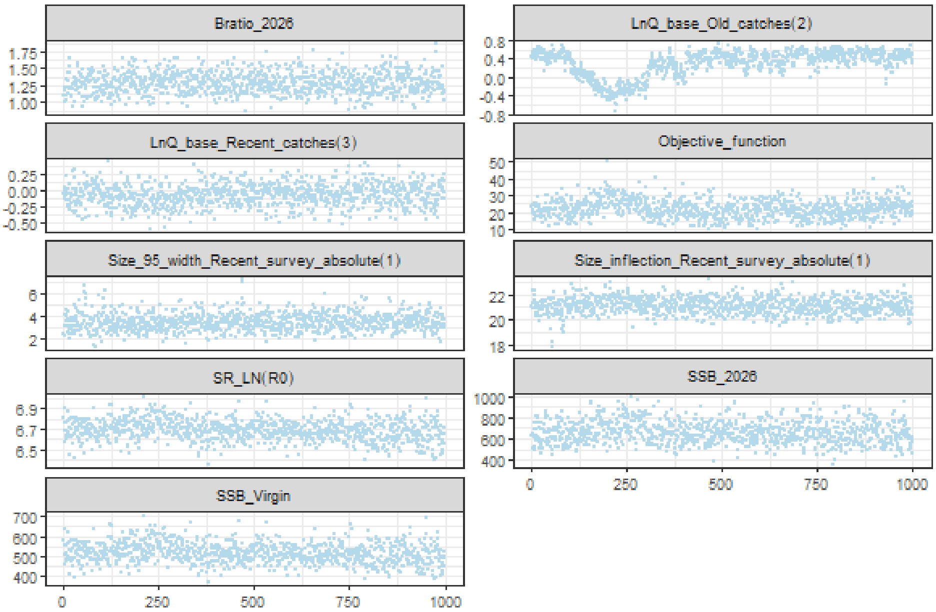

Figure D.27: MCMC trace plots for the Steepness = 0.7 scenario

D.1.4 Natural mortality = 0.2

This section presents results for the Natural mortality = 0.2 scenario.

Table D.4: Summary of parameter estimates for black teatfish the Natural mortality = 0.2 scenario. MCMC Median is median parameter value from robust MCMC scenarios. MCMC 2.5% and 97.5% indicates 95% credible interval.

Symbol	MCMC median	MCMC 2.5%	MCMC 97.5%
SR_LN(R0)	5.6	5.5	5.7
SSB_Virgin	1263.1	1105.2	1424.5
SSB_2026	665.56	474.61	942.32
Bratio_2026	0.5	0.4	0.7
LnQ_base_Old_catches(2)	-0.6	-0.9	-0.3
LnQ_base_Recent_catches(3)	-0.36	-0.68	-0.02
Size_inflection_Recent_survey_absolute(1)	19.9	18.4	21.3
Size_95%width_Recent_survey_absolute(1)	3.4	1.4	5.6

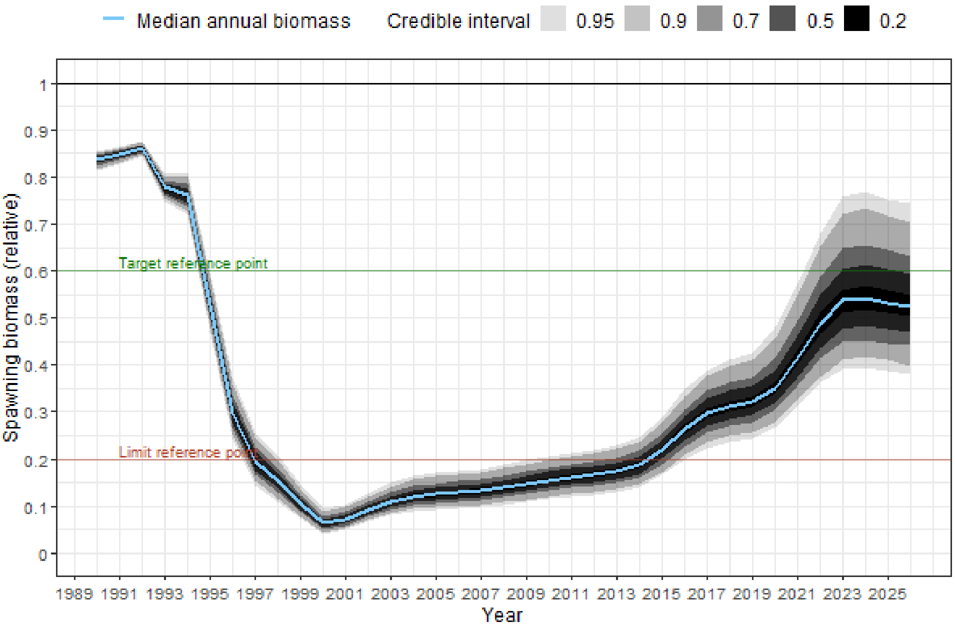

Figure D.28: Relative spawning biomass for the Natural mortality = 0.2 scenario

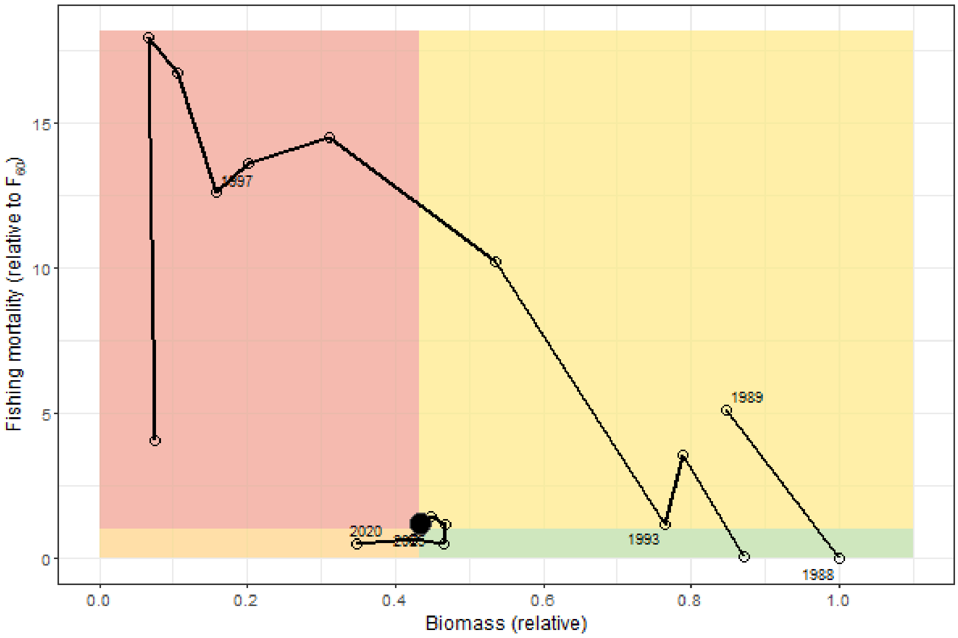

Figure D.29: Phase plot for the Natural mortality = 0.2 scenario

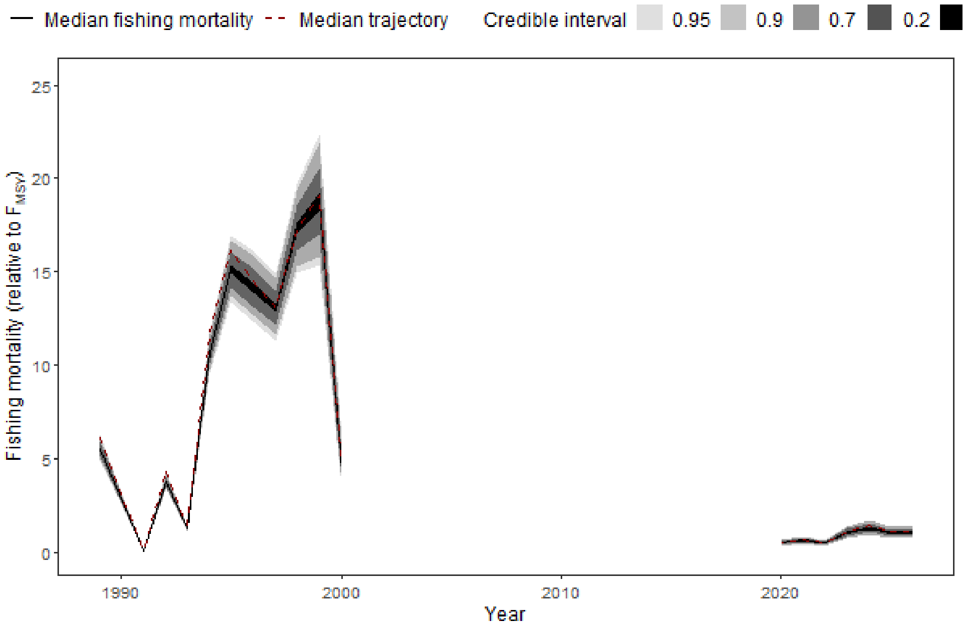

Figure D.30: Fishing mortality for the Natural mortality = 0.2 scenario

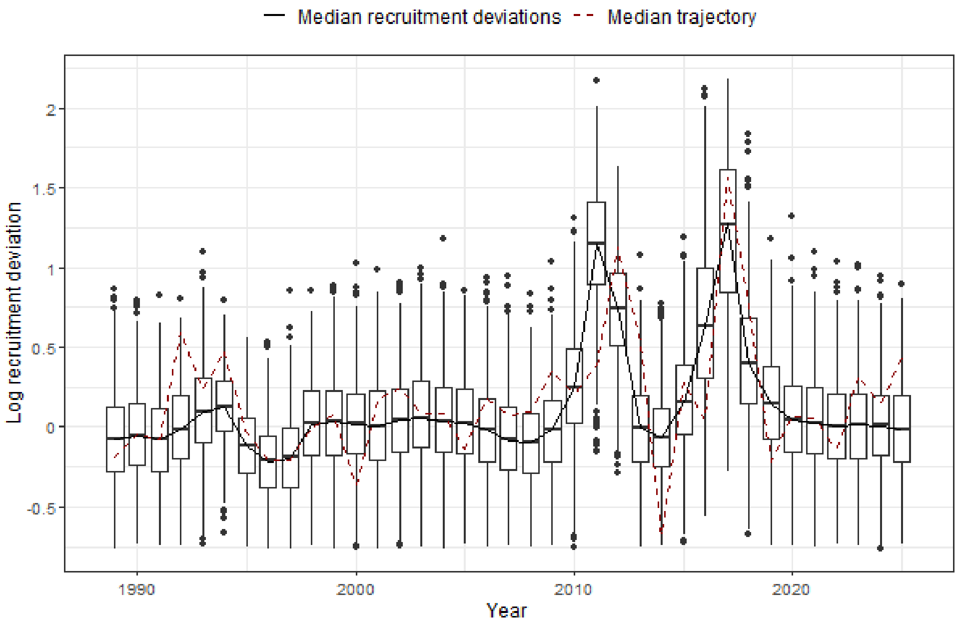

Figure D.31: Recruitment deviations for the Natural mortality = 0.2 scenario

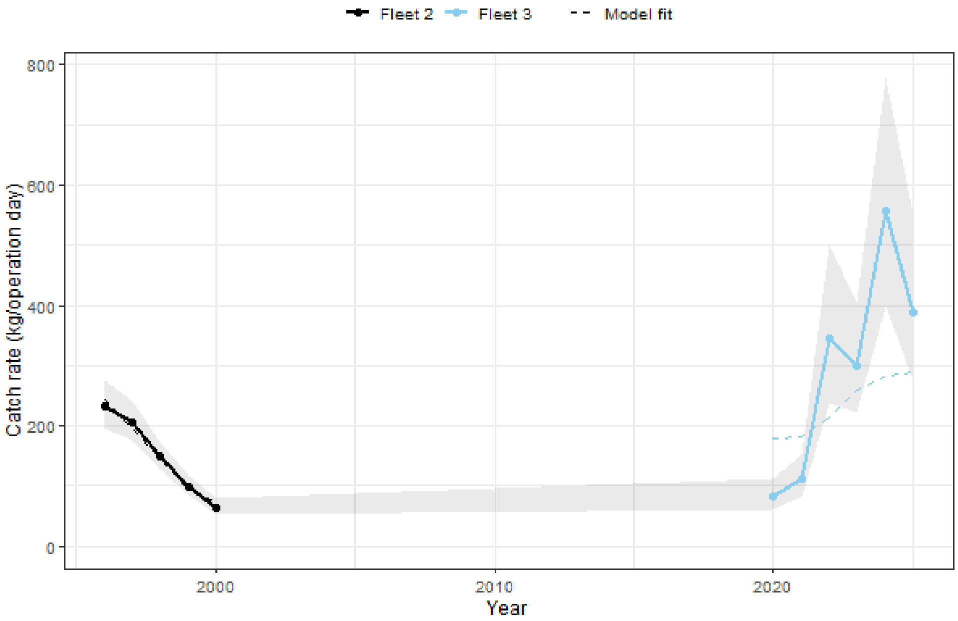

Figure D.32: CPUE fit for the Natural mortality = 0.2 scenario

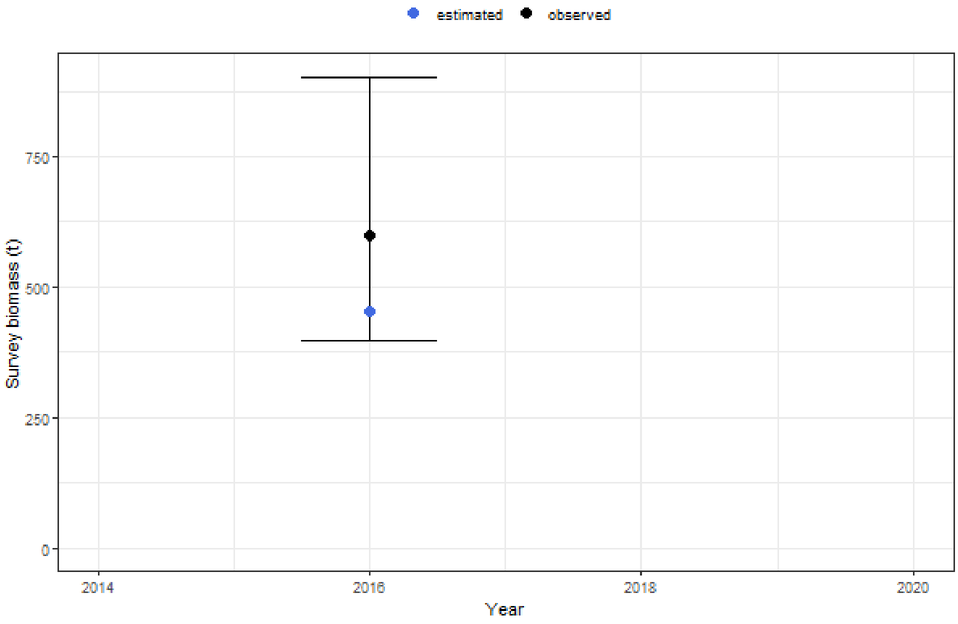

Figure D.33: Surveyed biomass fit for the Natural mortality = 0.2 scenario

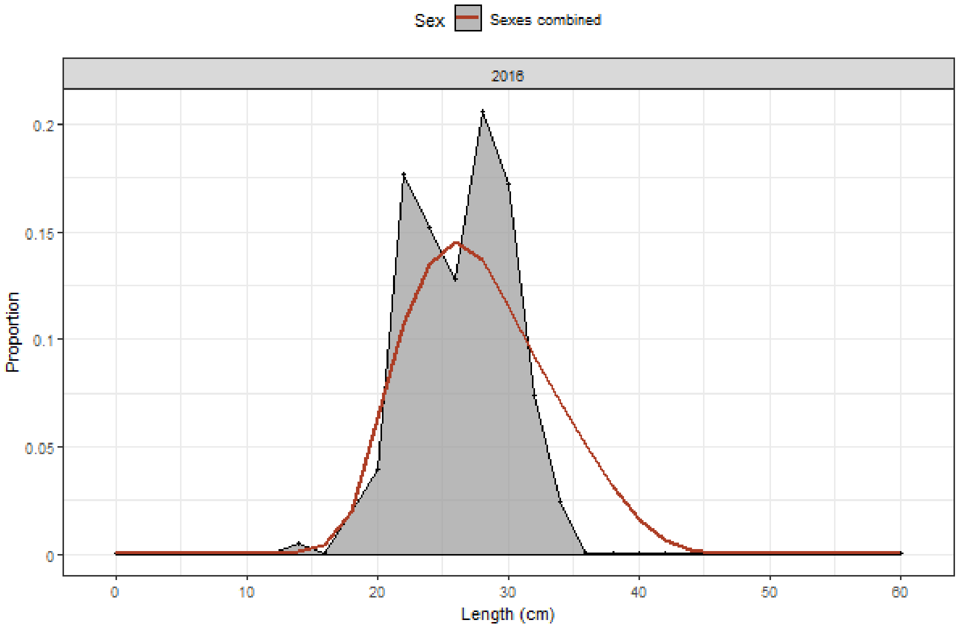

Figure D.34: Length composition fit for the Natural mortality = 0.2 scenario

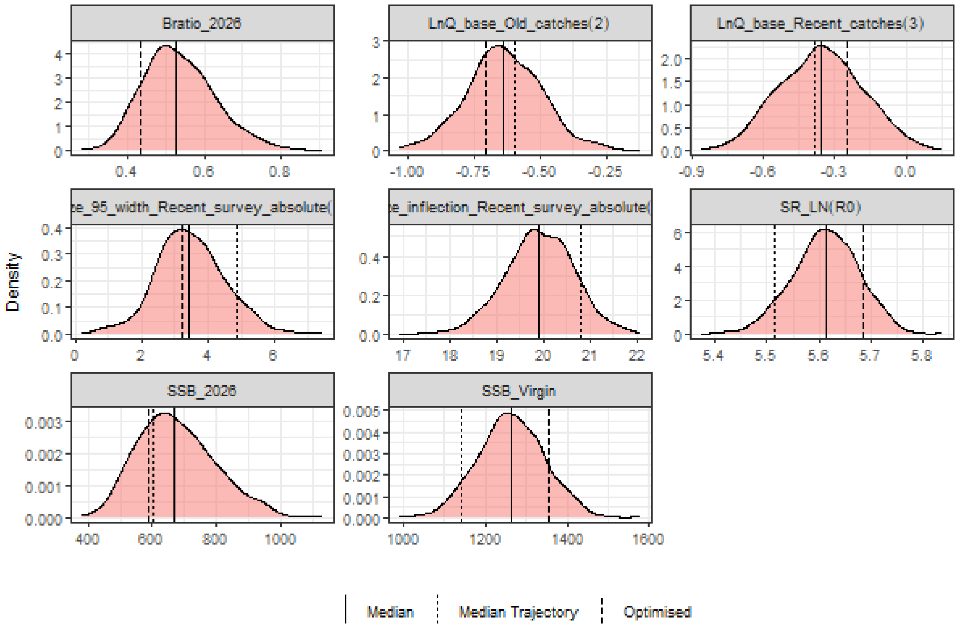

Figure D.35: MCMC parameter posterior densities for the Natural mortality = 0.2 scenario

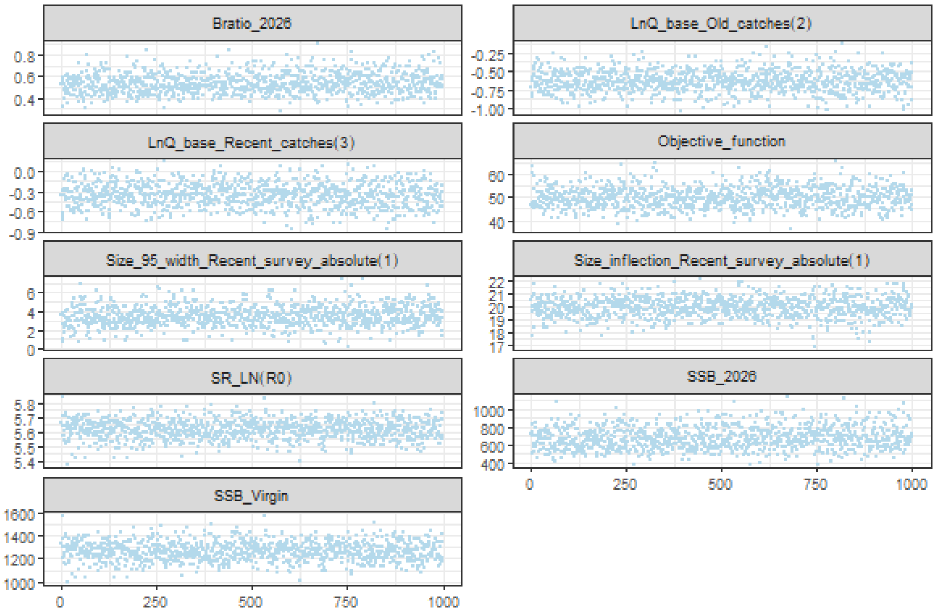

Figure D.36: MCMC trace plots for the Natural mortality = 0.2 scenario

D.1.5 Natural mortality = 0.6

This section presents results for the Natural mortality = 0.6 scenario.

Table D.5: Summary of parameter estimates for black teatfish the Natural mortality = 0.6 scenario. MCMC Median is median parameter value from robust MCMC scenarios. MCMC 2.5% and 97.5% indicates 95% credible interval.

Symbol	MCMC median	MCMC 2.5%	MCMC 97.5%
SR_LN(R0)	7.8	7.6	8
SSB_Virgin	552.4	434.9	700.6
SSB_2026	502.46	348.39	737.97
Bratio_2026	0.9	0.6	1.3
LnQ_base_Old_catches(2)	-0.2	-0.7	0.3
LnQ_base_Recent_catches(3)	0.6	0.21	0.99
Size_inflection_Recent_survey_absolute(1)	22.1	21	23.5
Size_95%width_Recent_survey_absolute(1)	3.8	2.5	5.6

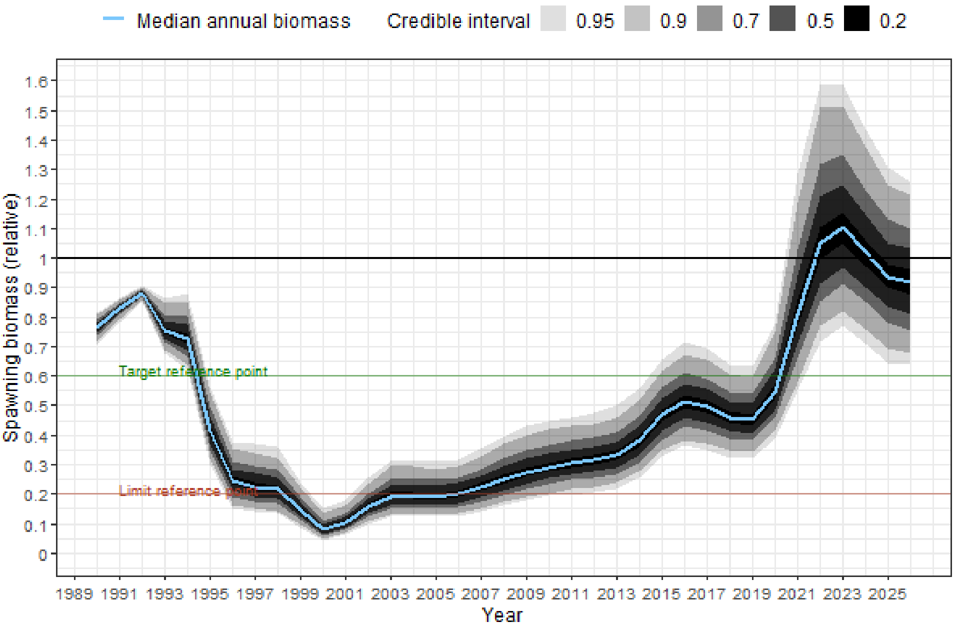

Figure D.37: Relative spawning biomass for the Natural mortality = 0.6 scenario

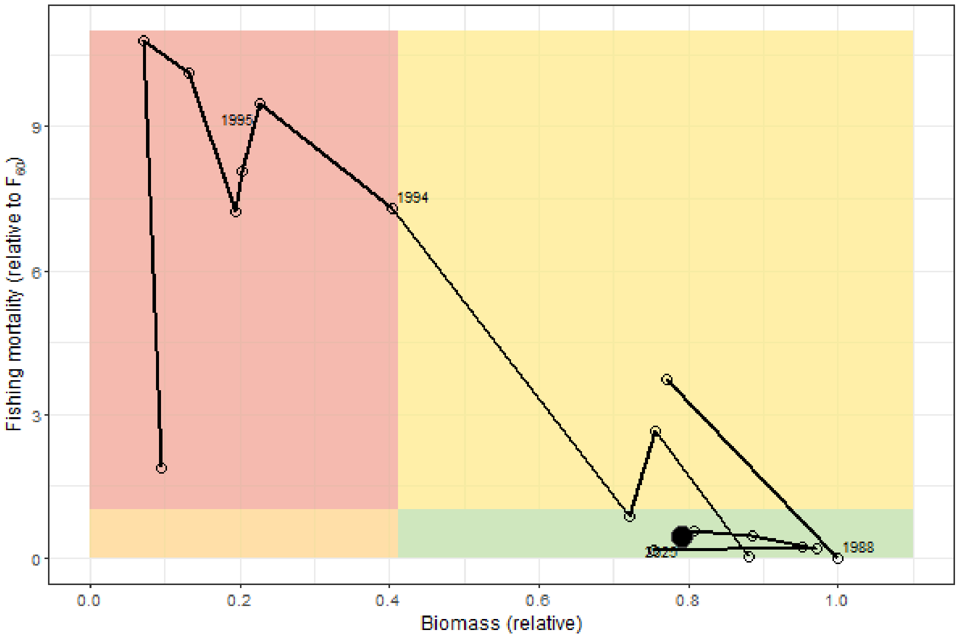

Figure D.38: Phase plot for the Natural mortality = 0.6 scenario

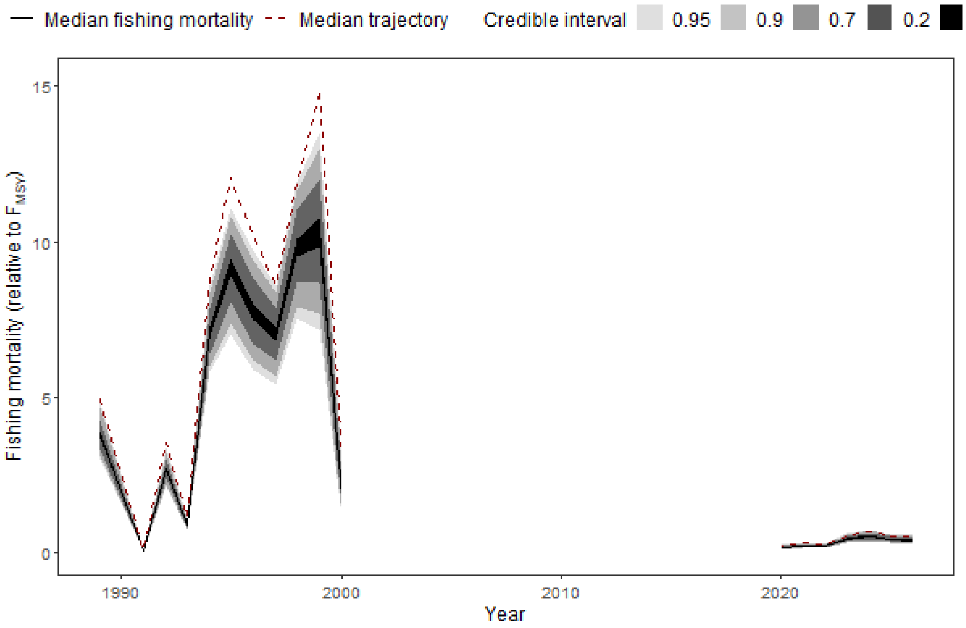

Figure D.39: Fishing mortality for the Natural mortality = 0.6 scenario

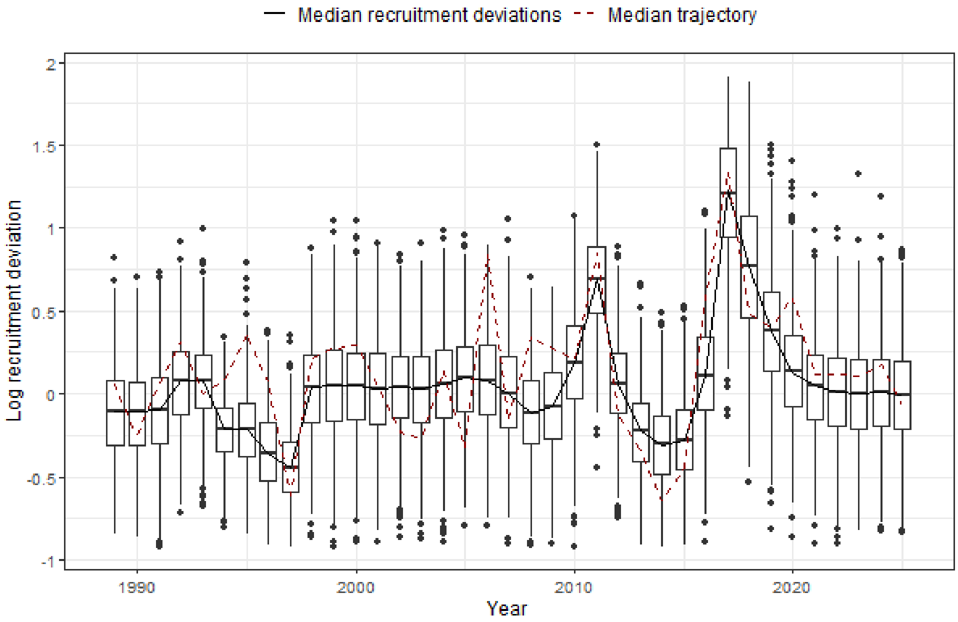

Figure D.40: Recruitment deviations for the Natural mortality = 0.6 scenario

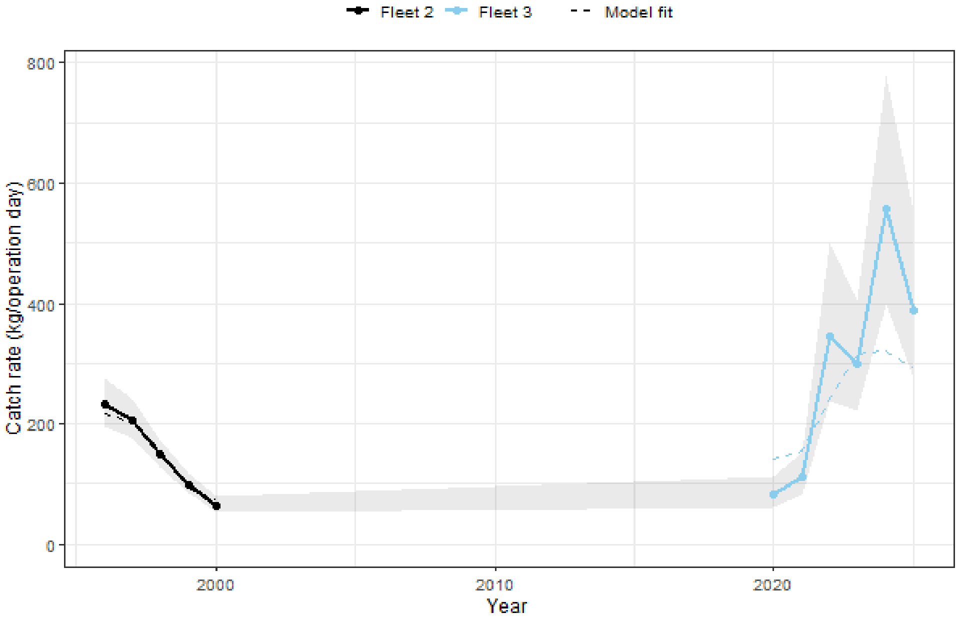

Figure D.41: CPUE fit for the Natural mortality = 0.6 scenario

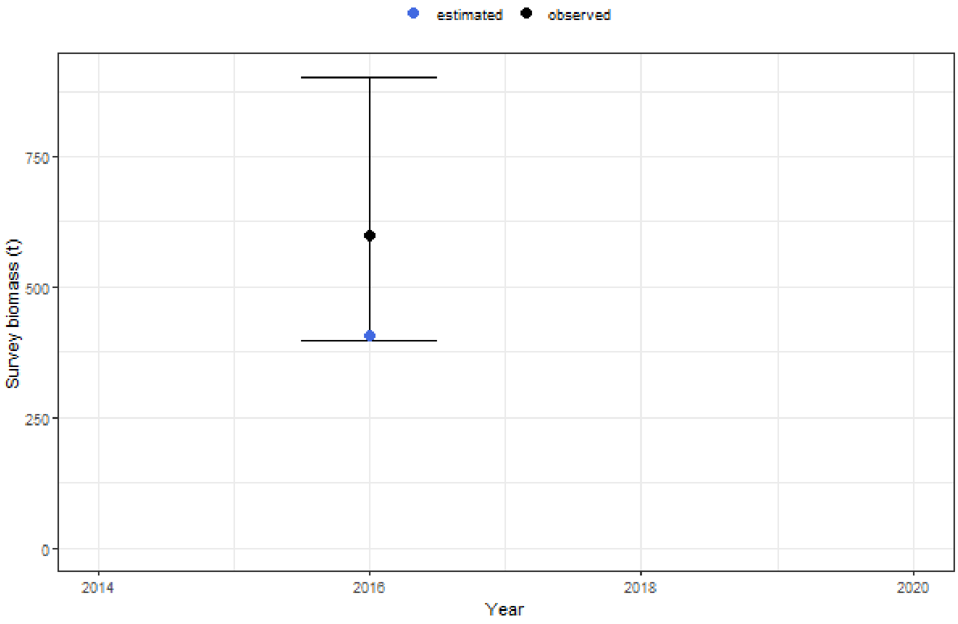

Figure D.42: Surveyed biomass fit for the Natural mortality = 0.6 scenario

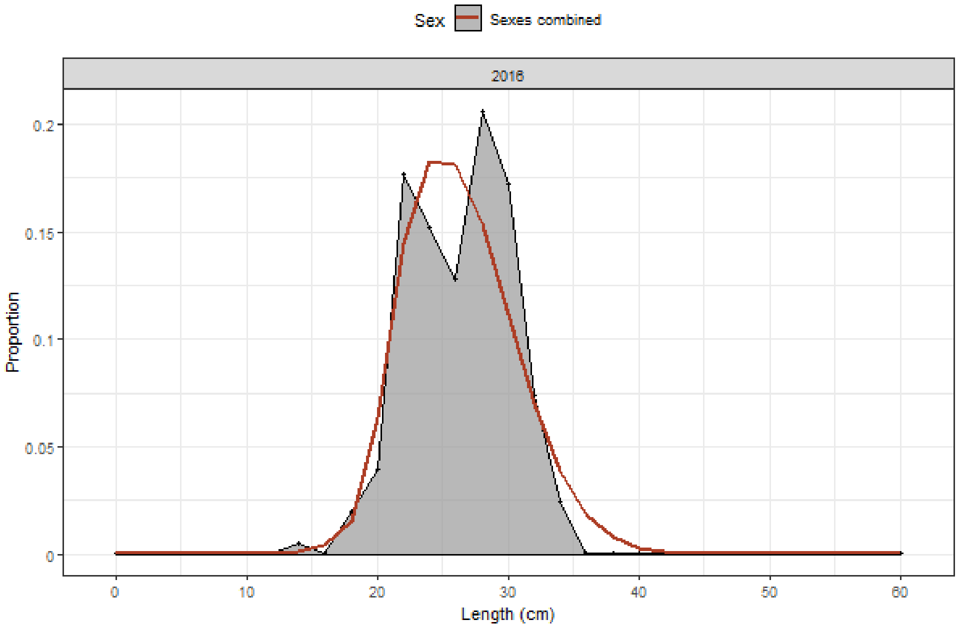

Figure D.43: Length composition fit for the Natural mortality = 0.6 scenario

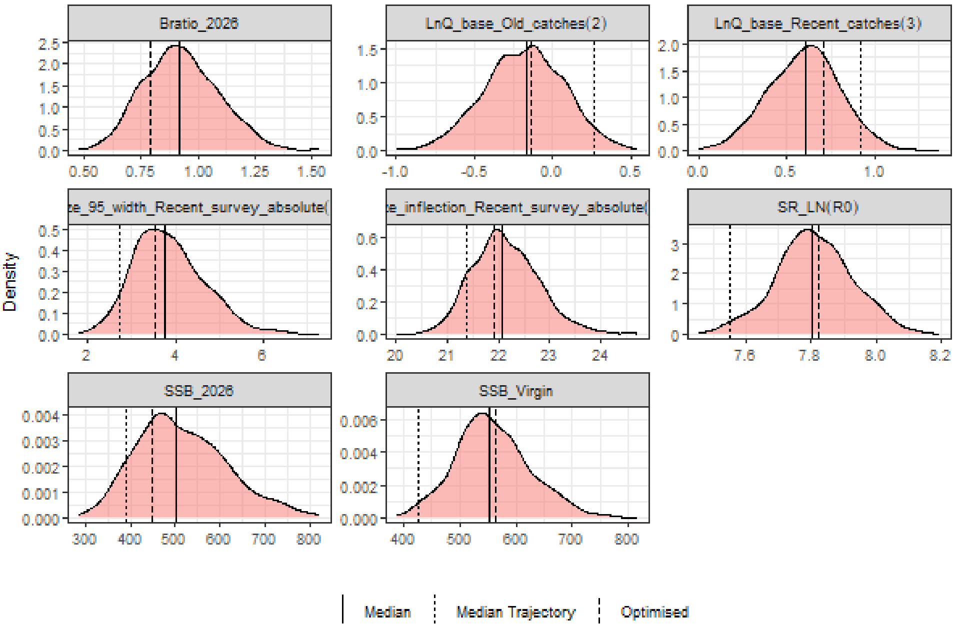

Figure D.44: MCMC parameter posterior densities for the Natural mortality = 0.6 scenario

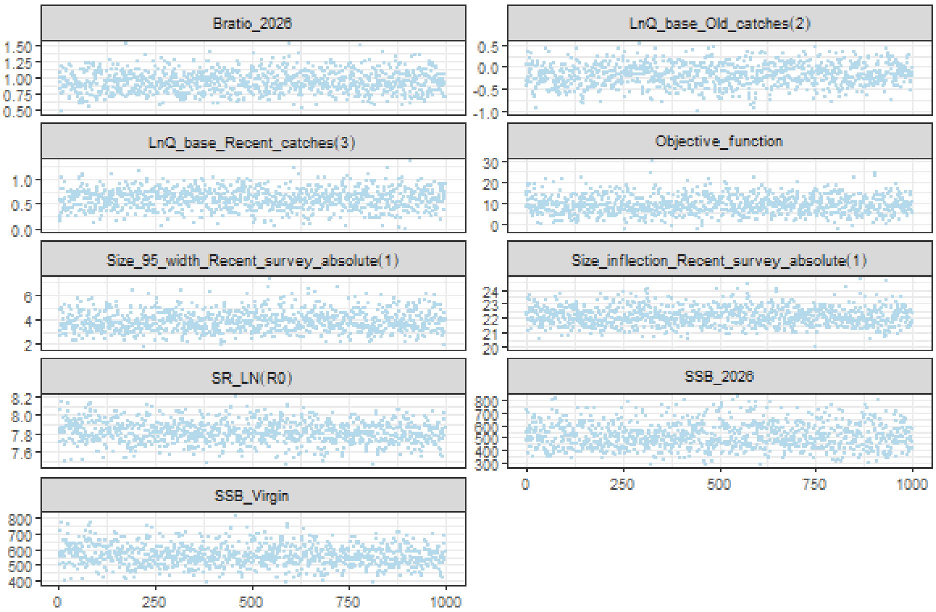

Figure D.45: MCMC trace plots for the Natural mortality = 0.6 scenario

D.1.6 No shrinkage applied

This section presents results for the No shrinkage applied scenario.

Table D.6: Summary of parameter estimates for black teatfish the No shrinkage applied scenario. MCMC Median is median parameter value from robust MCMC scenarios. MCMC 2.5% and 97.5% indicates 95% credible interval.

Symbol	MCMC median	MCMC 2.5%	MCMC 97.5%
SR_LN(R0)	7	6.8	7.2
SSB_Virgin	707.4	586.7	841.6
SSB_2026	526.92	364.66	751.57
Bratio_2026	0.8	0.5	1.1
LnQ_base_Old_catches(2)	-0.4	-0.7	0
LnQ_base_Recent_catches(3)	0.32	-0.08	0.69
Size_inflection_Recent_survey_absolute(1)	18.9	17.7	20.1
Size_95%width_Recent_survey_absolute(1)	3.4	2.1	5.4

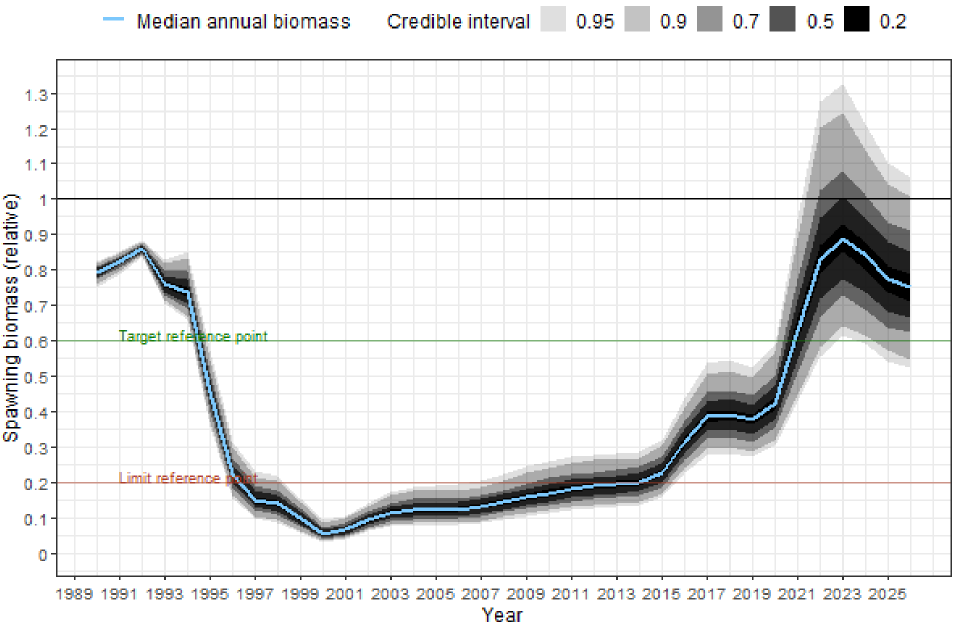

Figure D.46: Relative spawning biomass for the No shrinkage applied scenario

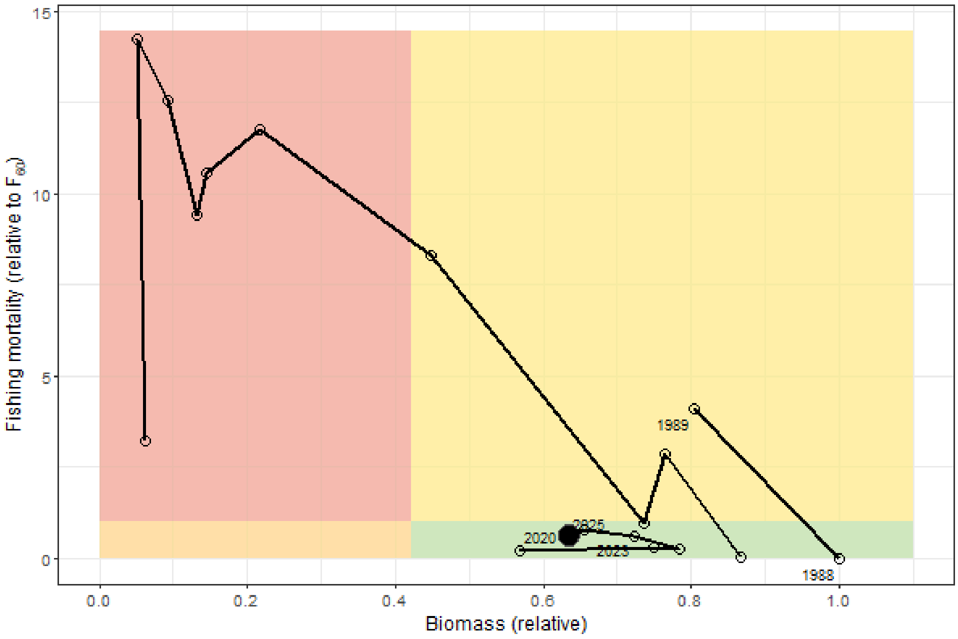

Figure D.47: Phase plot for the No shrinkage applied scenario

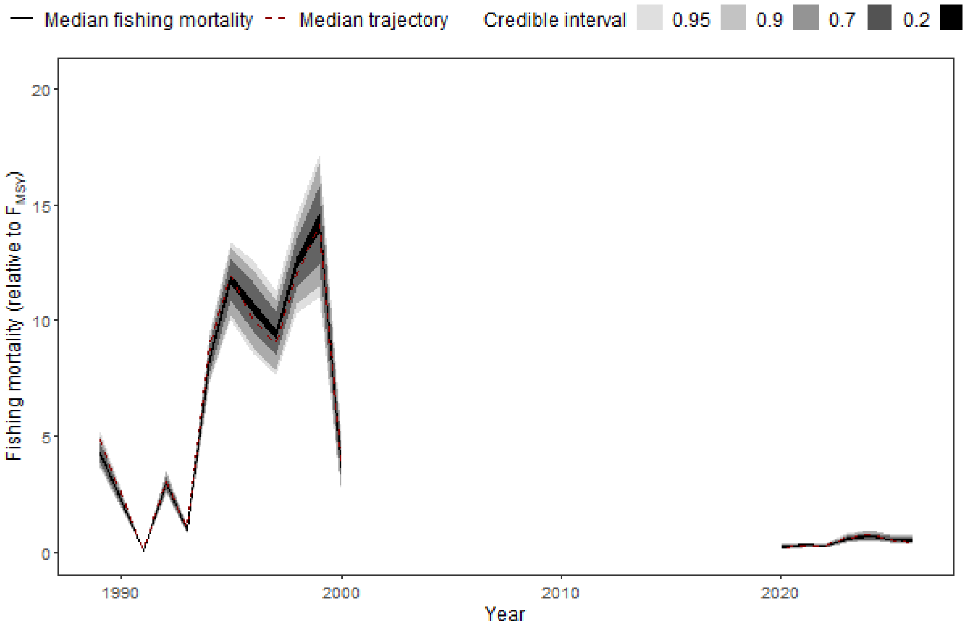

Figure D.48: Fishing mortality for the No shrinkage applied scenario

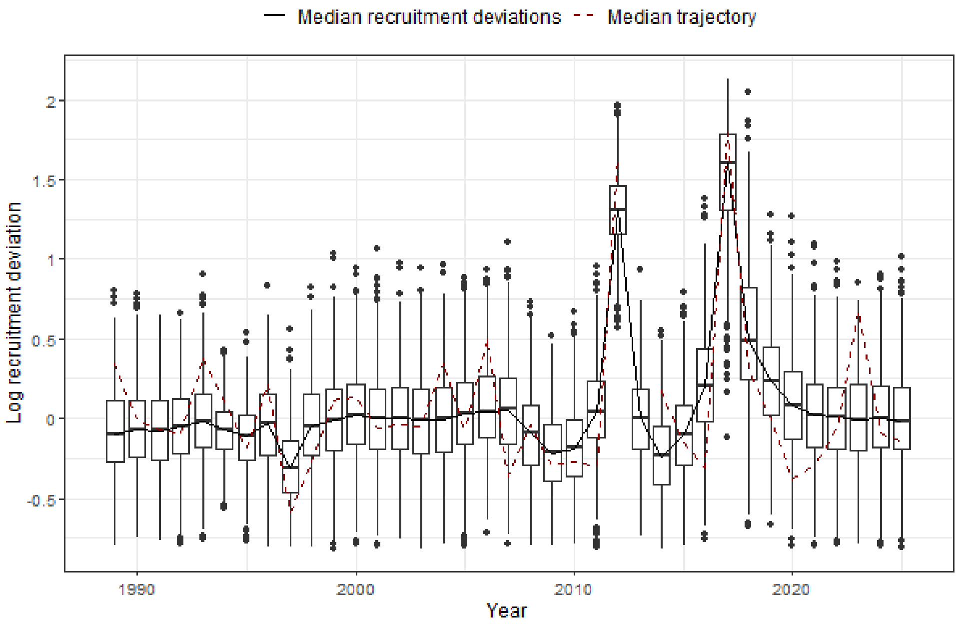

Figure D.49: Recruitment deviations for the No shrinkage applied scenario

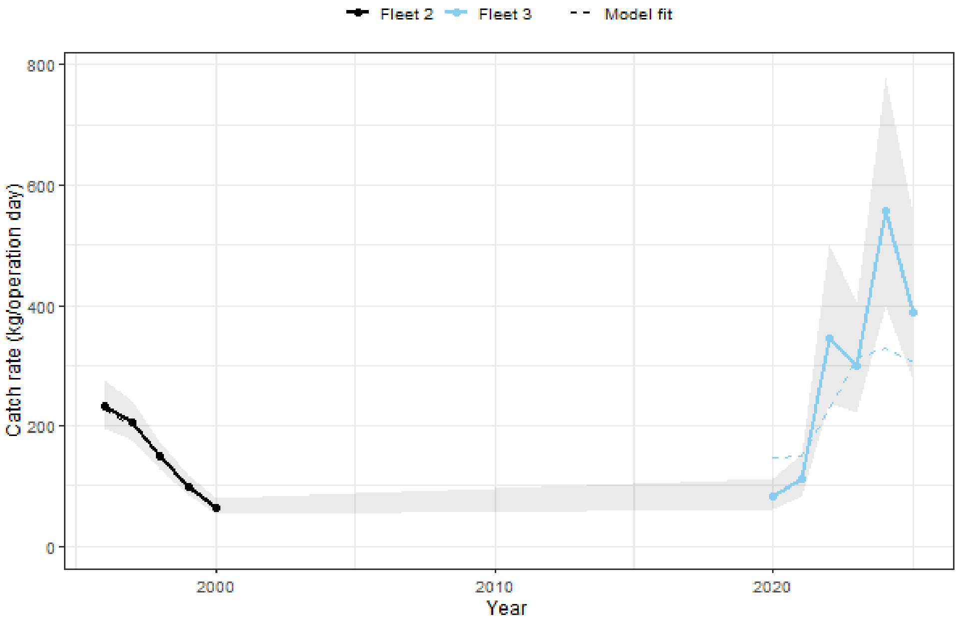

Figure D.50: CPUE fit for the No shrinkage applied scenario

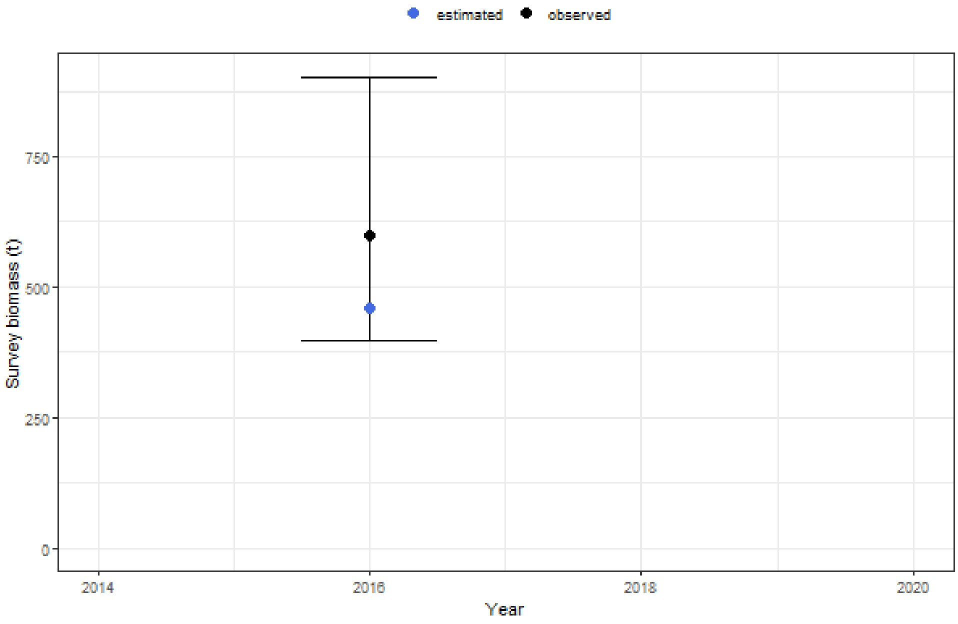

Figure D.51: Surveyed biomass fit for the No shrinkage applied scenario

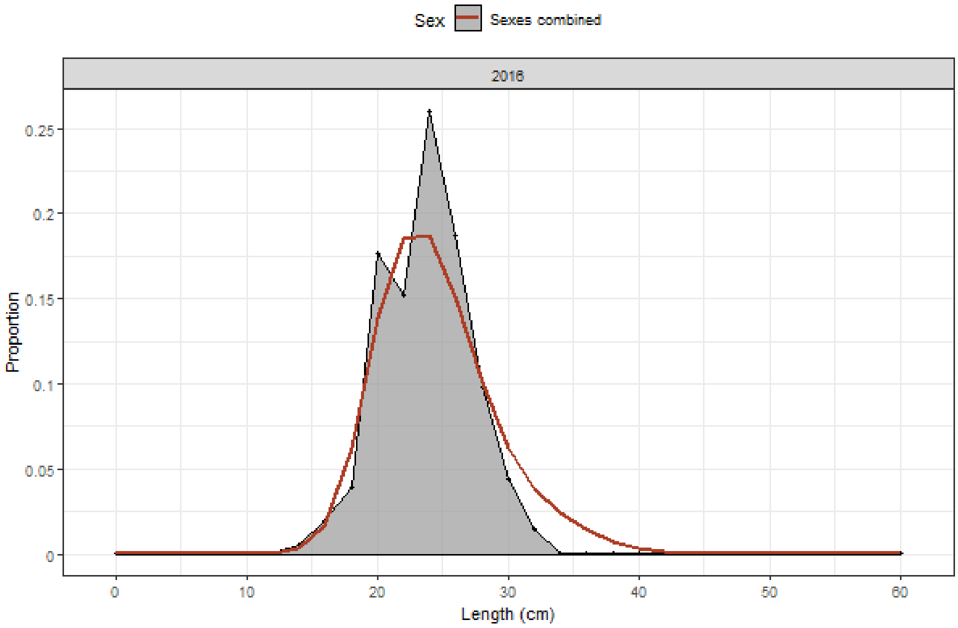

Figure D.52: Length composition fit for the No shrinkage applied scenario

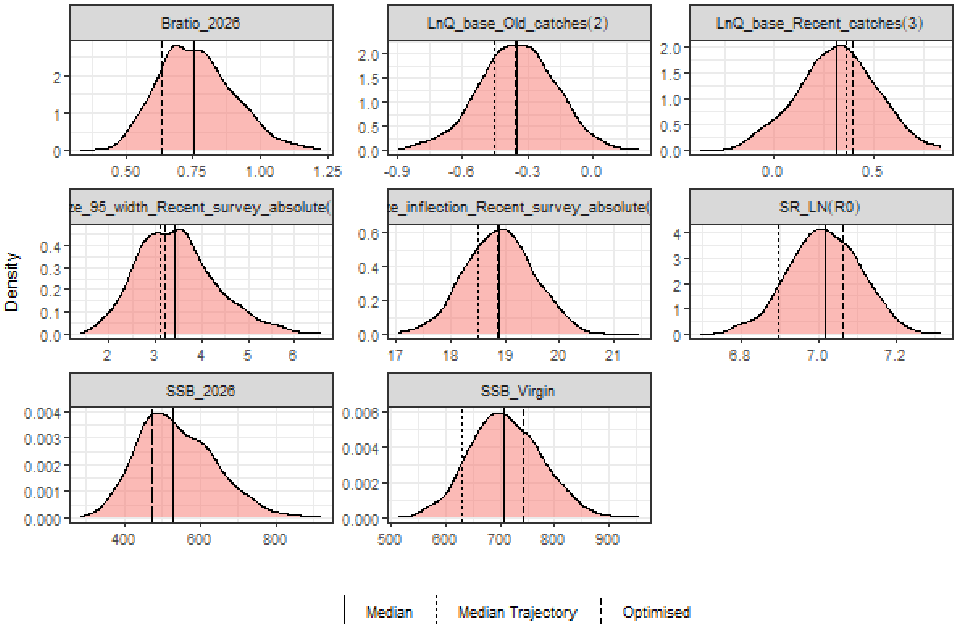

Figure D.53: MCMC parameter posterior densities for the No shrinkage applied scenario

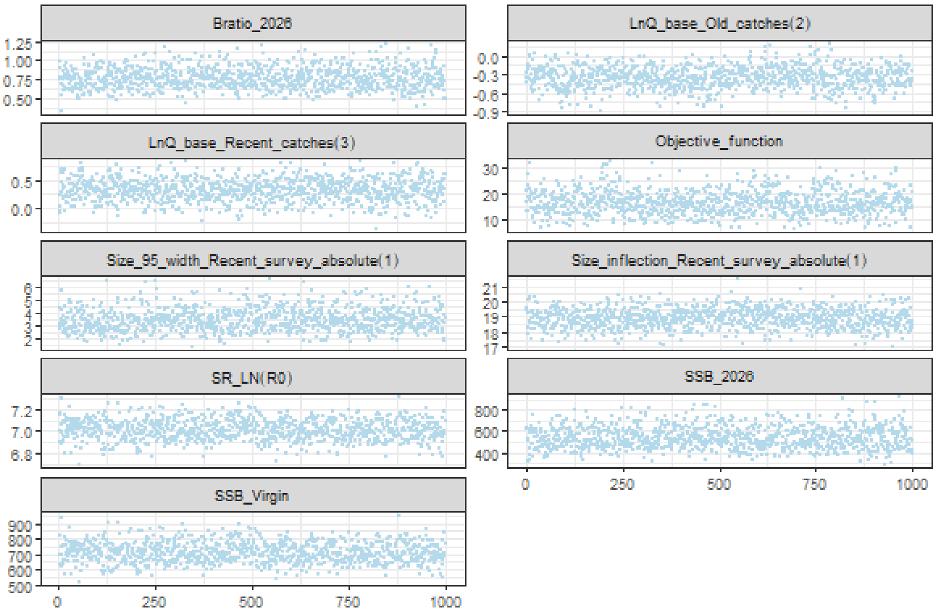

Figure D.54: MCMC trace plots for the No shrinkage applied scenario

D.1.7 Faster growth profile

This section presents results for the Faster growth profile scenario.

Table D.7: Summary of parameter estimates for black teatfish the Faster growth profile scenario. MCMC Median is median parameter value from robust MCMC scenarios. MCMC 2.5% and 97.5% indicates 95% credible interval.

Symbol	MCMC median	MCMC 2.5%	MCMC 97.5%
SR_LN(R0)	6.8	6.6	7
SSB_Virgin	835.2	687.7	1024.2
SSB_2026	739.93	522.61	1053.26
Bratio_2026	0.9	0.6	1.3
LnQ_base_Old_catches(2)	-0.2	-0.6	0.2
LnQ_base_Recent_catches(3)	-0.34	-0.7	0.06
Size_inflection_Recent_survey_absolute(1)	21.7	20.6	22.8
Size_95%width_Recent_survey_absolute(1)	3.7	2.2	5.7

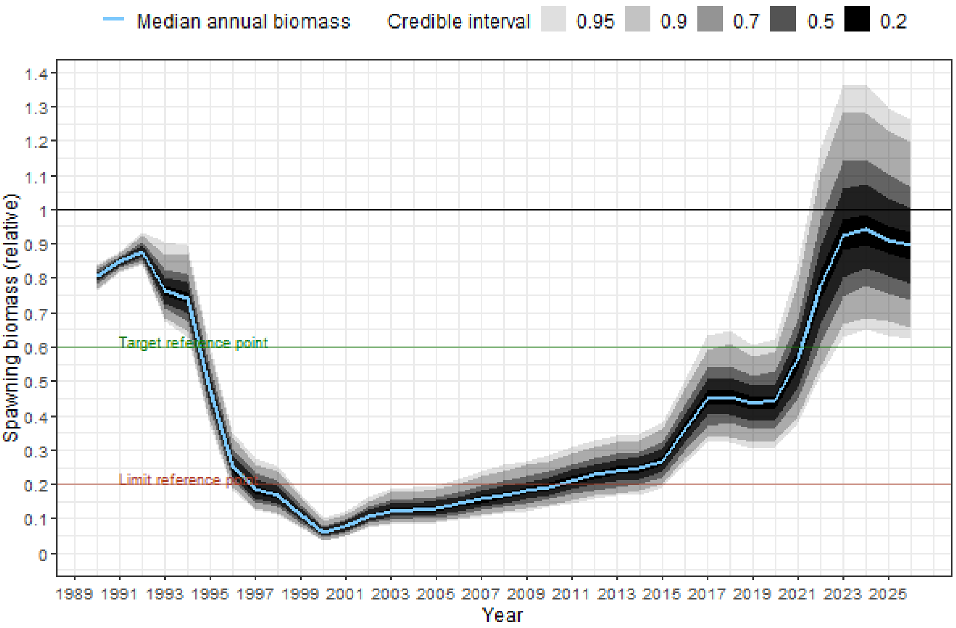

Figure D.55: Relative spawning biomass for the Faster growth profile scenario

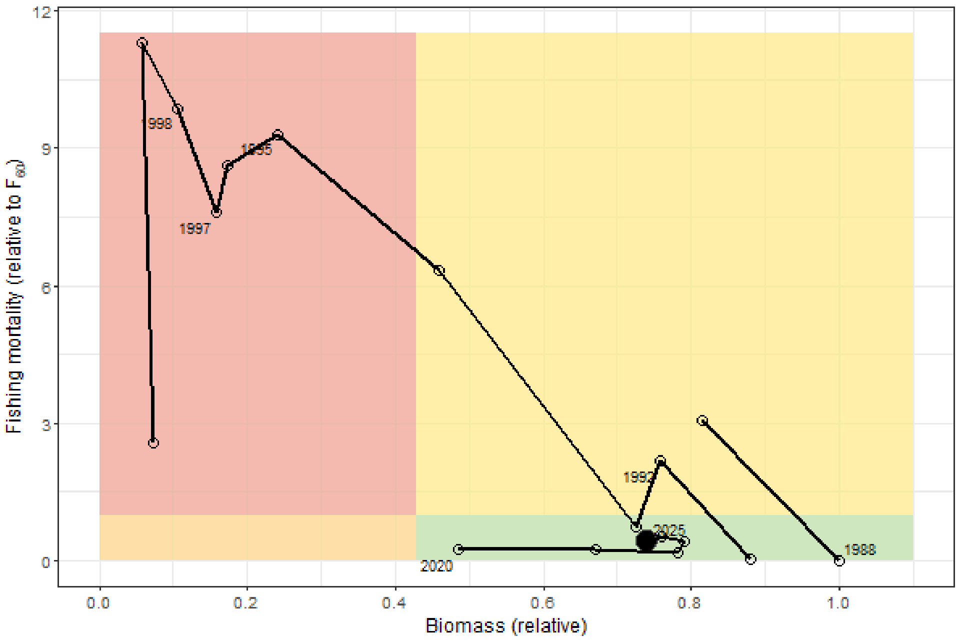

Figure D.56: Phase plot for the Faster growth profile scenario

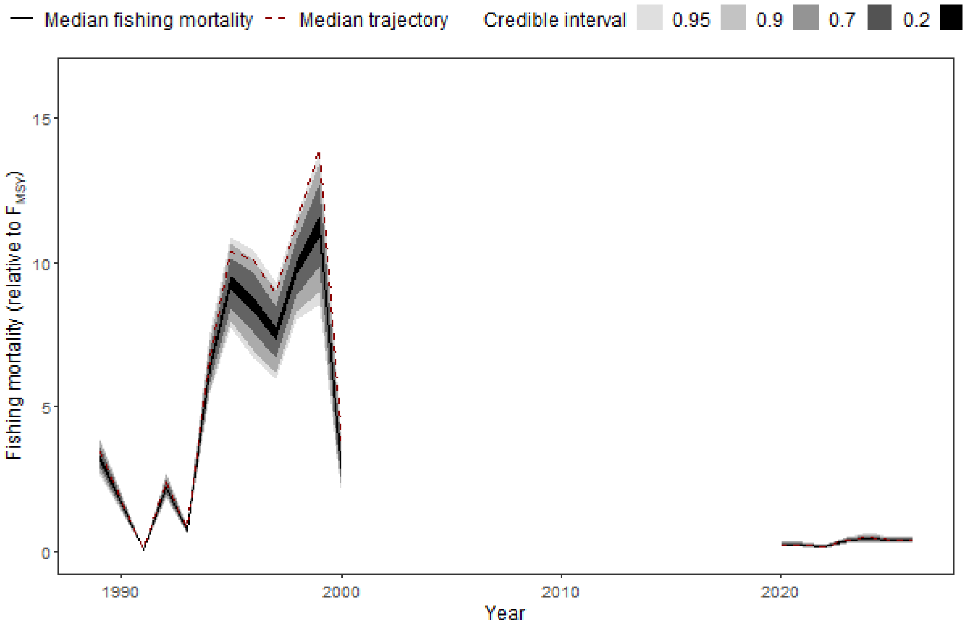

Figure D.57: Fishing mortality for the Faster growth profile scenario

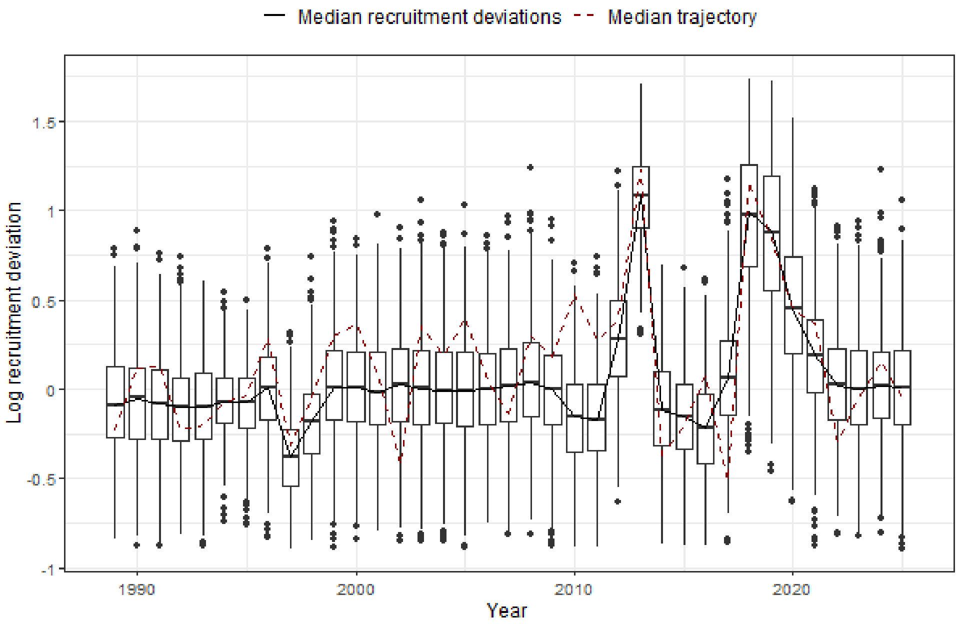

Figure D.58: Recruitment deviations for the Faster growth profile scenario

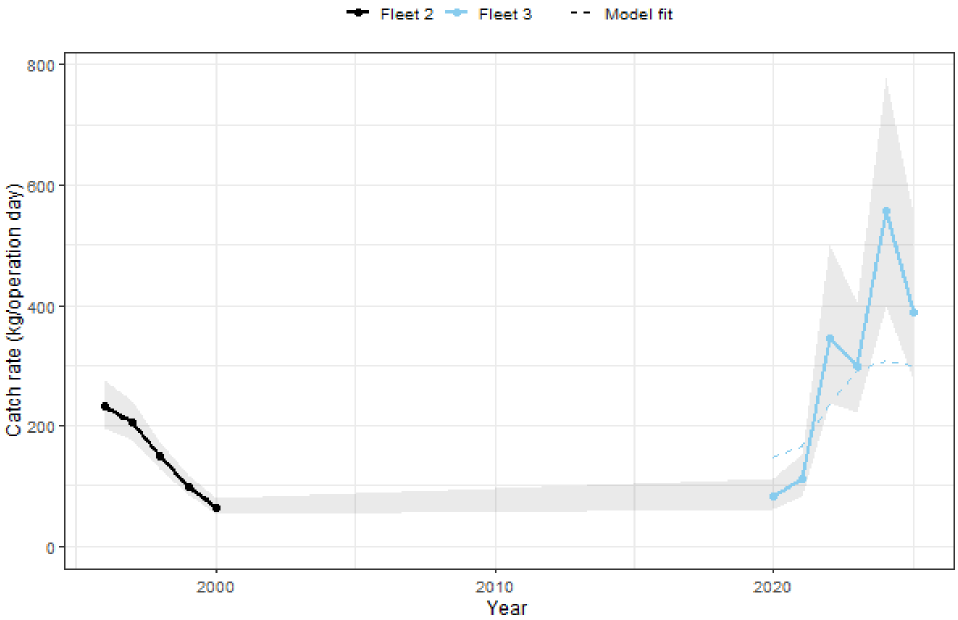

Figure D.59: CPUE fit for the Faster growth profile scenario

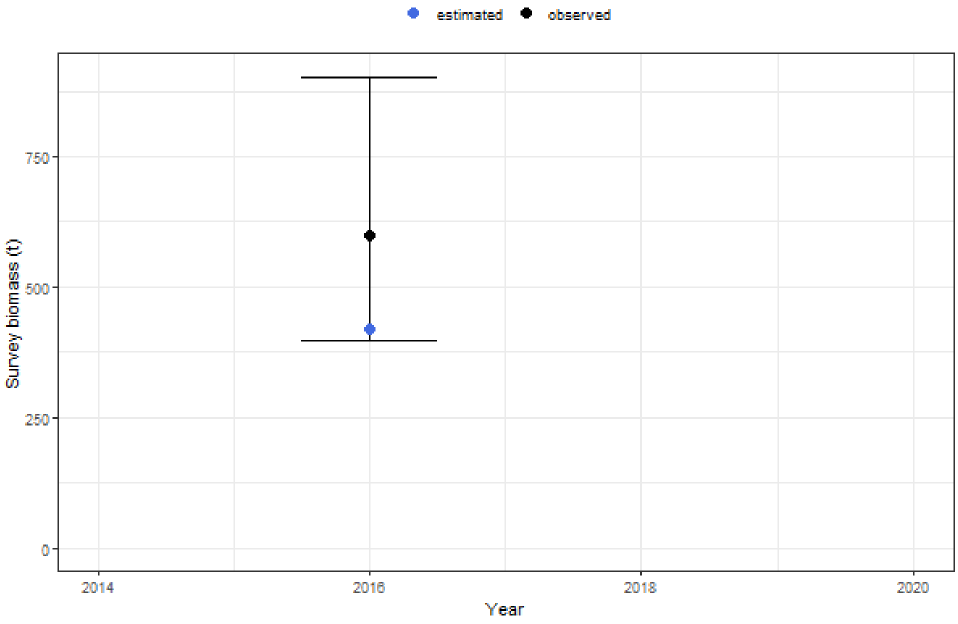

Figure D.60: Surveyed biomass fit for the Faster growth profile scenario

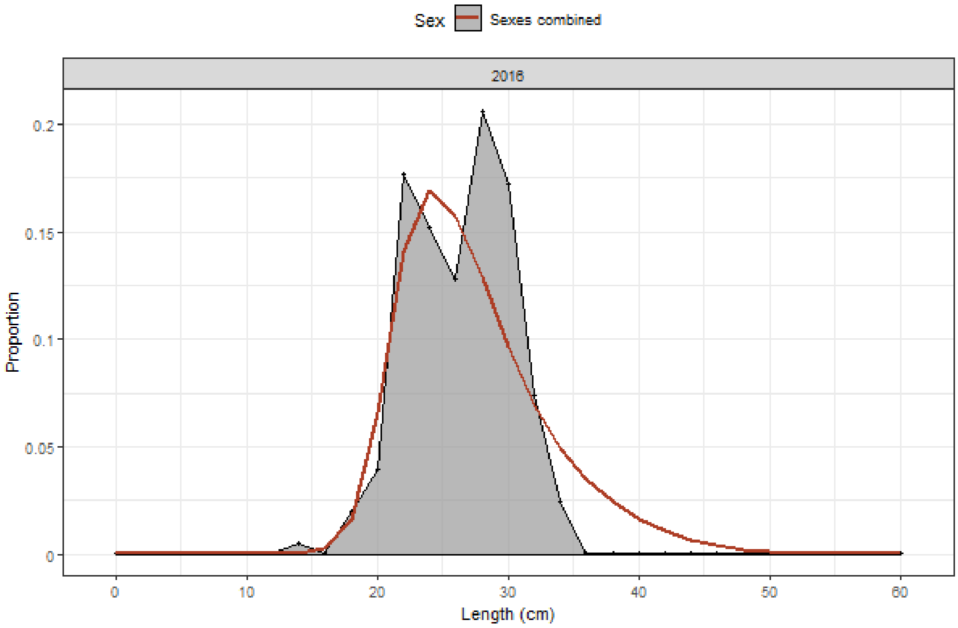

Figure D.61: Length composition fit for the Faster growth profile scenario

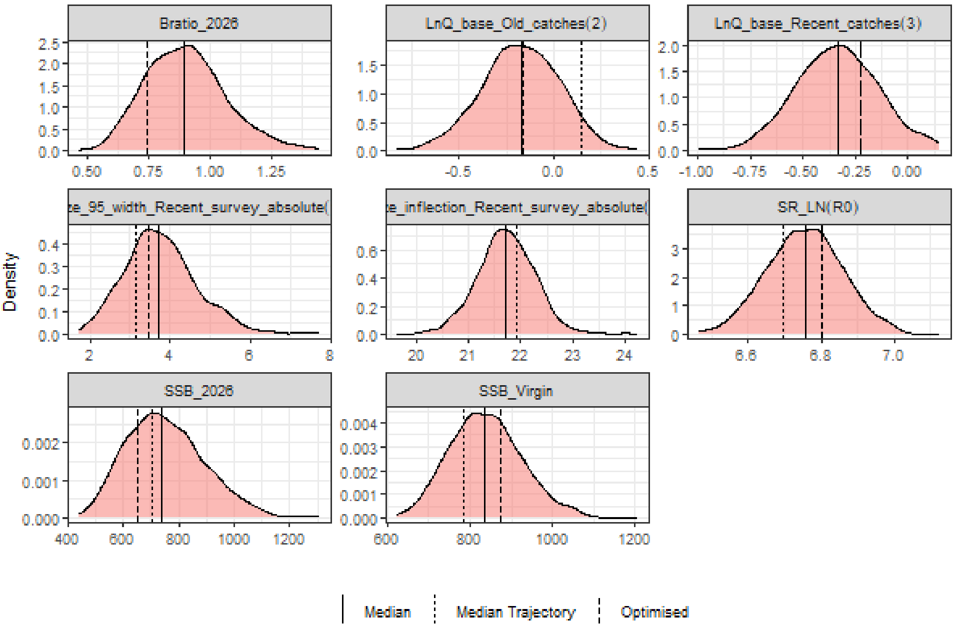

Figure D.62: MCMC parameter posterior densities for the Faster growth profile scenario

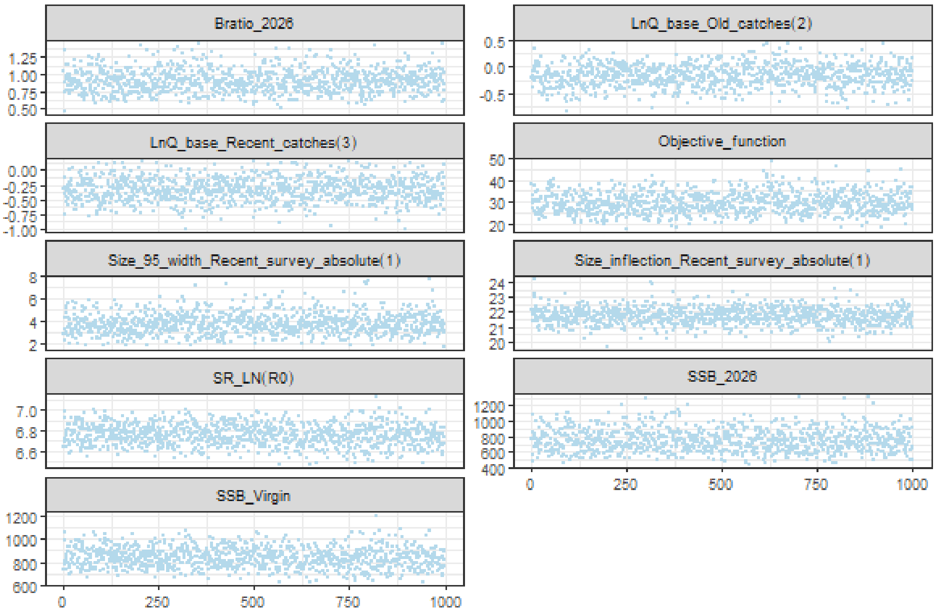

Figure D.63: MCMC trace plots for the Faster growth profile scenario

D.1.8 Slower growth profile

This section presents results for the Slower growth profile scenario.

Table D.8: Summary of parameter estimates for black teatfish the Slower growth profile scenario. MCMC Median is median parameter value from robust MCMC scenarios. MCMC 2.5% and 97.5% indicates 95% credible interval.

Symbol	MCMC median	MCMC 2.5%	MCMC 97.5%
SR_LN(R0)	7	6.8	7.2
SSB_Virgin	708.9	585.5	856.5
SSB_2026	562.55	373.36	791.96
Bratio_2026	0.8	0.5	1.1
LnQ_base_Old_catches(2)	-0.1	-0.5	0.4
LnQ_base_Recent_catches(3)	-0.09	-0.46	0.3
Size_inflection_Recent_survey_absolute(1)	21.6	20.5	22.8
Size_95%width_Recent_survey_absolute(1)	3.6	2.3	5.5

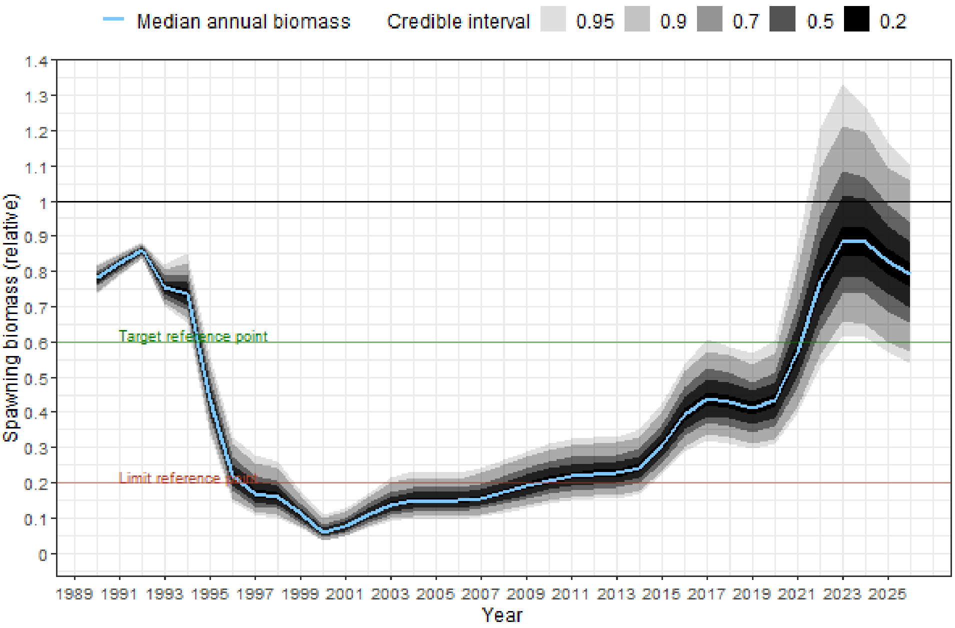

Figure D.64: Relative spawning biomass for the Slower growth profile scenario

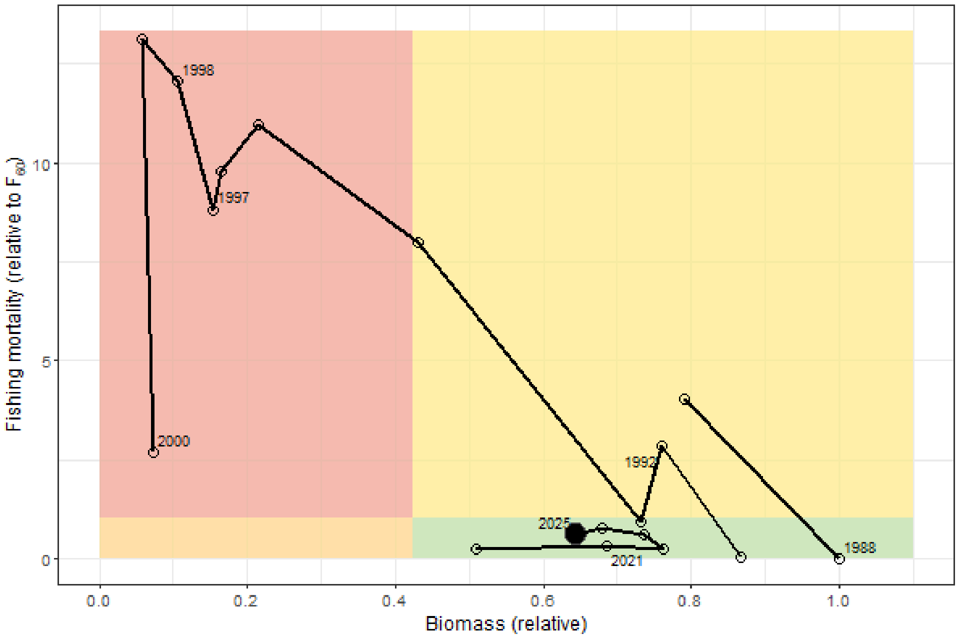

Figure D.65: Phase plot for the Slower growth profile scenario

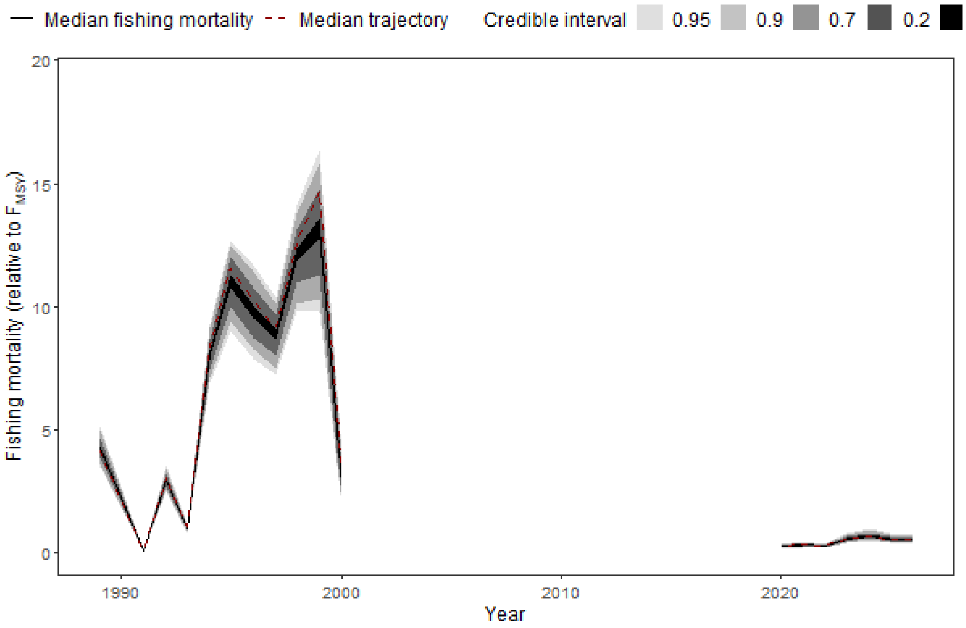

Figure D.66: Fishing mortality for the Slower growth profile scenario

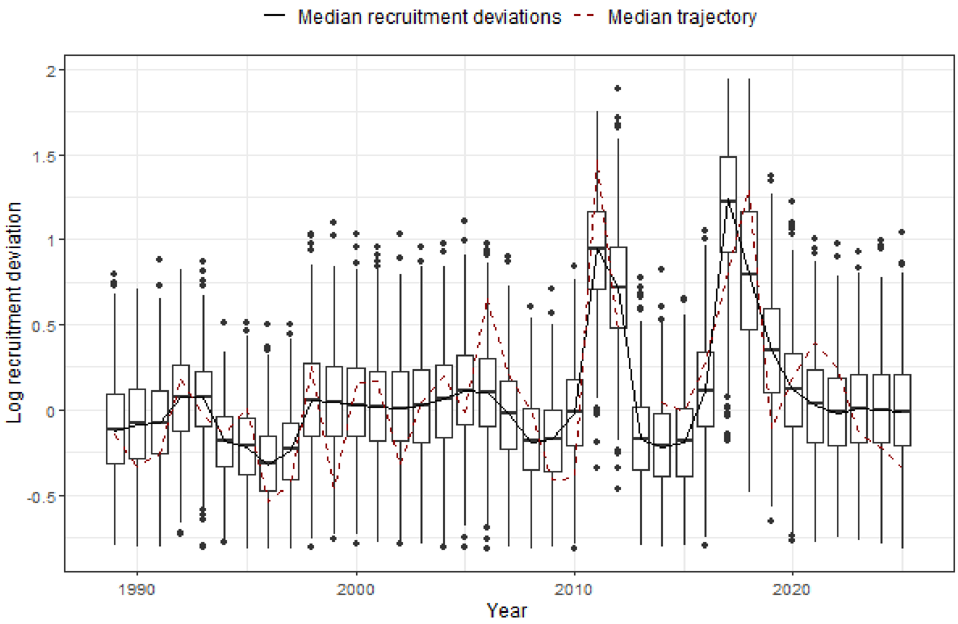

Figure D.67: Recruitment deviations for the Slower growth profile scenario

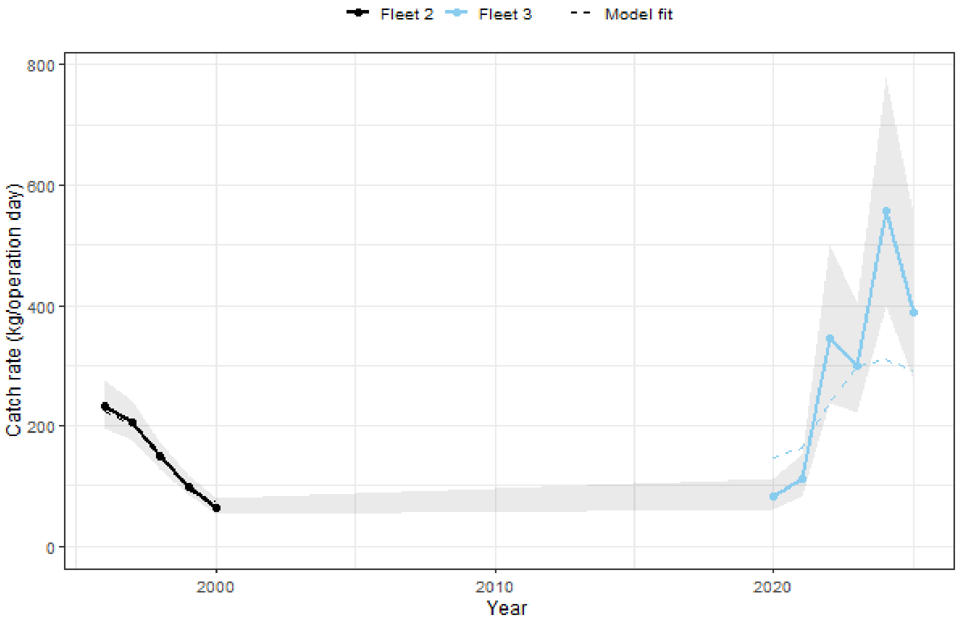

Figure D.68: CPUE fit for the Slower growth profile scenario

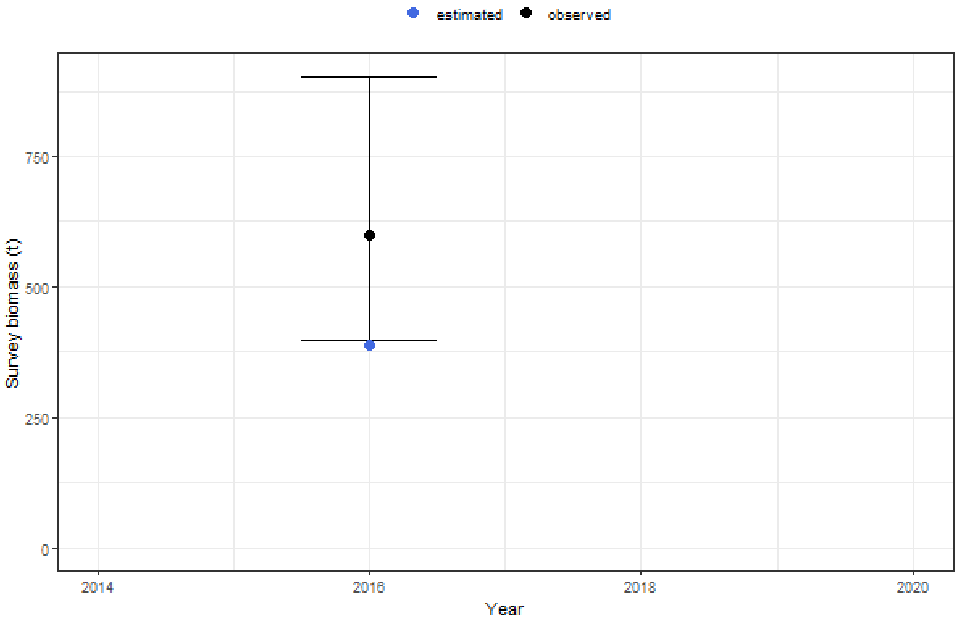

Figure D.69: Surveyed biomass fit for the Slower growth profile scenario

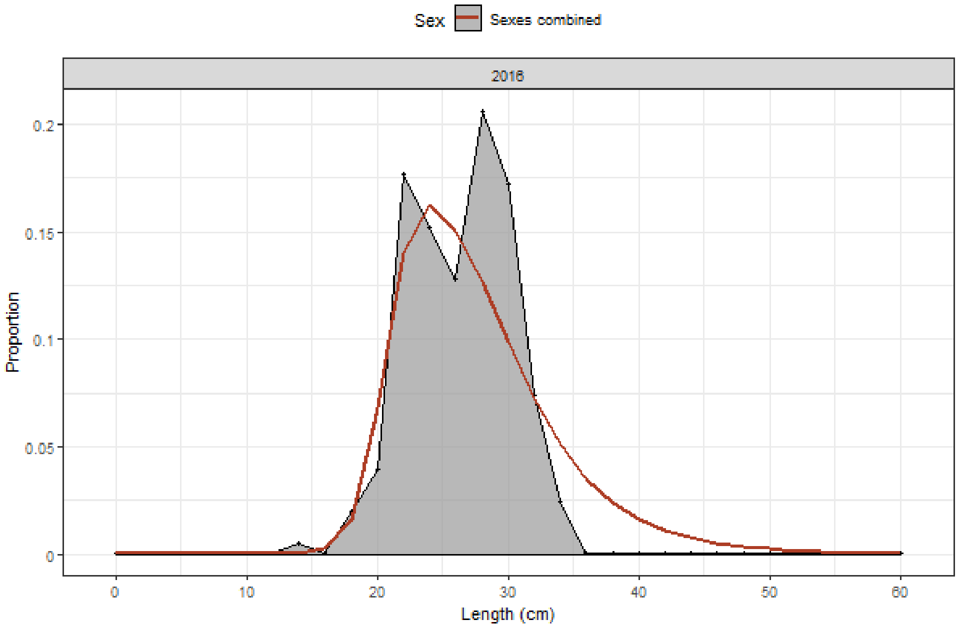

Figure D.70: Length composition fit for the Slower growth profile scenario

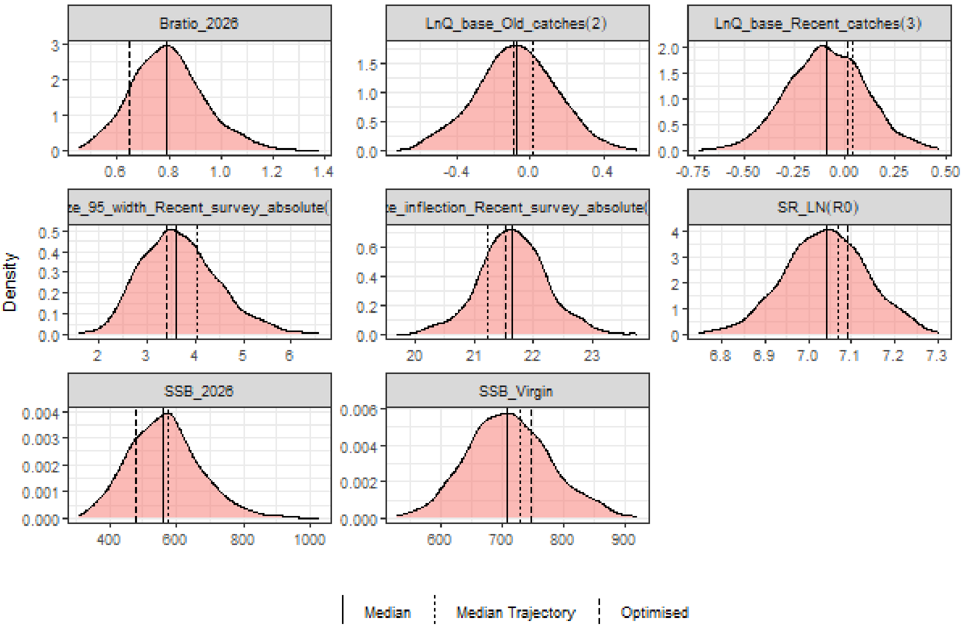

Figure D.71: MCMC parameter posterior densities for the Slower growth profile scenario

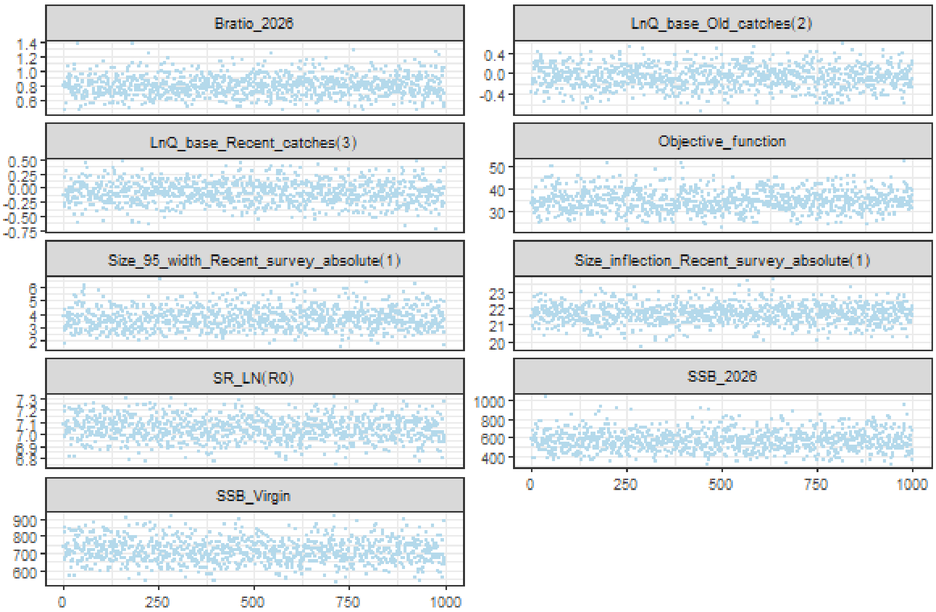

Figure D.72: MCMC trace plots for the Slower growth profile scenario

D.1.9 SigmaR = 0.4

This section presents results for the SigmaR = 0.4 scenario.

Table D.9: Summary of parameter estimates for black teatfish the SigmaR = 0.4 scenario. MCMC Median is median parameter value from robust MCMC scenarios. MCMC 2.5% and 97.5% indicates 95% credible interval.

Symbol	MCMC median	MCMC 2.5%	MCMC 97.5%
SR_LN(R0)	7.1	6.8	7.3
SSB_Virgin	748.1	586.6	959.9
SSB_2026	722.6	470.78	1104.91
Bratio_2026	1	0.6	1.5
LnQ_base_Old_catches(2)	-0.3	-0.8	0.1
LnQ_base_Recent_catches(3)	-0.01	-0.43	0.41
Size_inflection_Recent_survey_absolute(1)	21.2	19.6	22.5
Size_95%width_Recent_survey_absolute(1)	3.7	2.2	5.9

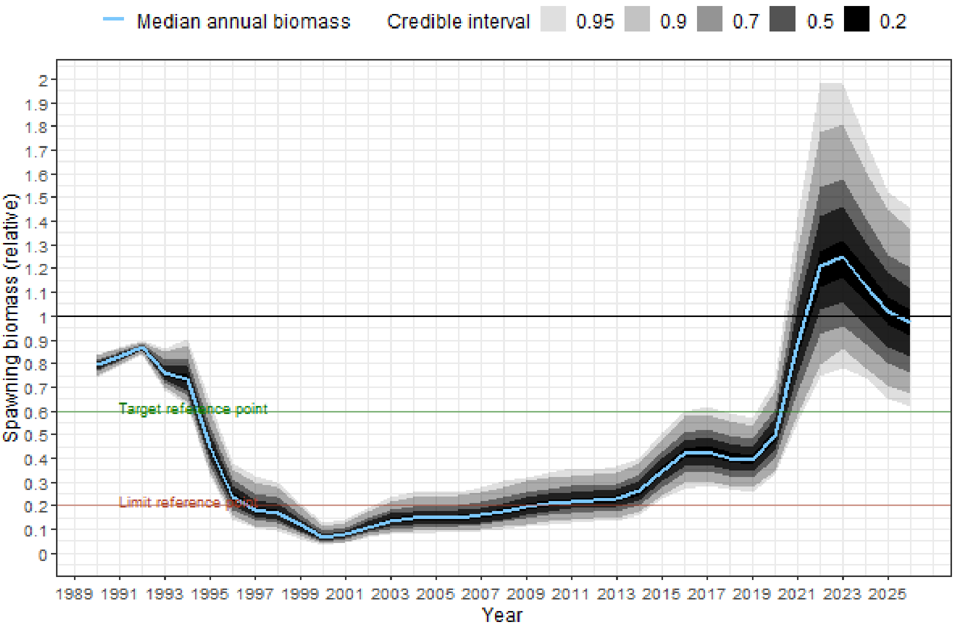

Figure D.73: Relative spawning biomass for the SigmaR = 0.4 scenario

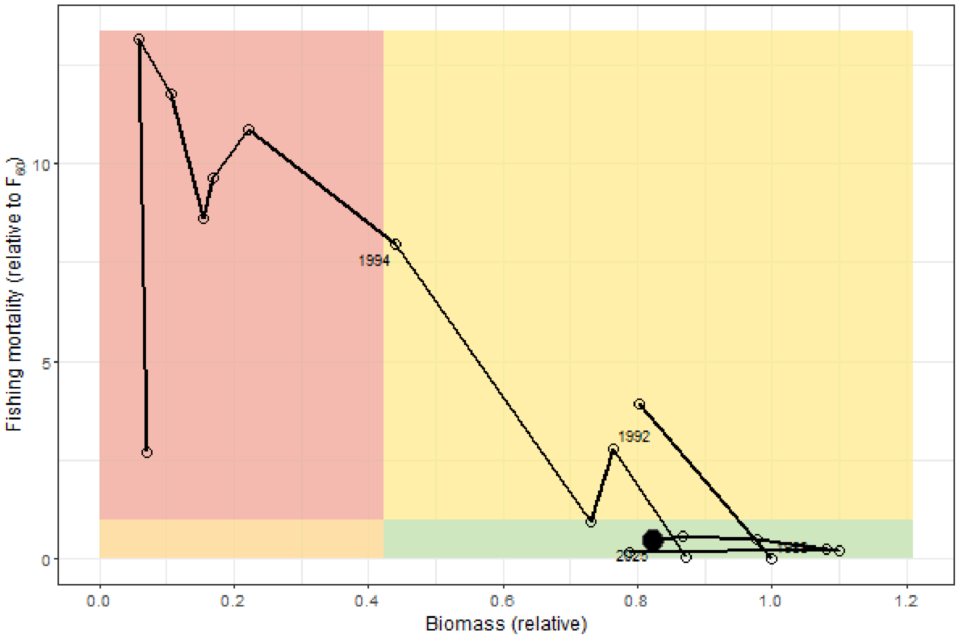

Figure D.74: Phase plot for the SigmaR = 0.4 scenario

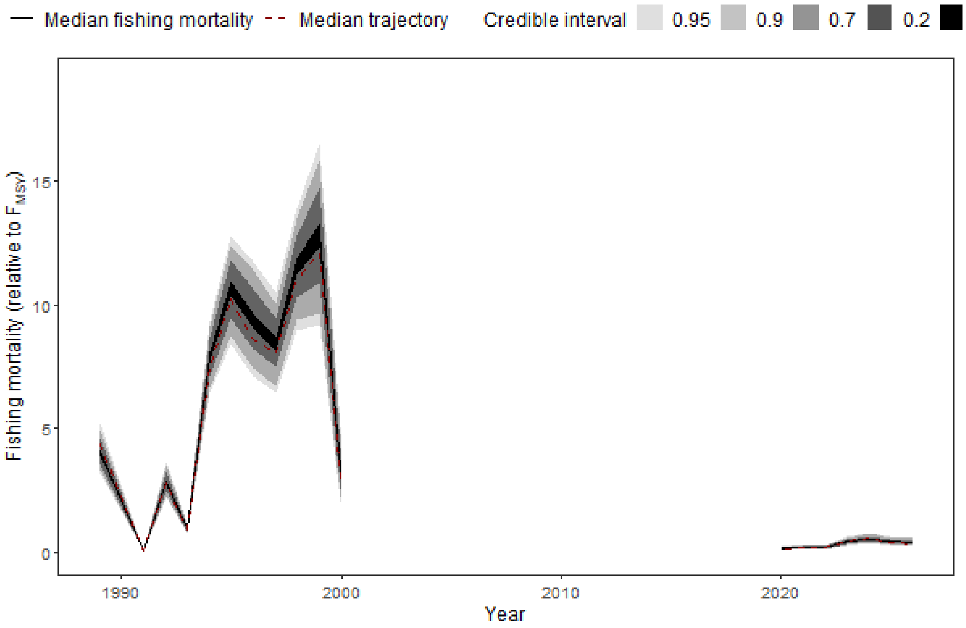

Figure D.75: Fishing mortality for the SigmaR = 0.4 scenario

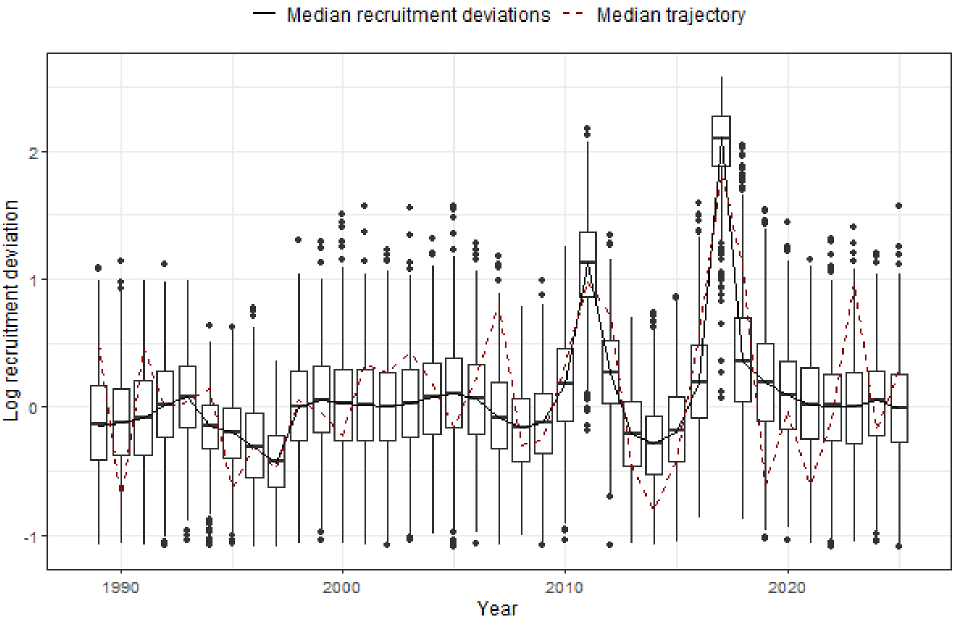

Figure D.76: Recruitment deviations for the SigmaR = 0.4 scenario

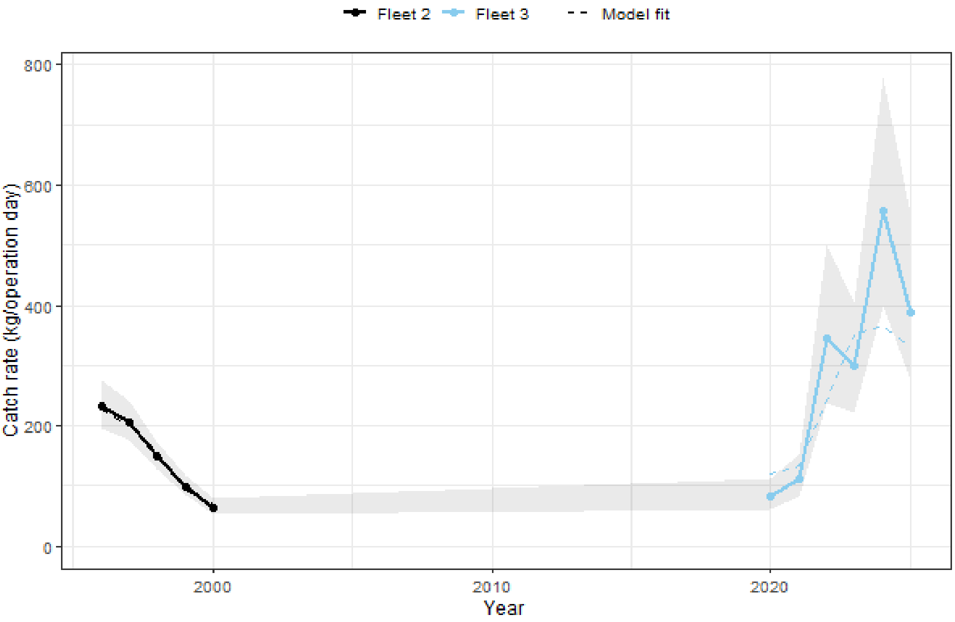

Figure D.77: CPUE fit for the SigmaR = 0.4 scenario

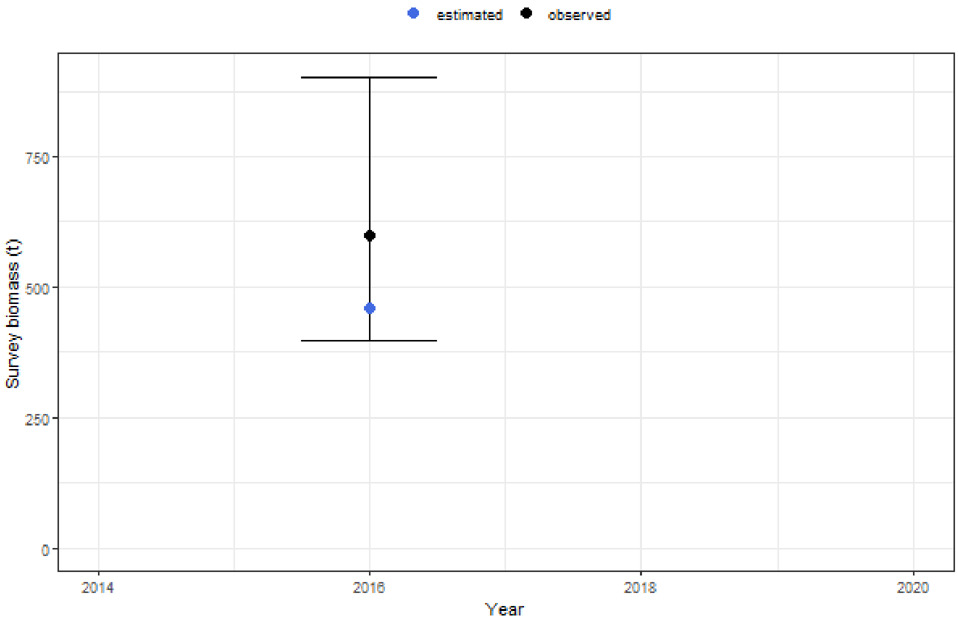

Figure D.78: Surveyed biomass fit for the SigmaR = 0.4 scenario

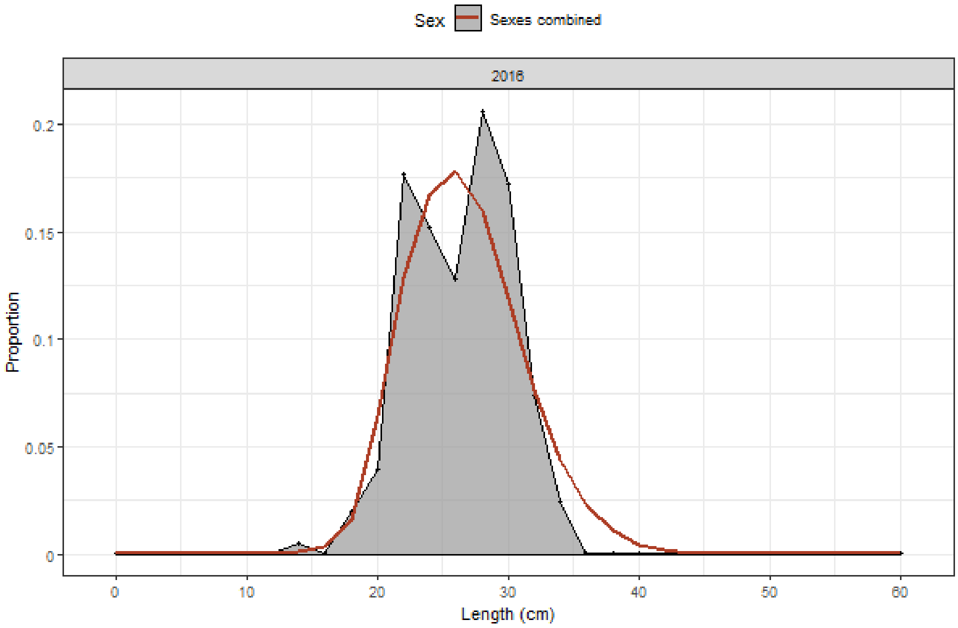

Figure D.79: Length composition fit for the SigmaR = 0.4 scenario

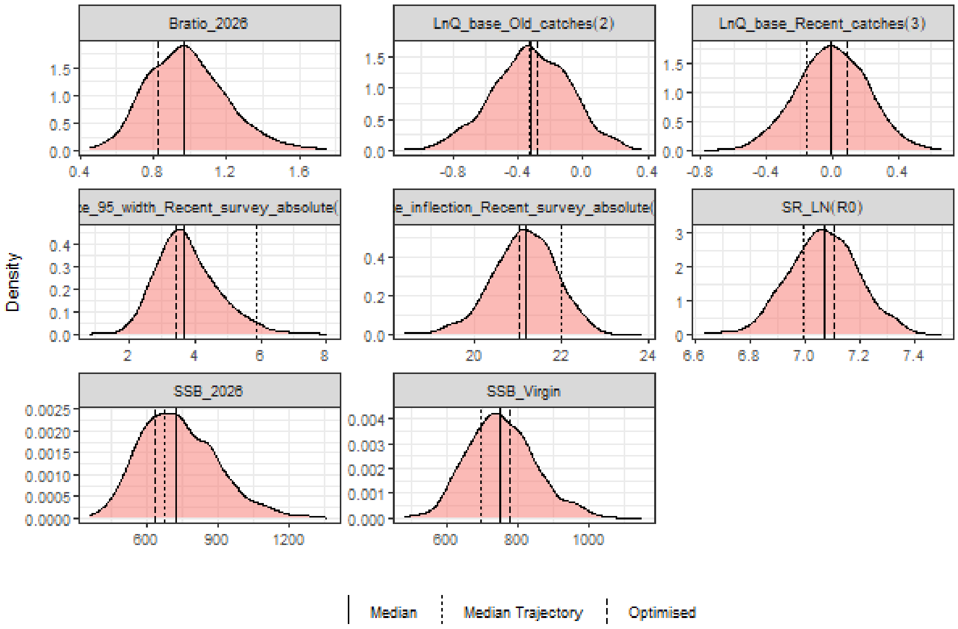

Figure D.80: MCMC parameter posterior densities for the SigmaR = 0.4 scenario

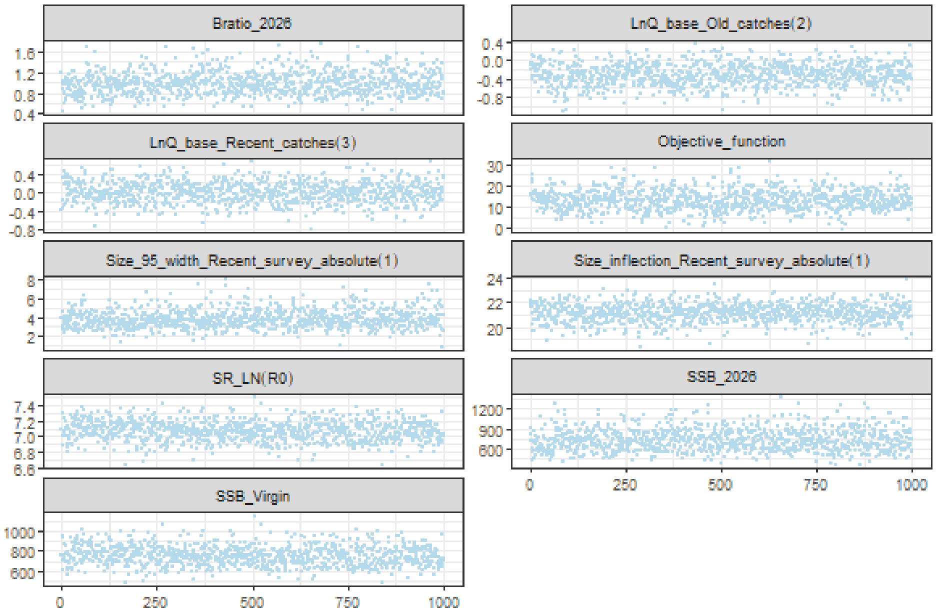

Figure D.81: MCMC trace plots for the SigmaR = 0.4 scenario

D.1.10 SigmaR = 0.6

This section presents results for the SigmaR = 0.6 scenario.

Table D.10: Summary of parameter estimates for black teatfish the SigmaR = 0.6 scenario. MCMC Median is median parameter value from robust MCMC scenarios. MCMC 2.5% and 97.5% indicates 95% credible interval.

Symbol	MCMC median	MCMC 2.5%	MCMC 97.5%
SR_LN(R0)	7.1	6.8	7.5
SSB_Virgin	805.2	560.2	1170.2
SSB_2026	921.15	540.32	1592.58
Bratio_2026	1.1	0.7	1.9
LnQ_base_Old_catches(2)	-0.4	-1.1	0.2
LnQ_base_Recent_catches(3)	-0.25	-0.77	0.28
Size_inflection_Recent_survey_absolute(1)	20.9	19.1	22.8
Size_95%width_Recent_survey_absolute(1)	3.8	2	7

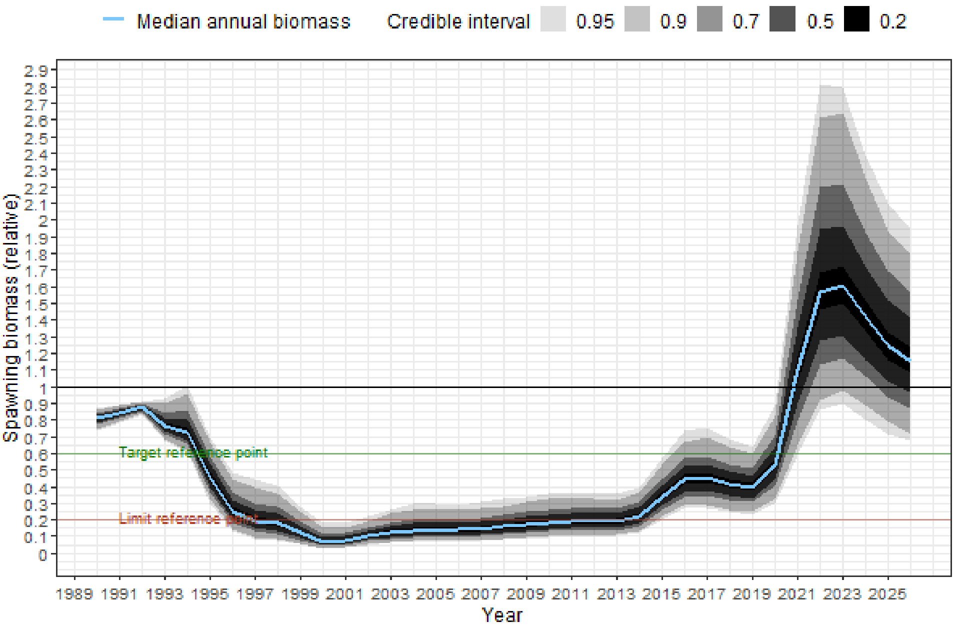

Figure D.82: Relative spawning biomass for the SigmaR = 0.6 scenario

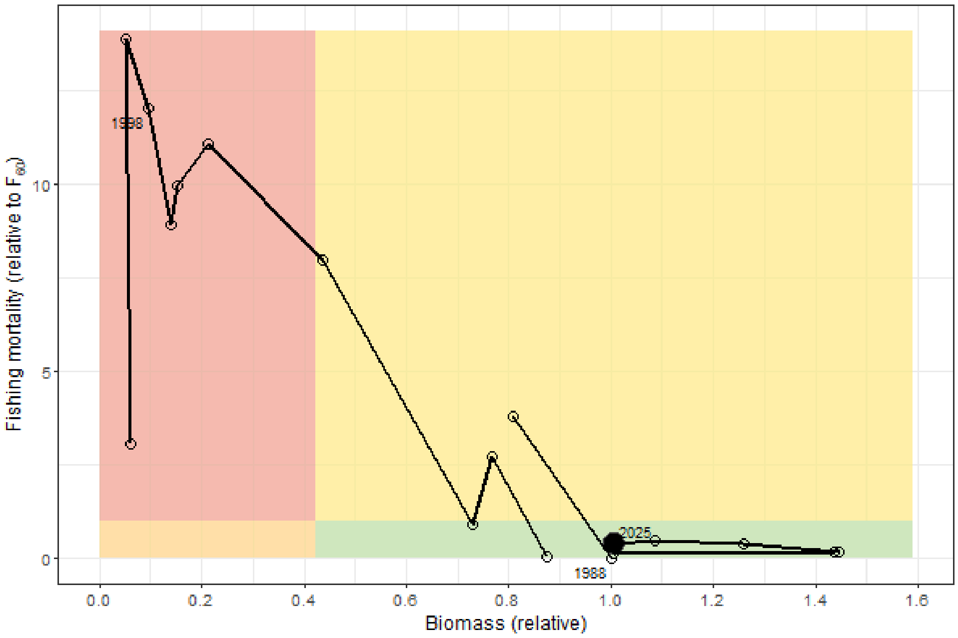

Figure D.83: Phase plot for the SigmaR = 0.6 scenario

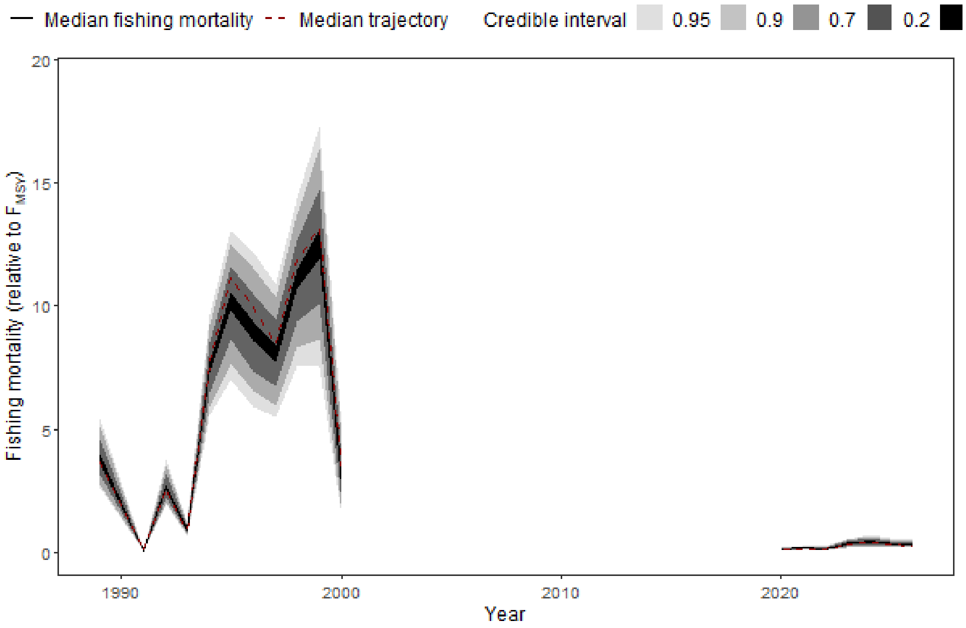

Figure D.84: Fishing mortality for the SigmaR = 0.6 scenario

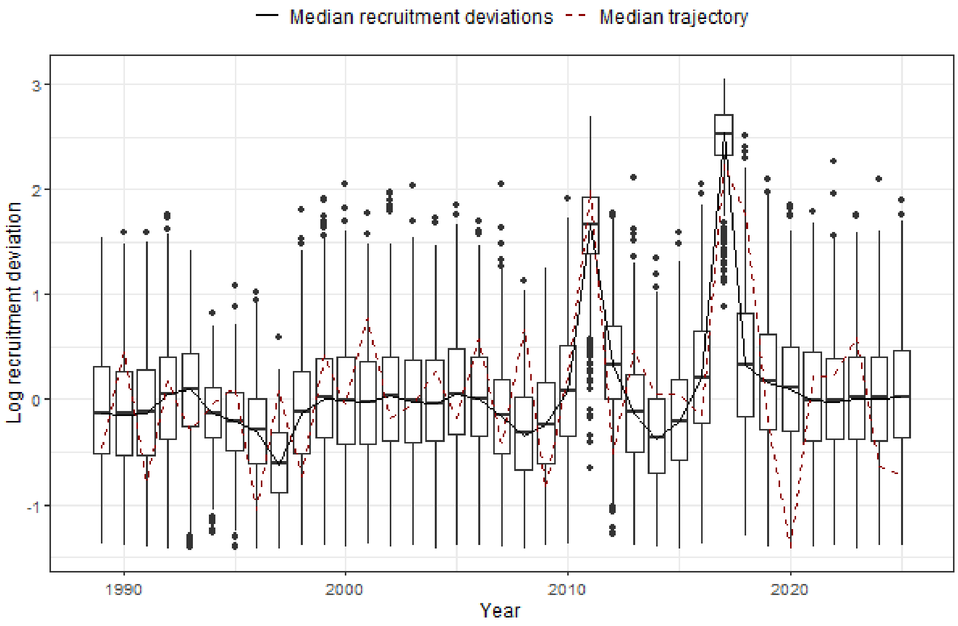

Figure D.85: Recruitment deviations for the SigmaR = 0.6 scenario

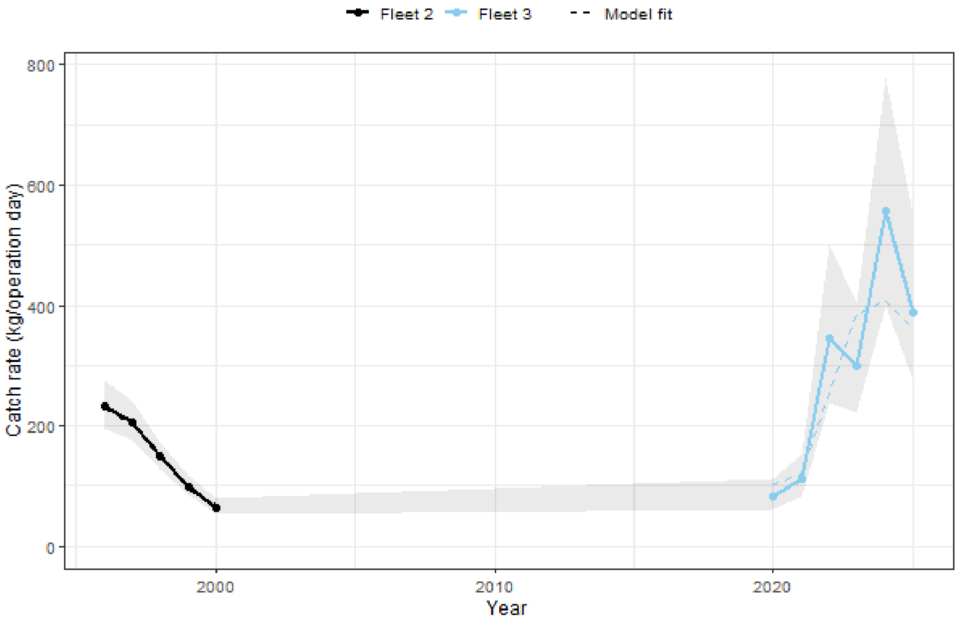

Figure D.86: CPUE fit for the SigmaR = 0.6 scenario

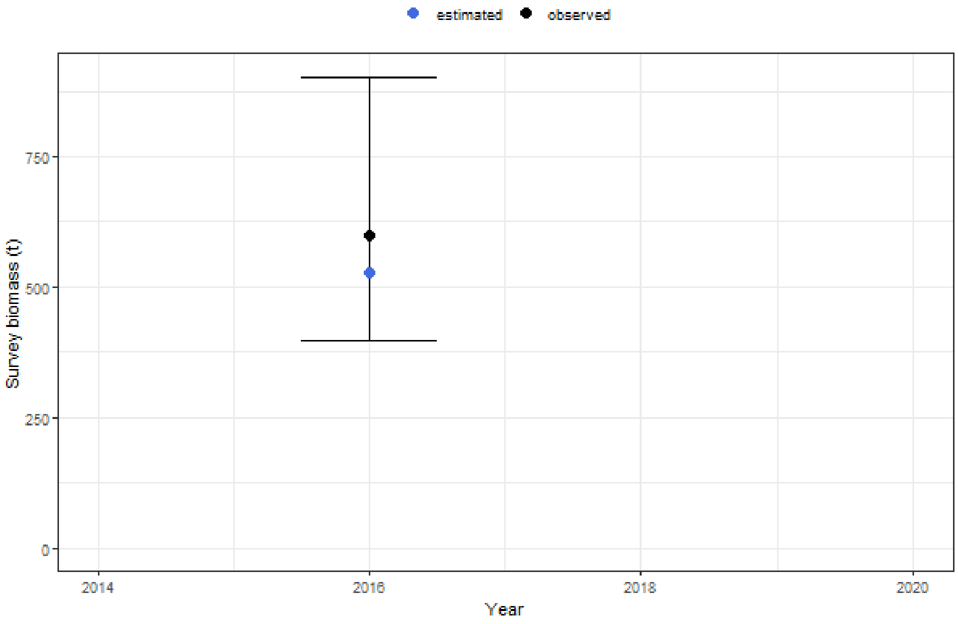

Figure D.87: Surveyed biomass fit for the SigmaR = 0.6 scenario

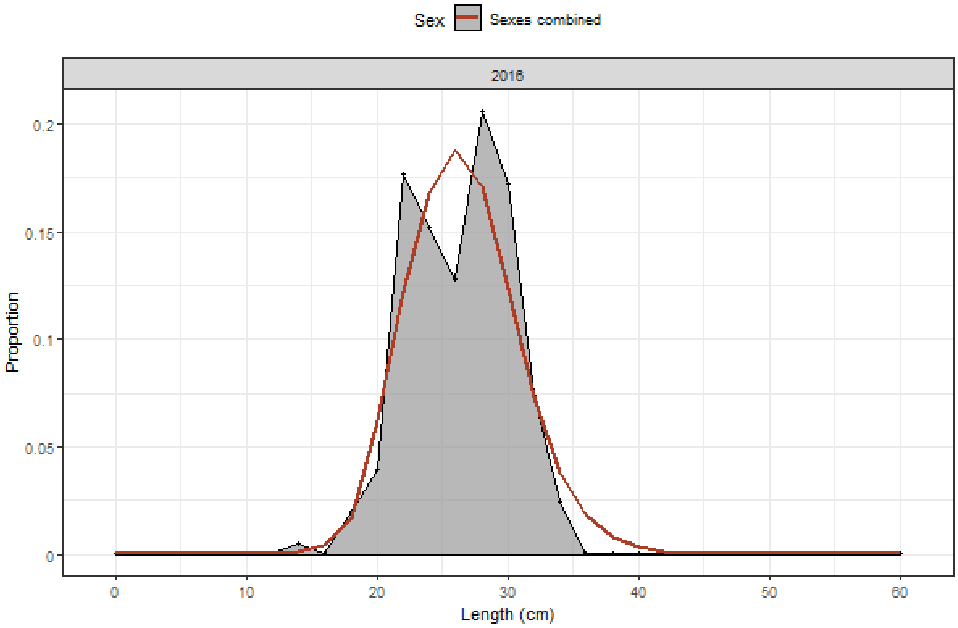

Figure D.88: Length composition fit for the SigmaR = 0.6 scenario

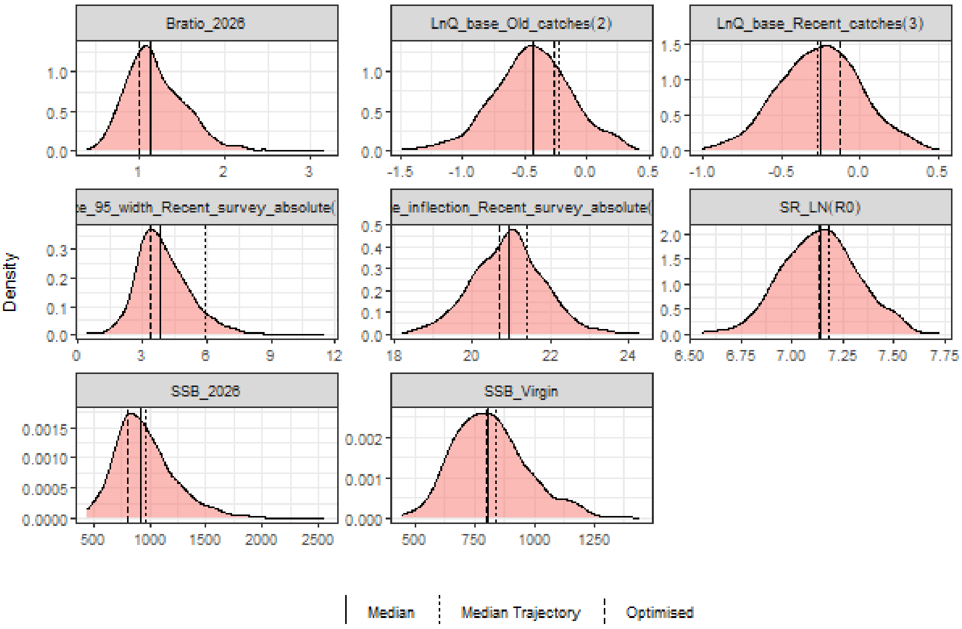

Figure D.89: MCMC parameter posterior densities for the SigmaR = 0.6 scenario

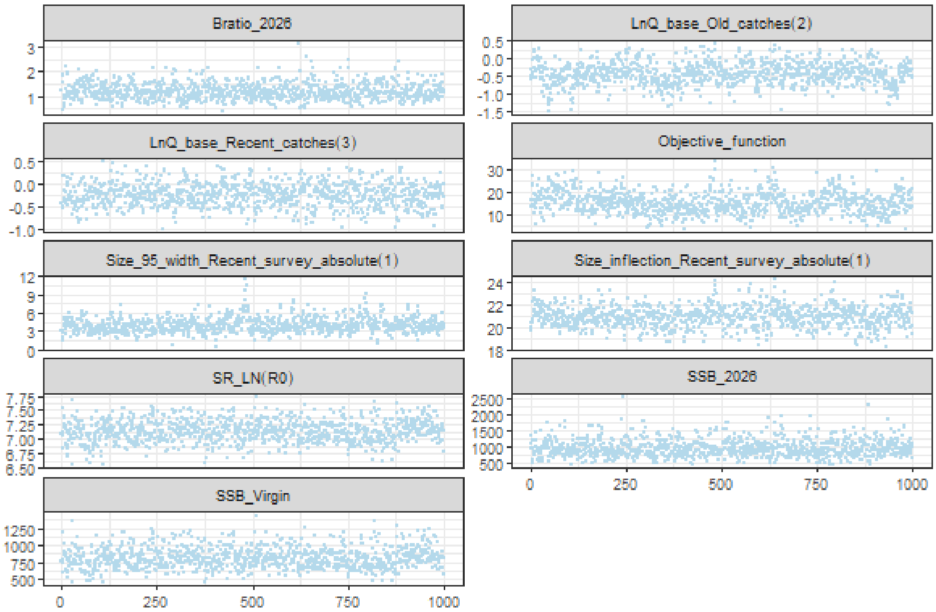

Figure D.90: MCMC trace plots for the SigmaR = 0.6 scenario

D.1.11 Historical survey and virgin biomass estimates included

This section presents results for the Historical survey and virgin biomass estimates included scenario.

Table D.11: Summary of parameter estimates for black teatfish the Historical survey and virgin biomass estimates included scenario. MCMC Median is median parameter value from robust MCMC scenarios. MCMC 2.5% and 97.5% indicates 95% credible interval.

Symbol	MCMC median	MCMC 2.5%	MCMC 97.5%
SR_LN(R0)	8.5	8.2	8.8
SSB_Virgin	3108	2228.9	4364.2
SSB_2026	3710.03	2463.61	5515.39
Bratio_2026	1.2	0.9	1.6
LnQ_base_Old_catches(2)	-3.2	-3.6	-2.8
LnQ_base_Recent_catches(3)	-1.76	-2.17	-1.35
Size_inflection_Recent_survey_absolute(1)	21.3	20.2	22.5
Size_95%width_Recent_survey_absolute(1)	3.3	2.1	4.8

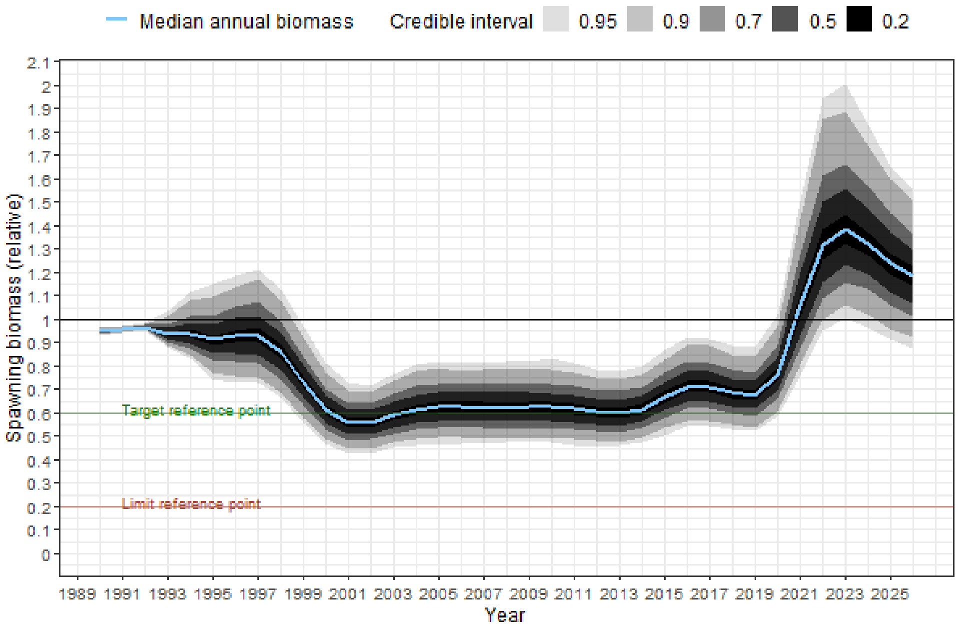

Figure D.91: Relative spawning biomass for the Historical survey and virgin biomass estimates included scenario

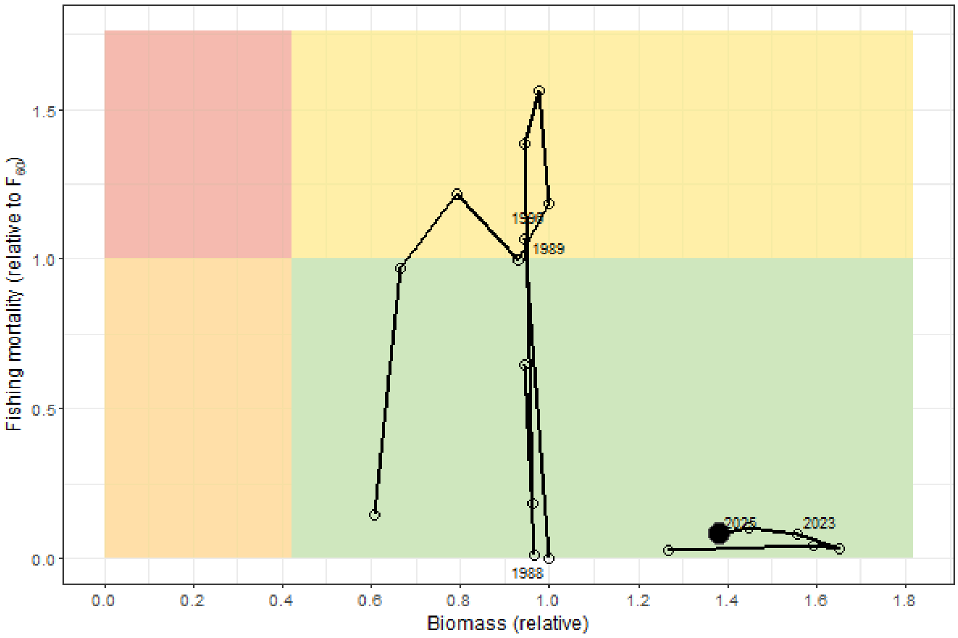

Figure D.92: Phase plot for the Historical survey and virgin biomass estimates included scenario

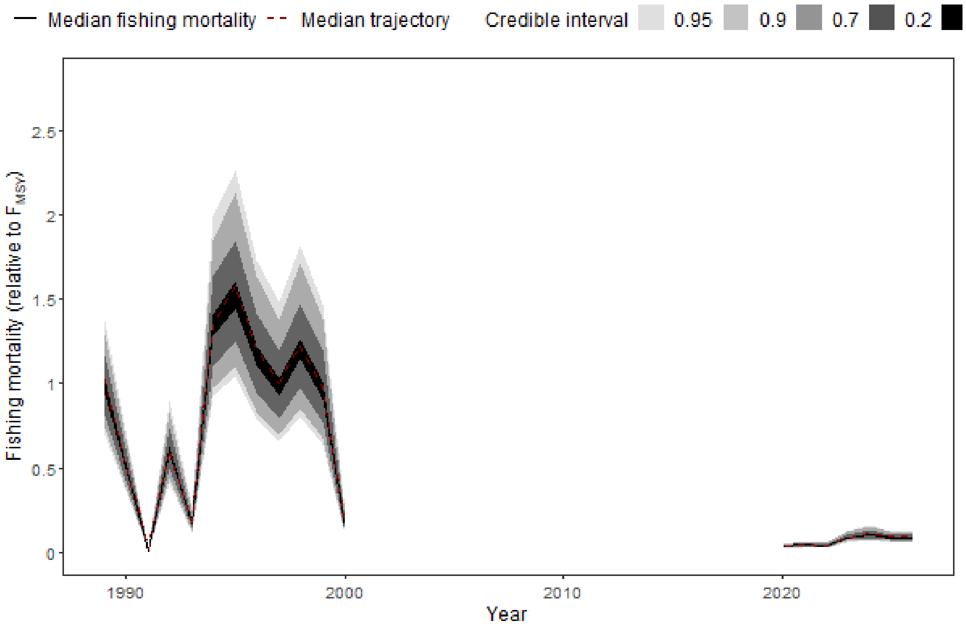

Figure D.93: Fishing mortality for the Historical survey and virgin biomass estimates included scenario

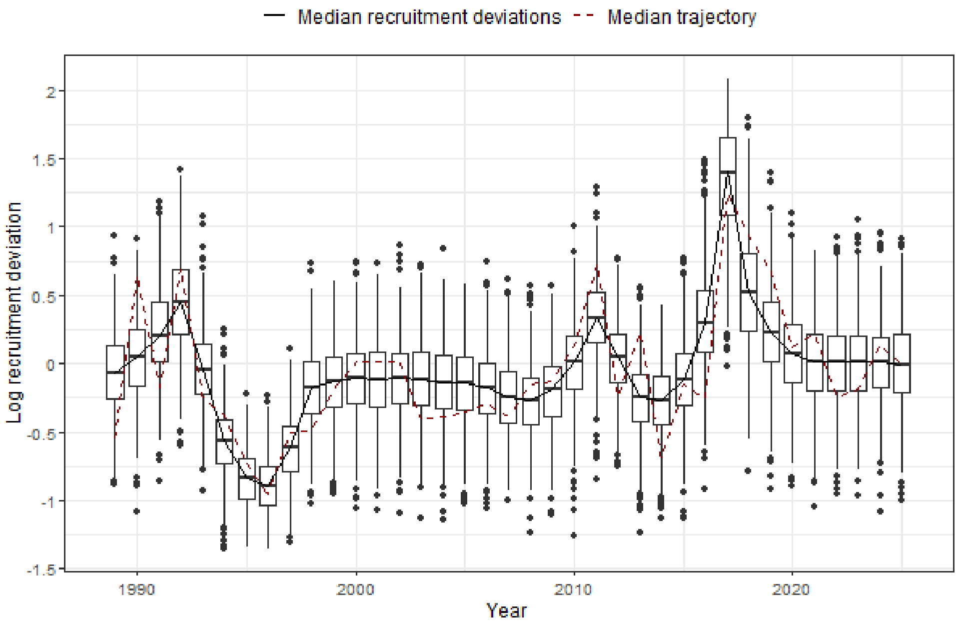

Figure D.94: Recruitment deviations for the Historical survey and virgin biomass estimates included scenario

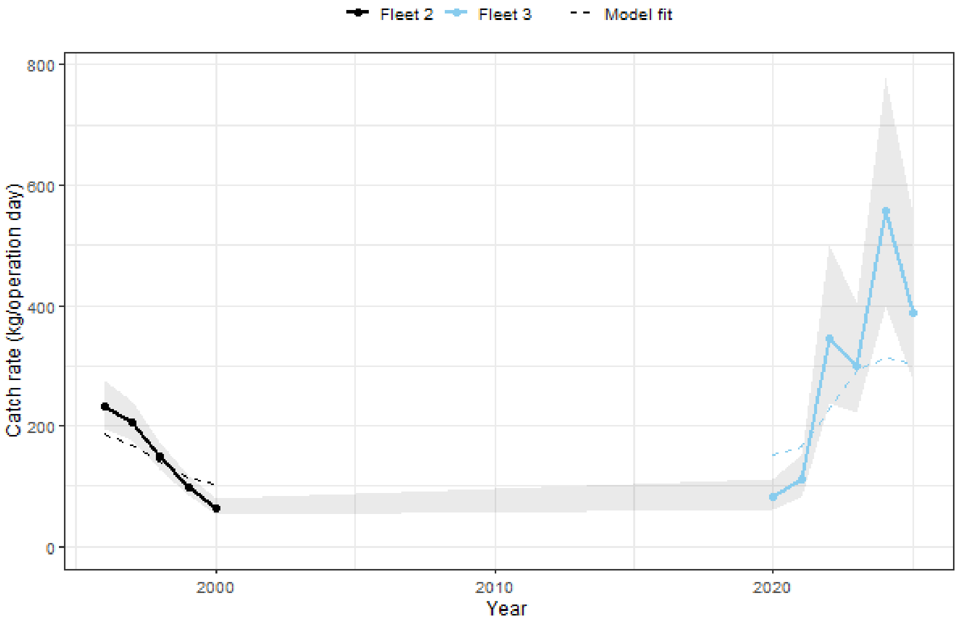

Figure D.95: CPUE fit for the Historical survey and virgin biomass estimates included scenario

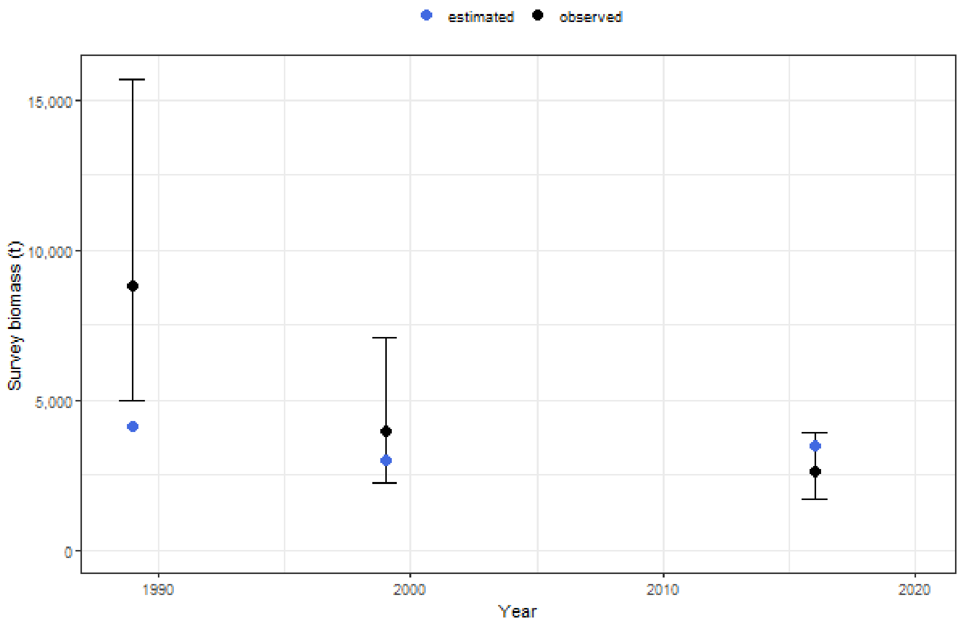

Figure D.96: Surveyed biomass fit for the Historical survey and virgin biomass estimates included scenario

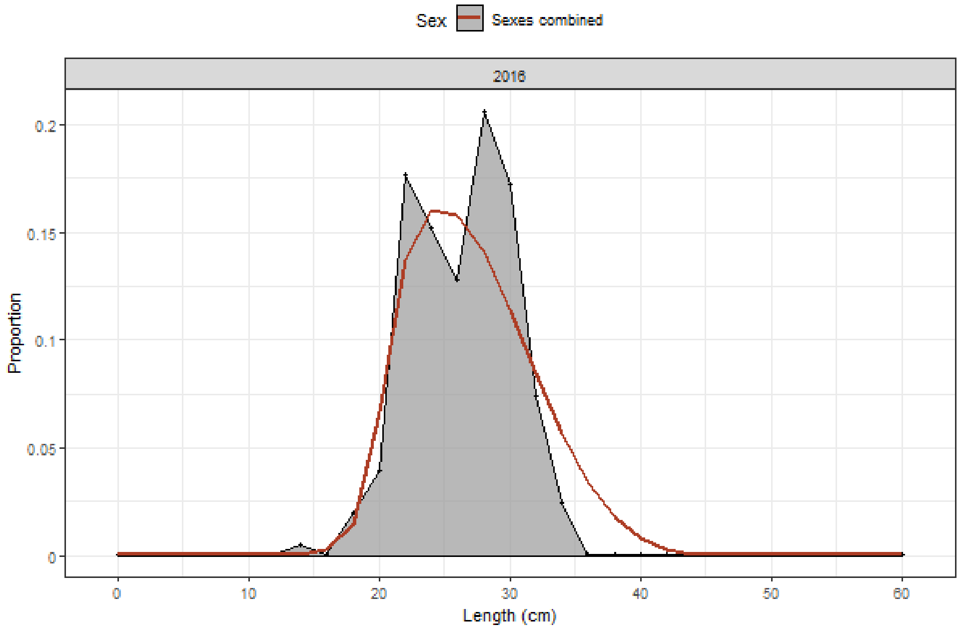

Figure D.97: Length composition fit for the Historical survey and virgin biomass estimates included scenario

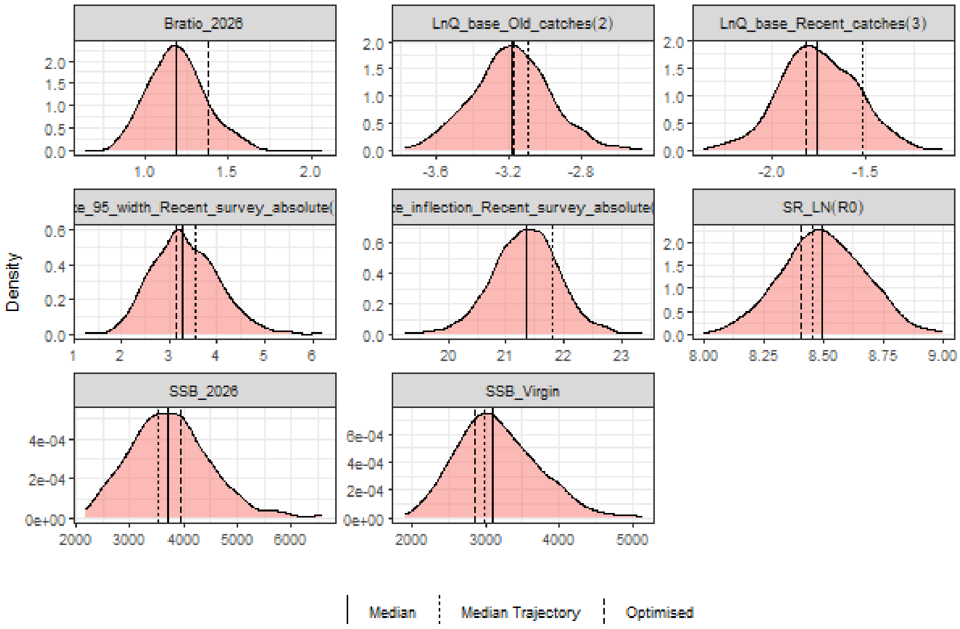

Figure D.98: MCMC parameter posterior densities for the Historical survey and virgin biomass estimates included scenario

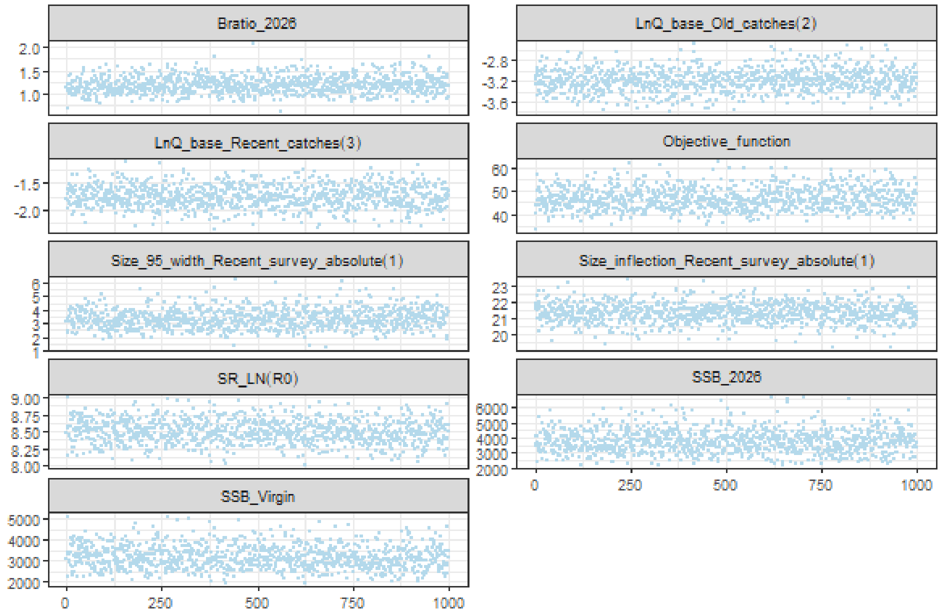

Figure D.99: MCMC trace plots for the Historical survey and virgin biomass estimates included scenario

D.1.12 Historical survey estimate included

This section presents results for the Historical survey estimate included scenario.

Table D.12: Summary of parameter estimates for black teatfish the Historical survey estimate included scenario. MCMC Median is median parameter value from robust MCMC scenarios. MCMC 2.5% and 97.5% indicates 95% credible interval.

Symbol	MCMC median	MCMC 2.5%	MCMC 97.5%
SR_LN(R0)	8.2	7.8	8.6
SSB_Virgin	2326.9	1544.3	3472.6
SSB_2026	2884.98	1832.01	4362.35
Bratio_2026	1.2	0.9	1.6
LnQ_base_Old_catches(2)	-2.9	-3.4	-2.4
LnQ_base_Recent_catches(3)	-1.53	-1.96	-1.07
Size_inflection_Recent_survey_absolute(1)	21.3	20.1	22.4
Size_95%width_Recent_survey_absolute(1)	3.3	2	4.9

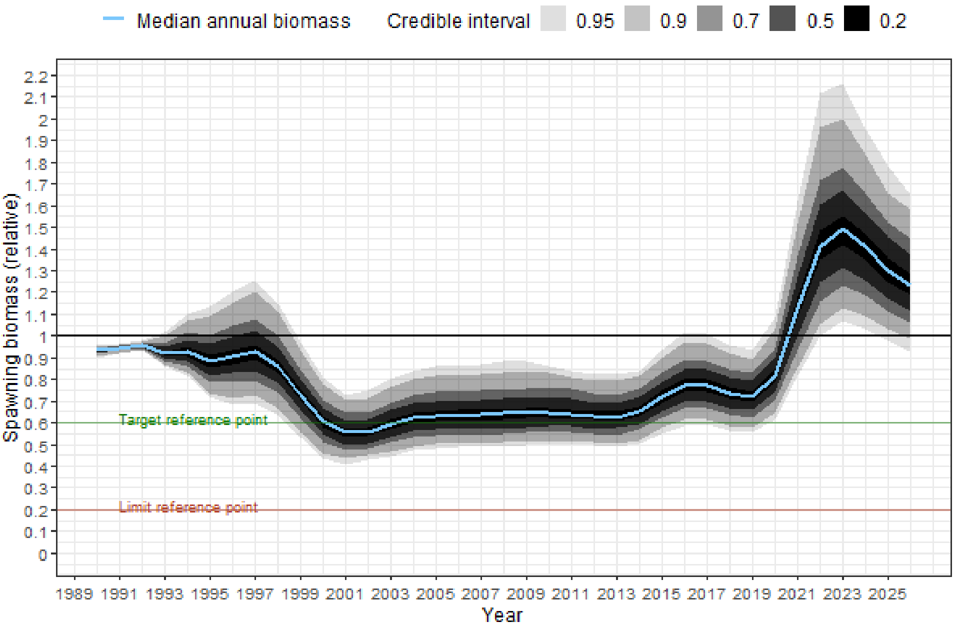

Figure D.100: Relative spawning biomass for the Historical survey estimate included scenario

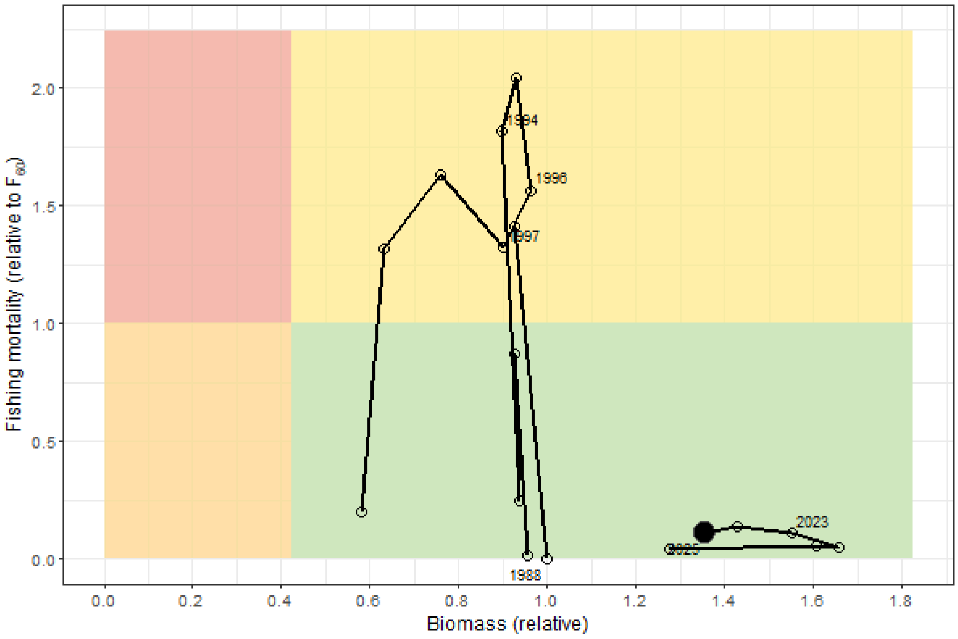

Figure D.101: Phase plot for the Historical survey estimate included scenario

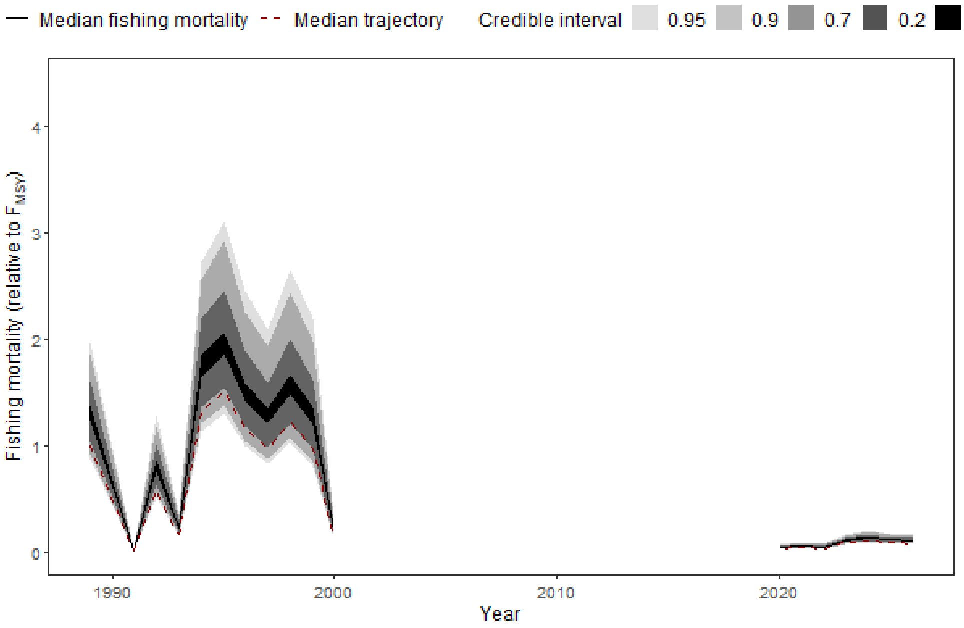

Figure D.102: Fishing mortality for the Historical survey estimate included scenario

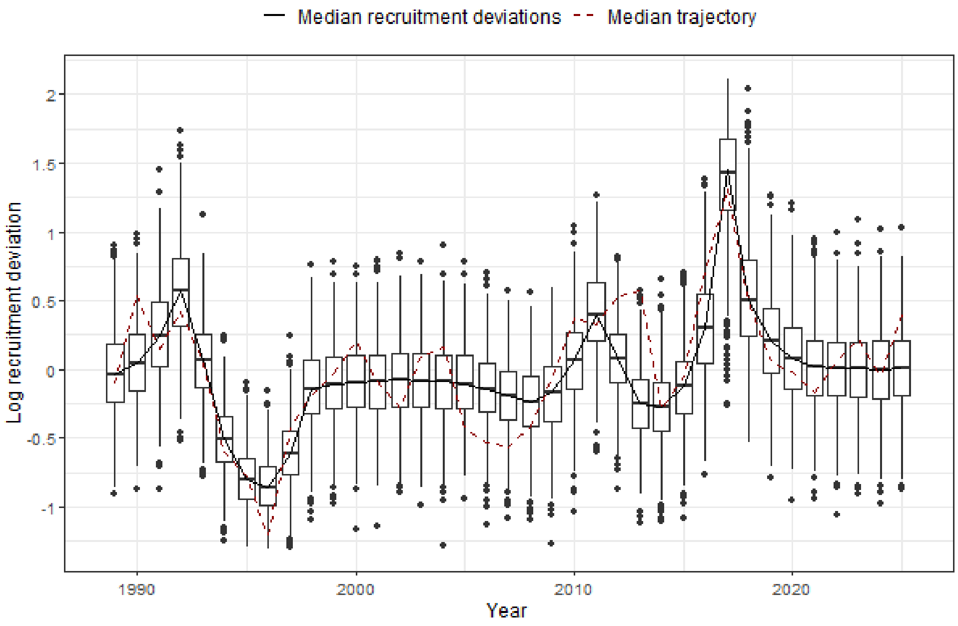

Figure D.103: Recruitment deviations for the Historical survey estimate included scenario

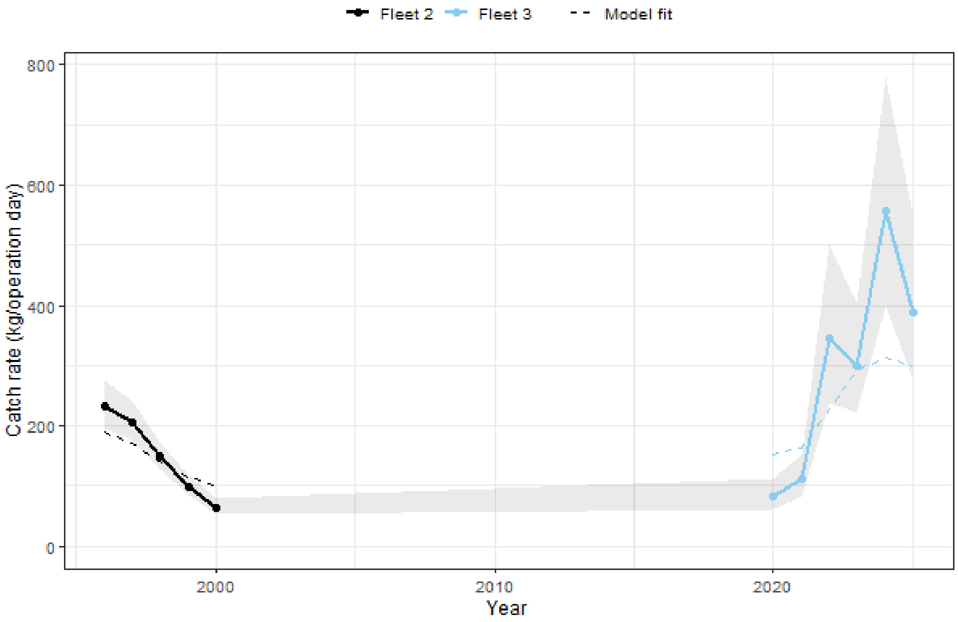

Figure D.104: CPUE fit for the Historical survey estimate included scenario

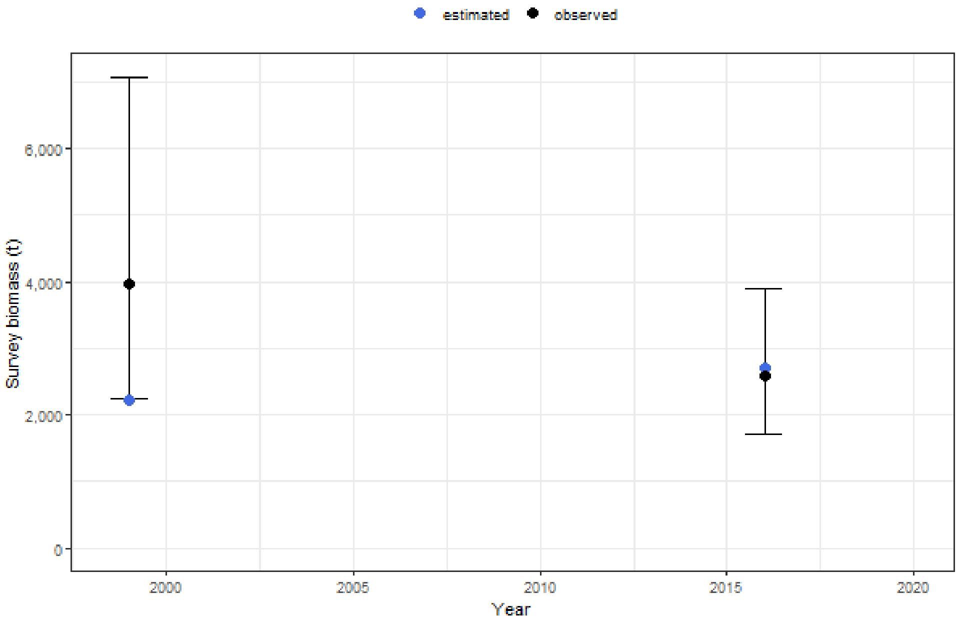

Figure D.105: Surveyed biomass fit for the Historical survey estimate included scenario

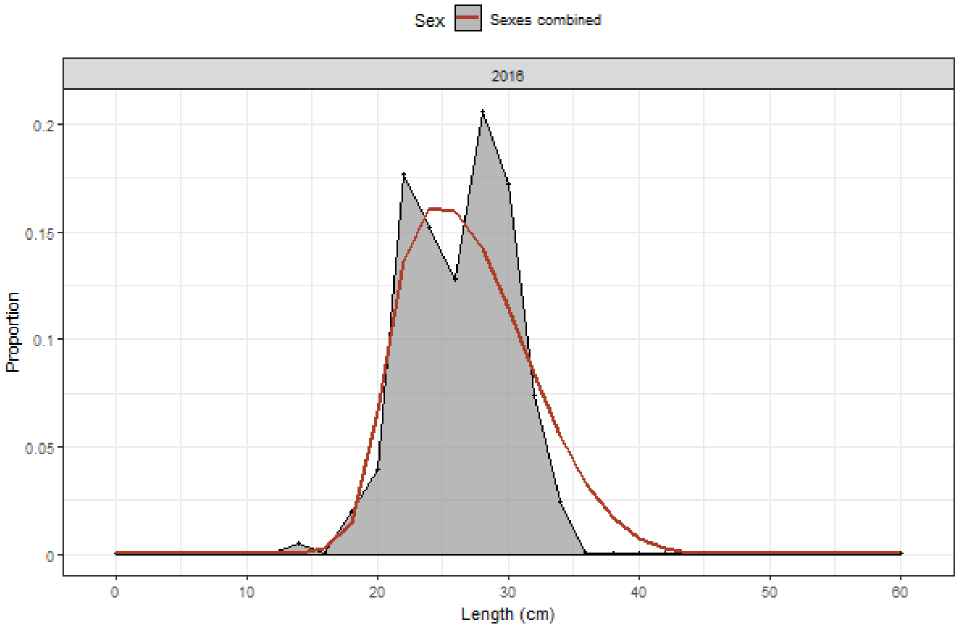

Figure D.106: Length composition fit for the Historical survey estimate included scenario

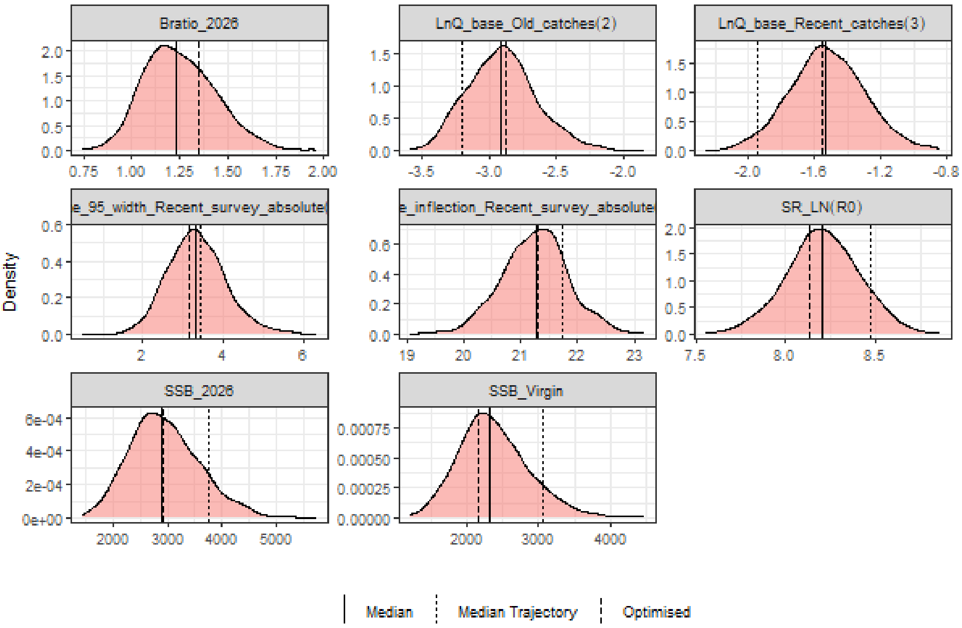

Figure D.107: MCMC parameter posterior densities for the Historical survey estimate included scenario

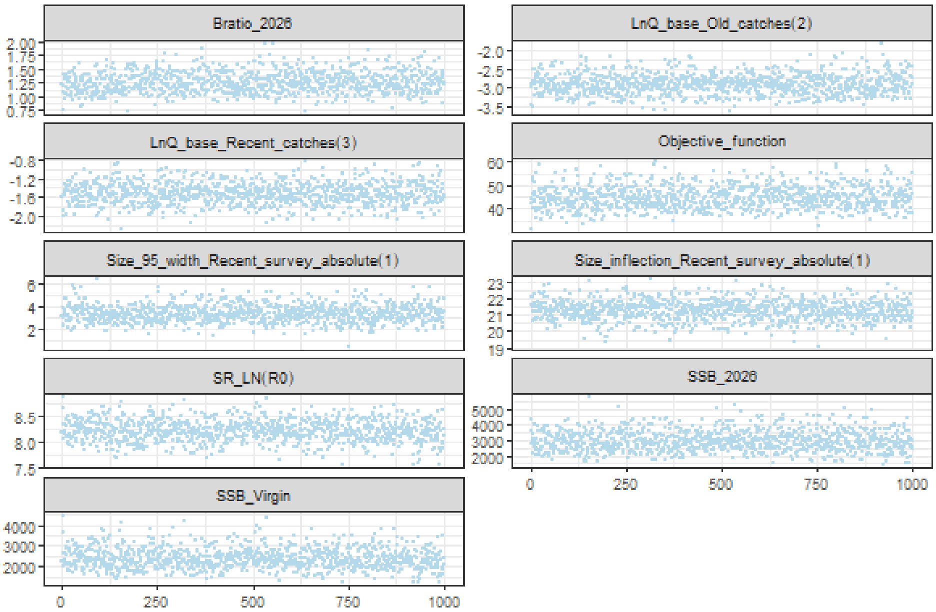

Figure D.108: MCMC trace plots for the Historical survey estimate included scenario

D.2 South stock

D.2.1 Base Case

This section presents results for the Base Case scenario.

Table D.13: Summary of parameter estimates for black teatfish the Base Case scenario. MCMC Median is median parameter value from robust MCMC scenarios. MCMC 2.5% and 97.5% indicates 95% credible interval.

Symbol	MCMC median	MCMC 2.5%	MCMC 97.5%
SR_LN(R0)	8.6	8.1	9.1
SSB_Virgin	3500.9	2073.9	5786.3
SSB_2026	3508.68	2121.1	5568.96
Bratio_2026	1	0.8	1.3
LnQ_base_Old_catches(2)	-2.7	-3.2	-2.1
LnQ_base_Recent_catches(3)	-1.12	-1.57	-0.64
Size_inflection_Recent_survey_absolute(1)	19.2	17.2	21.4
Size_95%width_Recent_survey_absolute(1)	3.2	0.7	6.3

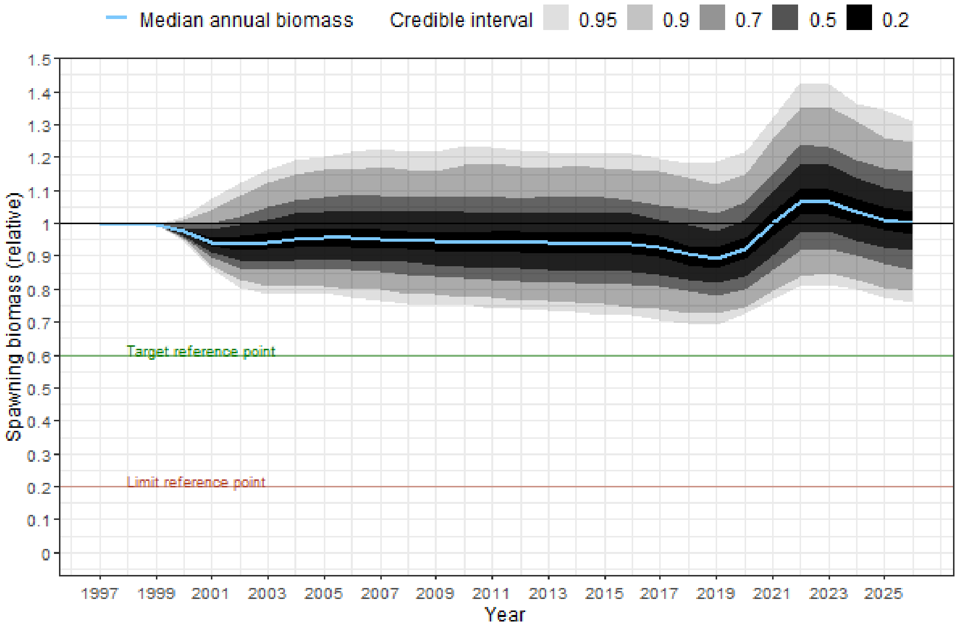

Figure D.109: Relative spawning biomass for the Base Case scenario

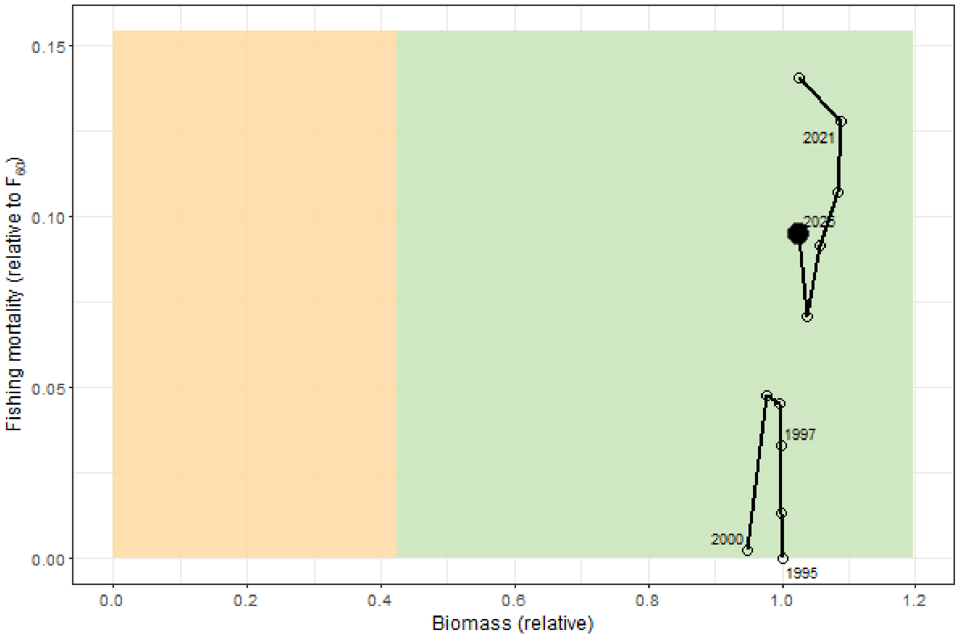

Figure D.110: Phase plot for the Base Case scenario

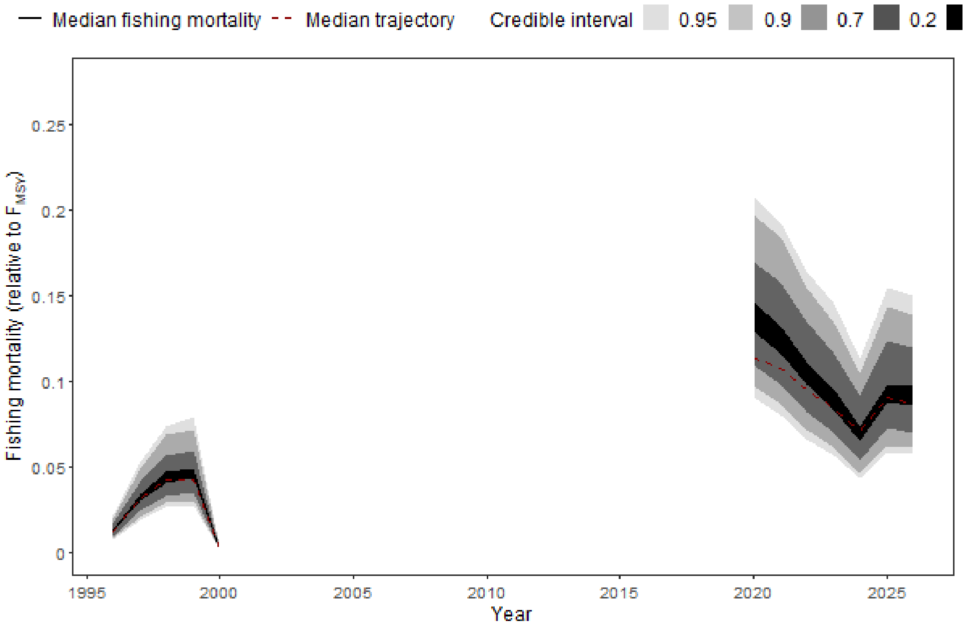

Figure D.111: Fishing mortality for the Base Case scenario

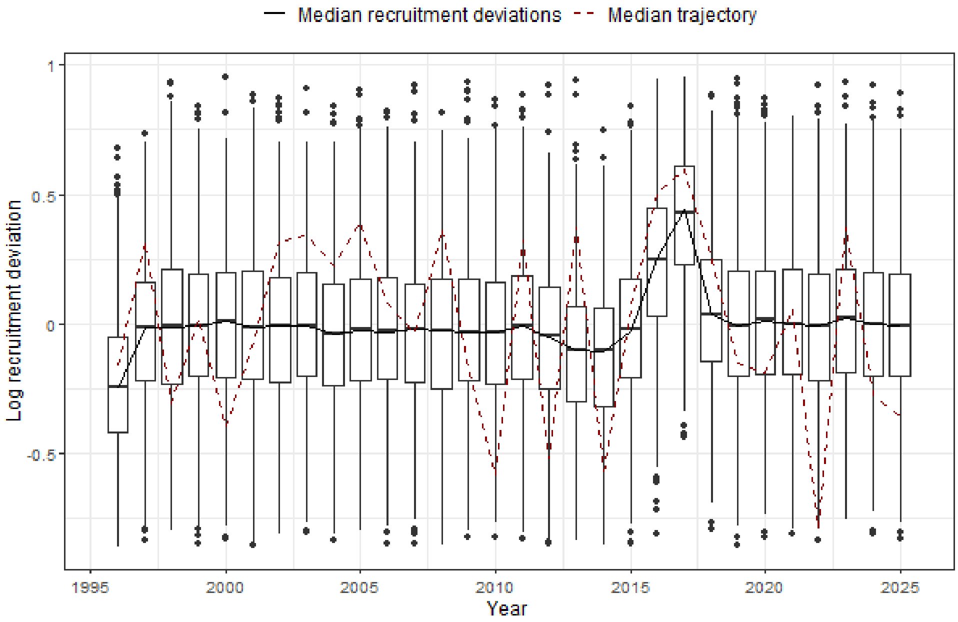

Figure D.112: Recruitment deviations for the Base Case scenario

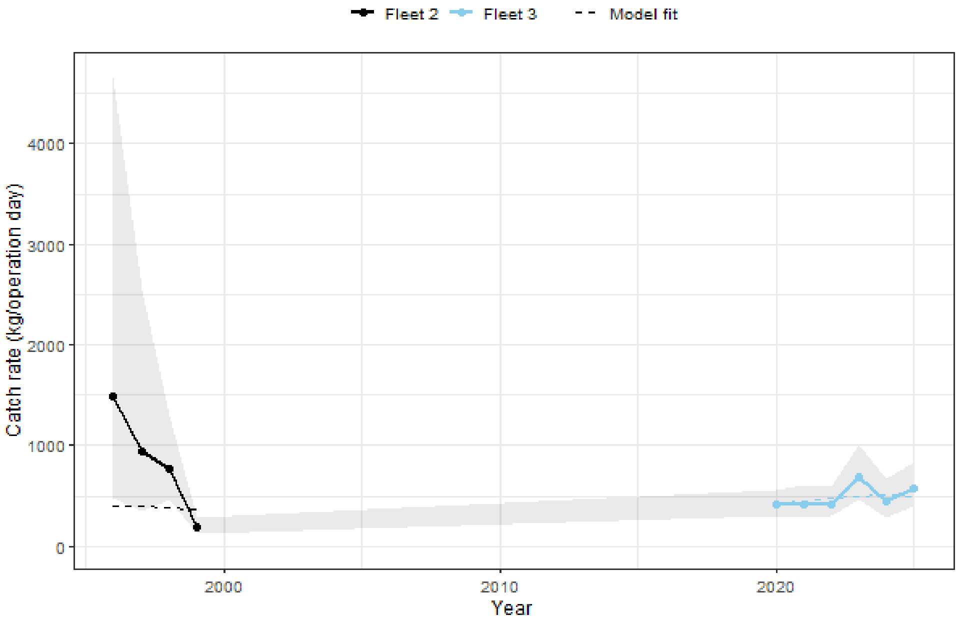

Figure D.113: CPUE fit for the Base Case scenario

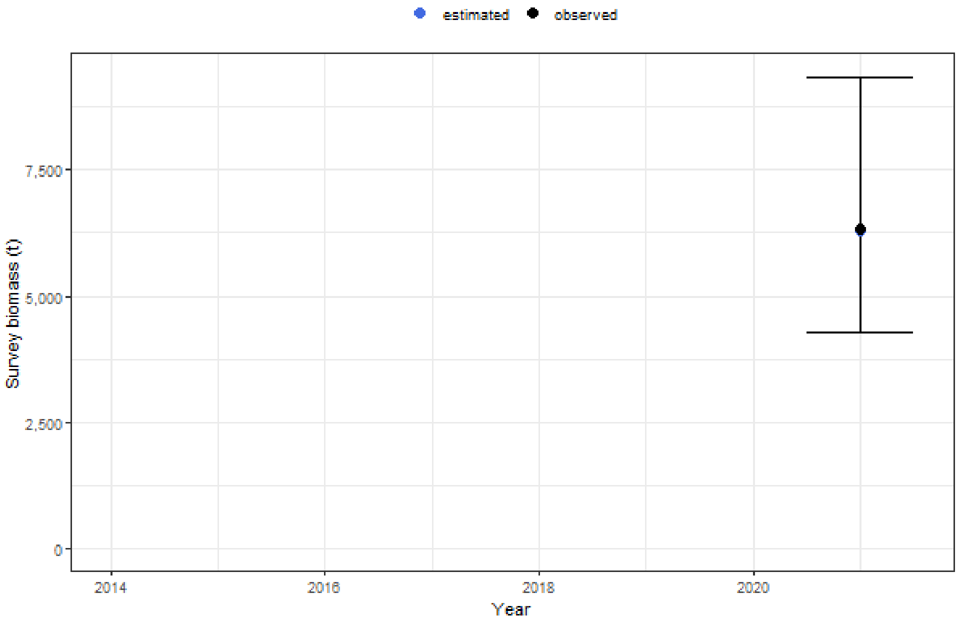

Figure D.114: Surveyed biomass fit for the Base Case scenario

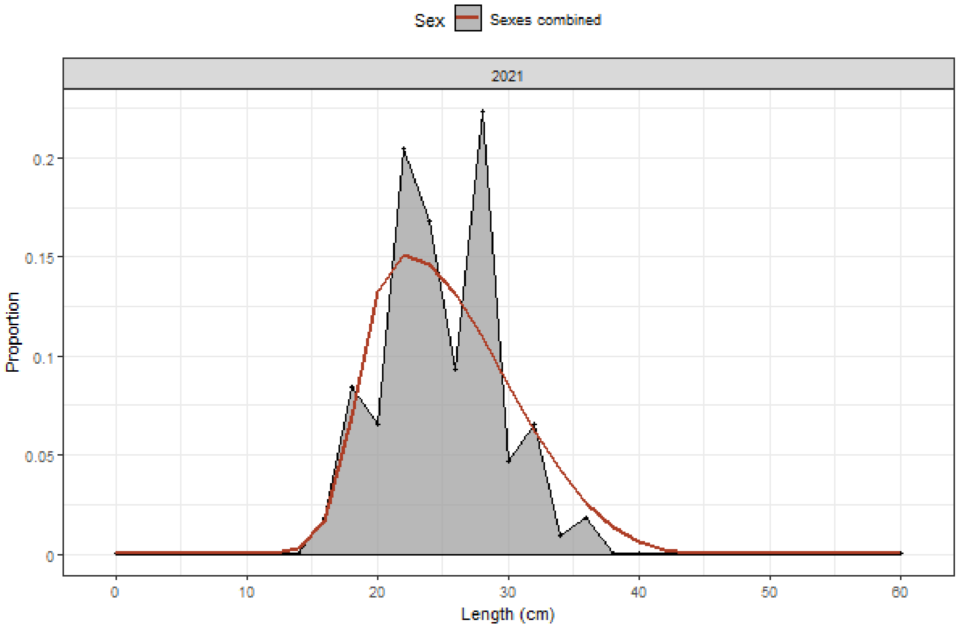

Figure D.115: Length composition fit for the Base Case scenario

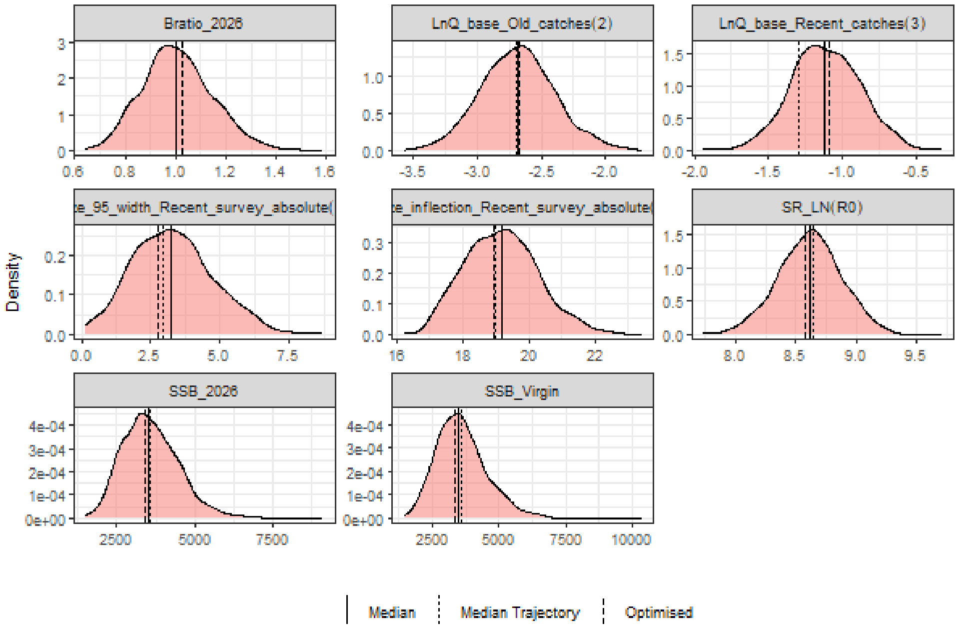

Figure D.116: MCMC parameter posterior densities for the Base Case scenario

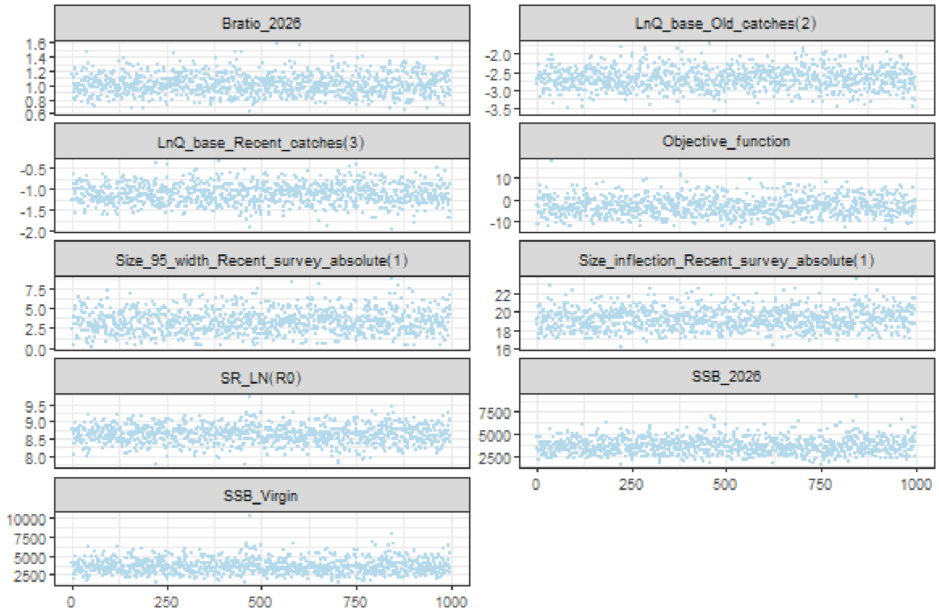

Figure D.117: MCMC trace plots for the Base Case scenario

D.2.2 Steepness = 0.5

This section presents results for the Steepness = 0.5 scenario.

Table D.14: Summary of parameter estimates for black teatfish the Steepness = 0.5 scenario. MCMC Median is median parameter value from robust MCMC scenarios. MCMC 2.5% and 97.5% indicates 95% credible interval.

Symbol	MCMC median	MCMC 2.5%	MCMC 97.5%
SR_LN(R0)	8.6	8.1	9.1
SSB_Virgin	3455.5	2133.7	5739.4
SSB_2026	3536.64	2152	5991.9
Bratio_2026	1	0.8	1.3
LnQ_base_Old_catches(2)	-2.7	-3.3	-2.1
LnQ_base_Recent_catches(3)	-1.13	-1.59	-0.7
Size_inflection_Recent_survey_absolute(1)	19.2	17.3	21.7
Size_95%width_Recent_survey_absolute(1)	3.3	0.8	6.4

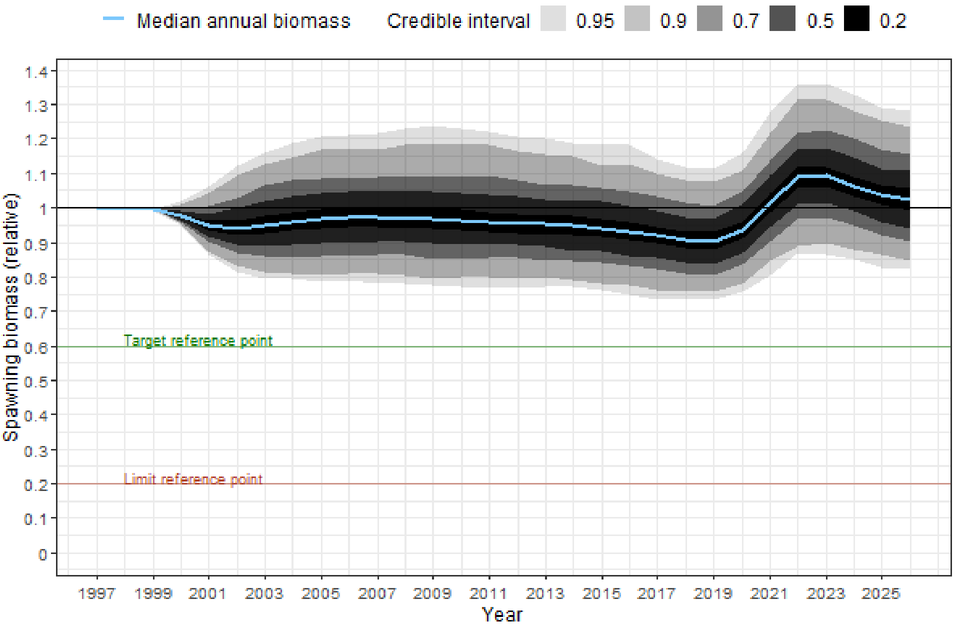

Figure D.118: Relative spawning biomass for the Steepness = 0.5 scenario

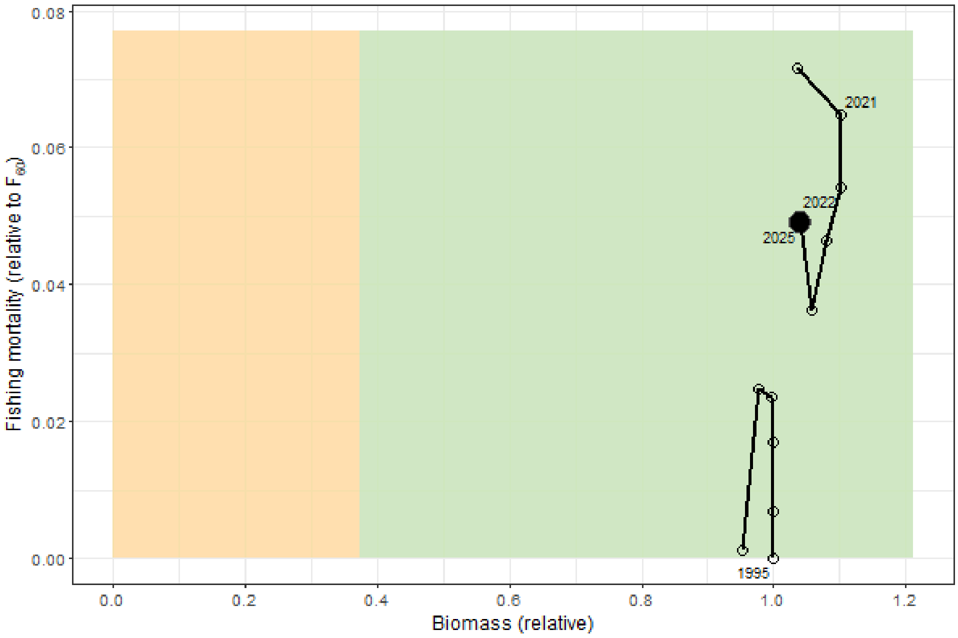

Figure D.119: Phase plot for the Steepness = 0.5 scenario

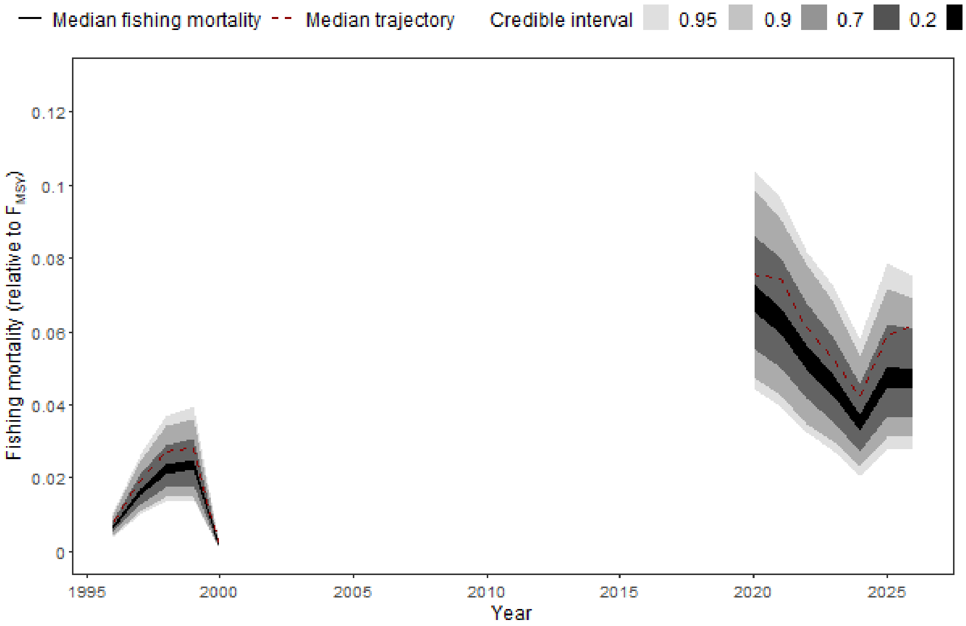

Figure D.120: Fishing mortality for the Steepness = 0.5 scenario

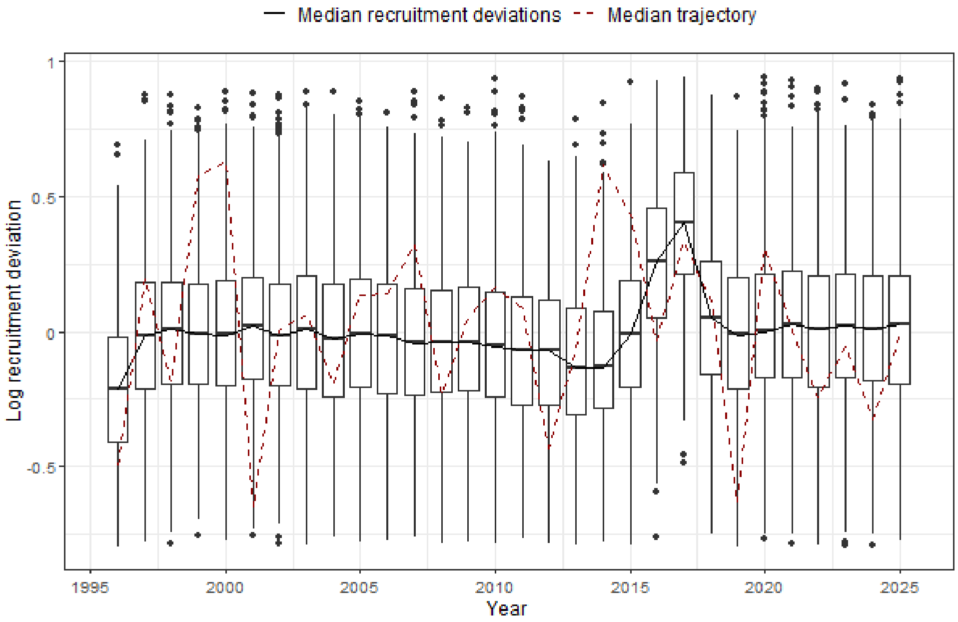

Figure D.121: Recruitment deviations for the Steepness = 0.5 scenario

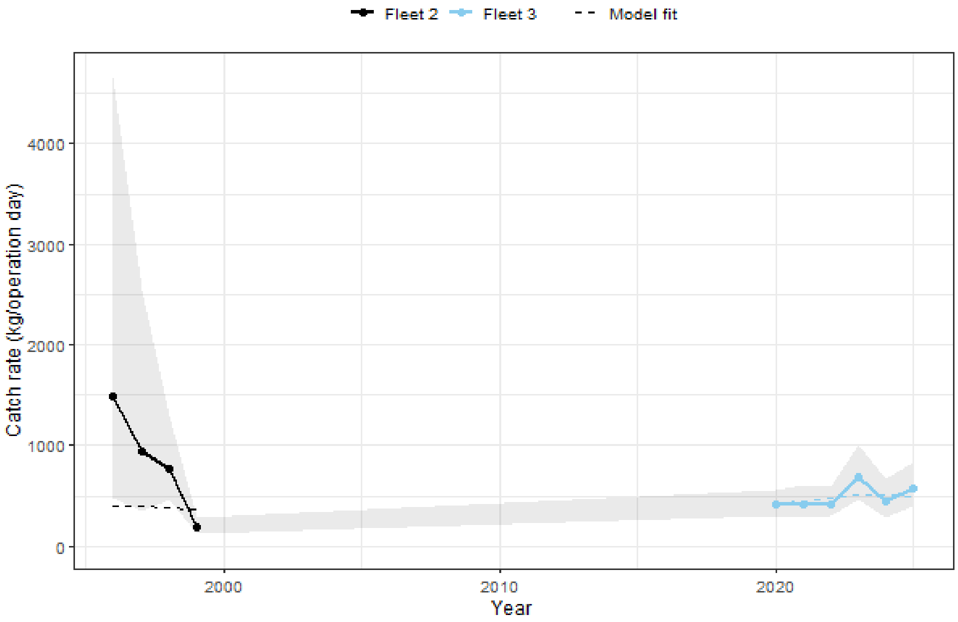

Figure D.122: CPUE fit for the Steepness = 0.5 scenario

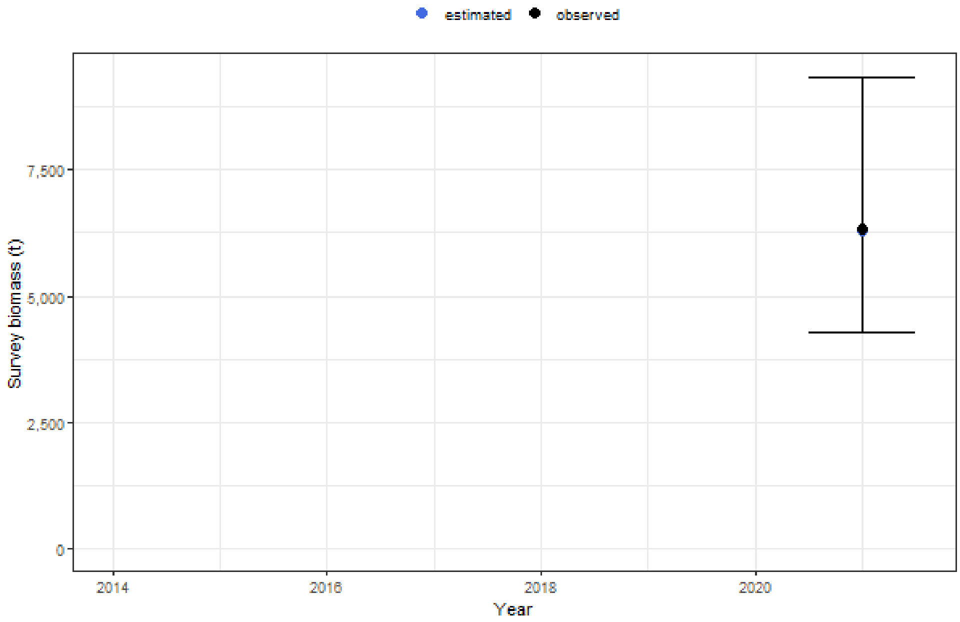

Figure D.123: Surveyed biomass fit for the Steepness = 0.5 scenario

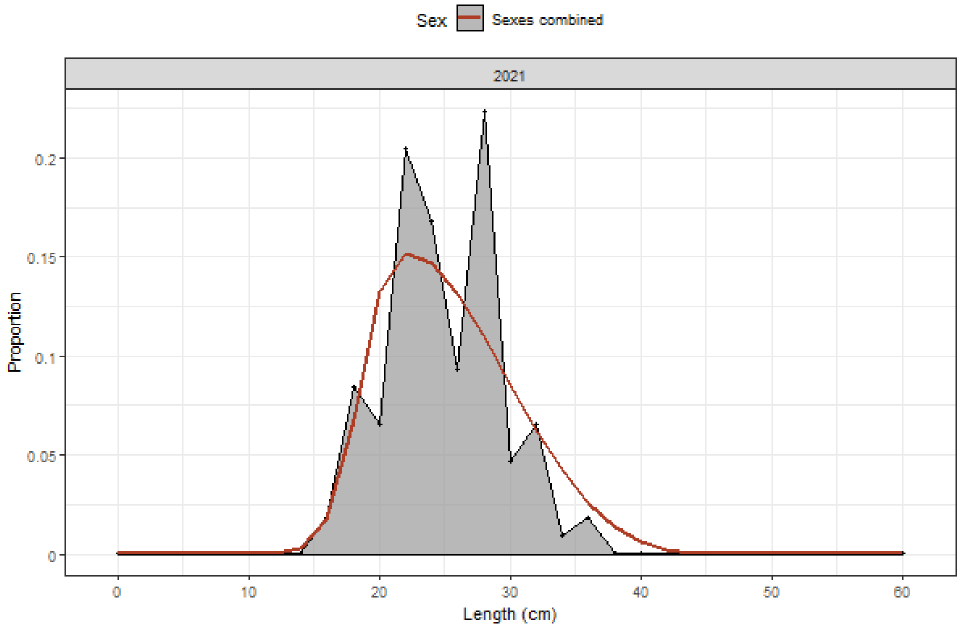

Figure D.124: Length composition fit for the Steepness = 0.5 scenario

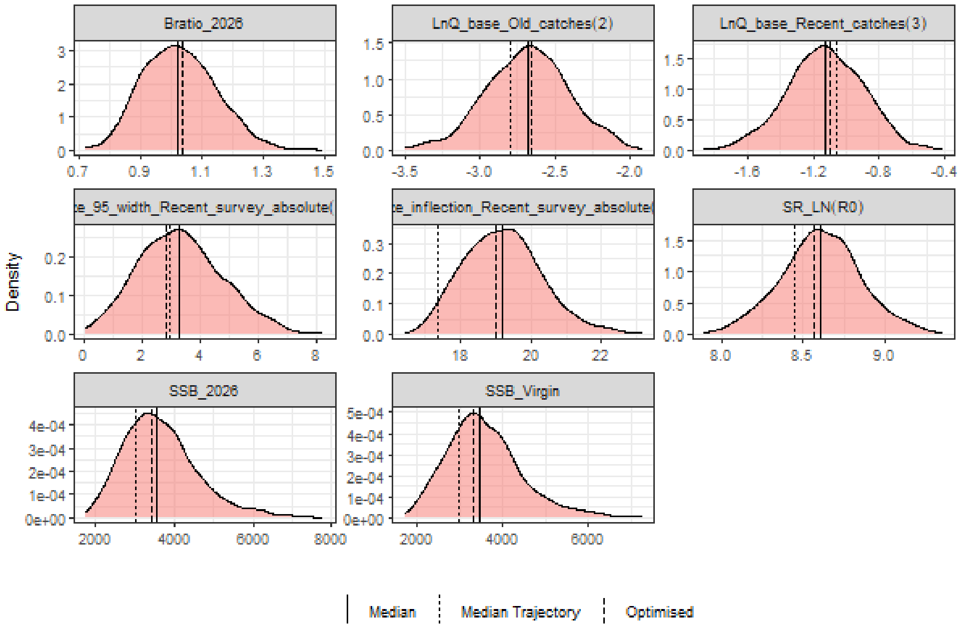

Figure D.125: MCMC parameter posterior densities for the Steepness = 0.5 scenario

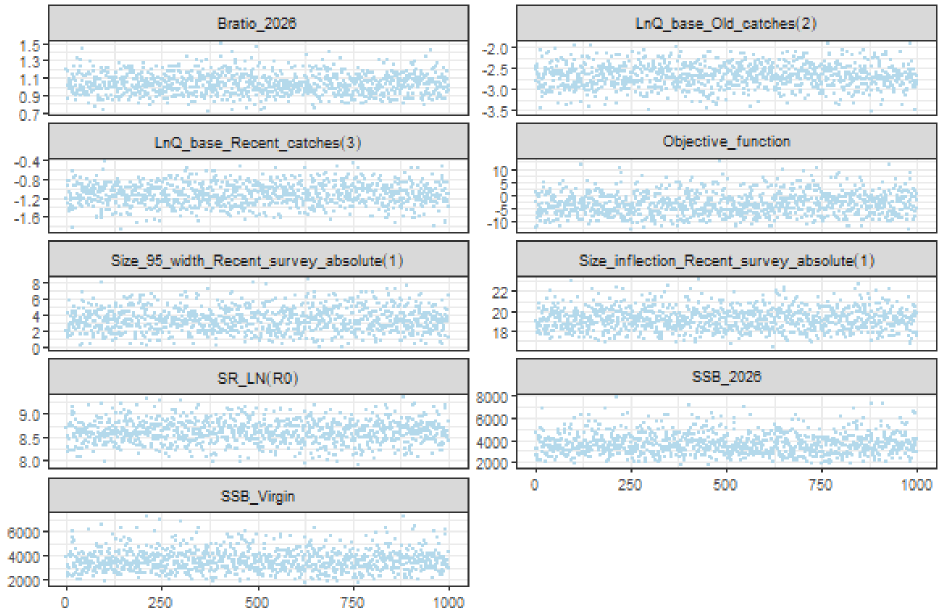

Figure D.126: MCMC trace plots for the Steepness = 0.5 scenario

D.2.3 Steepness = 0.7

This section presents results for the Steepness = 0.7 scenario.

Table D.15: Summary of parameter estimates for black teatfish the Steepness = 0.7 scenario. MCMC Median is median parameter value from robust MCMC scenarios. MCMC 2.5% and 97.5% indicates 95% credible interval.

Symbol	MCMC median	MCMC 2.5%	MCMC 97.5%
SR_LN(R0)	8.6	8.1	9.1
SSB_Virgin	3384.3	2117	5549.5
SSB_2026	3484.3	2110.97	5463.42
Bratio_2026	1	0.8	1.3
LnQ_base_Old_catches(2)	-2.7	-3.2	-2.1
LnQ_base_Recent_catches(3)	-1.1	-1.54	-0.66
Size_inflection_Recent_survey_absolute(1)	19.2	17.3	21.6
Size_95%width_Recent_survey_absolute(1)	3.3	0.9	6.7

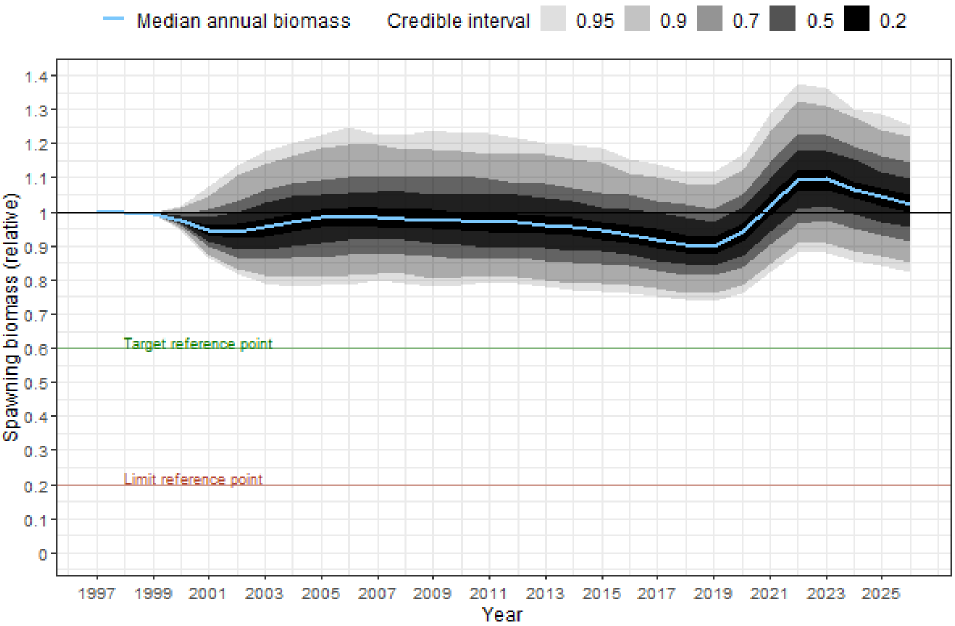

Figure D.127: Relative spawning biomass for the Steepness = 0.7 scenario

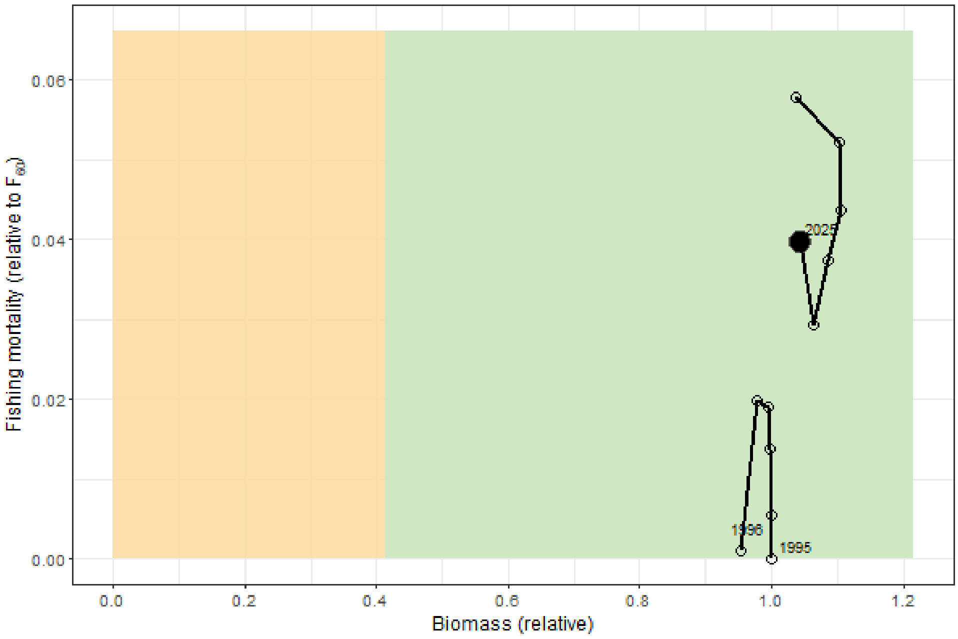

Figure D.128: Phase plot for the Steepness = 0.7 scenario

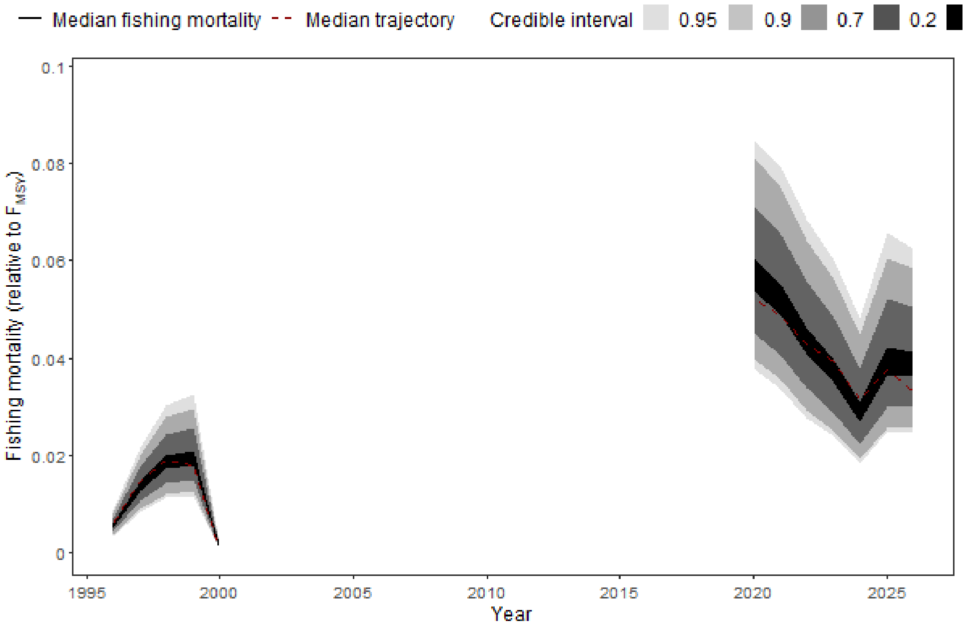

Figure D.129: Fishing mortality for the Steepness = 0.7 scenario

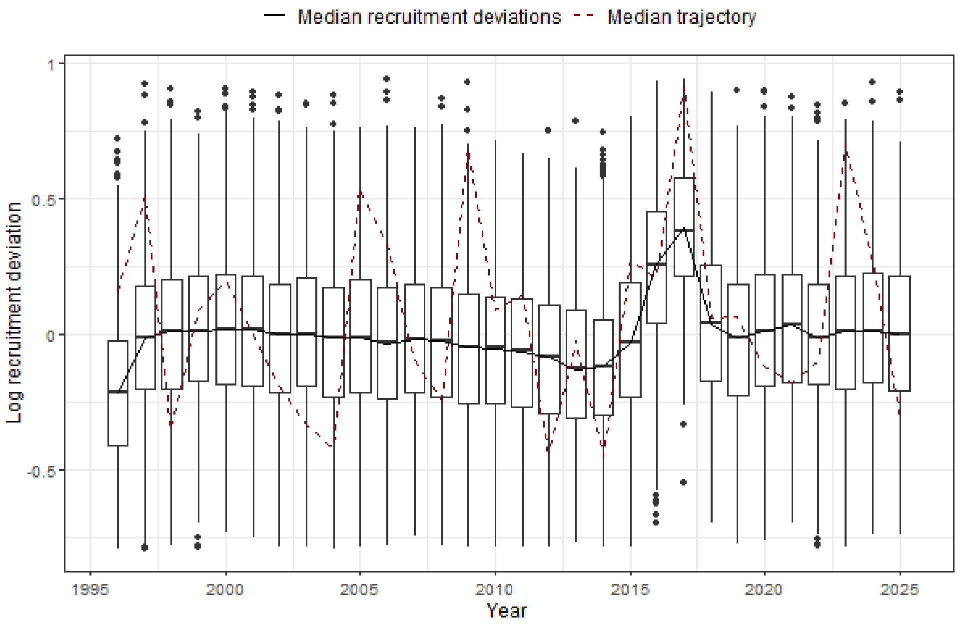

Figure D.130: Recruitment deviations for the Steepness = 0.7 scenario

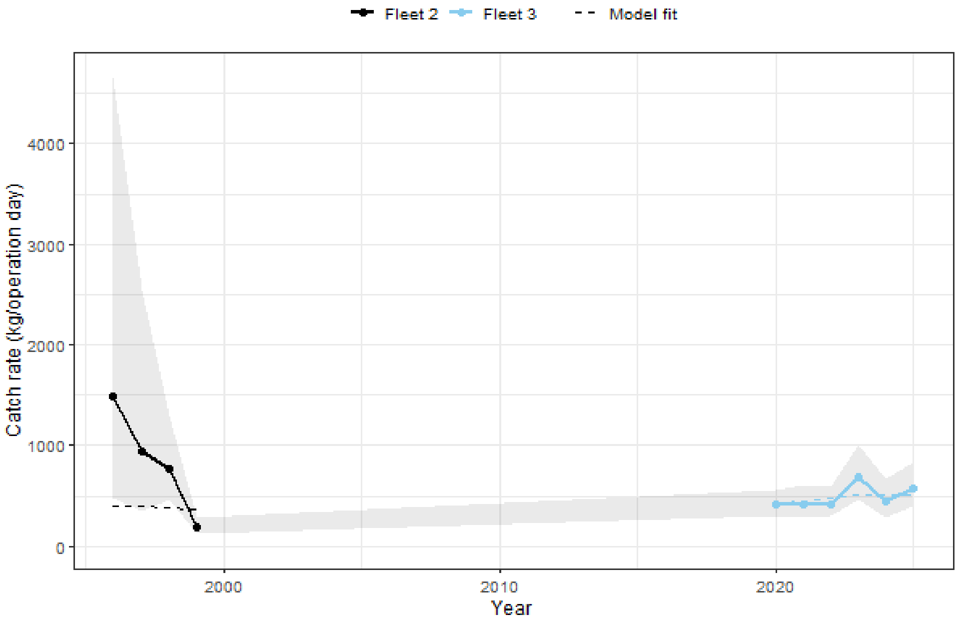

Figure D.131: CPUE fit for the Steepness = 0.7 scenario

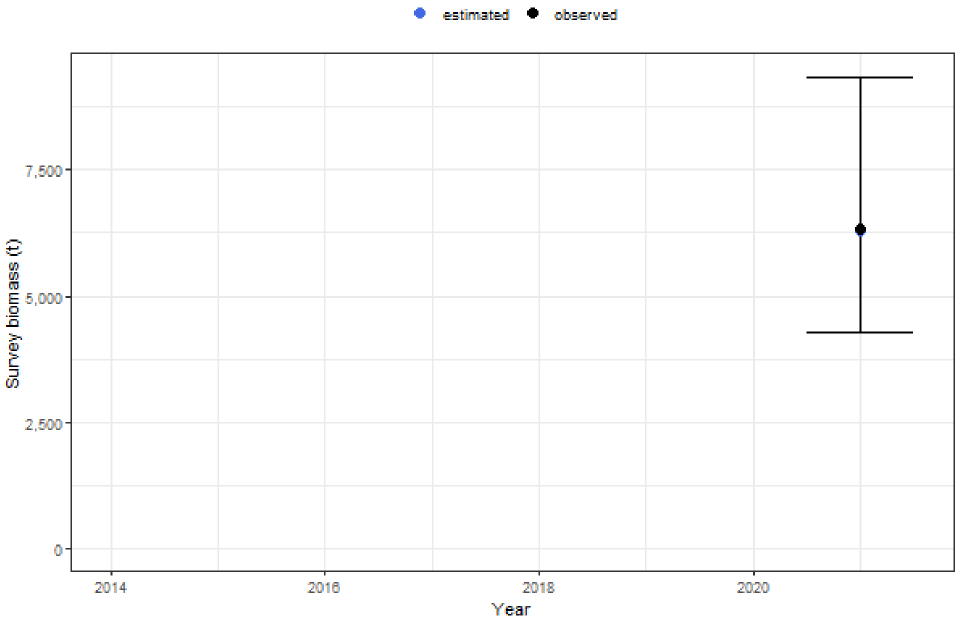

Figure D.132: Surveyed biomass fit for the Steepness = 0.7 scenario

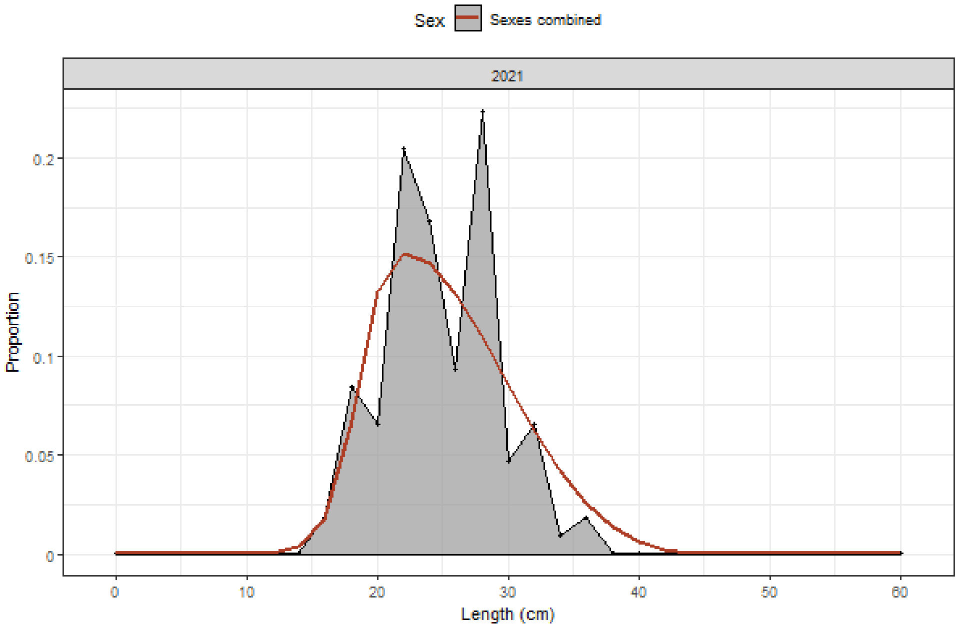

Figure D.133: Length composition fit for the Steepness = 0.7 scenario

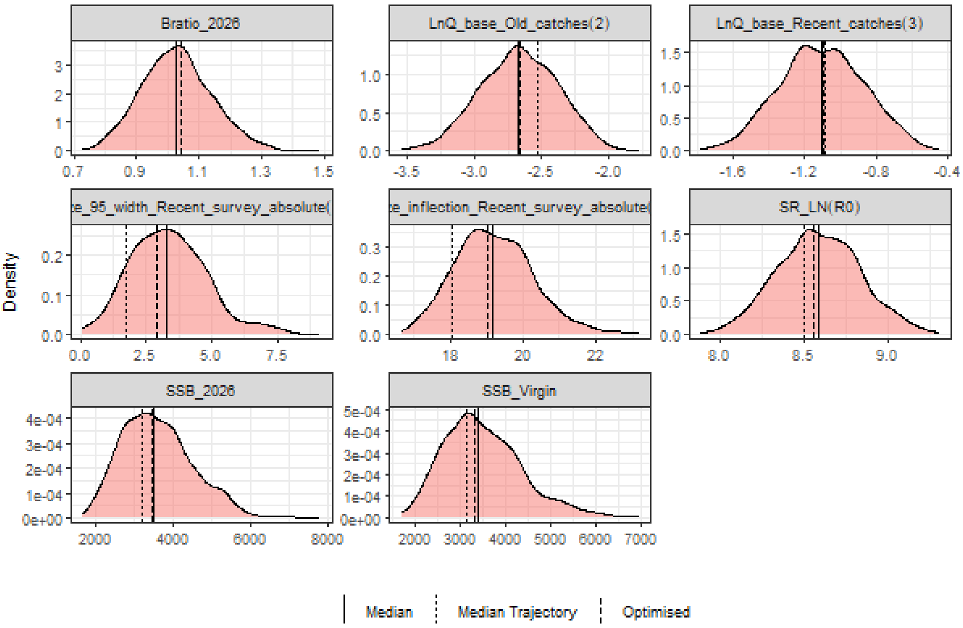

Figure D.134: MCMC parameter posterior densities for the Steepness = 0.7 scenario

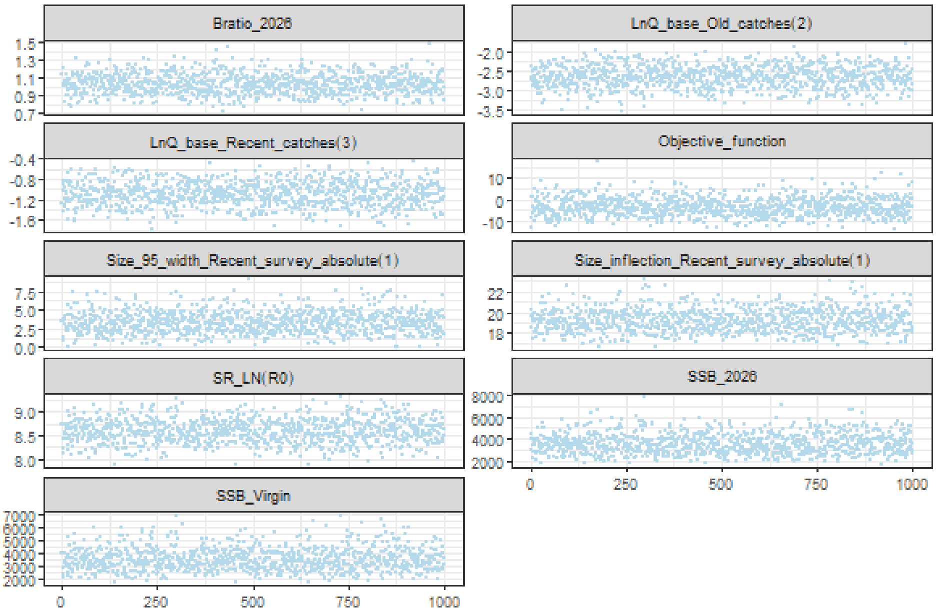

Figure D.135: MCMC trace plots for the Steepness = 0.7 scenario

D.2.4 Natural mortality = 0.2

This section presents results for the Natural mortality = 0.2 scenario.

Table D.16: Summary of parameter estimates for black teatfish the Natural mortality = 0.2 scenario. MCMC Median is median parameter value from robust MCMC scenarios. MCMC 2.5% and 97.5% indicates 95% credible interval.

Symbol	MCMC median	MCMC 2.5%	MCMC 97.5%
SR_LN(R0)	6.8	6.3	7.2
SSB_Virgin	4044.1	2492.8	6352.7
SSB_2026	4523.24	2918.68	7186.29
Bratio_2026	1.1	0.9	1.4
LnQ_base_Old_catches(2)	-2.6	-3.1	-2
LnQ_base_Recent_catches(3)	-1.69	-2.15	-1.25
Size_inflection_Recent_survey_absolute(1)	17.2	14.7	18.8
Size_95%width_Recent_survey_absolute(1)	2.2	0.1	6.3

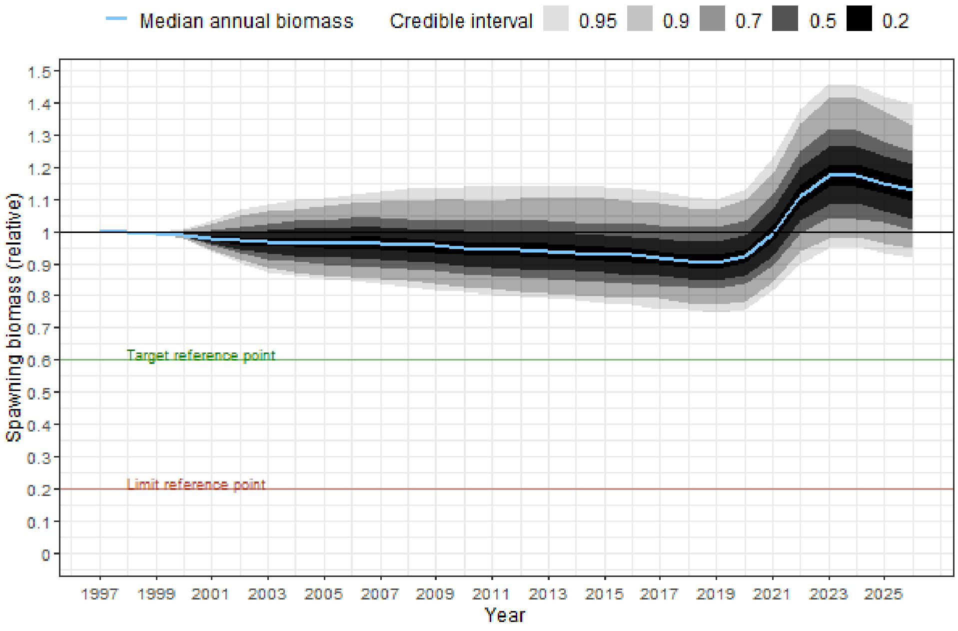

Figure D.136: Relative spawning biomass for the Natural mortality = 0.2 scenario

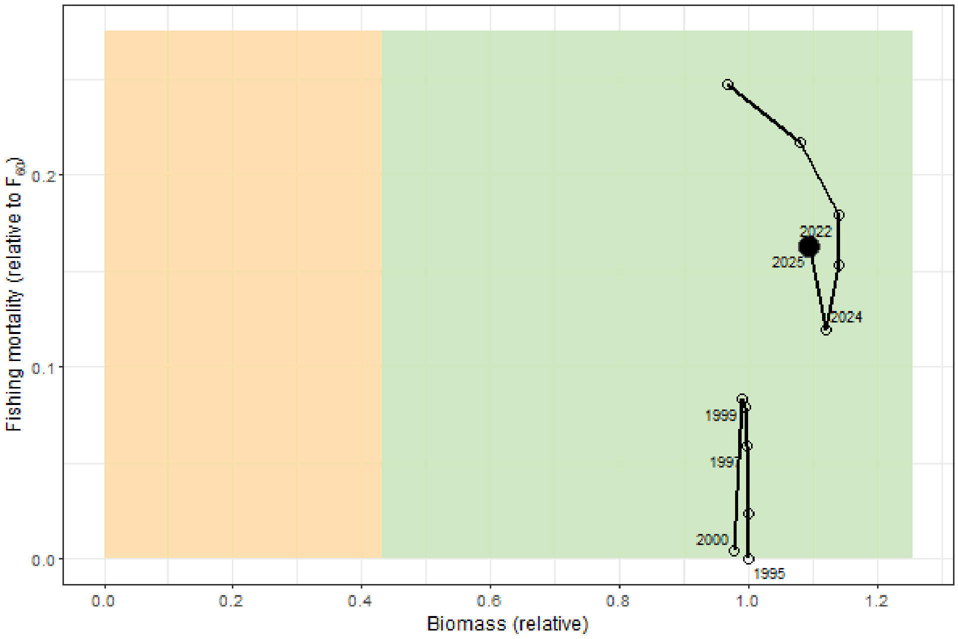

Figure D.137: Phase plot for the Natural mortality = 0.2 scenario

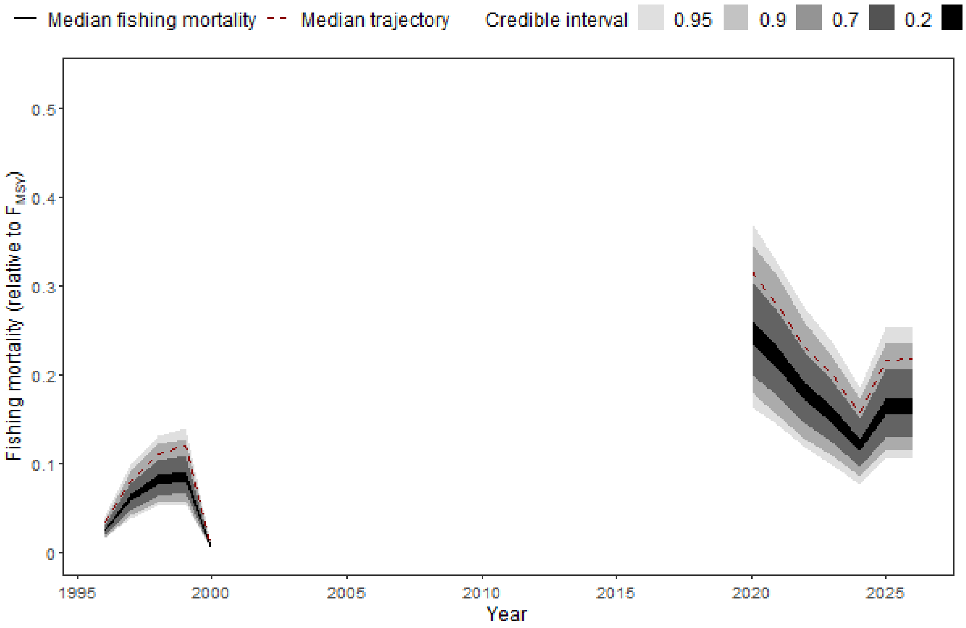

Figure D.138: Fishing mortality for the Natural mortality = 0.2 scenario

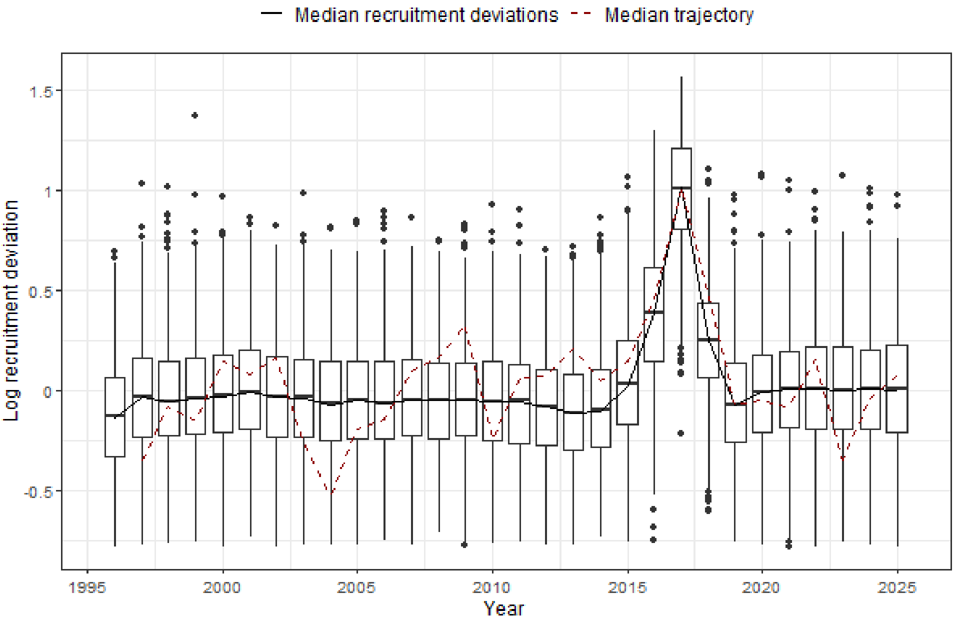

Figure D.139: Recruitment deviations for the Natural mortality = 0.2 scenario

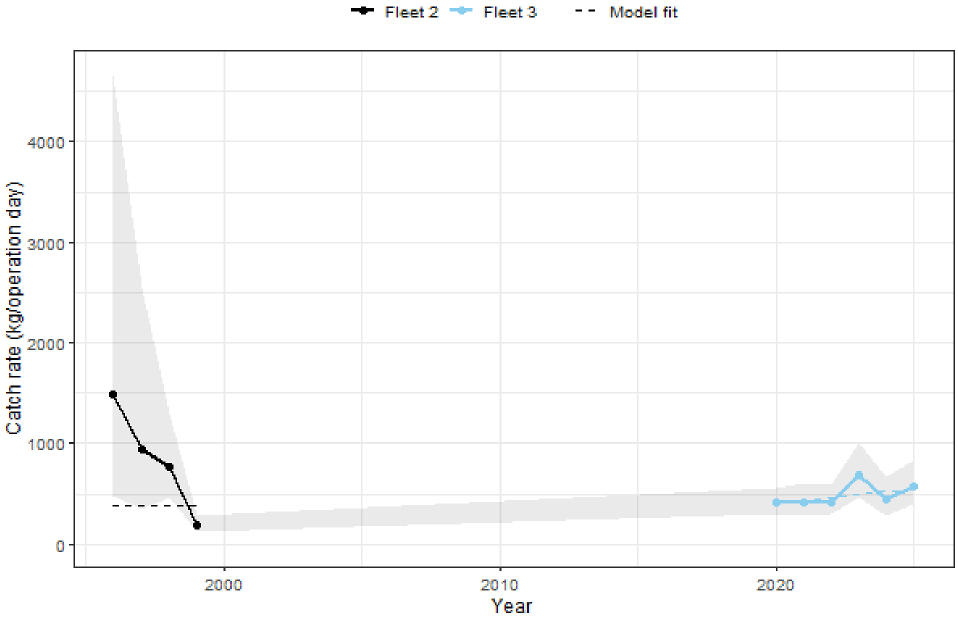

Figure D.140: CPUE fit for the Natural mortality = 0.2 scenario

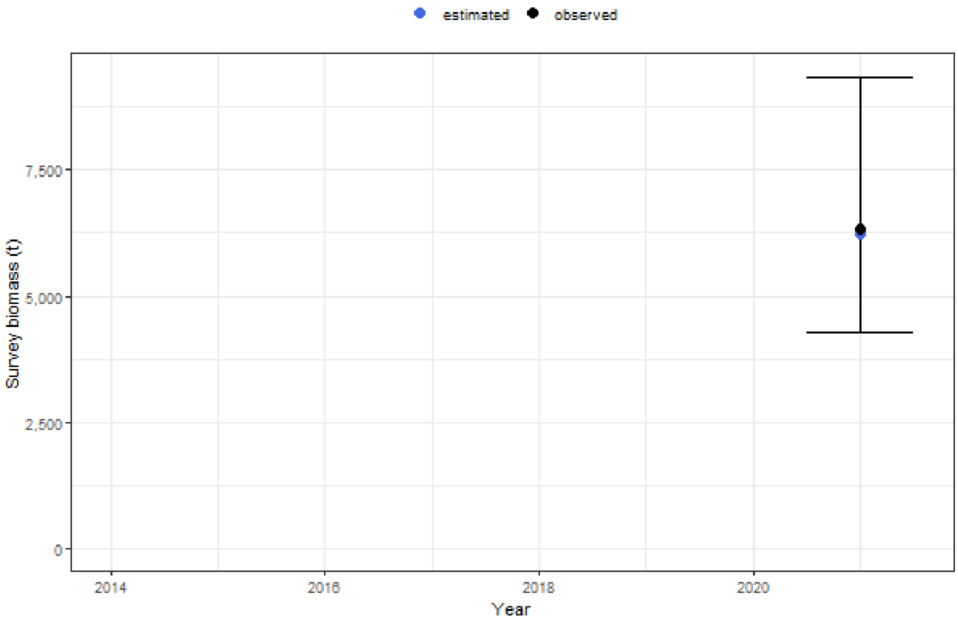

Figure D.141: Surveyed biomass fit for the Natural mortality = 0.2 scenario

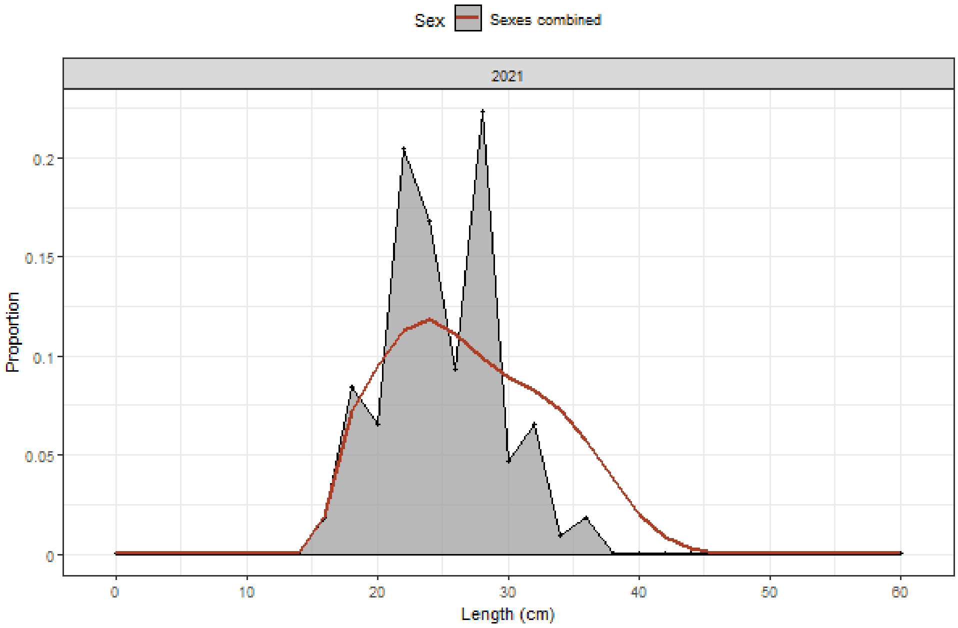

Figure D.142: Length composition fit for the Natural mortality = 0.2 scenario

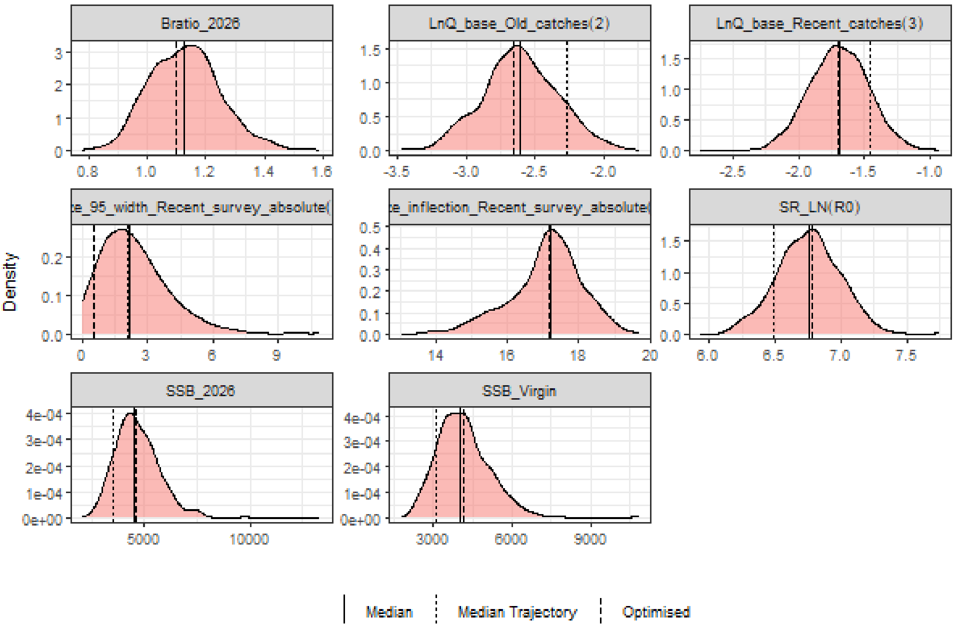

Figure D.143: MCMC parameter posterior densities for the Natural mortality = 0.2 scenario

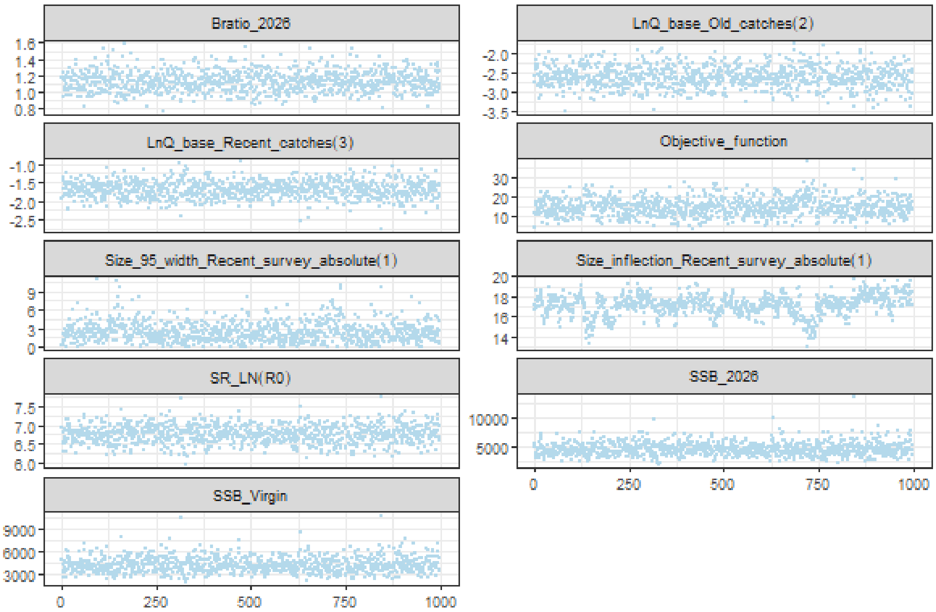

Figure D.144: MCMC trace plots for the Natural mortality = 0.2 scenario

D.2.5 Natural mortality = 0.6

This section presents results for the Natural mortality = 0.6 scenario.

Table D.17: Summary of parameter estimates for black teatfish the Natural mortality = 0.6 scenario. MCMC Median is median parameter value from robust MCMC scenarios. MCMC 2.5% and 97.5% indicates 95% credible interval.

Symbol	MCMC median	MCMC 2.5%	MCMC 97.5%
SR_LN(R0)	9.7	9.1	10.2
SSB_Virgin	3468.4	1997.8	6065.3
SSB_2026	3456.7	1975.99	5696.7
Bratio_2026	1	0.7	1.3
LnQ_base_Old_catches(2)	-2.7	-3.3	-2.1
LnQ_base_Recent_catches(3)	-0.86	-1.33	-0.36
Size_inflection_Recent_survey_absolute(1)	20.7	18.3	23.3
Size_95%width_Recent_survey_absolute(1)	4.3	1.8	6.9

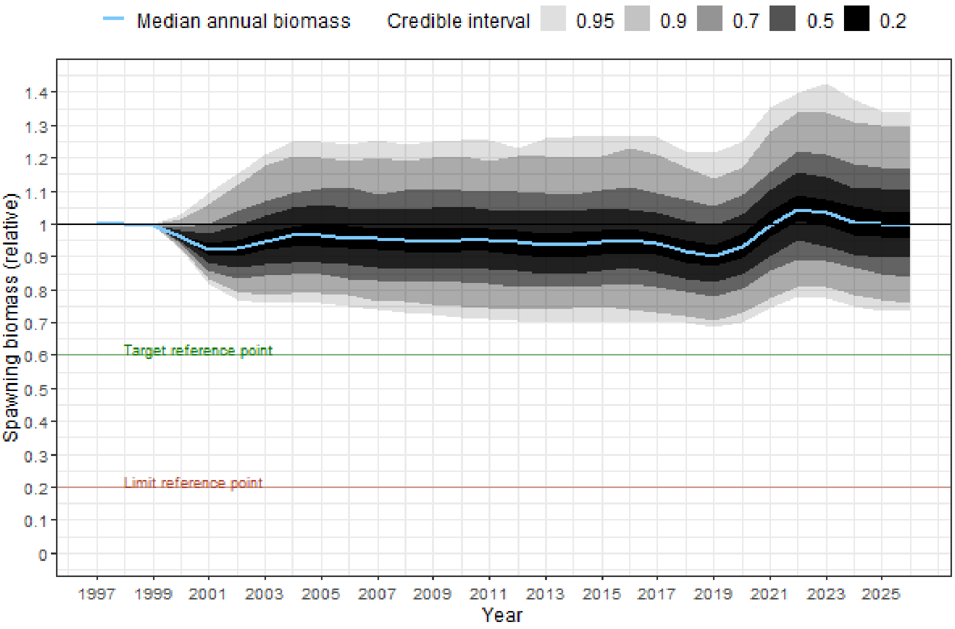

Figure D.145: Relative spawning biomass for the Natural mortality = 0.6 scenario

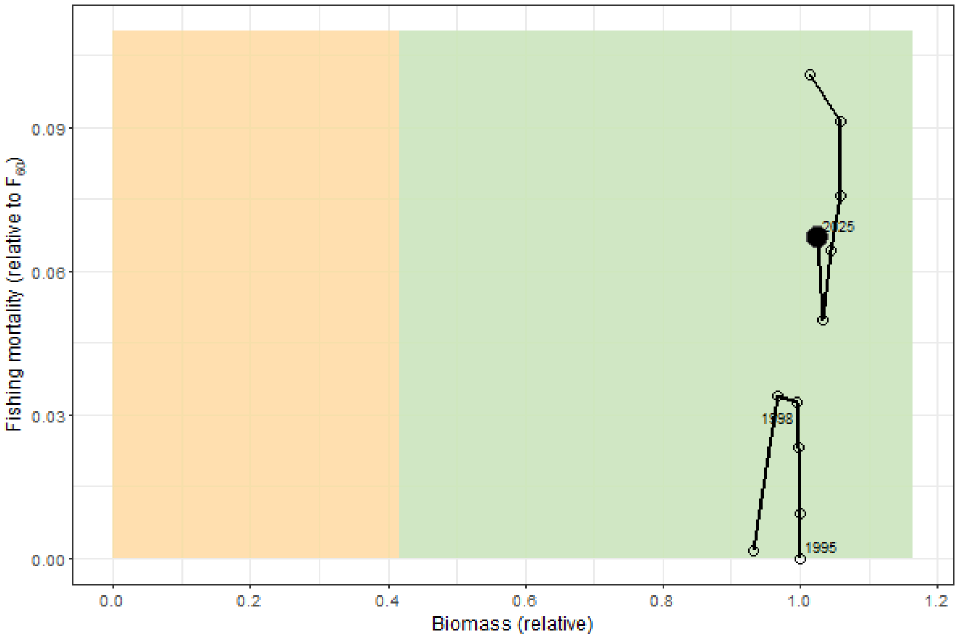

Figure D.146: Phase plot for the Natural mortality = 0.6 scenario

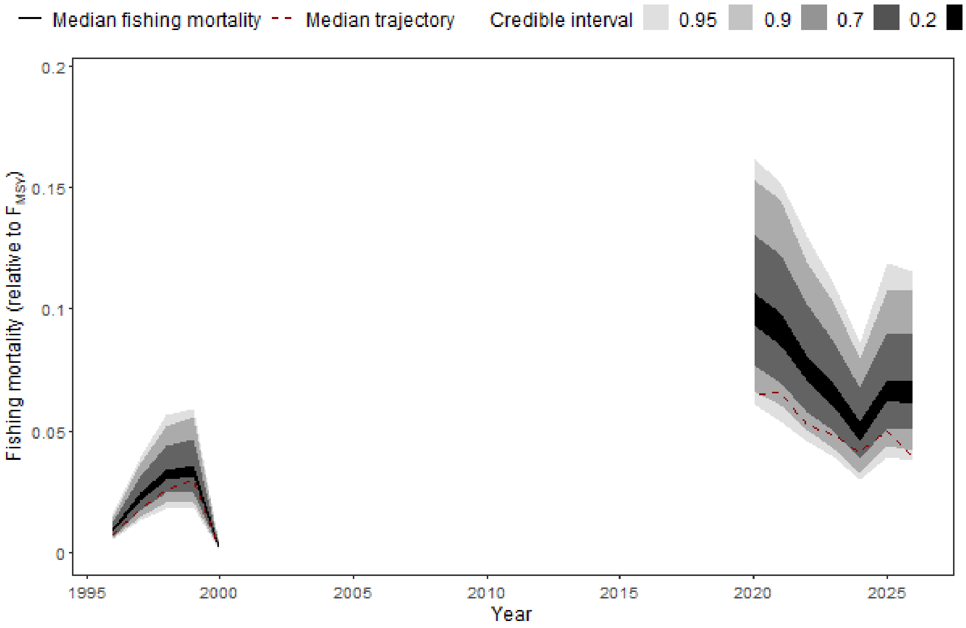

Figure D.147: Fishing mortality for the Natural mortality = 0.6 scenario

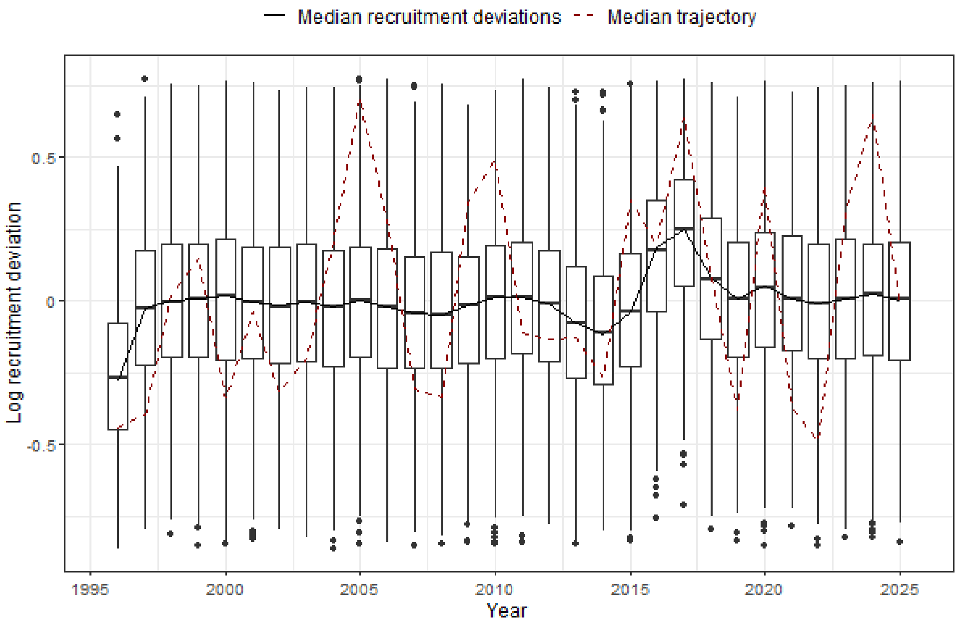

Figure D.148: Recruitment deviations for the Natural mortality = 0.6 scenario

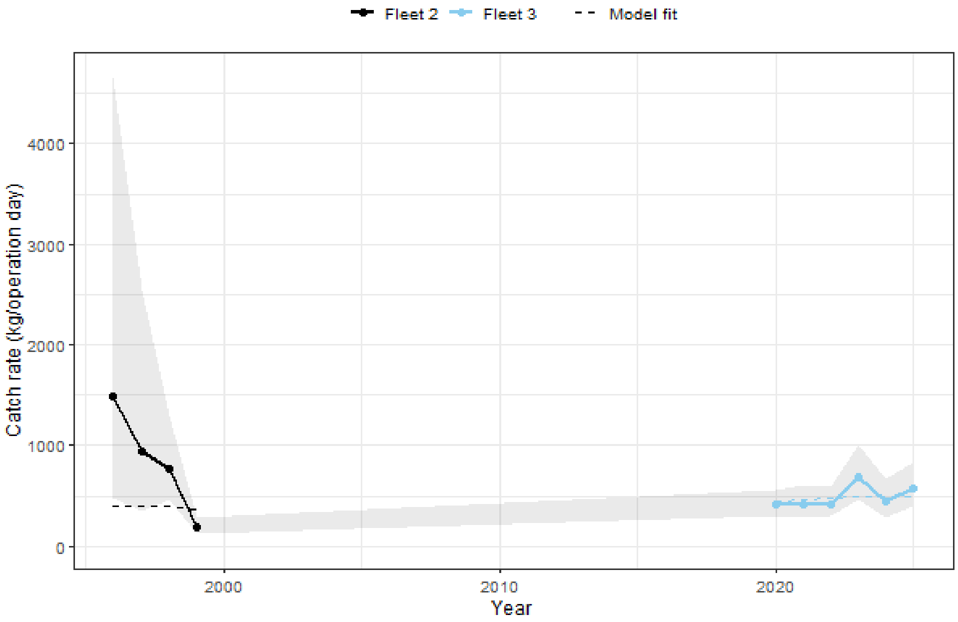

Figure D.149: CPUE fit for the Natural mortality = 0.6 scenario

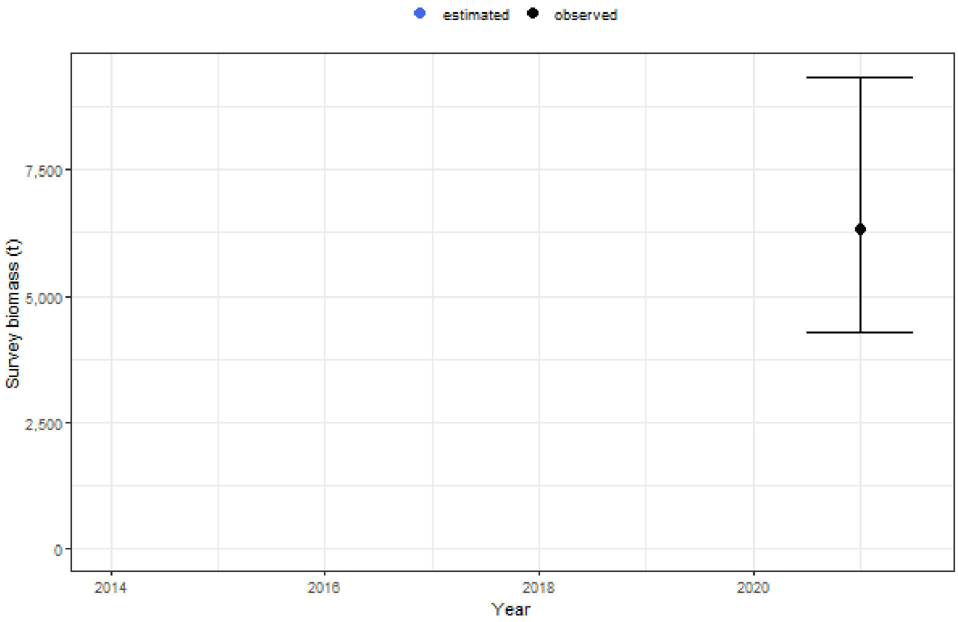

Figure D.150: Surveyed biomass fit for the Natural mortality = 0.6 scenario

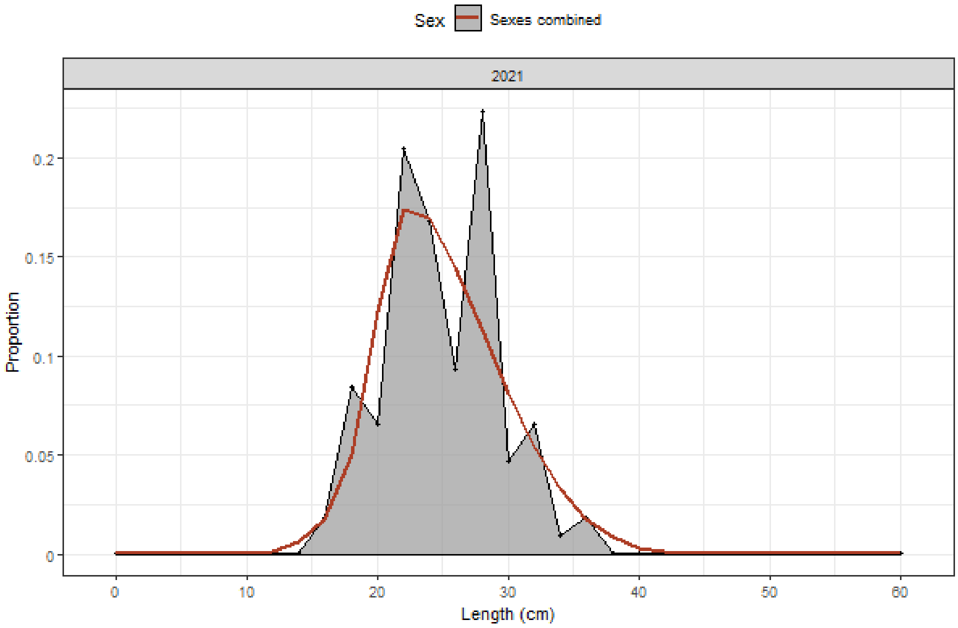

Figure D.151: Length composition fit for the Natural mortality = 0.6 scenario

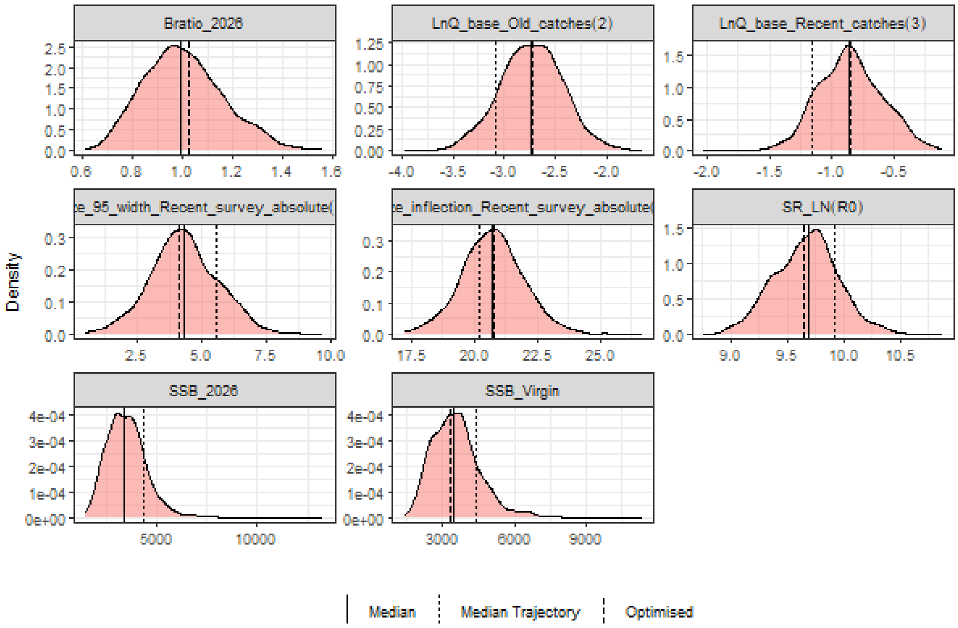

Figure D.152: MCMC parameter posterior densities for the Natural mortality = 0.6 scenario

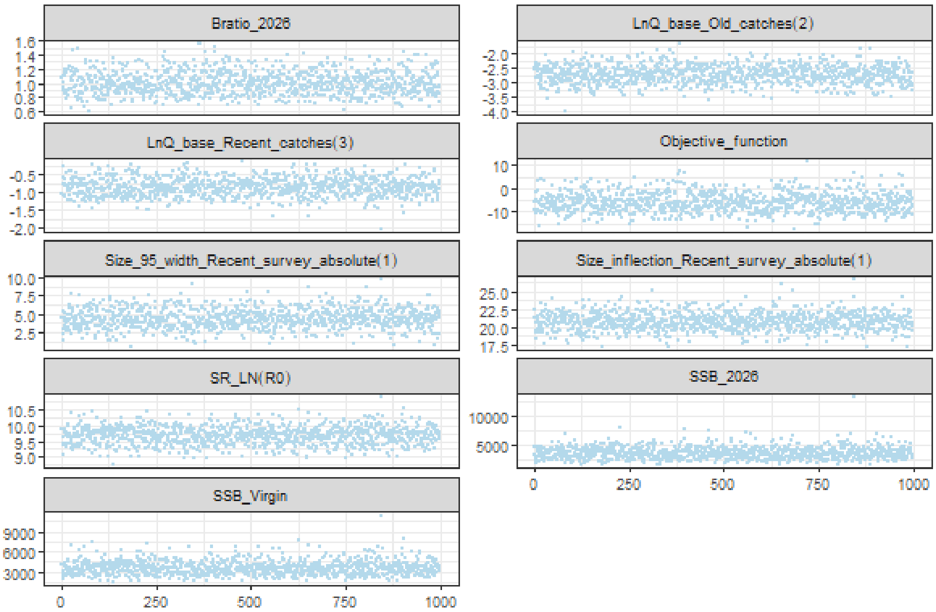

Figure D.153: MCMC trace plots for the Natural mortality = 0.6 scenario

D.2.6 No shrinkage applied

This section presents results for the No shrinkage applied scenario.

Table D.18: Summary of parameter estimates for black teatfish the No shrinkage applied scenario. MCMC Median is median parameter value from robust MCMC scenarios. MCMC 2.5% and 97.5% indicates 95% credible interval.

Symbol	MCMC median	MCMC 2.5%	MCMC 97.5%
SR_LN(R0)	8.5	7.9	9
SSB_Virgin	2961.6	1780.3	4968.8
SSB_2026	3075.99	1854.59	4872.51
Bratio_2026	1	0.8	1.3
LnQ_base_Old_catches(2)	-2.6	-3.2	-2
LnQ_base_Recent_catches(3)	-0.94	-1.43	-0.48
Size_inflection_Recent_survey_absolute(1)	17.4	15.6	19.1
Size_95%width_Recent_survey_absolute(1)	3	1	5.7

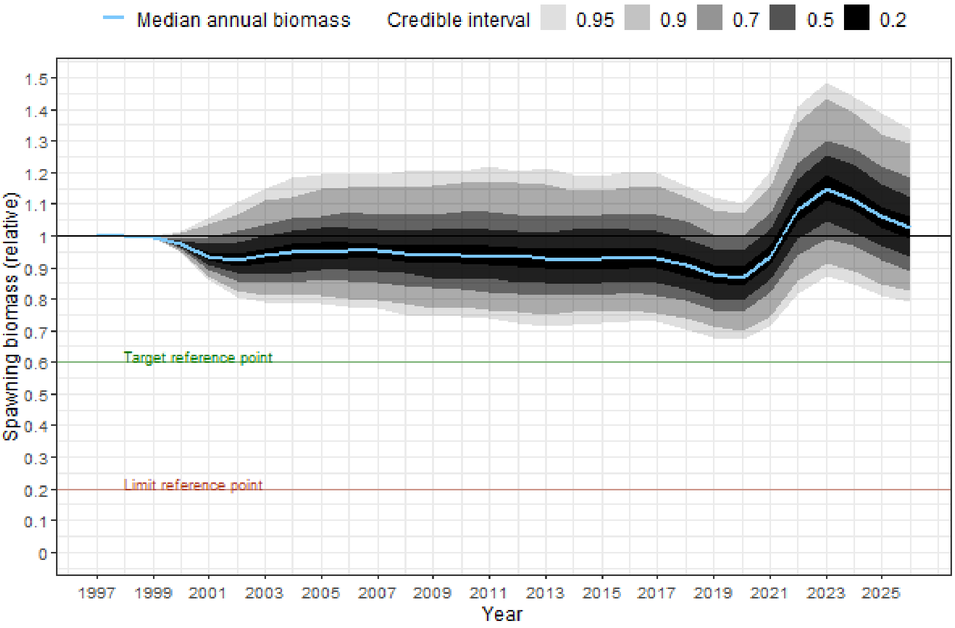

Figure D.154: Relative spawning biomass for the No shrinkage applied scenario

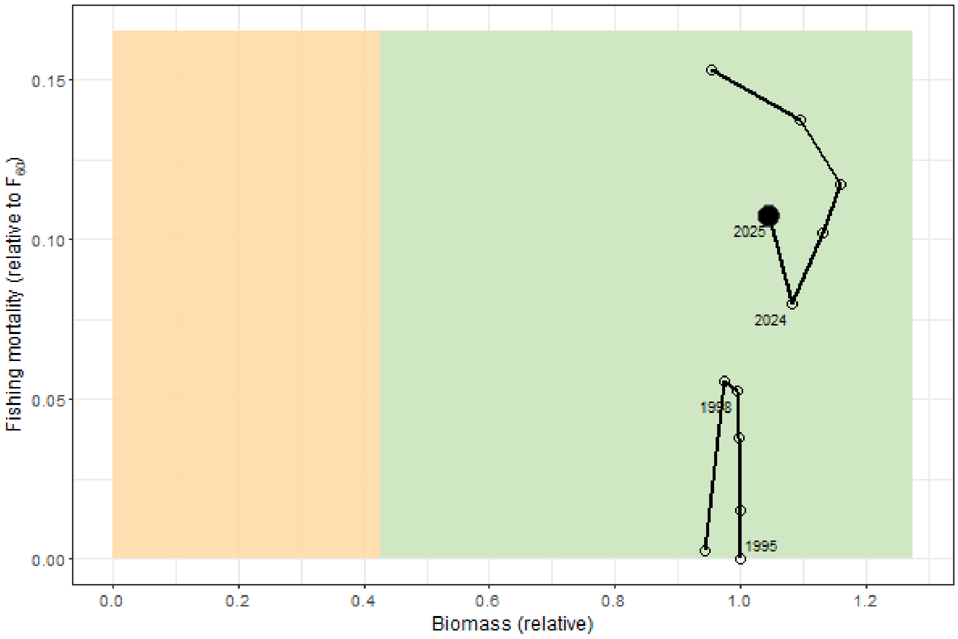

Figure D.155: Phase plot for the No shrinkage applied scenario

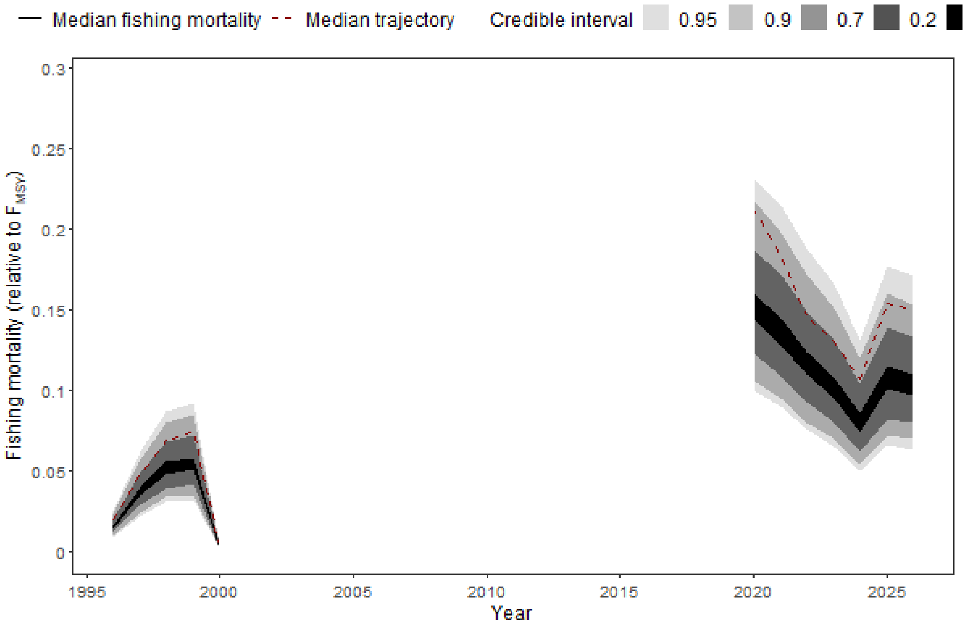

Figure D.156: Fishing mortality for the No shrinkage applied scenario

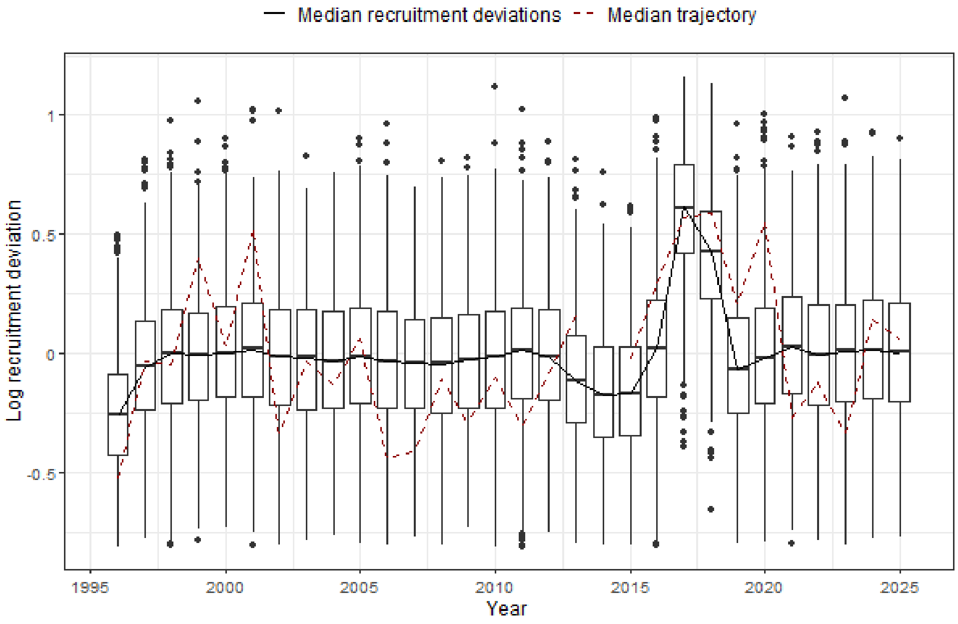

Figure D.157: Recruitment deviations for the No shrinkage applied scenario

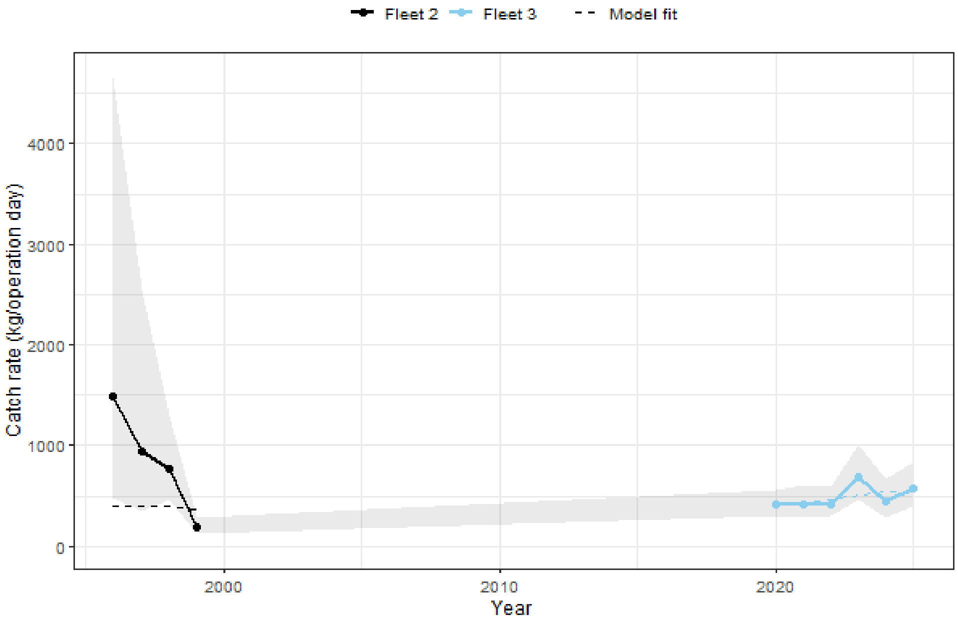

Figure D.158: CPUE fit for the No shrinkage applied scenario

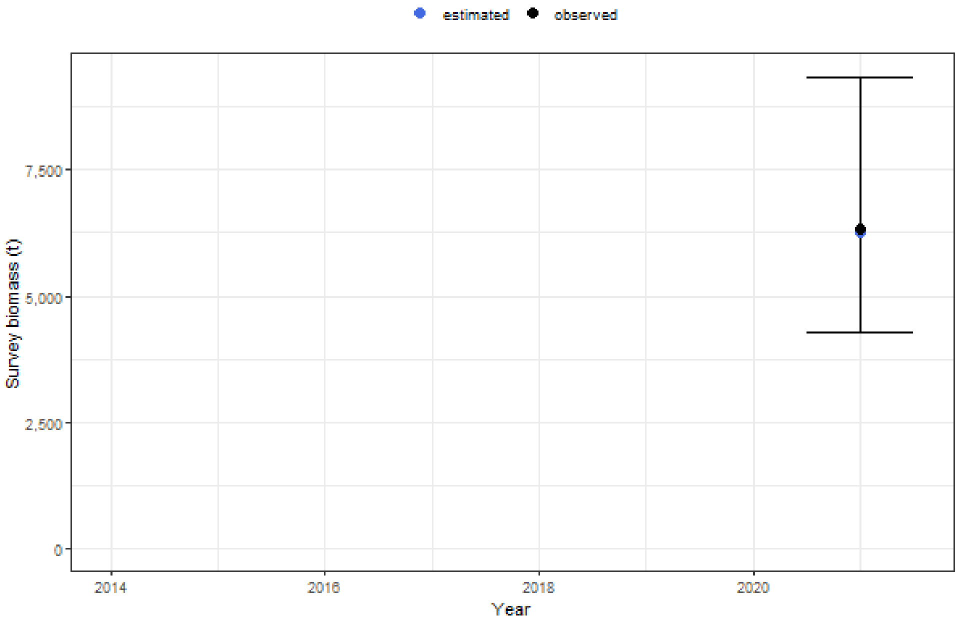

Figure D.159: Surveyed biomass fit for the No shrinkage applied scenario

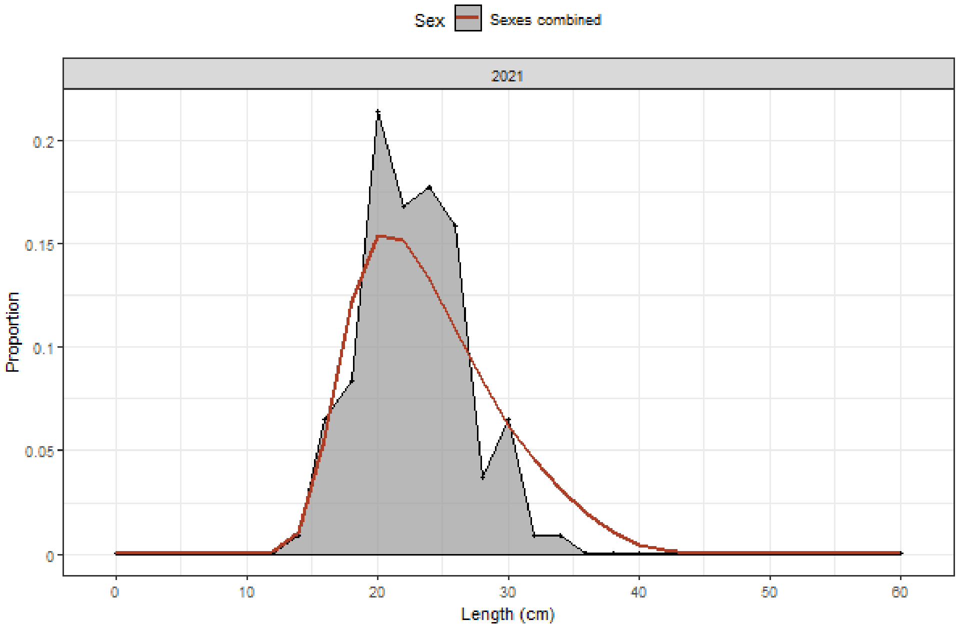

Figure D.160: Length composition fit for the No shrinkage applied scenario

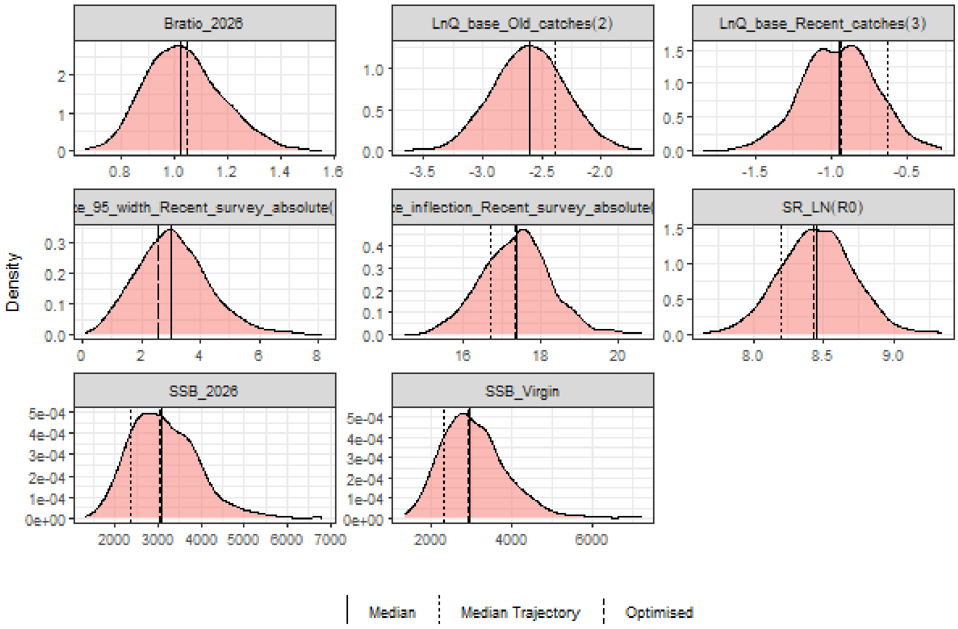

Figure D.161: MCMC parameter posterior densities for the No shrinkage applied scenario

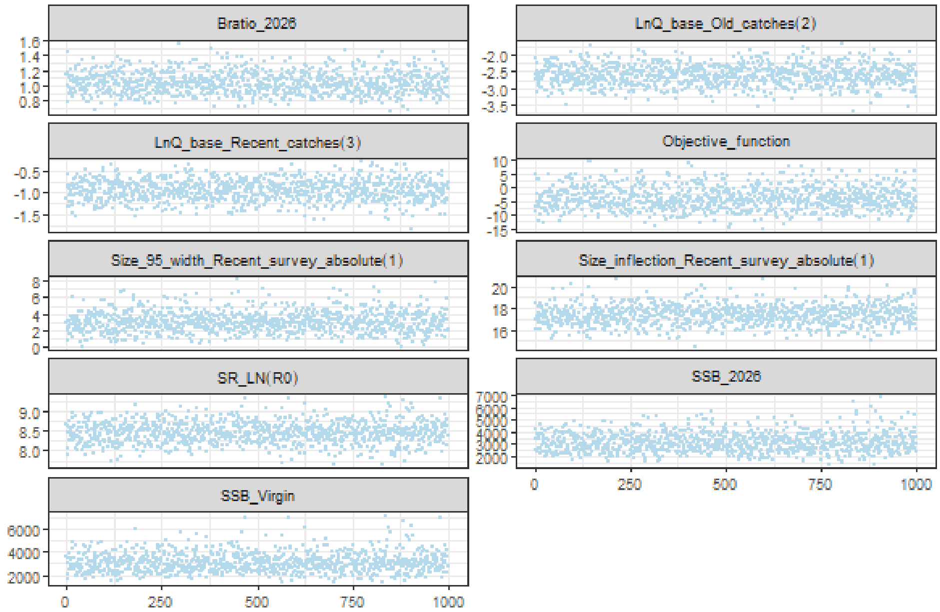

Figure D.162: MCMC trace plots for the No shrinkage applied scenario

D.2.7 Faster growth profile

This section presents results for the Faster growth profile scenario.

Table D.19: Summary of parameter estimates for black teatfish the Faster growth profile scenario. MCMC Median is median parameter value from robust MCMC scenarios. MCMC 2.5% and 97.5% indicates 95% credible interval.

Symbol	MCMC median	MCMC 2.5%	MCMC 97.5%
SR_LN(R0)	8.3	7.8	8.8
SSB_Virgin	3911.1	2294.6	6485.2
SSB_2026	4030.45	2524.48	6559.54
Bratio_2026	1.1	0.8	1.4
LnQ_base_Old_catches(2)	-2.7	-3.2	-2.1
LnQ_base_Recent_catches(3)	-1.56	-1.99	-1.08
Size_inflection_Recent_survey_absolute(1)	19.1	17.2	20.8
Size_95%width_Recent_survey_absolute(1)	3.6	1.1	6.4

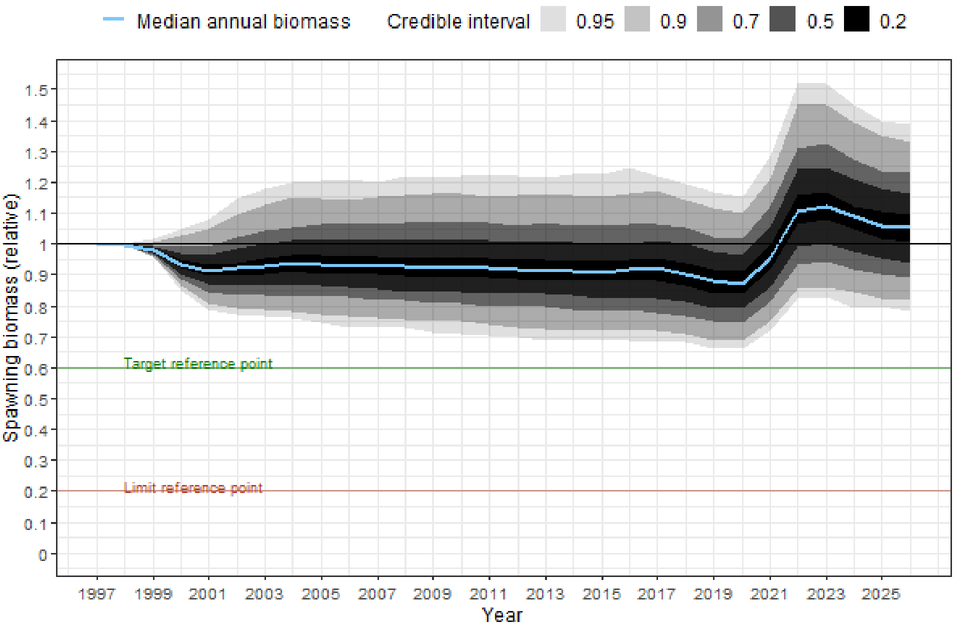

Figure D.163: Relative spawning biomass for the Faster growth profile scenario

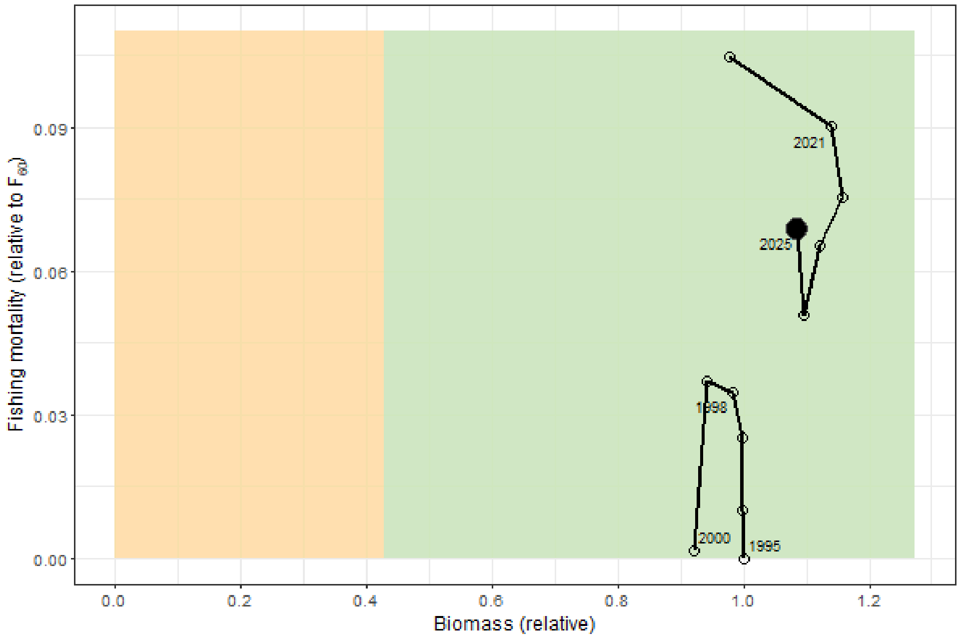

Figure D.164: Phase plot for the Faster growth profile scenario

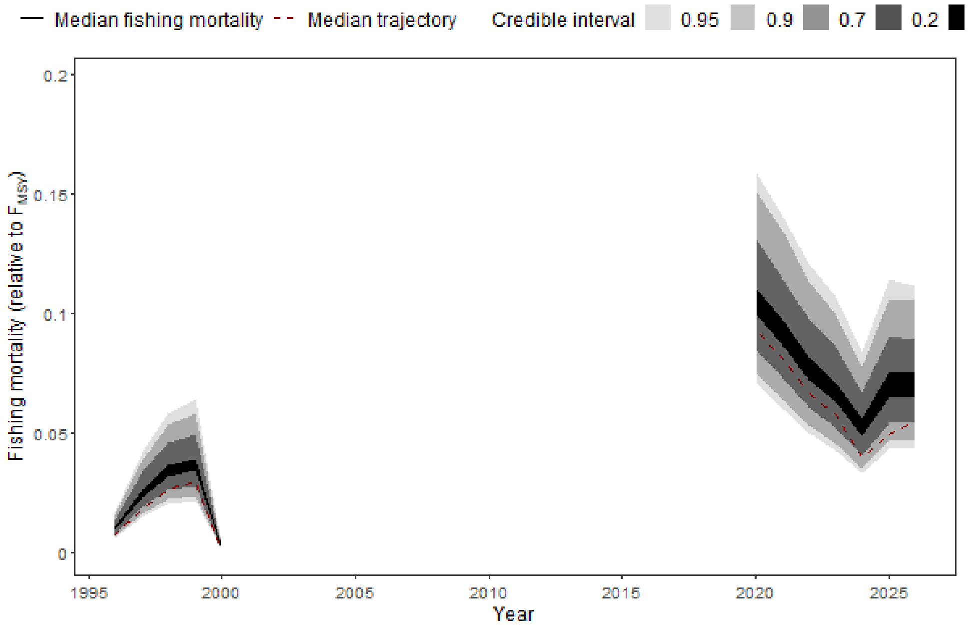

Figure D.165: Fishing mortality for the Faster growth profile scenario

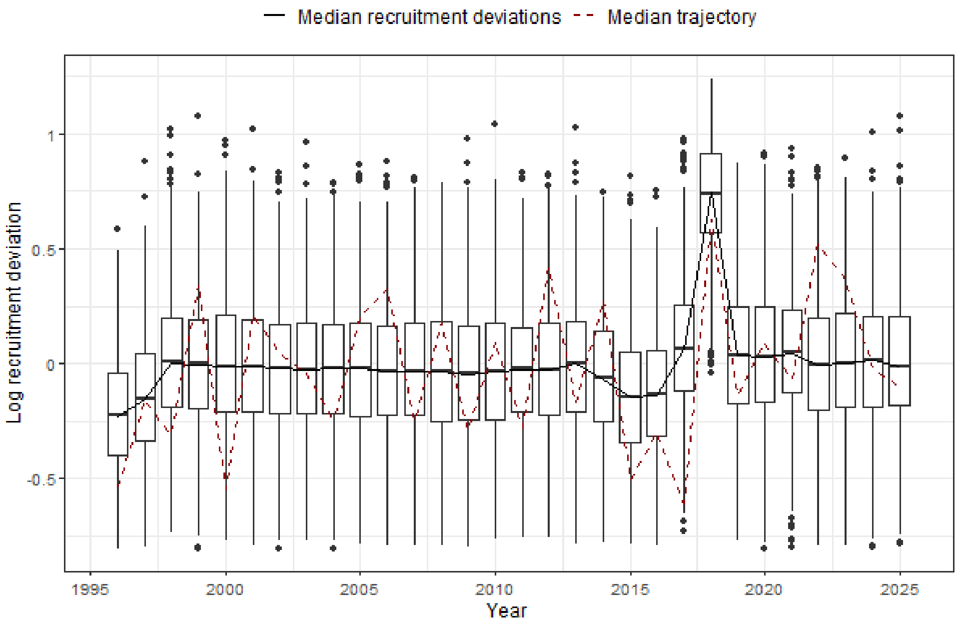

Figure D.166: Recruitment deviations for the Faster growth profile scenario

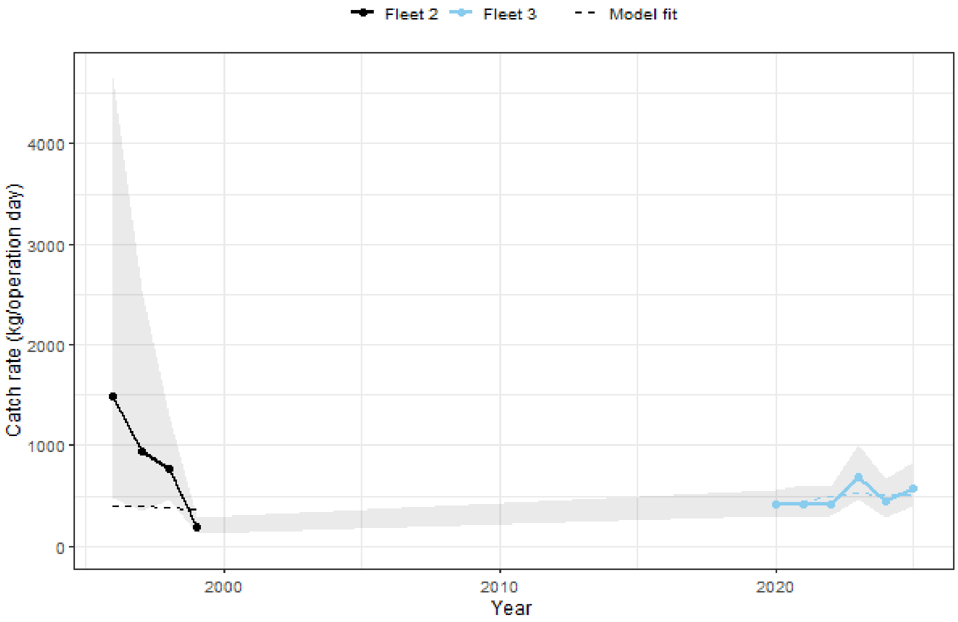

Figure D.167: CPUE fit for the Faster growth profile scenario

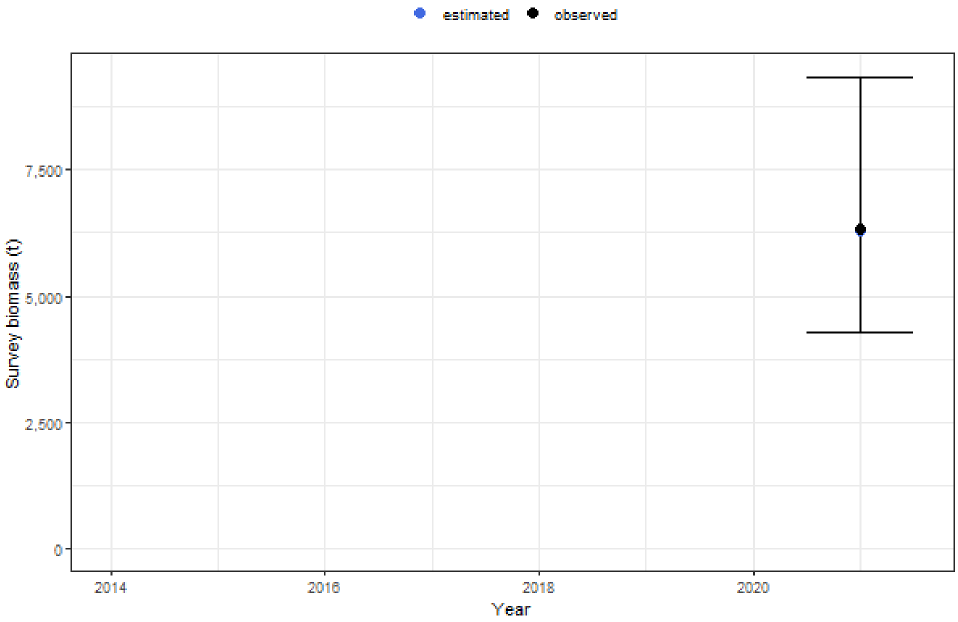

Figure D.168: Surveyed biomass fit for the Faster growth profile scenario

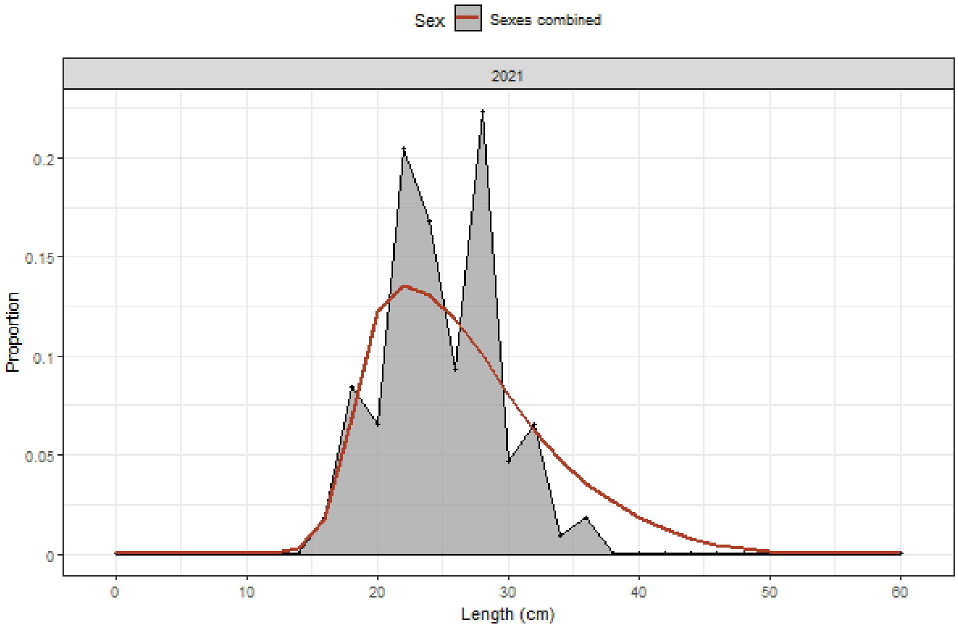

Figure D.169: Length composition fit for the Faster growth profile scenario

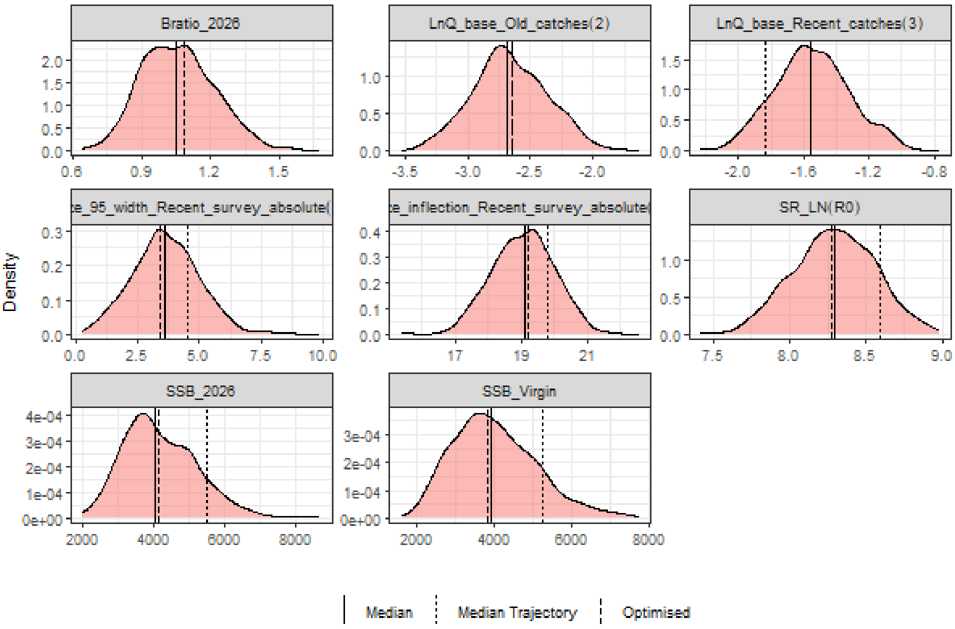

Figure D.170: MCMC parameter posterior densities for the Faster growth profile scenario

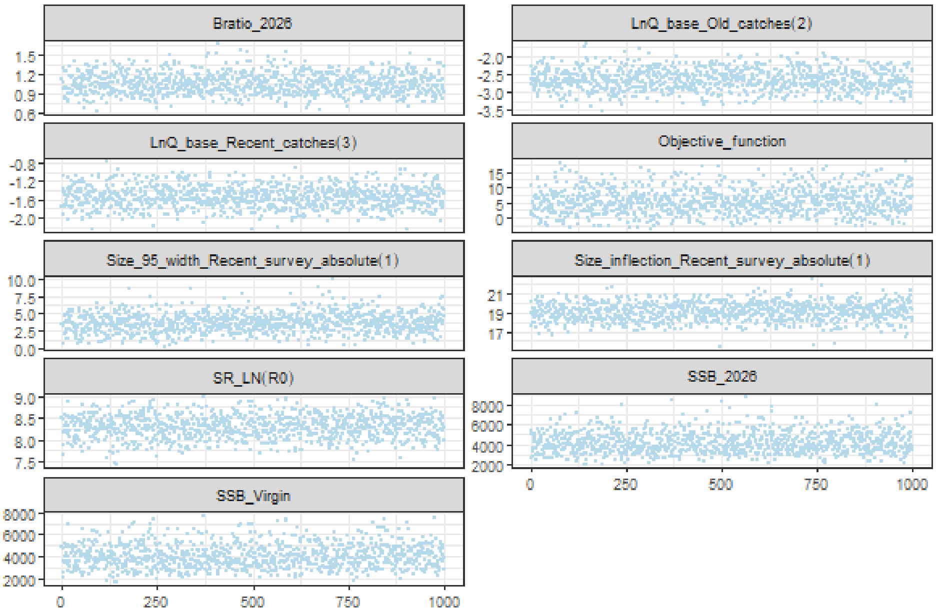

Figure D.171: MCMC trace plots for the Faster growth profile scenario

D.2.8 Slower growth profile

This section presents results for the Slower growth profile scenario.

Table D.20: Summary of parameter estimates for black teatfish the Slower growth profile scenario. MCMC Median is median parameter value from robust MCMC scenarios. MCMC 2.5% and 97.5% indicates 95% credible interval.

Symbol	MCMC median	MCMC 2.5%	MCMC 97.5%
SR_LN(R0)	8.7	8.2	9.2
SSB_Virgin	3744.9	2233.5	6080.9
SSB_2026	3816.25	2322.42	6261.09
Bratio_2026	1	0.8	1.3
LnQ_base_Old_catches(2)	-2.7	-3.2	-2.1
LnQ_base_Recent_catches(3)	-1.52	-1.99	-1.04
Size_inflection_Recent_survey_absolute(1)	19.6	17.6	21.5
Size_95%width_Recent_survey_absolute(1)	3.6	1.3	6.1

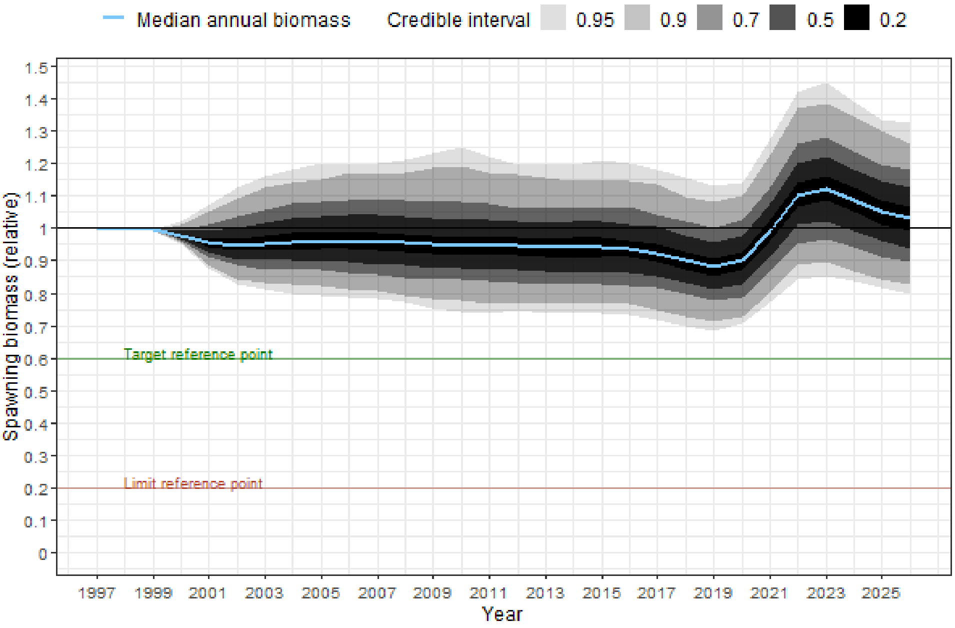

Figure D.172: Relative spawning biomass for the Slower growth profile scenario

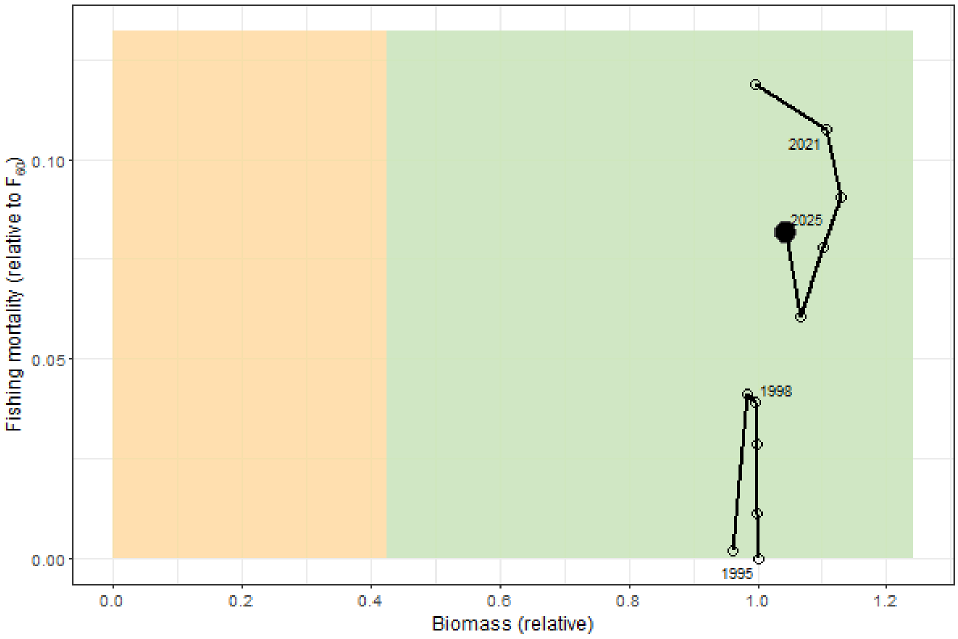

Figure D.173: Phase plot for the Slower growth profile scenario

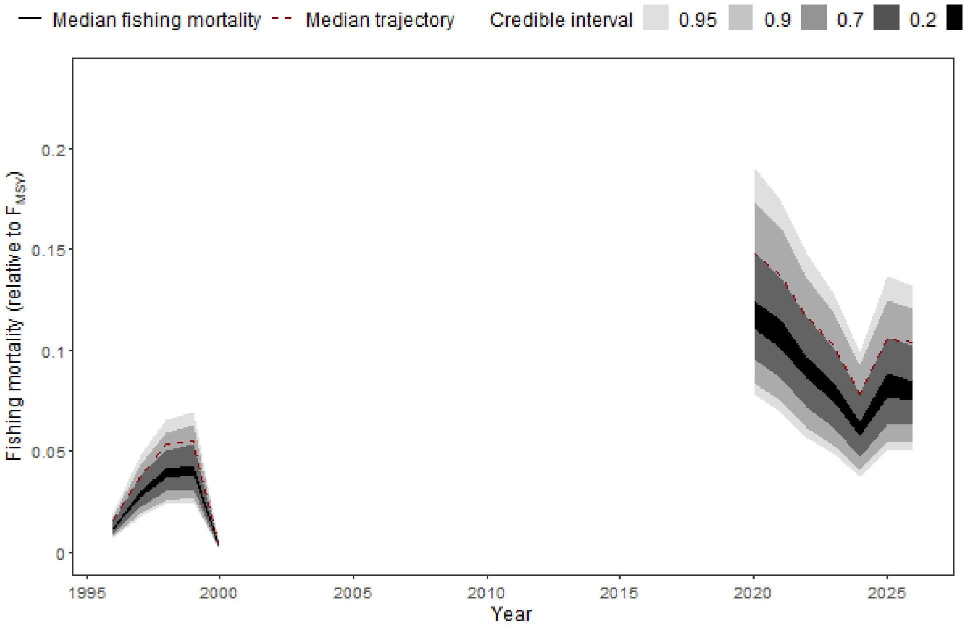

Figure D.174: Fishing mortality for the Slower growth profile scenario

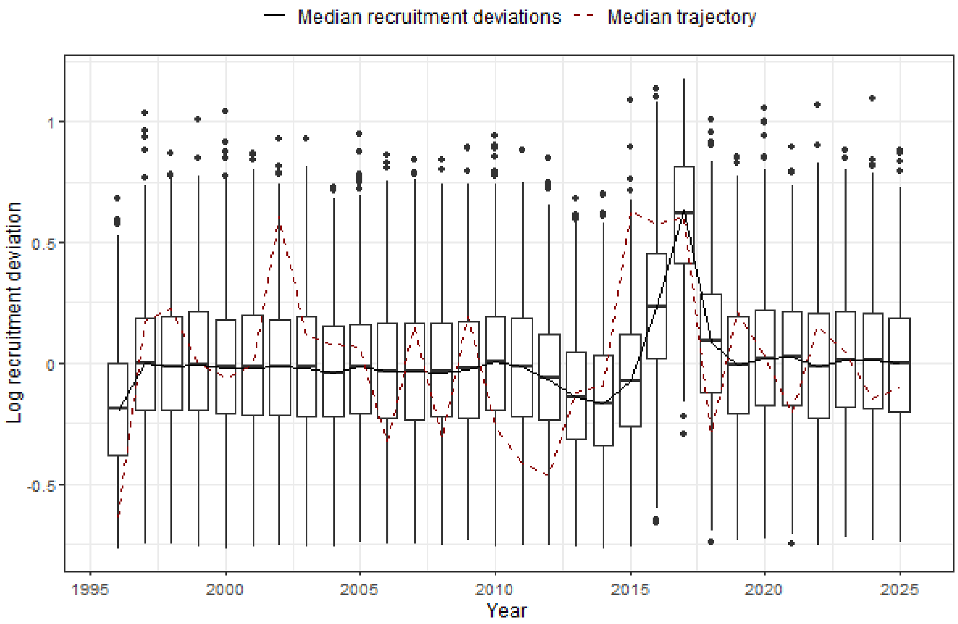

Figure D.175: Recruitment deviations for the Slower growth profile scenario

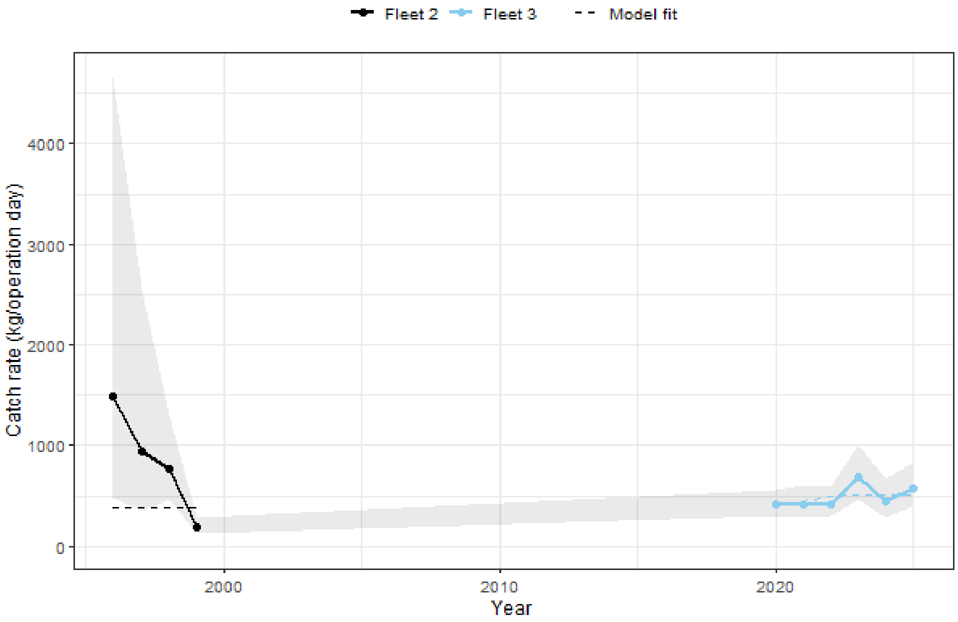

Figure D.176: CPUE fit for the Slower growth profile scenario

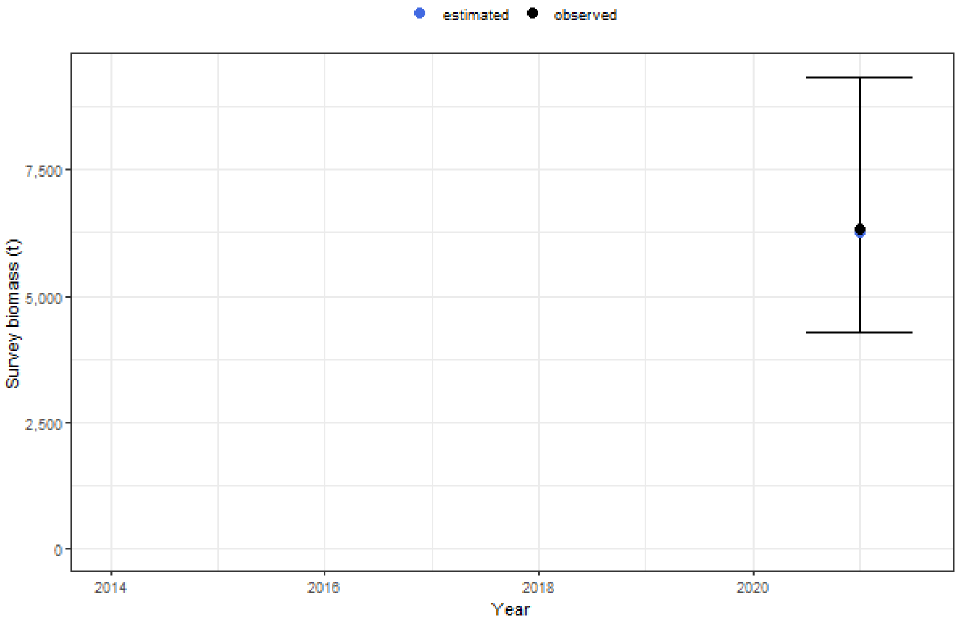

Figure D.177: Surveyed biomass fit for the Slower growth profile scenario

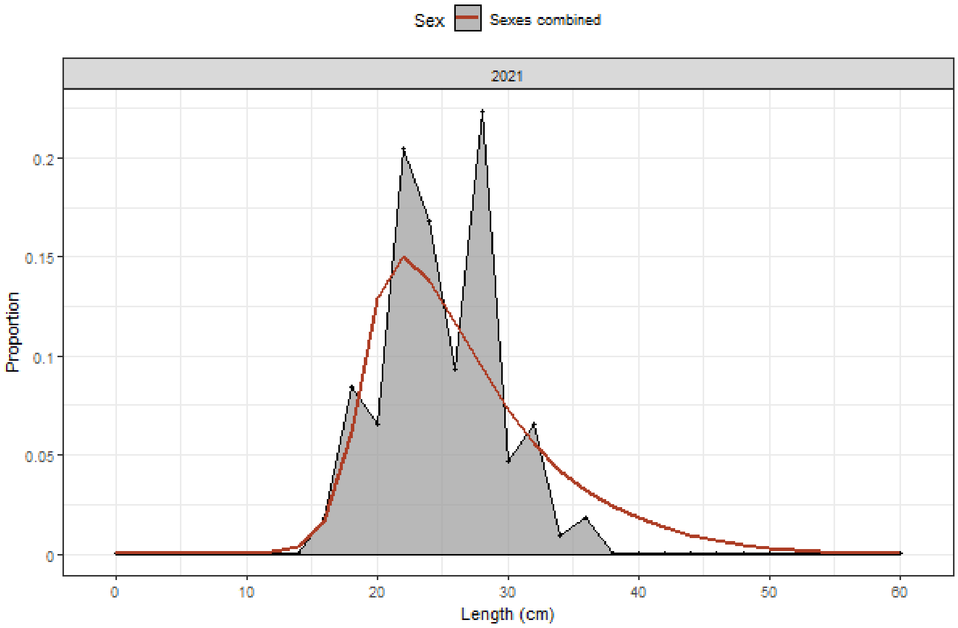

Figure D.178: Length composition fit for the Slower growth profile scenario

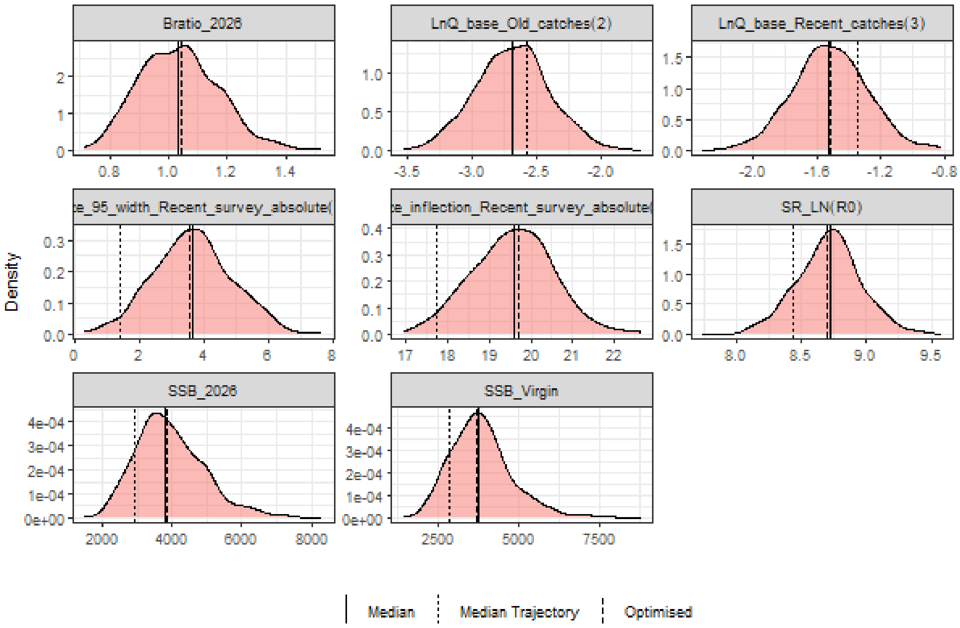

Figure D.179: MCMC parameter posterior densities for the Slower growth profile scenario

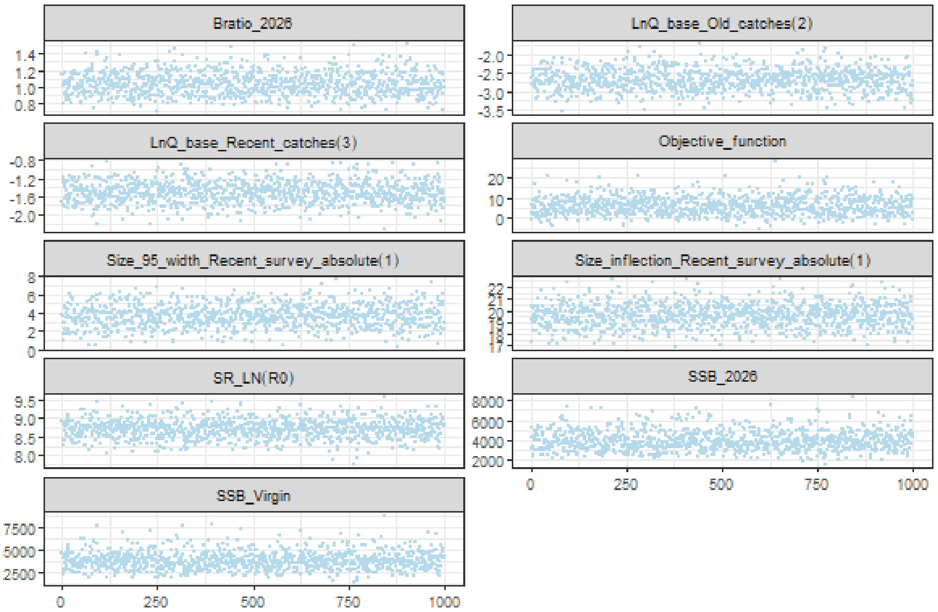

Figure D.180: MCMC trace plots for the Slower growth profile scenario

D.2.9 SigmaR = 0.4

This section presents results for the SigmaR = 0.4 scenario.

Table D.21: Summary of parameter estimates for black teatfish the SigmaR = 0.4 scenario. MCMC Median is median parameter value from robust MCMC scenarios. MCMC 2.5% and 97.5% indicates 95% credible interval.

Symbol	MCMC median	MCMC 2.5%	MCMC 97.5%
SR_LN(R0)	8.5	8	9.1
SSB_Virgin	3266.5	1904.1	5945.1
SSB_2026	3261.54	1926.89	5557.45
Bratio_2026	1	0.7	1.4
LnQ_base_Old_catches(2)	-2.6	-3.3	-2
LnQ_base_Recent_catches(3)	-1.04	-1.52	-0.57
Size_inflection_Recent_survey_absolute(1)	18.8	17.1	21.5
Size_95%width_Recent_survey_absolute(1)	3.1	0.7	6.7

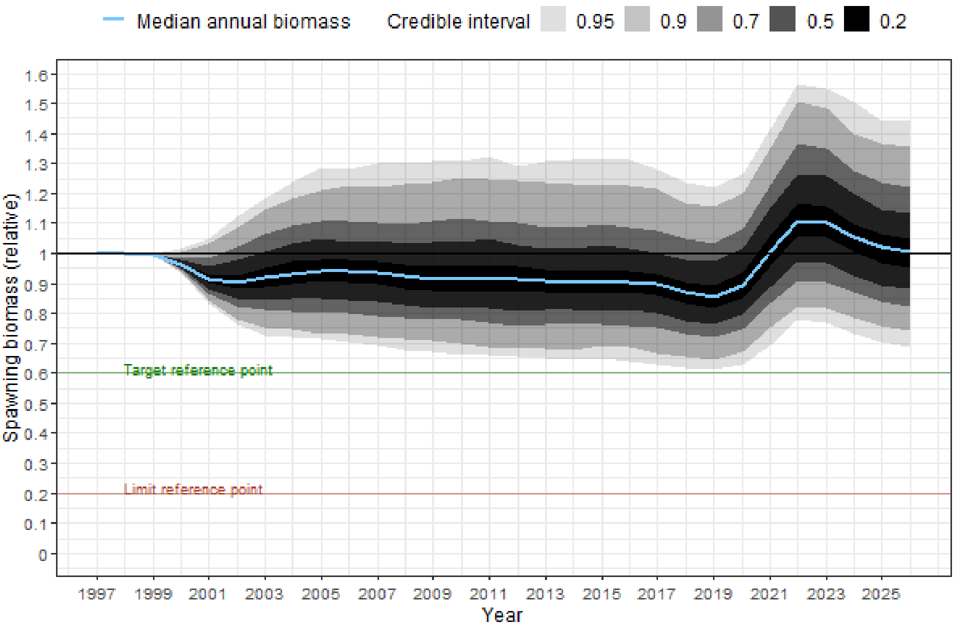

Figure D.181: Relative spawning biomass for the SigmaR = 0.4 scenario

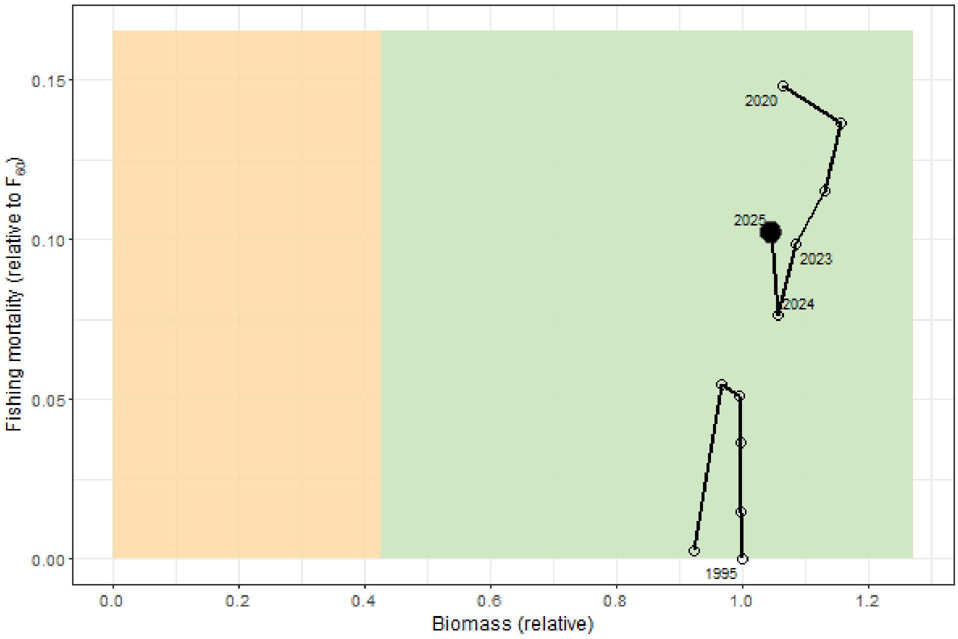

Figure D.182: Phase plot for the SigmaR = 0.4 scenario

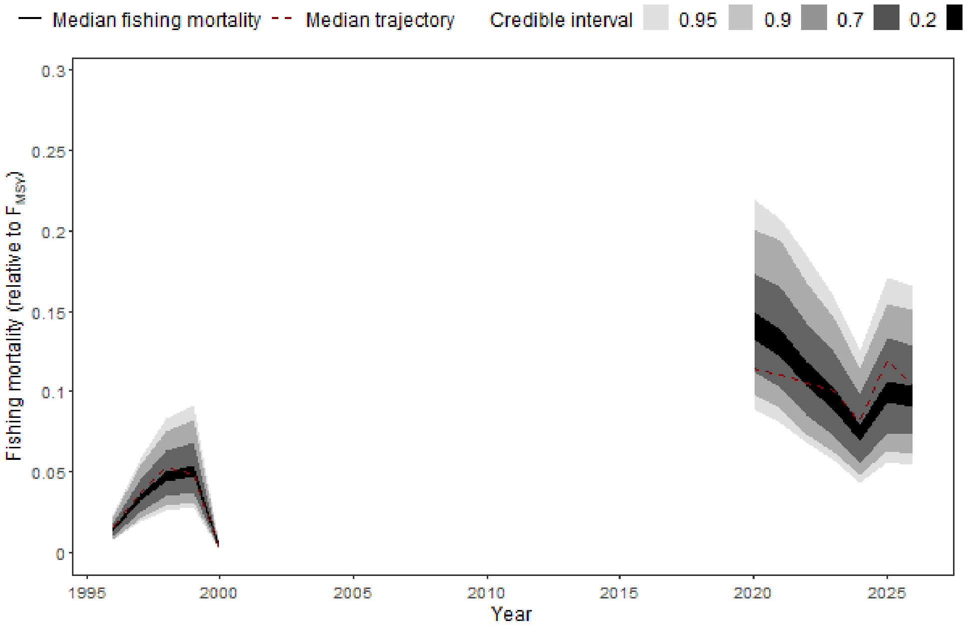

Figure D.183: Fishing mortality for the SigmaR = 0.4 scenario

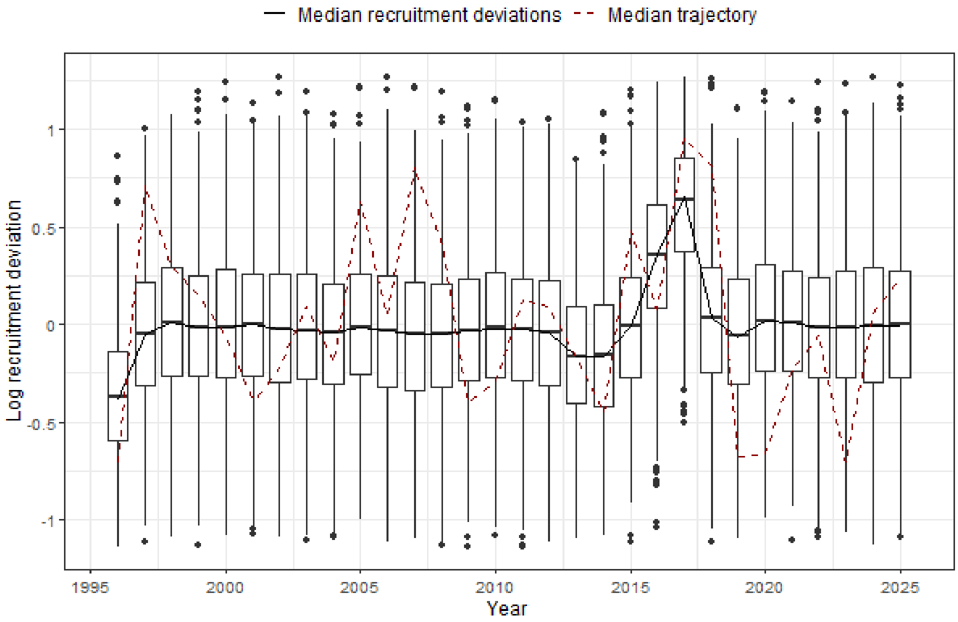

Figure D.184: Recruitment deviations for the SigmaR = 0.4 scenario

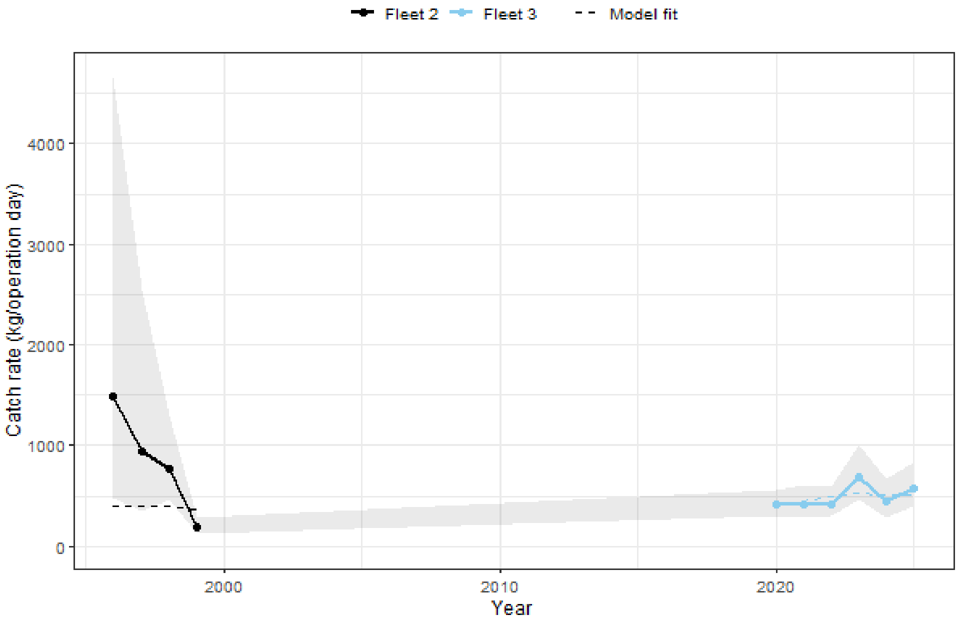

Figure D.185: CPUE fit for the SigmaR = 0.4 scenario

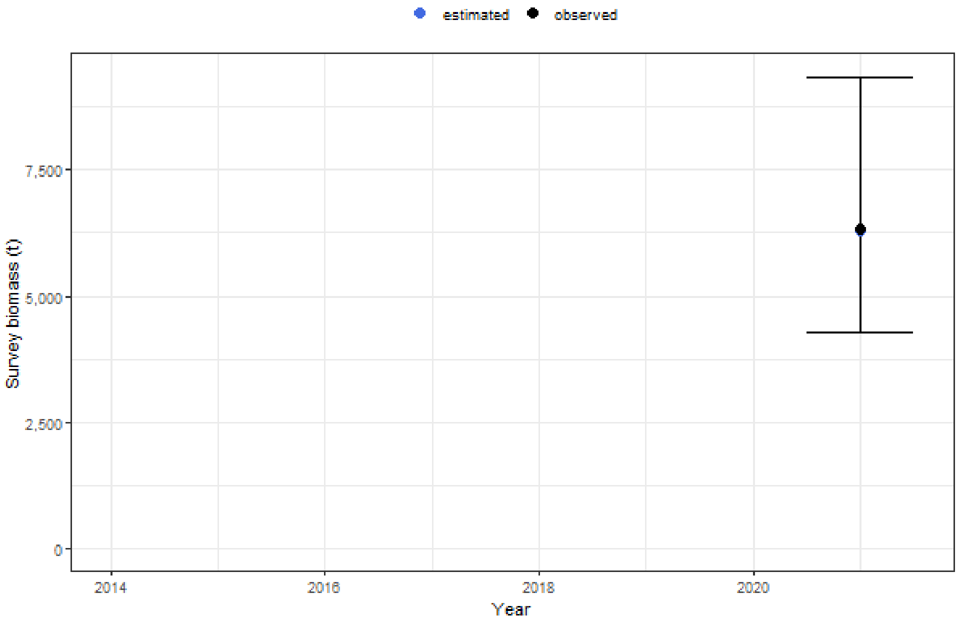

Figure D.186: Surveyed biomass fit for the SigmaR = 0.4 scenario

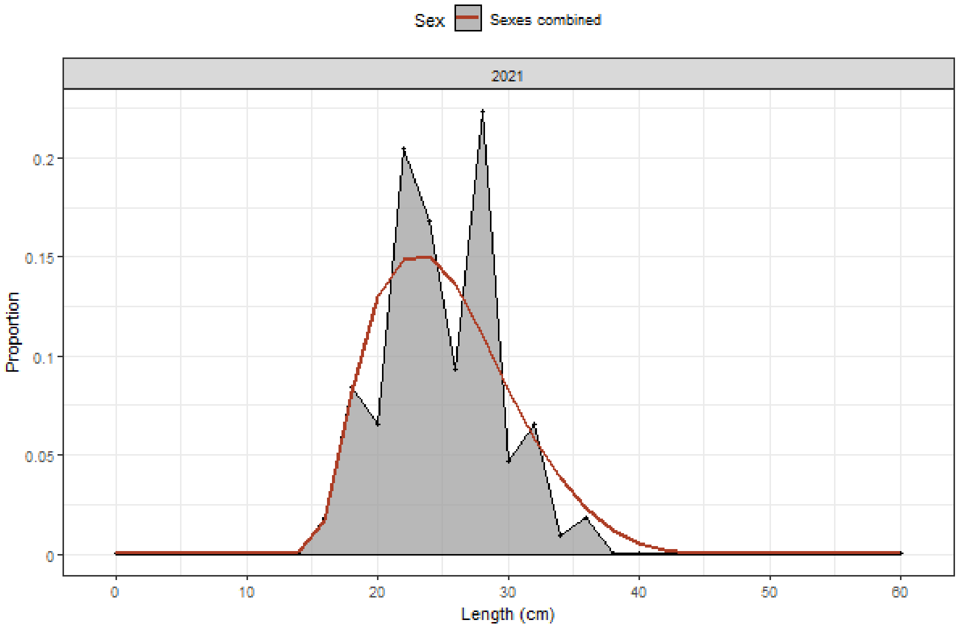

Figure D.187: Length composition fit for the SigmaR = 0.4 scenario

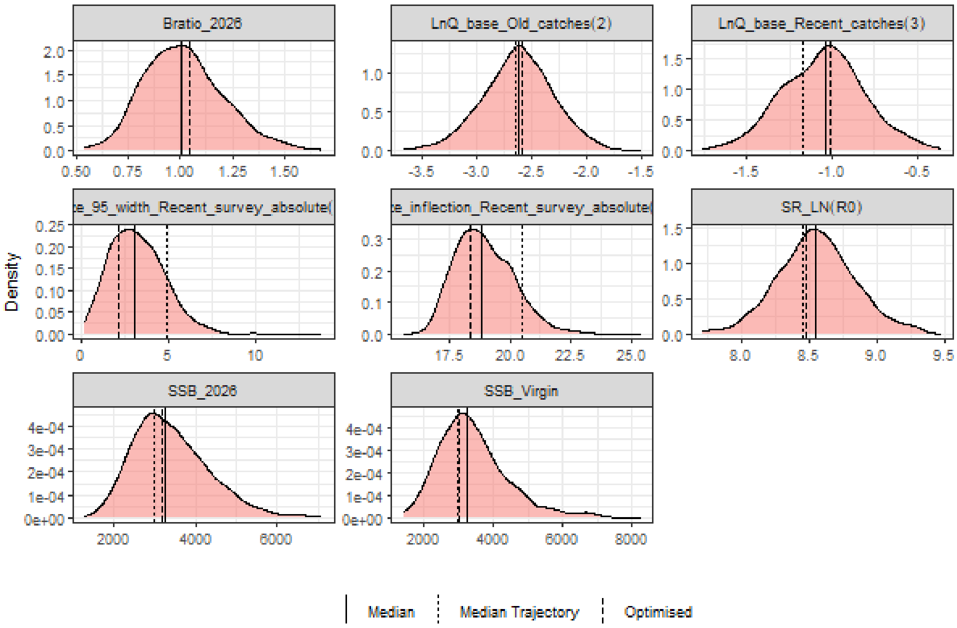

Figure D.188: MCMC parameter posterior densities for the SigmaR = 0.4 scenario

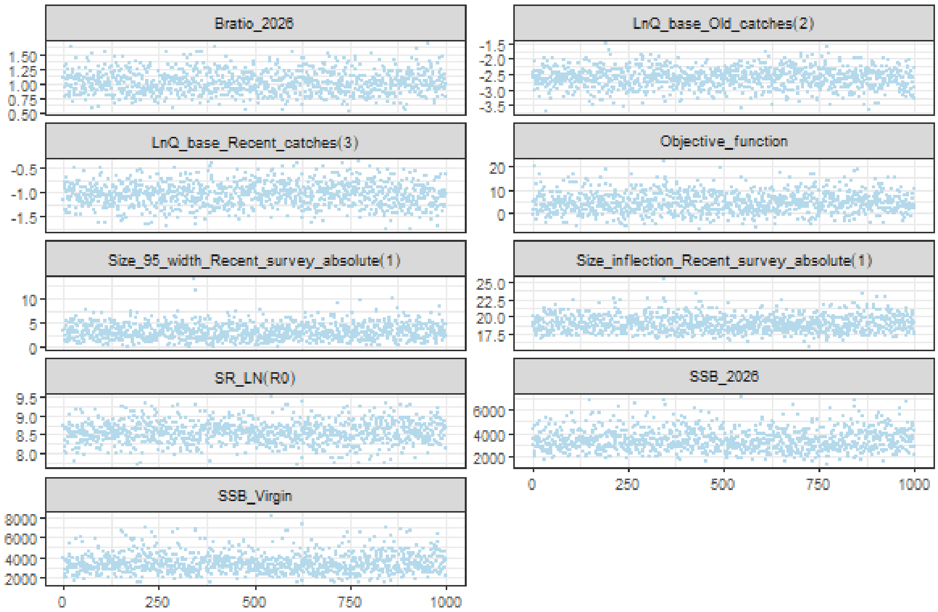

Figure D.189: MCMC trace plots for the SigmaR = 0.4 scenario

D.2.10 SigmaR = 0.6

This section presents results for the SigmaR = 0.6 scenario.

Table D.22: Summary of parameter estimates for black teatfish the SigmaR = 0.6 scenario. MCMC Median is median parameter value from robust MCMC scenarios. MCMC 2.5% and 97.5% indicates 95% credible interval.

Symbol	MCMC median	MCMC 2.5%	MCMC 97.5%
SR_LN(R0)	8.5	7.8	9.2
SSB_Virgin	3088.3	1516.6	6500.1
SSB_2026	2932.8	1674.06	5563.75
Bratio_2026	1	0.6	1.7
LnQ_base_Old_catches(2)	-2.6	-3.4	-1.8
LnQ_base_Recent_catches(3)	-0.97	-1.47	-0.5
Size_inflection_Recent_survey_absolute(1)	18.3	16.5	21.6
Size_95%width_Recent_survey_absolute(1)	2.7	0.4	7.5

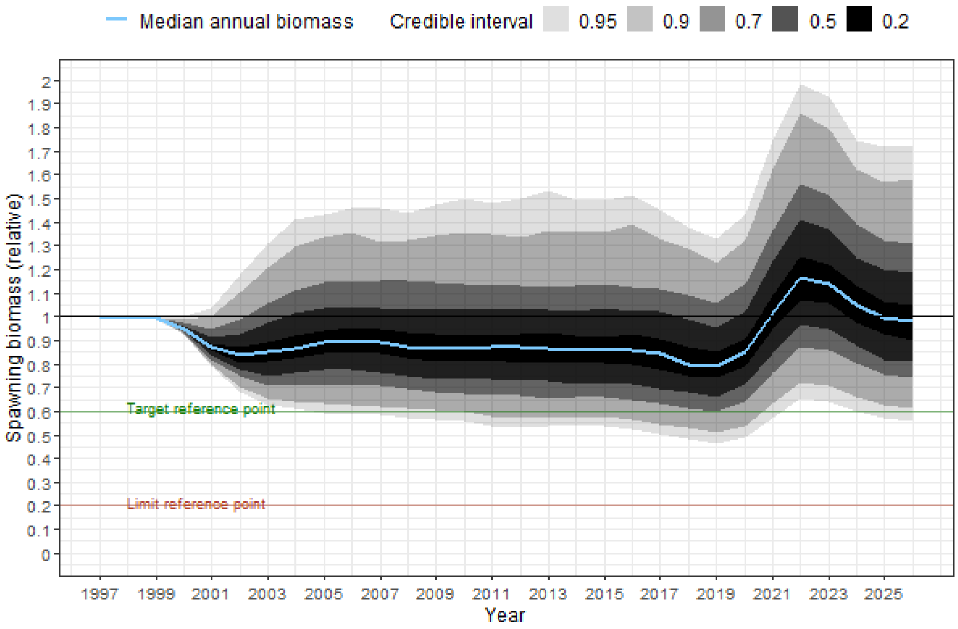

Figure D.190: Relative spawning biomass for the SigmaR = 0.6 scenario

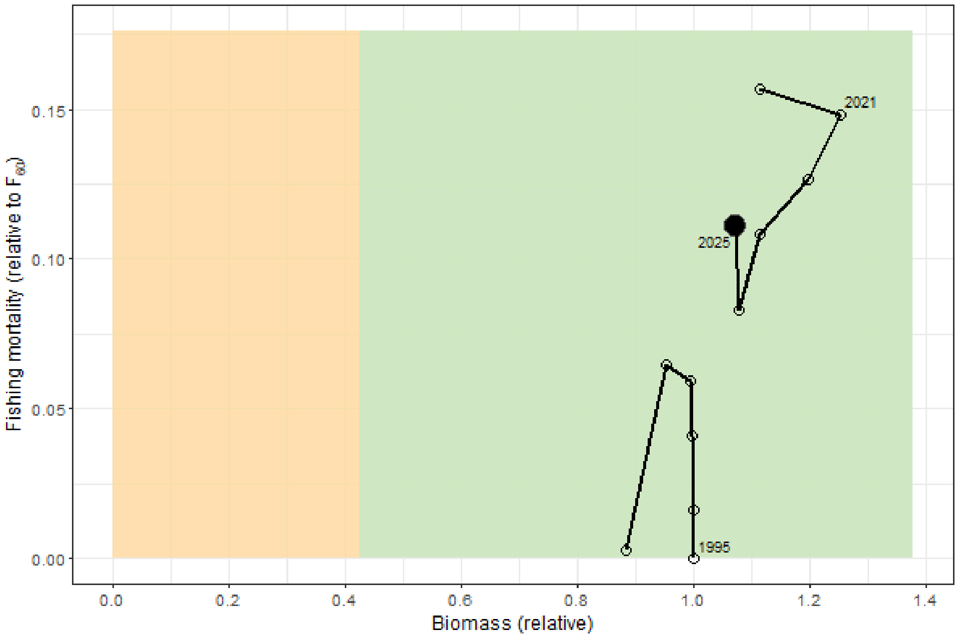

Figure D.191: Phase plot for the SigmaR = 0.6 scenario

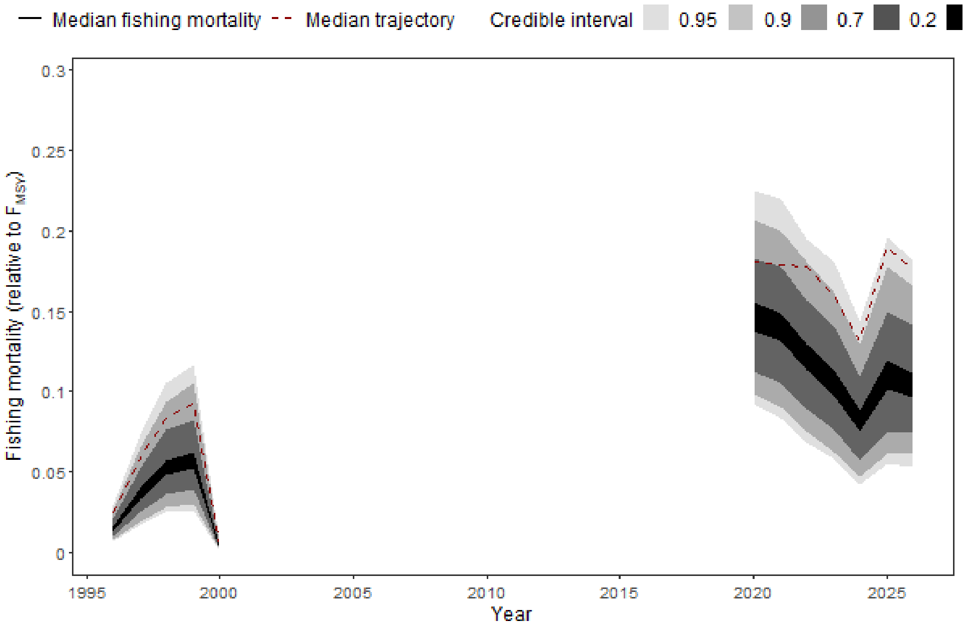

Figure D.192: Fishing mortality for the SigmaR = 0.6 scenario

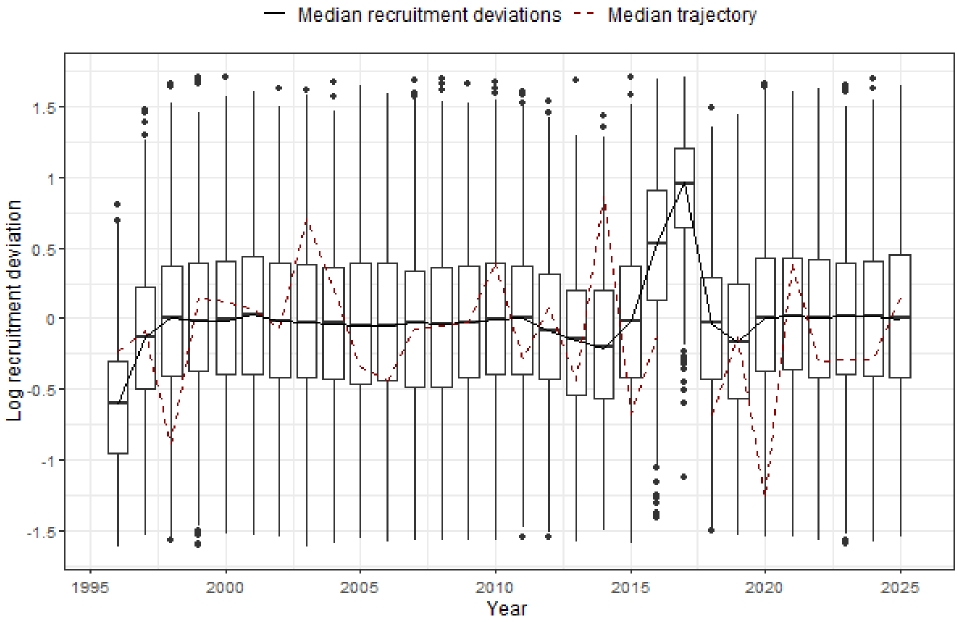

Figure D.193: Recruitment deviations for the SigmaR = 0.6 scenario

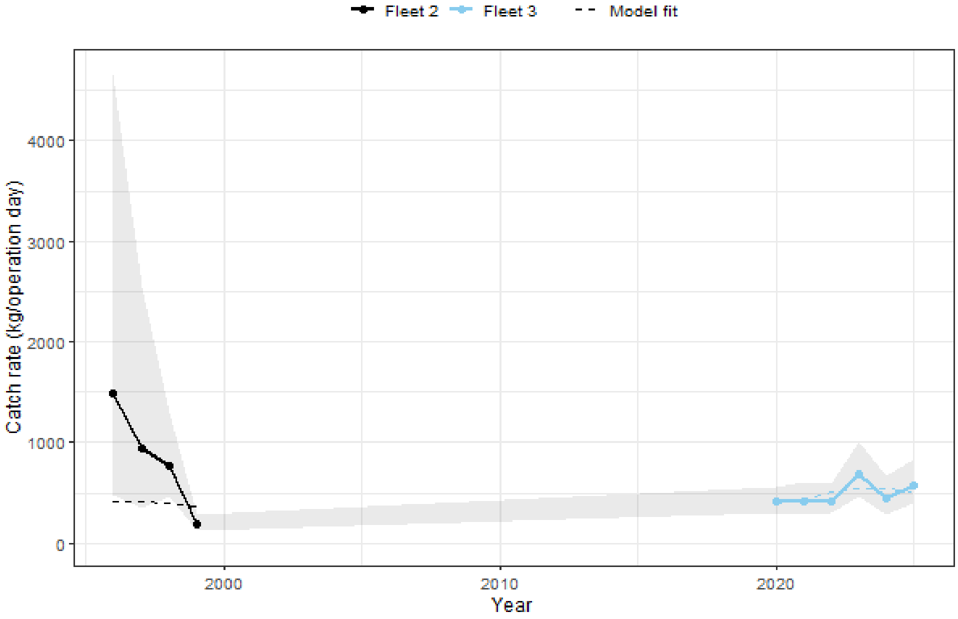

Figure D.194: CPUE fit for the SigmaR = 0.6 scenario

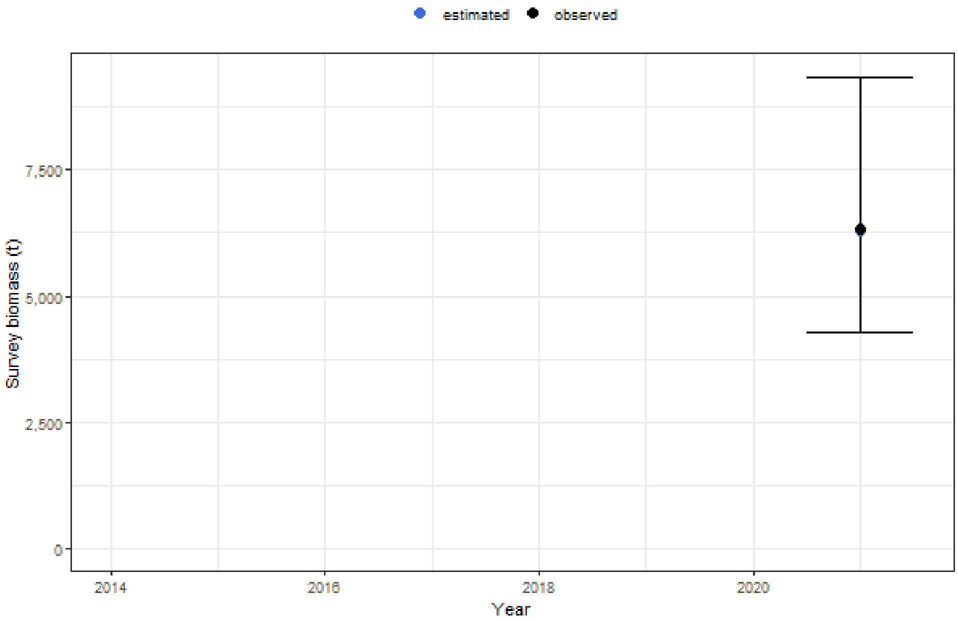

Figure D.195: Surveyed biomass fit for the SigmaR = 0.6 scenario

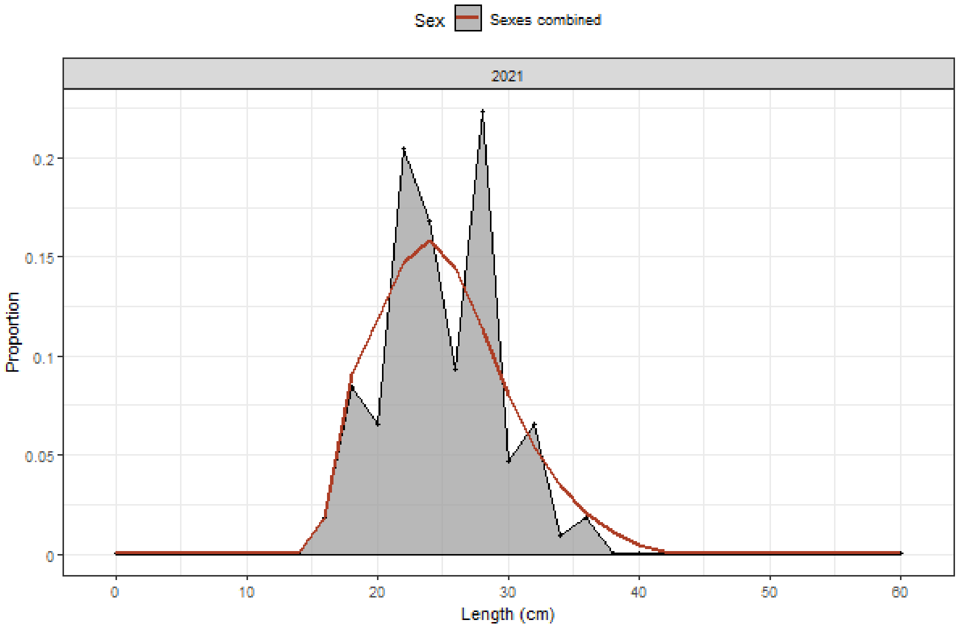

Figure D.196: Length composition fit for the SigmaR = 0.6 scenario

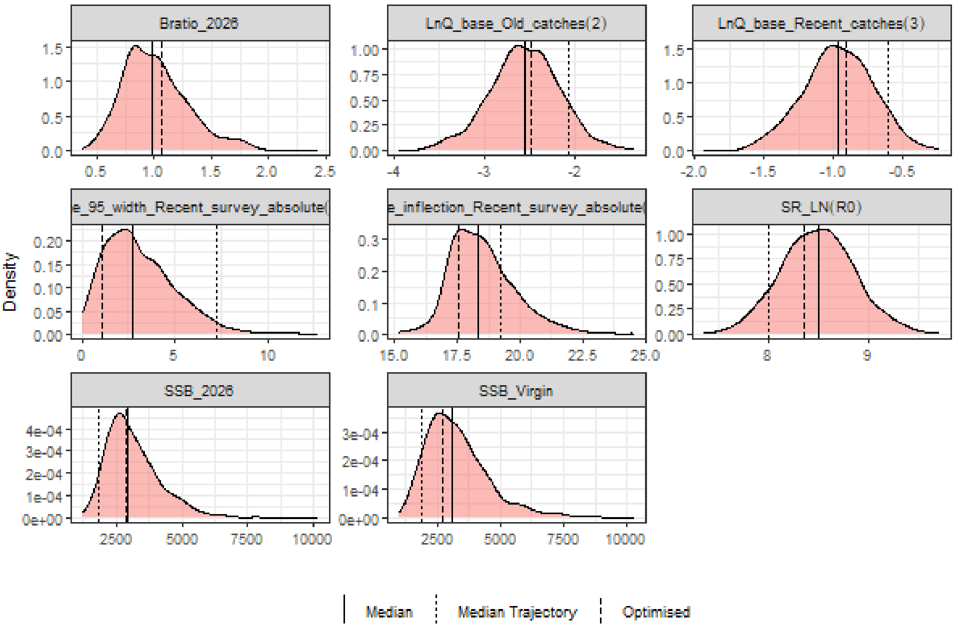

Figure D.197: MCMC parameter posterior densities for the SigmaR = 0.6 scenario

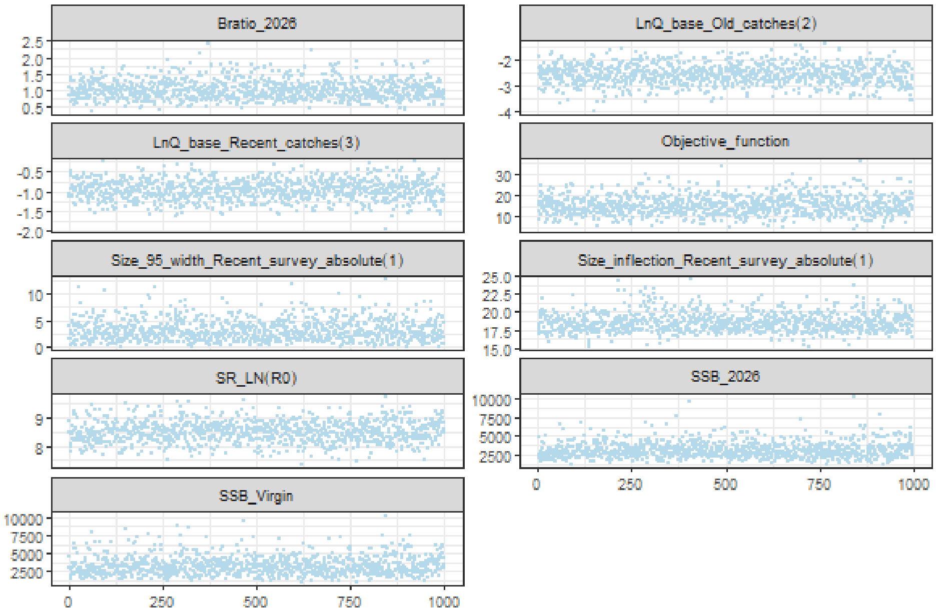

Figure D.198: MCMC trace plots for the SigmaR = 0.6 scenario