Stock assessment of white teatfish (*Holothuria fuscogilva*) in Queensland, Australia, with data to December 2025

June 2026

Queensland
Government

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Executive summary

Introduction

The Queensland Sea Cucumber Fishery (QSCF) operates on the Great Barrier Reef. Within the QSCF, white teatfish contribute a significant portion of the current annual catches and have one of the highest selling prices, making them an important species for the fishery. The white teatfish fishery is generally considered to have commenced in 1995. White teatfish have a lifespan of potentially in the range of several decades. White teatfish mature at a relatively large size, with 50% of animals mature by about 32 cm or 1.2 kg.

This stock assessment estimated the spawning biomass at the beginning of 2026 (i.e. 1 January 2026). The stock was assumed to be in an unfished state in 1995. The term ‘biomass’ referred to the total weight of a biological population or stock. ‘Spawning biomass’ referred to the total weight of mature or reproductively capable individuals within the stock. The ‘spawning biomass ratio’ was the key biomass estimate presented in this stock assessment. This ratio was simply the spawning biomass in a year as a percentage of the unfished spawning biomass in 1995.

This stock assessment estimated spawning biomass ratios at the beginning of 2026 between 67% and 115% of an assumed unfished state in 1995.

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 undertaken for white teatfish on the GBR, with the previous assessment undertaken in 2021 (Helidoniotis 2021). The previous assessment estimated stock status in 2021 for the whole GBR as 78% relative to 1995 (Helidoniotis 2021). This was consistent with the present assessment. Several key aspects of this assessment differ from the previous white teatfish assessment:

- The present assessment was performed using Stock Synthesis whereas the previous assessment was performed using an age-structured surplus production model (ASPM).
- The biological parameters have been updated to values provided in Purcell et al. (2025), or with more conservative assumed values. Uncertainty in these values was addressed through the ensemble modelling approach applied.
- The current assessment used whole wet weight units for catch, whereas the previous assessment used landed salted weight for catch units.
- The present assessment included surveyed estimates of biomass (Koopman et al. unpublished; Koopman and Knuckey unpublished) that were not available when the previous assessment was undertaken. These were used to condition the model on estimates of absolute biomass in specific years.

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 1995–2026, 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.

This assessment modelled the east coast white teatfish population as a single genetic stock. A full list of model assumptions can be found in Section 2.8.2.

A calendar year time step was applied even though fishing seasons align with financial years. This was necessary as a recent survey was undertaken in late 2025, and therefore a calendar year timestep was needed to include these data in the stock assessment model within the assessment reporting time requirements.

Unlike the previous assessment, this assessment used an ensemble approach to combine the outcomes from a suite of seven chosen models. The previous stock assessment used outputs from a single 'base case' model chosen from the suite of models built on a consensus of the opinions of experts in the project team. The ensemble approach, used here, allocated equal weighting to each of the seven models and combined their outputs. This reduced reliance on experts correctly choosing a single 'most likely' model among the suite of realistic models. The ensemble definitions were:

Seven scenarios were chosen from combinations of three values of steepness (0.3, 0.5 and 0.7), two values of natural mortality (0.2, 0.4 yr^{-1}), three values of recruitment variability (0.3, 0.4 and 0.6) and two growth profiles (moderate and faster growth).

The scenarios are described in Section 2.8.6 where each scenario was run using a Markov chain Monte Carlo framework, for 250 000 iterations per scenario.

This report 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.

Results

Biomass

The results of this assessment (Table 1 and Figure 1) indicate that at the start of 2026, the biomass was between 67% and 115% of an assumed unfished state in 1995.

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%.

Table 1: Stock status indicators for white teatfish in Queensland

Indicator	Value
Biomass ratio (relative to unfished)	
Range (95% credible interval)	67–115%
Median	86%
Probability below 20%	0%
Probability between 20% and 40%	0%
Probability between 40% and 60%	0%
Probability above 60%	100%
Fishing pressure ratio (relative to F_{60})	
Range (95% credible interval)	0.16–0.91
Probability exceeds F_{B60}	1%

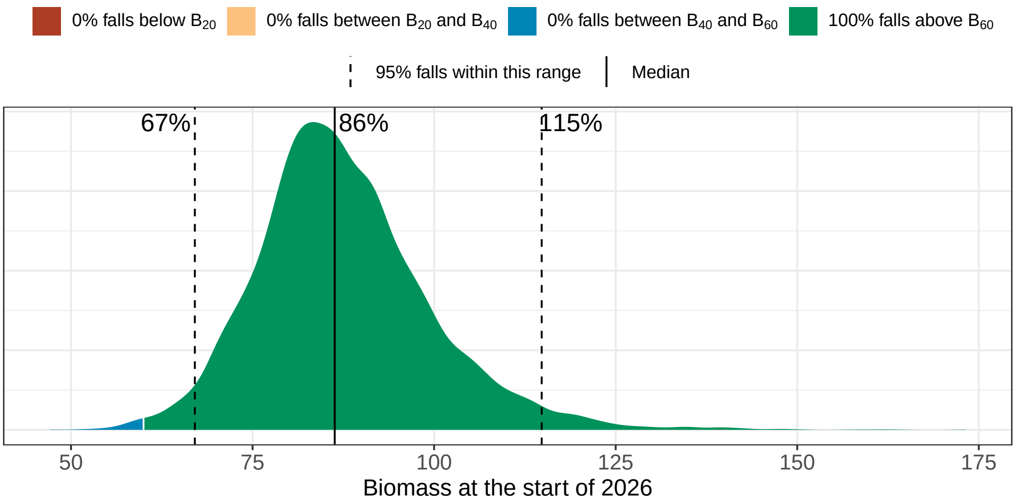

Figure 1: Probability distribution of the biomass ratio at the beginning of 2026 across the full ensemble of scenarios with the credible interval and probability of biomass falling into the four categories indicated

The biomass trajectory (Figure 2) indicates that this is a lightly exploited stock that has never declined below the target biomass reference point.

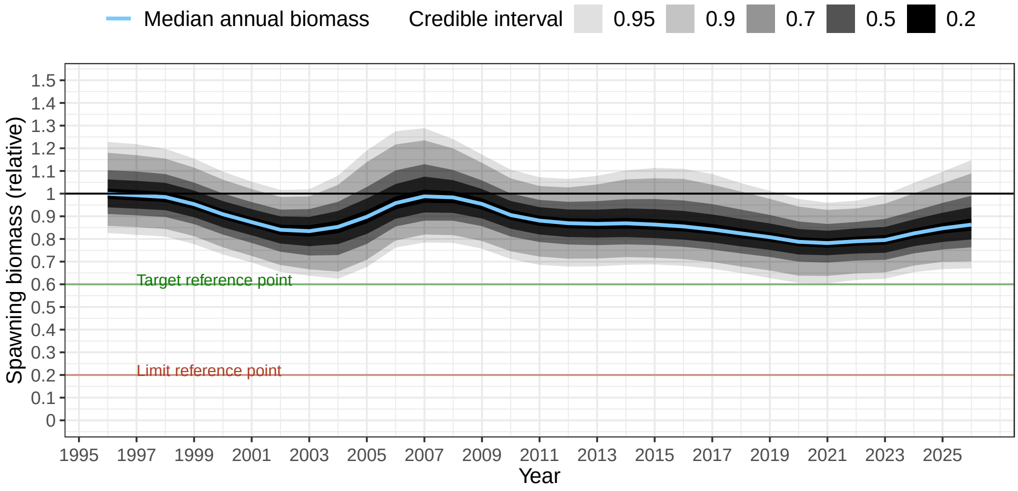

Figure 2: Estimated spawning biomass trajectory relative to unfished levels for white teatfish, from MCMC ensemble scenarios.

Catch

Over the last five years, 2020 to 2025, total retained catch averaged 90 tonnes per year (Figure 3). Only commercial harvest is included in the assessment as it accounts for 99% of the sector allocations and no data on recreational nor Indigenous catch is available.

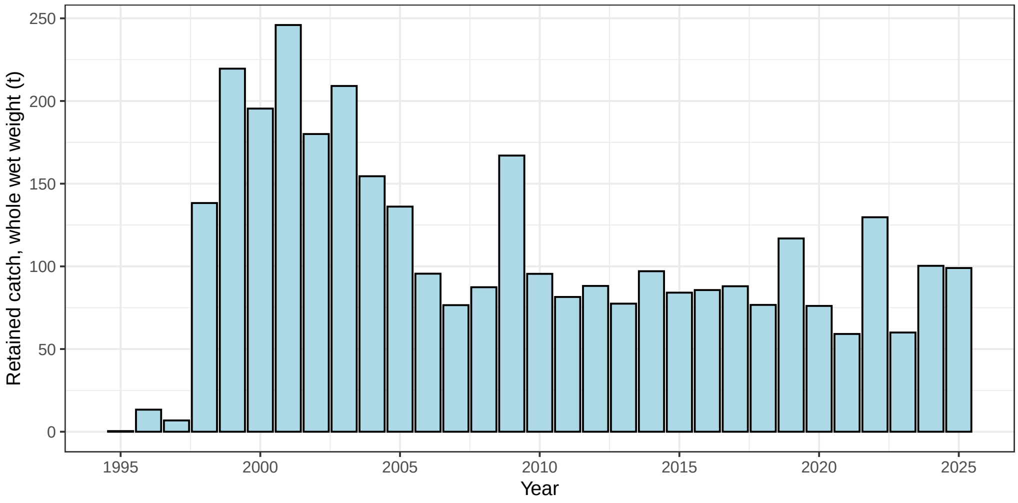

Figure 3: Estimated retained catch between 1995 and 2025 for white teatfish in Queensland

Catch rates

Catch rates from the commercial sectors were standardised, using statistical methods, to estimate an annual index of abundance of white teatfish through time (Figure 4). The response variable for the commercial catch rates model was based on kilograms of white teatfish caught per daily fishing operation. The commercial catch rate model included terms for year, number of fishers, latitude band, wind speed, depth and an identifier for the fishing operator.

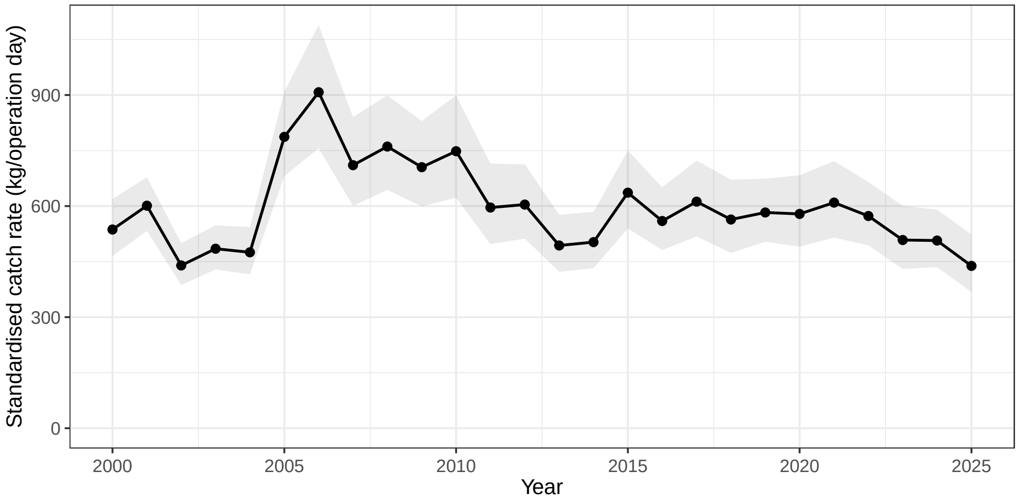

Figure 4: Annual standardised catch rates for white teatfish in Queensland

Length data

The population model was fit to length composition data. The majority of measured individuals were below the minimum legal size of 40 cm (Figure 5).

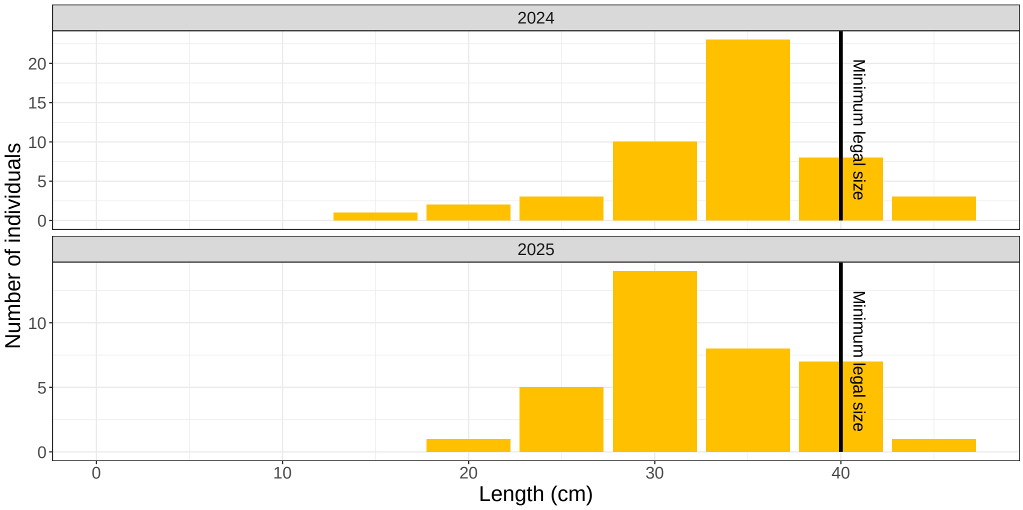

Figure 5: Length composition of white teatfish from the 2024 and 2025 biomass surveys.

Key model influences

The key influences on the stock assessment 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 and growth parameters. The biomass trajectory, that indicates that this is a lightly exploited stock that has never declined below the target biomass reference point, appeared to be driven largely by the flat catch rate signals and estimated recruitment pulses. Because of this, the most recent biomass surveys provide the strongest and most defensible evidence of the standing stock size.

von Bertalanffy growth parameters: The ’slow’ growth scenario that used the parameters from Purcell et al. (2025) was not included in the ensemble model due to the large cryptic biomass that was estimated.

Natural mortality: The scenario that used high natural mortality of $M = 0.6yr^{-1}$ had poor model convergence and was not included in the ensemble scenarios.

Biomass scaling: This was intended as a sensitivity scenario and was not included in the ensemble.

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 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:** 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 often missing or 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 white 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 white teatfish (WTF) assessment indicated that the stock is not below the 20% limit reference point, and likely above 60%, but exact stock status is 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.

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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
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
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

White teatfish (*Holothuria fuscogilva*) is a species of sea cucumber from the family *Holothuriidae* with a wide distribution extending from Madagascar, throughout the Northern Indian Ocean to southern China, the northern waters of Australia, the Pacific islands, and Hanga Roa (Easter Island) (Uthicke et al. 2004a). They are typically found in depths of 10 – 50 metres in outer barrier reef slopes, lagoon pinnacles, back reefs, reef passes and sandy areas in semi-sheltered reef habitats (Purcell et al. 2012; Skewes 2017). White teatfish was distinguished from black teatfish in Cherbonnier (1980) by recognising the black and white mottled form of *H. fuscogilva* to be different than the all black teatfish species (*H. whitmaei*). White teatfish looks more similar to the Indian black teatfish *H. nobilis*, despite *H. nobilis* being more closely related to *H. whitmaei*.

In this assessment, white teatfish is considered a single genetic stock across the Queensland Sea Cucumber Fishery (QSCF) that operates on the Great Barrier Reef (GBR). White teatfish has many colour variations, a much higher genetic variability than *H. whitmaei*, and a larger distribution than *H. whitmaei*, leading some to suggest white teatfish may be a species complex (Uthicke et al. 2004a; Koopman et al. unpublished). Between the Torres Strait, Coral Sea and Queensland East Coast, it is possible that genetic connectivity is maintained through ‘stepping stone’ mechanisms (Benzie and Uthicke 2003; Ceccarelli et al. 2013).

The most thorough information on white teatfish life history comes from Conand (1989) and Purcell et al. (2025) in New Caledonia although the biological characteristics of white teatfish vary regionally. The maximum length reported is 32 cm in the Coral Sea (Skewes 2017), 37 cm in the Torres Strait (Murphy et al. 2021a), 42 cm in the Western Pacific (CITES 2019) and 57 cm in New Caledonia (Conand 1989). Conand (1989) found that white teatfish mature at a relatively large size, with 50% of animals mature by 32 cm or 1.175 kg. It is likely this estimate does not hold for populations with smaller body size in the Coral Sea and Torres Strait, for example. In addition, white teatfish are one of the most rotund species of sea cucumbers, resulting in a weak relationship between length and weight. White teatfish ”are rather long-lived, potentially in the range of several decades”, may not experience senescence and may shrink (Uthicke et al. 2004b; Purcell et al. 2025).

In terms of reproduction, there is little information on white teatfish on the GBR but they are known to spawn in summer in New Caledonia and winter to spring in the Solomon Islands. Larvae are planktonic and planktotrophic with a larval duration of around 2 – 4 weeks (Burgy and Purcell 2024). When larvae settle, the animal is likely restricted to that reef for the rest of their life (Skewes 2024).

The white teatfish population in Australia is considered a collective of “local populations with maximum connectivity within the meta-population” (Skewes 2024). This population structure encourages depensatory effects, whereby depleted stocks result in diluted gametes in the water column and slow recovery of populations, despite the cessation of fishing (Skewes 2024). This phenomenon may be occurring in the Seychelles fishery, where a stock estimate suggested that “the species may be below the level of recruitment impairment” (MRAG 2017).

In the QSCF, white teatfish contribute a significant portion of the current annual catches and have one of the highest selling prices, making them a very important species for the fishery. The fishery grants 18 licences which are held by two operators who nominate up to 3 persons to take or sell sea cucumbers per licence. Sea cucumbers must be harvested by hand while free diving or using hookah or SCUBA.

White teatfish, like most species in the QSCF, are subject to the Rotational Harvest Arrangement (RHA) which divides the fishery into 158 areas and opens each area every three years. The number of days spent in each area is legislatively limited to 18 days and voluntarily limited to 15 days. Areas north of 11^o S are exempt from the three year rotational access but maintain the 18 day limit. Stocks are also protected by the GBR Representative Areas Program (RAP) which has prohibited fishing in green zones implemented 2004. The RAP accounts for 33% of the GBR Marine Park (GBRMP).

White teatfish were historically harvested year-round, with harvest slowing in autumn. Since the TAC was reduced from 89 (t) to 64 (t) in July 2007 and then to 53 (t) in July 2011, the amount of white teatfish harvested during autumn and early winter has decreased as the catch allocation is fulfilled earlier in the fishing season.

The 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).

A calendar year time step was applied even though fishing seasons align with financial years. This was necessary as a recent survey was undertaken in late 2025, and therefore a calendar year timestep was needed to include these data in the stock assessment model within the assessment reporting time requirements.

Table 1.1: Management measures applied to white 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 – catch recorded in numbers and kilograms; Fishery entry limited to existing licence holders
1997	Total allowable catch (TAC) of 500 tonnes for all sea cucumber species with only 380 tonnes allocated to licence holders; Minimum legal size of 15 cm for all sea cucumber species (Benzie and Uthicke 2003)
1999	Total allowable catch of white teatfish set to 127 tonnes (Skewes 2024)
July 2000	Introduction of logbook version BD02 – catch reported in numbers; Total allowable catch of white teatfish increased by 25% (total of 158.75 tonnes) as a ‘one-off’ to ease the transitional management arrangements following the closure of black teatfish stocks (Skewes 2024; Breen 2001)
July 2001	Total allowable catch of white teatfish restored to 127 tonnes
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 (now Rotational Harvest Arrangement) to distribute effort across the fishery area; Fishery split into North and South zones at 19° S; Total allowable catch of white teatfish set to 89 tonnes (57 tonnes in North zone and 32 tonnes in South zone)

July 2006	Introduction of logbook version BD03 – catch reported in numbers, weights recorded in buyer return logbook; Total allowable catch of white teatfish set to 69.8 tonnes
July 2007	Total allowable catch of white teatfish set to 64 tonnes (51 tonnes in North zone and 13 tonnes in South zone)
November 2008	Implemented performance management system to formalise objectives, performance indicators, performance measures and management responses (Queensland Government 2008)
July 2009	Mandatory reporting of RHA zone and burrowing blackfish zone (BBZ)
July 2011	Total allowable catch of white teatfish set to 53 tonnes (40 tonnes in North zone and 13 tonnes in South zone)
November 2013	Introduction of logbook version BD04 – catch reported in kilograms
July 2014	North and South zoning removed (Skewes 2024); Combined total allowable catch for white teatfish of 53 tonnes
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)
September 2021	Queensland Sea Cucumber Fishery harvest strategy: 2021–2026 released
November 2021	Granted export approval for three years, until 30 November 2024 (Anonymous 2021)
September 2021	Introduction of logbook version BD05 – catch recorded in kilograms
November 2024	Positive (conditional) non-detriment finding (DCCEEW 2024)

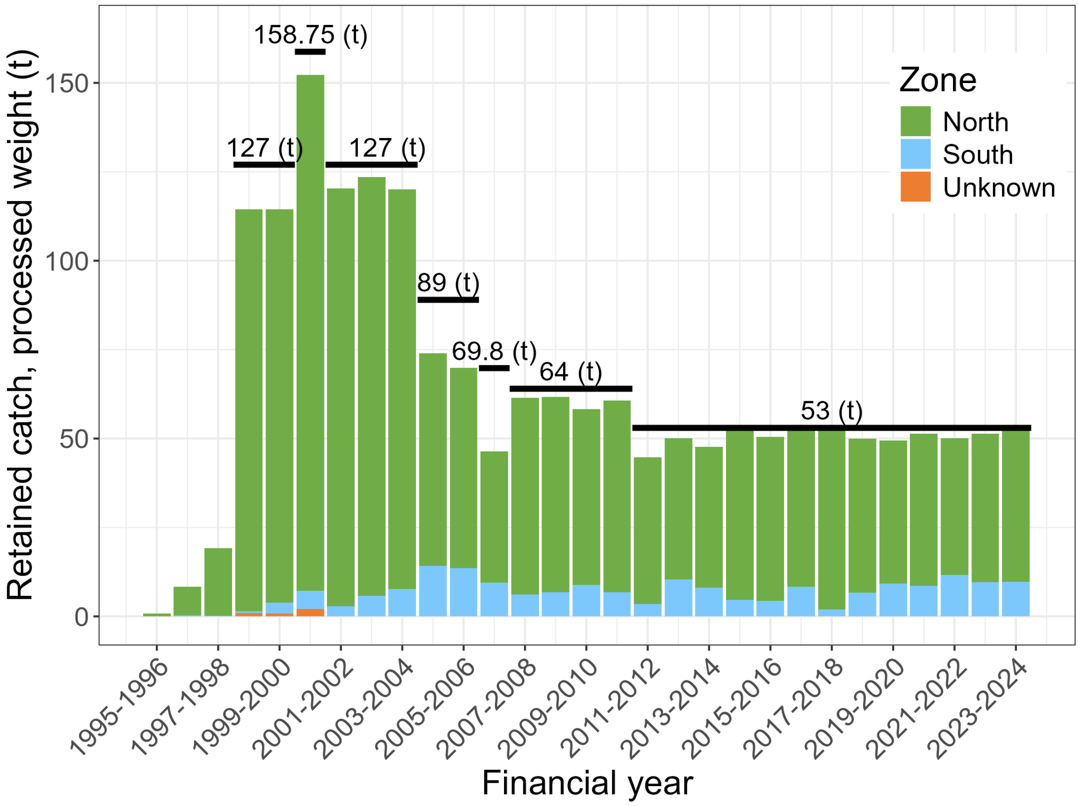


Figure 1.1: Changes in total allowable catch (TAC) of white teatfish. Note that the TAC is set on a financial year season but this assessment uses a calendar year timestep. Therefore, catches in other plots may not align with the TACs presented here.

2 Methods

2.1 Data sources

Data sources included in this assessment (Table 2.1) were used to determine catch rates (CPUE), length compositions, estimates of survey biomass, and annual harvests. The assessment period commenced when logbooks began in 1995 up until 2025 inclusive.

Table 2.1: Data sources for the white teatfish Stock Synthesis assessment

Data	Years	Source
Commercial logbook	1995–2025	Compulsory commercial logbook database (CFISH) collected by Fisheries Queensland
Buyer returns logbook (now called catch disposal records)	1995–2025	Compulsory commercial logbook database (CFISH) collected by Fisheries Queensland
Fishery independent survey	2024	Koopman et al. (unpublished)
Fishery independent survey	2025	Koopman and Knuckey (unpublished)

2.2 Stock identification information

White teatfish has a wide distribution extending from Madagascar, throughout the Northern Indian Ocean to southern China, the northern waters of Australia, the Pacific islands, and Hanga Roa (Easter Island) (Uthicke et al. 2004a). *Holothuria fuscogilva* was formally distinguished from the two black teatfish species found in the Indian Ocean (*Holothuria nobilis* and *Holothuria whitmaei*) by (Cherbonnier 1980) and confirmed through mtDNA sequencing in 2004 (Uthicke et al. 2004a). The spatial range of the QSCF extends from 10.68° S to 26° S, along the Queensland east coast. The white teatfish species complex contains a range of colour morphs but is most commonly described as mottled black-and-white (Uthicke et al. 2004a). Prior to 2004, literature often confused the scientific names of all three species so marking descriptions and location are used to identify the true species in each analysis.

While the population structure of white teatfish on the GBR is unknown, inferences from similar species would suggest that a single stock exists (Skewes 2024).

2.3 Retained catch estimates

2.3.1 Commercial

Reports of white teatfish commercial catch were identified in the Fisheries Queensland commercial logbooks from 1995 to 2025 inclusive. From 2000 to 2008, white teatfish were only reported by the number of animals. All other years had white teatfish reported using a mix of total daily weight (kilograms) and total daily number of animals (Figure 2.1). Records reported as catch in numbers were converted to catch in kg using a number-to-weight conversion determined from records that contained both measurements (catch by weight and number).

Note that financial years are used to set TACs. However, calendar year time steps are applied in this assessment in order to include the 2025 biomass survey (Koopman and Knuckey unpublished) that occurred in November 2025.

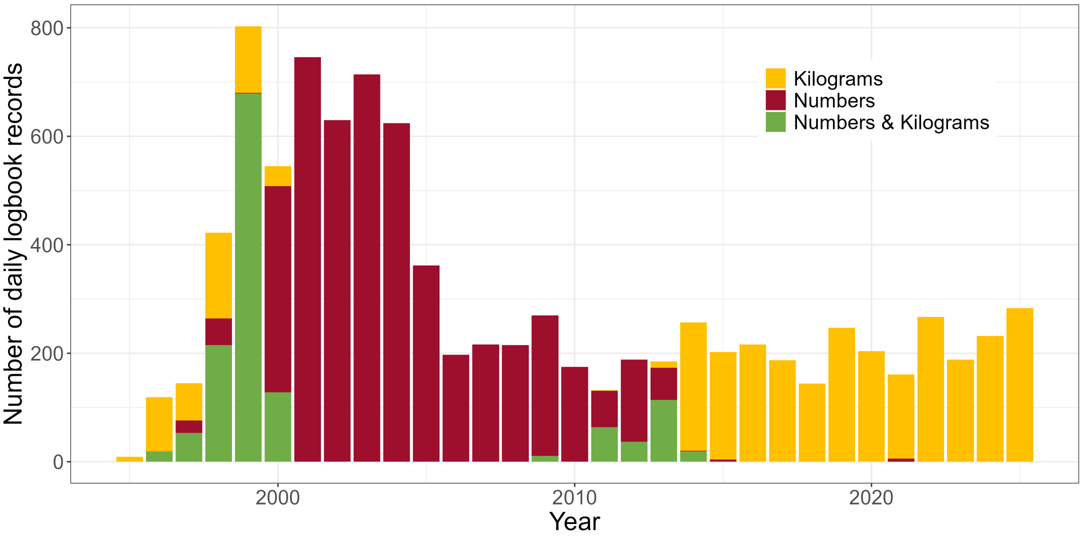


Figure 2.1: Reported units of white teatfish catch for commercial logbook records

White teatfish are processed at sea so the commercial logbooks record the product form of the landed catch and the total weight is confirmed once landed. Prior to 2000, all white teatfish commercial logbook records had the product form entered as 'Whole Dead'. However, from 2000 onwards, most records had the product form entered as 'Salted' and 'Frozen & Boiled' as the first and second most common product forms, respectively. 'Whole Dead' was the default product form for earlier logbooks and was replaced with the most common product form – 'Salted' as this is understood to have been incorrectly documented in the early years of the fishery. Processed weight was converted to live weight using the conversion factors in Table 2.2.

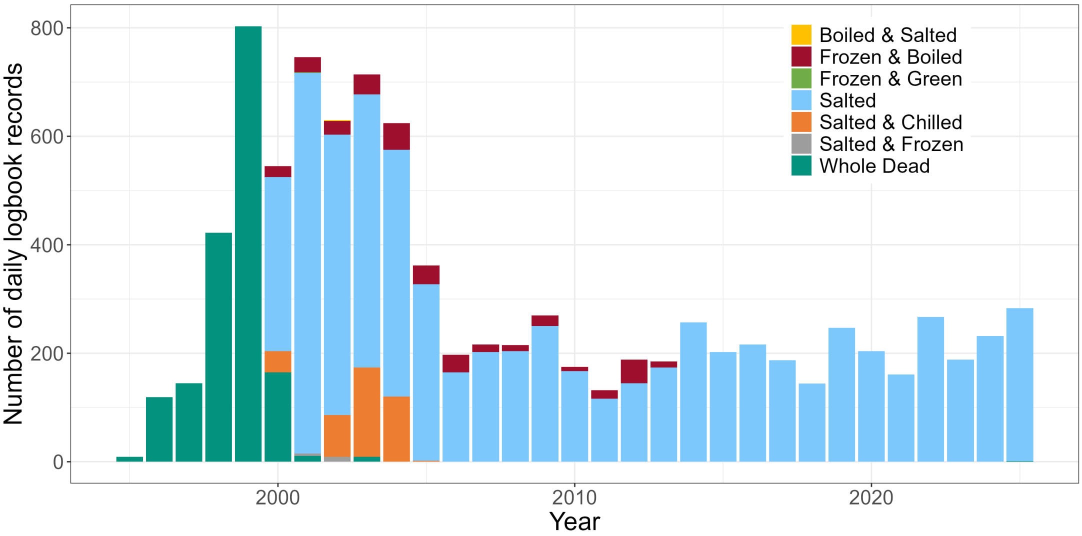


Figure 2.2: Reported product form of catch for commercial logbook records.

Table 2.2: Conversion ratios for processed white teatfish.

Processed form	Conversion	Source
Salted	0.593	Table 1 of Murphy et al. (2021b) but missing from primary source (Purcell et al. 2009a)
Salted & Chilled	0.593	Same as ‘Salted’
Frozen & Boiled	0.627	Gutted conversion from Table 1 of Murphy et al. (2021b)
Salted & Frozen	0.593	Same as ‘Salted’
Boiled & Salted	0.593	Same as ‘Salted’
Frozen & Green	0.627	Same as ‘Frozen & Boiled’

The TAC for white teatfish is set according to processed weight, was processing occurs at sea. However, the stock assessment model requires catches to be input as live weight (i.e. whole wet weight) as this corresponds with biological information such as growth and the weight-length relationship. Therefore all catches used in the stock assessment model, and presented in this report (with the exception of Figure 1.1), are whole wet weight.

2.3.2 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).

2.3.3 Indigenous

The traditional fishing rights of Aboriginal peoples and Torres Strait Islanders are protected under legislation and accordingly there is no defined allocation. However, it is assumed that large catches do not occur via traditional fishing methods given the depth that white teatfish typically occur (Fisheries Queensland 2021).

2.4 Standardised indices of abundance

Queensland commercial logbook records of retained white teatfish per day were used to produce an index of abundance. Fishery-dependent logbook CPUE are driven by the industry’s search for productive areas and profitable fishing practices. The CPUE standardisation procedure aims to remove the effects of fishing behaviour to produce a time series indicative of abundance.

2.4.1 Data preparation

Beche-de-mer daily logbook records were filtered to include data that are representative of the white teatfish fishery and provide sufficient coverage of model covariates. Daily records were filtered by excluding research vessels, excluding records with zero white teatfish and excluding records with no spatial information or incorrect spatial information. Further data filtering included operators in the top 95% by total catch with at least two years experience in the fishery.

The filtered data was then cleaned to account for changing logbook field names, logbook field instructions and add trip meta-data. Various degrees of spatial scale are reported in the logbooks which include BDM zone, 30nm fishing grid and latitude band (ranging from fine to coarse scale).

The number of crew was substituted with the number of fishers, hours were redesigned to capture the average hours per fisher and latitude was aggregated into latitude bands.

The data received via beche-de-mer logbooks has limited statistical power due to the sparsity of spatial and temporal samples. In order to gain the most out of fishery-dependent logbook CPUE, Bishop et al. (2008) suggests prioritising an accurate estimation of operator (authority chain number) effects and the use of external information for a fishing power offset. In this stock assessment, spatio-temporal interactions were not prioritised because the rotational harvest arrangement caused year and BDM zone to be wholly confounded in the majority of cases. Fishing methods were relatively unchanged (or undocumented) through time and fine-scale effort information was inconsistent.

2.4.2 Model design

Catch per unit effort (CPUE) as catch per operation day was modelled with a generalised linear model (GLM) with a gamma error distribution and log link function. Whole, live weight (converted from product weight reported in logbooks) 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 white teatfish are a highly targeted species and targeted effort was not identifiable from logbook data.

The form of the white teatfish GLM was:

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

For the GLM, year, operator, and latitude band were factors and the number of fishers, wind speed, and depth were numeric. Model performance and diagnostics were assessed using the ‘performance‘ R package. These are presented in Appendix A.

2.5 Biomass surveys

White teatfish in the QSCF have been surveyed explicitly on two occasions (Table 2.3). The first survey, conducted during October and November of 2024, surveyed habitat preferred by white teatfish. Through discussions with fishery operators, Koopman et al. (unpublished) found that white teatfish are generally found in paddock country - a strip that spans from about 3nm to 9nm inside the barrier outer reefs. Fishers locate depressions in the reef sediment colloquially named ‘sinkies’ and raised beds named ‘table tops’ and find white teatfish to inhabit the slopes surrounding table tops and upper slopes of sinkies. Koopman et al. (unpublished) likened this description to the mapped area of halimeda bioherms from McNeil et al. (2021). Koopman et al. (unpublished) used the bathymetry model to classify 30 m cells as ‘high relief’ (most likely to contain sinkies) and ‘low relief’ (includes more of the flat ground around sinkies). These cells formed the basis for survey design.

The survey was completed on reefs around Lizard Island, where high catches of white teatfish originate. Transects followed a random stratified survey design using the high and low relief strata. Trained divers followed 200 m transects with a 2 m wide pole, following the hip-chain method described by Leeworthy and Skewes (2007) and counted and measured white teatfish within the transect. Remote underwater vehicles were trialled during this survey, but various operational difficulties prevented this form of data being used in the survey results.

The data collected in the survey was analysed to obtain a biomass estimate for halimeda bioherm area. The number of white teatfish observed in each transect were transformed into a density for each halimeda bioherm stratum. The survey was not granted permission to remove animals from the water, so a weight-length conversion from Conand (1989) was applied to estimate the mean weight of white teatfish per stratum. The white teatfish density observations were bootstrapped and multiplied by the mean weight to obtain a median estimate and confidence interval for biomass in each stratum. The three strata were combined for an estimate of total white teatfish biomass in halimeda bioherm habitat.

The habitat methods developed by Koopman et al. (unpublished) are a valuable way to determine reef area and extrapolate a broader biomass estimate using available densities. However, since the area surveyed in 2024 represented one of the most productive areas of the fishery for white teatfish, a subsequent assessment was undertaken in a new area in 2025 (Koopman and Knuckey unpublished). Preliminary results of this survey have been included in this assessment in order to reduce the risk of conditioning the stock assessment model on a GBR wide biomass estimate derived from the most productive area of the fishery (Koopman and Knuckey unpublished).

Table 2.3: Biomass estimates used as stock assessment inputs

Years	Surveyed Biomass (whole weight)	Scaled biomass (whole weight)	Scaling factor	Source
2024	1,702 (t)	4,266 (t)	40%	Koopman et al. (unpublished)
2025	3,584 (t)	8,012 (t)	45%	Koopman and Knuckey (unpublished)

The 2024 survey provided a biomass estimate for halimeda bioherm habitat in the ’central’ region of the fishery from 16.35° S to 14.15° S, while the 2025 survey provided an estimate north of 14.15° S. Therefore, these biomass estimates needed to be scaled to the extent of the fishery to include them as inputs to the stock assessment model. This scaling was determined based on the average catch (kg) per day for each region. There is an increasing south to north gradient for CPUE, with much lower catch rates occurring in the southern GBR versus the central and northern regions which were surveyed in 2024 and 2025, respectively. This gradient and the spatial extent of the regions is shown in Figure 2.3. The relative CPUE of each region was calculated using fishing records from the last ten years (2016 – 2025) and was used to scale the biomass survey estimates to the whole fishery in 2024 and 2025 (Figure 2.3; Table 2.3). Given the importance of this scaling, a sensitivity scenario was undertaken using unscaled biomasses. This provides a conservative scenario that shows the impact of the applied scaling on stock status.

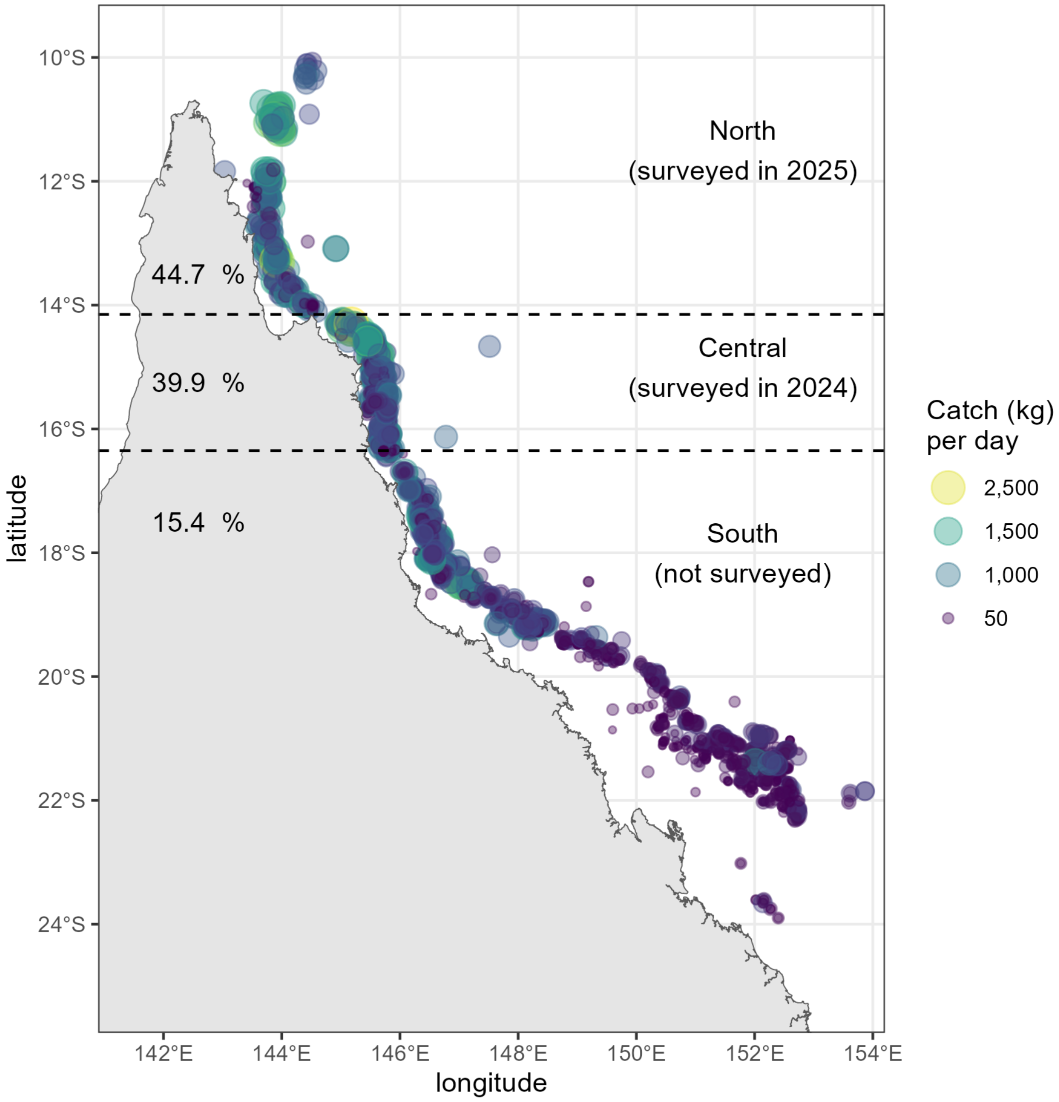


Figure 2.3: Catch (kg) of white teatfish per day across the GBR. The survey regions are delineated and the relative biomass scalers based on CPUE differences across regions are shown over the mainland.

2.6 Length data

Limited length data were available from the 2024 (Koopman et al. unpublished) and 2025 surveys (Koopman and Knuckey unpublished) which were input to the Stock Synthesis model in five-cm length bins. No age data were available. Sea cucumbers can truncate and elongate their lengths, potentially biasing length compositions. However, all measurements collected were in-situ on the seafloor and thus are the most accurate measure of natural length available (Koopman et al. unpublished; Koopman and Knuckey unpublished). Therefore, no further adjustments for length shrinkage were required, as has been necessary in other assessments (Murphy et al. 2024; Smart et al. 2024b).

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 40 cm following this).

2.7 Biological relationships

2.7.1 Growth

The von Bertalanffy growth curve was used to specify growth in the Stock Synthesis model:

$$L_a = L_\infty \left(1 - \exp^{-k(a-a_0)}\right) \tag{2.2}$$

where L_∞ is the asymptotic length, k is the Brody growth coefficient and a_0 is the age where length is zero.

von Bertalanffy growth parameters were recently estimated for white teatfish from New Caledonia using length-frequency analyses (Purcell et al. 2025). These results were initially used to specify growth for the Stock Synthesis model. However, it soon became clear that there was a discrepancy between these parameters from New Caledonia and the biology of white teatfish on the GBR. Notably, the L_∞ estimated by Purcell et al. (2025) was very small at 41.3 cm. This contrasts with the sizes of white teatfish on the GBR which grow beyond 55 cm and are commonly found above the MLS of 40 cm. Therefore, while these estimates are the only growth information published for white teatfish, they could not be included in this stock assessment. Instead, assumed values that correspond to white teatfish biology on the GBR were applied (Figure 2.4, Table 2.4). These assumed values included a reasonably slow growth rate (k = 0.1) that approximated Purcell et al. (2025) but had an L_∞ of 57 cm. These parameters provided a growth curve that corresponded to a long lived (> 30 years) and late maturing (9 years) species; maintaining the biological observations of Purcell et al. (2025) but allowing individuals to grow above the 40 cm MLS at older ages.

The values provided by Purcell et al. (2025) were included as sensitivity analyses and are considered in detail in Section 3.2.5 and 4.3.1.

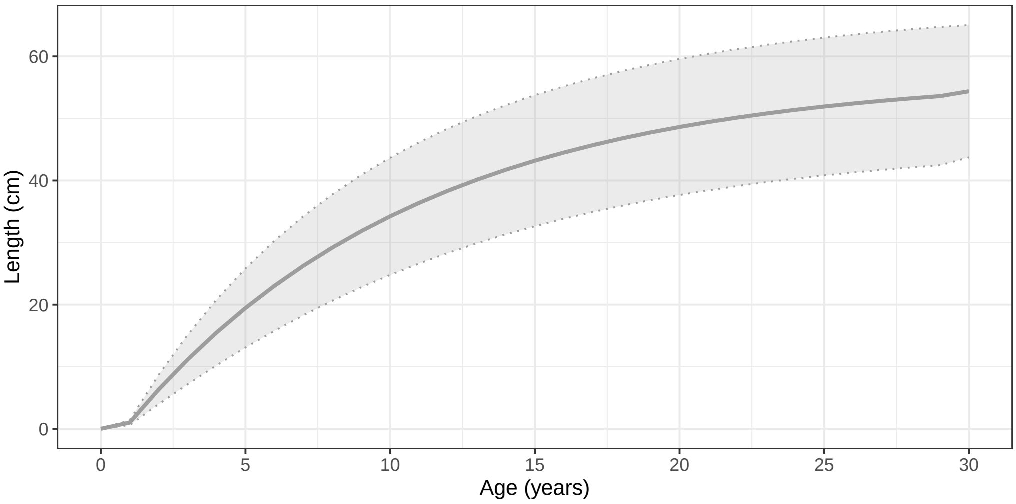


Figure 2.4: Growth curve of white teatfish (95% confidence intervals) used in the base case model (scenario 1)

2.7.2 Maturity and fecundity

Conand (1989) found that white teatfish mature at a relatively large size, with 50% of animals mature by 32 cm or 1.175 kg. Maturity was therefore specified with the lengths-at-50% and 95%-mature (L_{50} and L_{95}, respectively) set at 32 cm and 34 cm.

The probability of being mature at length L was:

$$P(L) = \left(1 + \exp^{-\ln(19)\left(\frac{L-L_{50}}{\Delta L}\right)}\right)^{-1} \tag{2.3}$$

where $\Delta L = L_{95} - L_{50}$.

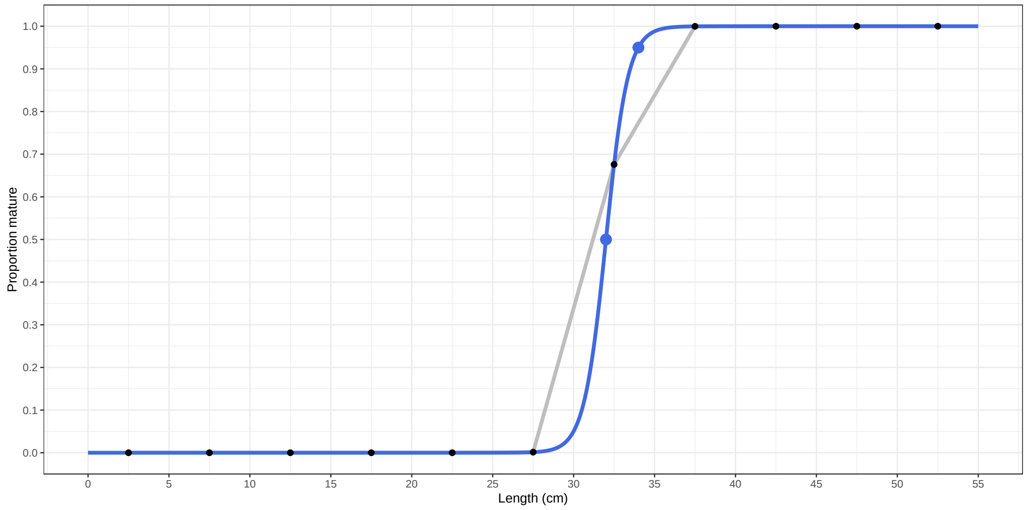


Figure 2.5: Length-at-maturity for white teatfish. The maturity ogive specified in stock synthesis is shown as the blue curve with L_{50} and L_{95} parameters. The maturity at each 5cm length bin modeled in stock synthesis is shown as the grey curve and black points.

2.7.3 Weight and length

The length and weight of white teatfish are difficult to measure as they elongate and shrink, especially when transported in and out of water. In addition, white teatfish are one of the most rotund species of sea cucumbers, resulting in a weak relationship between length and weight.

There are several estimates of the weight-length relationship for white teatfish from studies in New Caledonia and Kiribati (Conand 1989; Purcell et al. 2009b; Purcell and Tekanene 2006; Purcell et al. 2025).

Most recently, the weight-length relationship for white teatfish was estimated from 122 individuals from New Caledonia (Purcell et al. 2025). This was similar to estimates from other studies (Conand 1989; Purcell et al. 2009b) and was used in this stock assessment with units converted to kilograms and centimeters:

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

where W_L is average weight (kg) at total length L (cm), W_α = 0.07223 and W_β = 1.11.

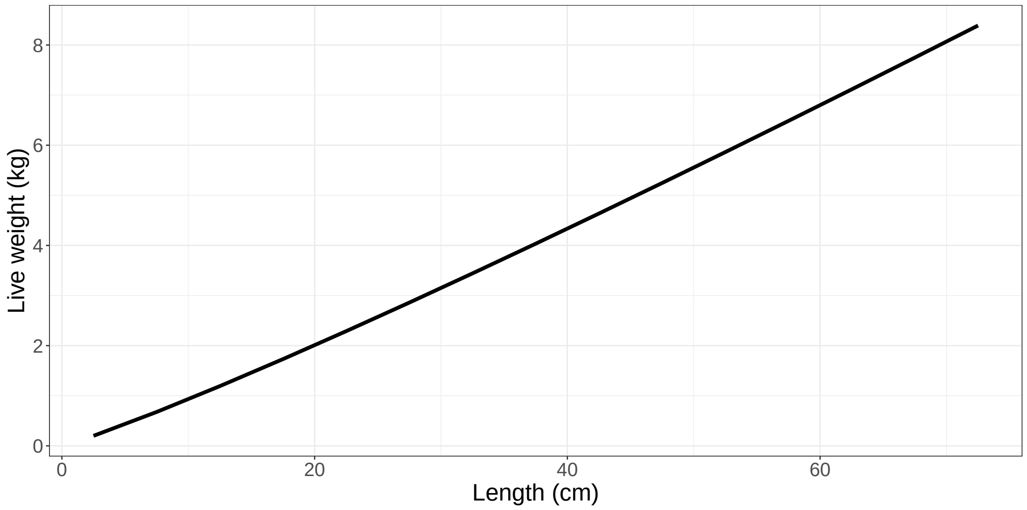


Figure 2.6: Weight-length relationship for white teatfish from Purcell et al. (2025)

2.8 Population model

2.8.1 Description

A single-sex population dynamic model was fitted to the data to determine the number of white 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.

2.8.2 Model assumptions

The main assumptions of the Stock Synthesis model were:

- The fishery began from an unfished state in 1995.
- 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.

2.8.3 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 2.4.

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 an 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 2.8.6).

Natural mortality (M) was pre-specified in the model as 0.2 yr^{-1} as per Purcell et al. (2025) who demonstrated that white teatfish are fairly long-lived. Alternate values of M were included in sensitivity testing (details in Section 2.8.6) 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 who counted sea cucumbers smaller and larger than the MLS, therefore the survey 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 CPUE 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 2.8.6).

Table 2.4: Parameters included in the population model

Symbol	Description	Treatment	Value
M	Natural mortality	Pre-specified	0.2 (yr^{-1})
a_0	Length-at-age-zero	Pre-specified	0
L_∞	Asymptotic length	Pre-specified	57 cm
K	Von Bertalanffy growth coefficient	Pre-specified	0.1 (yr^{-1})
SD_{young}	Standard deviation of length at minimum age (cm)	Pre-specified	0.2
SD_{old}	Standard deviation of length at maximum age (cm)	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	32 cm
L_{95}	Length at 95% selectivity (cm)	Pre-specified	34 cm
W_α	Weight-length relationship	Pre-specified	0.07223
W_β	Weight-length relationship	Pre-specified	1.11
recdev	Recruitment deviations between 1995 and 2024	Estimated	

2.8.4 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.

2.8.5 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.

2.8.6 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 model's sensitivity to this parameter.
  - "Mid": 0.4
  - "High": 0.6

- **Natural mortality (*M*):** Natural mortality was pre-specified in the models as 0.2 yr^{-1} as per (Purcell et al. 2025). Two higher values were tested as alternatives.
  - "Mid": 0.4 yr^{-1}
  - "High": 0.6 yr^{-1}

- **Growth:** As previously described in Section 2.7.1, existing information on growth for white teatfish does not correspond with population biology for the GBR. Therefore, assumed and pre-specified von Bertalanffy growth parameters were used to approximate growth. The influence of these assumed parameters were tested by providing alternative von Bertalanffy growth parameters (L_∞ and k) that result in faster or slower growth. The slower growth option includes the parameters estimated by (Purcell et al. 2025):
  - "Slow": L_∞ = 41.3 cm; k = 0.082 yr^{-1}; a_0 = 0
  - "Fast": L_∞ = 57 cm; k = 0.3 yr^{-1}; a_0 = 0

- **No biomass scaling:** The biomass estimates from the 2024 and 2025 were applied without any further scaling (Table 2.3). This provides conservative scenario that demonstrates whether or not a change in relative spawning biomass occurs as a result of the applied scaling.

In total, ten model runs were undertaken to determine the model's sensitivity to different parameter values and assumptions (Table 2.5). Detailed outputs of each scenario are presented in Appendix D.

Table 2.5: Scenario configuration for sensitivity analyses

Scenario number	Scenario Name	Steepness	Natural Mortality	Growth	SigmaR	Survey scaling
1	Base Case	0.30	0.20	moderate	0.30	Scaled
2	Steepness = 0.5	0.50	0.20	moderate	0.30	Scaled
3	Steepness = 0.7	0.70	0.20	moderate	0.30	Scaled
4	Natural mortality = 0.4	0.30	0.40	moderate	0.30	Scaled
5	Natural mortality = 0.6	0.30	0.60	moderate	0.30	Scaled
6	Faster growth profile	0.30	0.20	fast	0.30	Scaled
7	Slower growth profile	0.30	0.20	slow	0.30	Scaled
8	SigmaR = 0.4	0.30	0.20	moderate	0.40	Scaled
9	SigmaR = 0.6	0.30	0.20	moderate	0.60	Scaled
10	No biomass scaling applied	0.30	0.20	moderate	0.30	Unscaled

2.8.7 Ensemble

This assessment used an ensemble approach to combine the outcomes from a suite of seven 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.

All sensitivity scenarios listed in Section 2.8.6 were included in the ensemble approach with an equal weighting, with the exception of Scenarios 5 (M = 0.6 yr^{-1}) 7 (slow growth) and 10 (No biomass scaling). Scenario 5 had poor model convergence, demonstrated by multi-modal parameter posteriors and trace plots that showed poor convergence. Scenario 7 estimated a virgin biomass that was far larger than the other models and was omitted from the ensemble (Appendix D). This is discussed in detail in Section 4.3.1. Scenario 10 was intended as a sensitivity scenario to determine the impact of scaling the survey biomass inputs to the model. Therefore, it was not included in the ensemble.

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 white teatfish. Model outputs in this section relate to Scenario 1 as a reference scenario (as defined in Table 2.5). Results from all scenarios are presented in Appendix D.

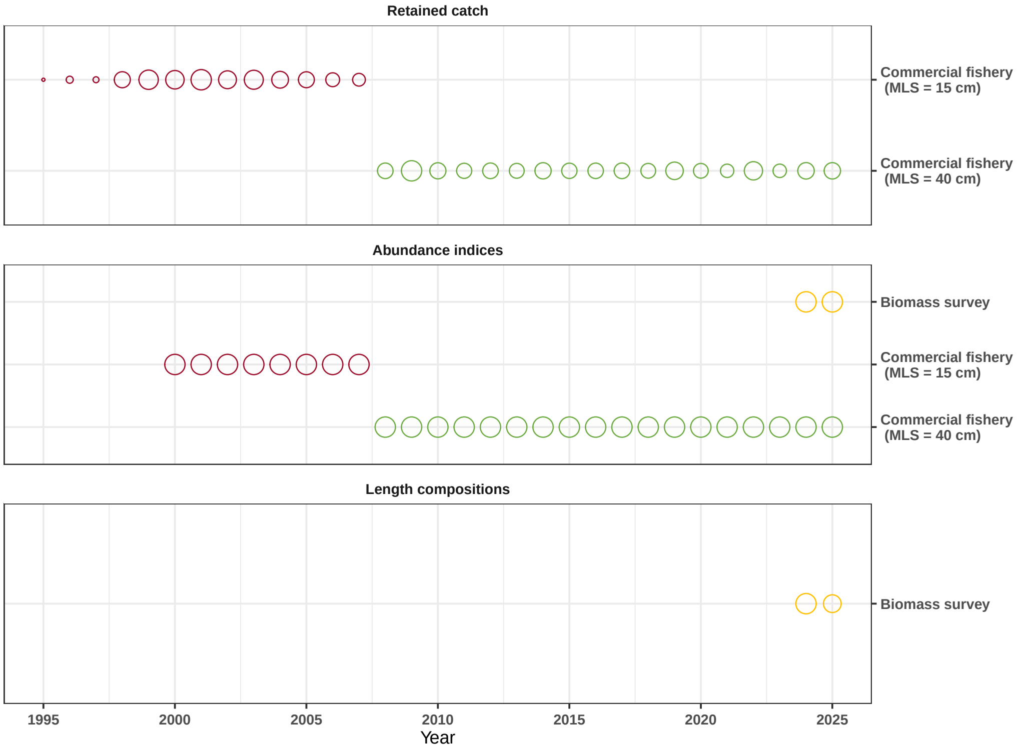


Figure 3.1: Data presence by year for each category of data type for white teatfish in Queensland

3.1.2 Retained catch estimates

Catches for white teatfish in the QSCF started in 1995 and quickly climbed to over 200 t (whole wet weight), before falling away to less than 100 t in 2006 (Figure 3.2) as a result of reductions to the TAC. The TAC was reasonably consistent following 2007, when it was set at 64 t salted weight from 2007/2008 to 2010/2011, and then reduced to 53 t onwards. Therefore, white teatfish catches have been limited by management through time. Note that TACs are set using salted weight on a financial year fishing season. Therefore, these will not align with the calendar year catches presented in Figure 3.2.

Catches only occur from the commercial sector and these are the only harvests included in the stock assessment model.

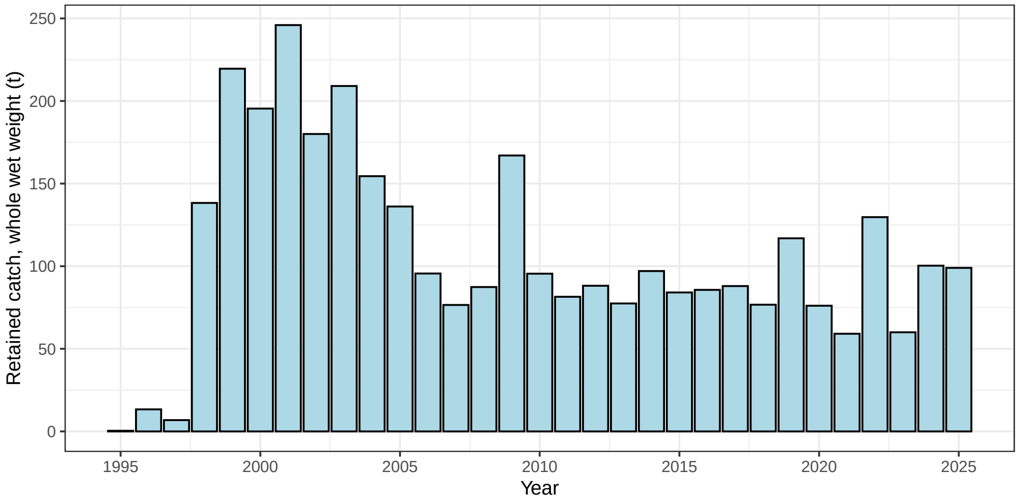


Figure 3.2: Estimated white teatfish catch between 1995 and 2025

3.1.3 Standardised indices of abundance

The standardised CPUE for white teatfish was initially quite low from 2000 to 2004 before increasing to its peak in 2006 (Figure 3.3). There is a clear declining trend from 2010 onwards (Figure 3.3). However, this decline is not particularly steep and the estimated confidence intervals overlap in many years.

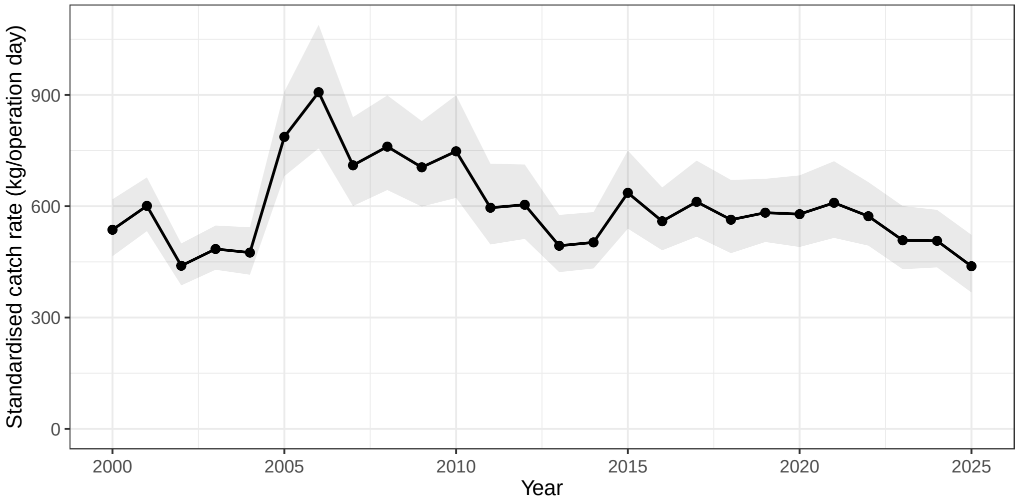


Figure 3.3: Annual standardised catch rate for white teatfish in Queensland

3.1.4 Length composition

Length structures from the 2024 (Koopman et al. unpublished) and 2025 (Koopman and Knuckey unpublished) surveys are presented in Figure 3.4. The majority of measured individuals were below the MLS of 40 cm (Figure 3.4). Note that sample sizes are quite small due to permit restrictions preventing ex-situ measurements during both surveys (Koopman et al. unpublished; Koopman and Knuckey unpublished).

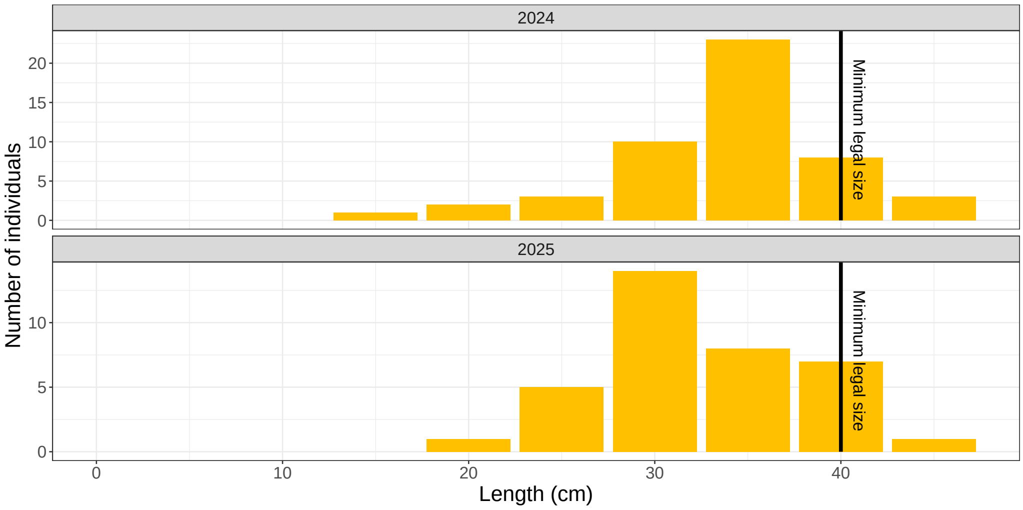


Figure 3.4: Length composition of white teatfish from the 2024 and 2025 biomass surveys.

3.2 Model outputs

3.2.1 Model parameters

Parameter estimates across the ensemble (see Table 2.5) are listed in Table 3.1. The full list of estimated parameters is given for each scenario in Appendices D.

Table 3.1: Summary of parameter estimates for white teatfish 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)	7.1	5.6	10
SSB_Virgin	4496.6	2894	7444.9
SSB_2026	3912.9	2398.2	6727.3
Bratio_2026	0.9	0.7	1.1
LnQ_base_Old_catches(2)	-2	-2.5	-1.5
LnQ_base_Recent_catches(3)	-0.6	-1.6	0.3
Size_inflection_Recent_survey_absolute(1)	29.7	23.5	34.7
Size_95%width_Recent_survey_absolute(1)	7	4.6	10.3

3.2.2 Model fits

3.2.2.1 CPUE fits

A close fit to CPUE was achieved between 2011 and 2025, tracking the population this period (Figure 3.5). However, prior to 2007, the fit to standardised CPUE was quite poor (Figure 3.5). This was the period of greatest variability which the model could not fit well to given the catches that occurred during this period. The timing of the MLS change from 15 cm to 40 cm in 2008 aligns with these two periods, suggesting that CPUE might have become a more meaningful indicator following this increase in size limit (Figure 3.5).

The poor fit to CPUE prior to 2011 for the base case scenario is caused by the model being conditioned on the survey biomass inputs. These demonstrate that the catches are relatively small relative biomass and therefore the population fluctuates very little in response to catch as it is only lightly exploited. The base case scenario was therefore insensitive to the period of higher CPUE in 2005 to 2010 (Figure 3.5). Alternative scenarios included in the ensemble model (scenarios 4 and 6) provided an improved fit to CPUE during this period as they included parameters that described a more productive population. Therefore, better fits to CPUE in those scenarios were achieved through larger recruitment in those years that gave the model freedom to fit to increases in CPUE.

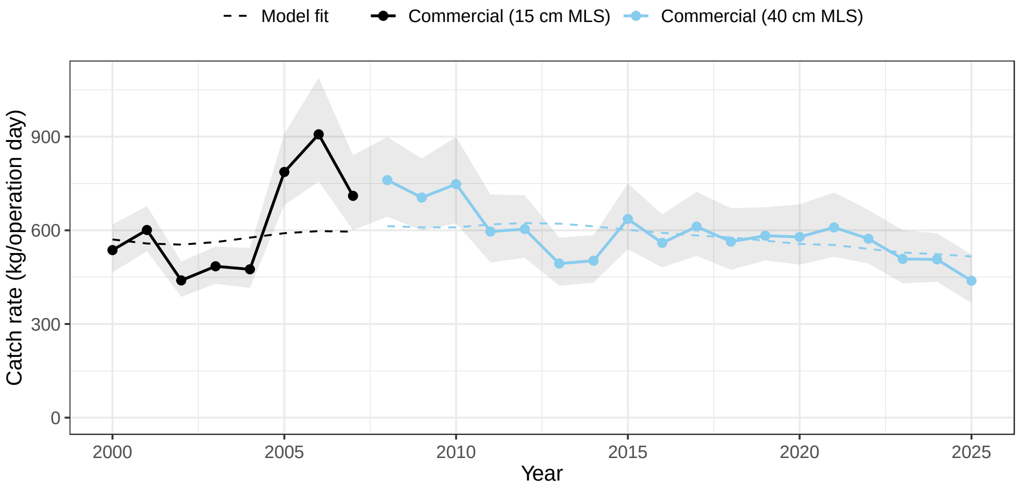


Figure 3.5: Model fit to catch rates for the base case model.

3.2.2.2 Biomass survey fits

The 2024 survey estimated a lower biomass (4,266 t; Koopman et al. (unpublished)) than the 2025 survey (8,012 t Koopman and Knuckey (unpublished)), but with large uncertainty around each estimate (Figure 3.6). As the confidence intervals of the surveys overlapped, the stock assessment model fit a straight line between them, effectively smoothing out the survey variability. As the variability was larger for the 2025 survey, the model fit more closely to the 2024 survey biomass input (Figure 3.6).

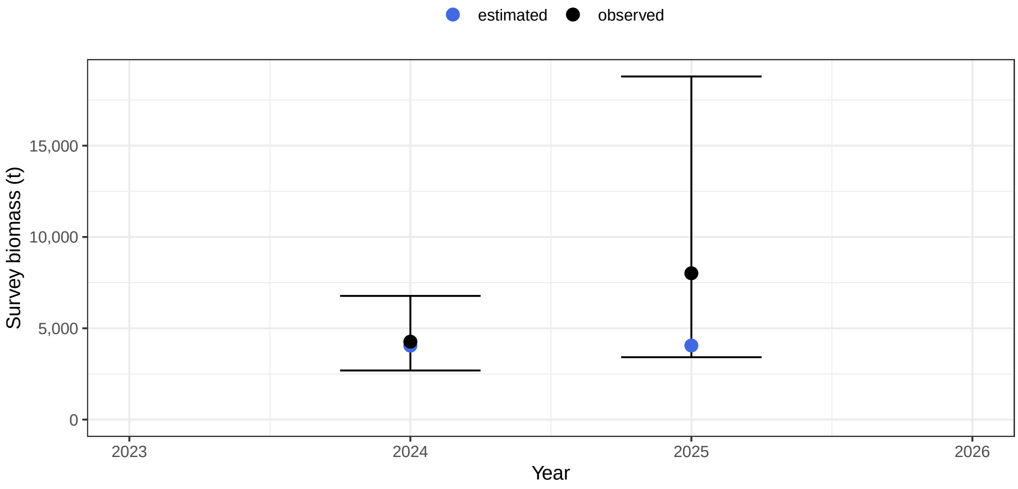


Figure 3.6: Model fit to survey biomass estimate for the base case model.

3.2.2.3 Length composition fits

The fit to the length compositions was reasonable considering the small sample sizes available from each survey (Figure 3.7). The left hand limb fits to the data well, but the model struggled to fit the pronounced peak in each year and the right hand limb as a result.

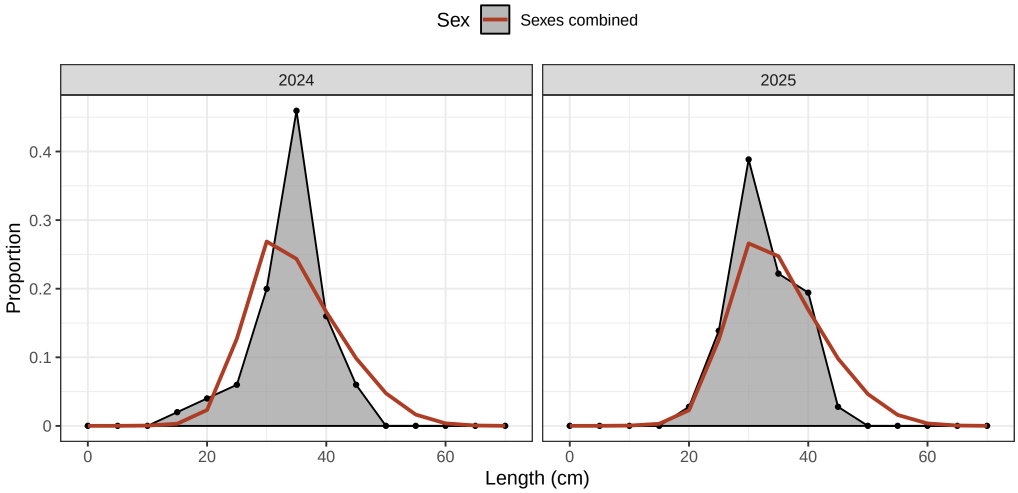


Figure 3.7: Model fit to length composition for the base case model.

3.2.3 Selectivity

The resulting selectivity functions (Figure 3.8) represent the relative proportion of white 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 was estimated, with commercial selectivity mirrored to these estimates above the MLS. The MLS in the QSCF was increased in 2008 from 15 cm to 40 cm. Therefore, the selectivity of the commercial fleet prior to 2008 was close to the selectivity estimated by the surveys (Figure 3.8). Given the low MLS prior to 2008, the commercial selectivity is almost identical to the survey selectivity and thus only the commercial selectivity is displayed in the graph in Figure 3.8.

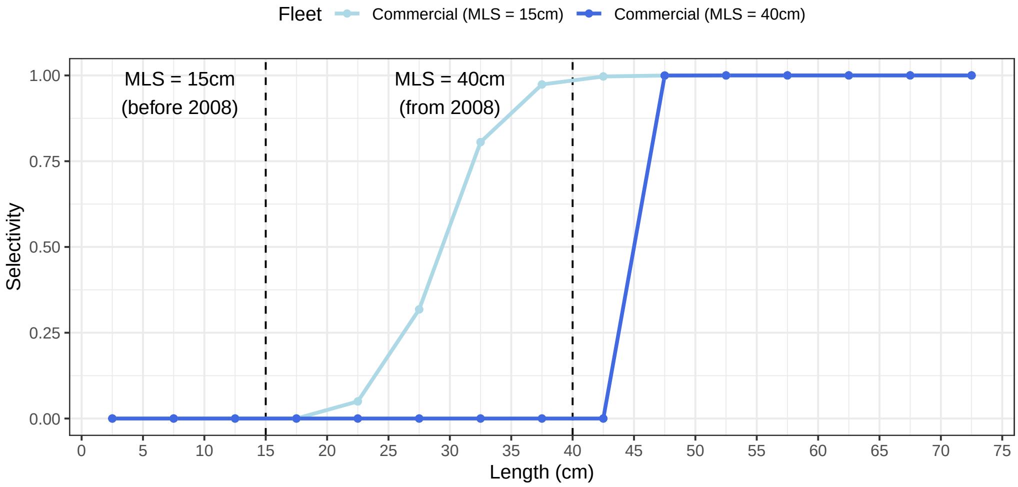


Figure 3.8: Model estimated length-based selectivity in 2026 for the representative MLE model—the dashed line shows the current minimum legal size. The selectivity of the commercial fleet prior to 2008 was close to the selectivity estimated by the surveys and thus the biomass survey selectivity is not shown

3.2.4 Spawning biomass estimates

The relative spawning biomass from the ensemble model for white teatfish at the start of 2026 was between 67% and 115% of an assumed unfished state in 1995 (Figure 3.9). There were seven model scenarios included in the ensemble model (Table 2.5), covering a range of modelling assumptions and sensitivity tests. Relative biomass trajectories for all scenarios are presented in Figure 3.10. In general, all scenarios followed a similar trend to the base case scenario (Figure 3.10). The base case model was the most pessimistic of the scenarios included in the ensemble, yet the relative spawning biomass in 2026 remained above 80% (Figure 3.10). Scenario 10 was the most pessimistic but the relative spawning biomass in 2026 remained above the target biomass level of 60%. This result occurred due to the lower biomass inputs that were not scaled beyond the survey areas. As the absolute spawning biomass estimates were lower, the fishing mortality estimates were higher, leading to a more depleted stock (Appendix D). This result was expected based on the underlying population dynamics and can be viewed as a positive result given that these unscaled biomass inputs would bias the spawning biomass downwards.

Scenarios 4, 5 and 6 all estimated relative spawning biomass trajectories that are well above the base case (Figure 3.10). These correspond to scenarios with higher M (scenario 4 where M = 0.4 yr^{-1} and scenario 5 where M = 0.6 yr^{-1}) or faster growth (scenario 6). Each of these scenarios estimated a more productive stock that could provide a better fit to increases in CPUE in the mid 2000's by estimating larger recruitment during this period (Figure 3.10; Figure 3.5; Appendix D). However, while each of these scenarios provide an improved fit to CPUE, scenarios 5 and 6 had quite poor model diagnostics. This included poor fits to the length composition for scenario 6 and poor parameter estimation for scenario 5 (parameter posteriors were multi-modal and trace plots show poor convergence) (Appendix D). The poor performance of scenario 5 meant that it was not included in the ensemble model.

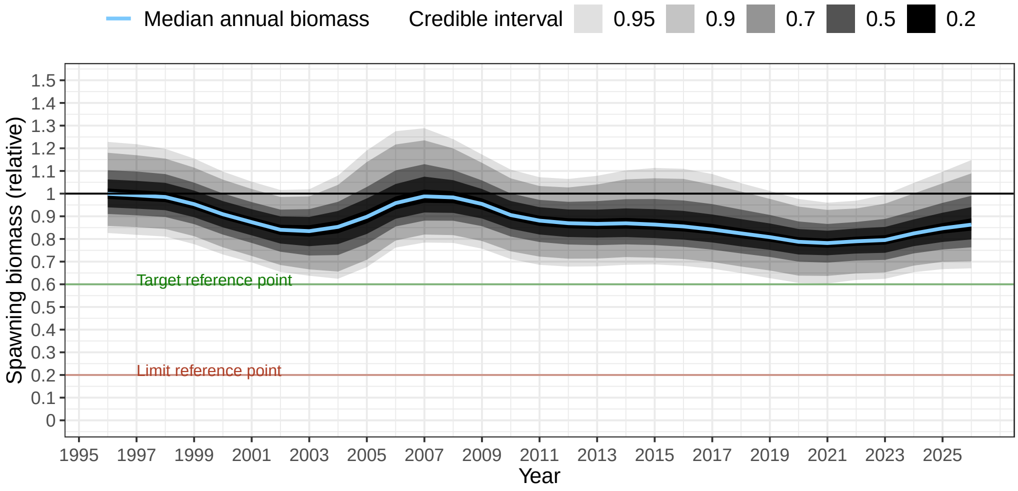


Figure 3.9: Estimated spawning biomass trajectory relative to unfished for white teatfish in Queensland, from MCMC ensemble scenarios

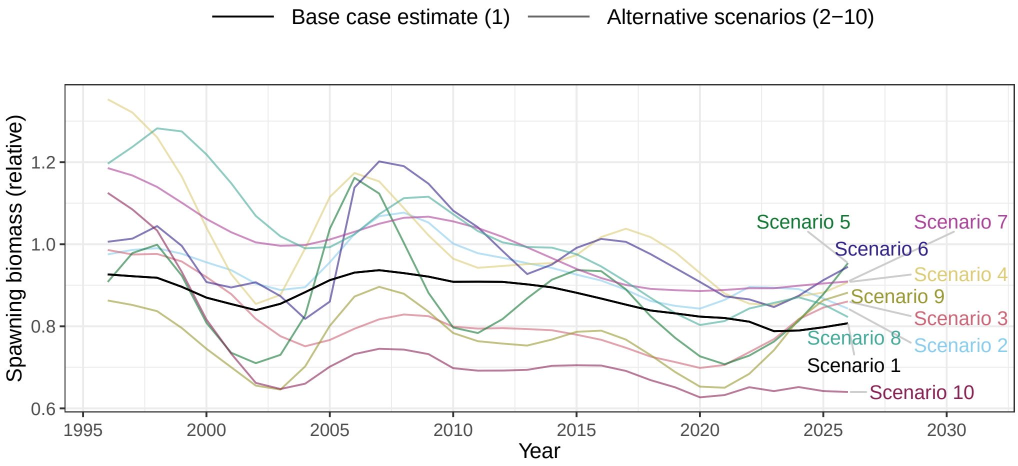


Figure 3.10: Estimated spawning biomass trajectory relative to unfished levels for white teatfish from 1995 to 2026 for all scenarios.

Table 3.2: Summary of model outcomes for all scenarios. $B_{2026}\%$ is the most likely biomass at the start of 2026 relative to unfished in 1995, 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	0.82	0.69	0.96	0.81	0.67	0.97
2	0.85	0.72	0.98	0.84	0.71	1.00
3	0.87	0.74	1.00	0.86	0.74	1.01
4	0.94	0.74	1.13	0.91	0.72	1.14
5	0.99	0.76	1.23	0.95	0.74	1.24
6	0.99	0.78	1.19	0.95	0.76	1.18
7	0.86	0.74	0.98	0.91	0.77	1.07
8	0.86	0.68	1.03	0.82	0.63	1.10
9	0.98	0.69	1.26	0.88	0.60	1.35
10	0.65	0.52	0.78	0.64	0.51	0.81

The posterior distribution of the ensemble model estimated that relative spawning biomass at the beginning of 2026 had an 100% probability of being above 60%, a 0% 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 3.11; Table 3.3).

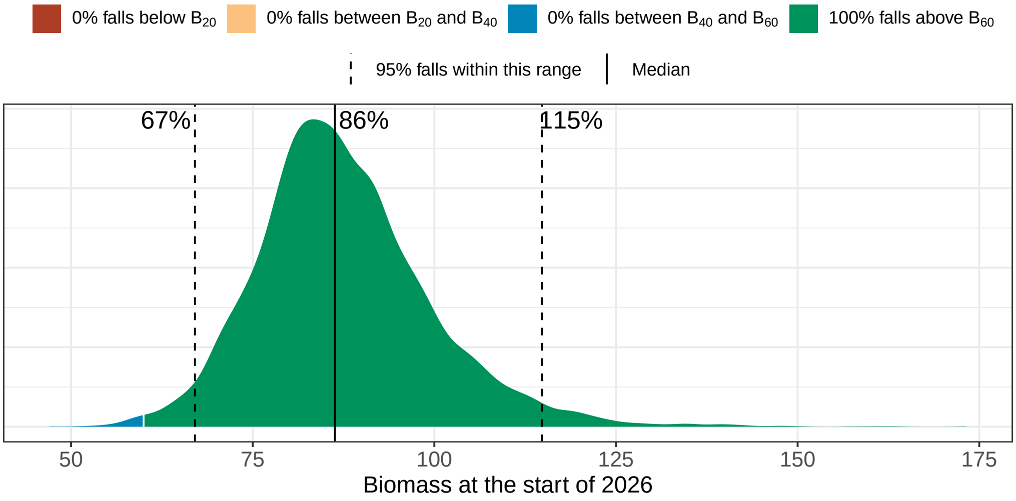


Figure 3.11: Probability distribution of the biomass ratio at the beginning of 2026 across the full ensemble of scenarios with the credible interval and probability of biomass falling into the four categories indicated

Table 3.3: Stock status indicators for white teatfish in Queensland

Indicator	Value
Biomass ratio (relative to unfished)	
Range (95% credible interval)	67–115%
Median	86%
Probability below 20%	0%
Probability between 20% and 40%	0%
Probability between 40% and 60%	0%
Probability above 60%	100%
Fishing pressure ratio (relative to F_{60})	
Range (95% credible interval)	0.16–0.91
Probability exceeds F_{B60}	1%

The absolute spawning biomass estimates for white teatfish had high variability across the ensemble due to the large range of productivity parameters included in the scenarios. Detailed outputs provided in Appendix D demonstrate that some scenarios had biomass trajectories that fluctuated when parameters such as h, M or σ_R were larger, creating wide upper confidence intervals when the MCMC iterations are combined across scenarios. However, what is clear from all scenarios is that little depletion has occurred across the stock's history due to its light levels of exploitation. Consequently, the virgin spawning biomass was estimated as 4,497 t (2,894 – 7,445 t 95% CI) and the spawning biomass at the beginning of 2026 was estimated as 3,913 t (2,398 – 6,727 t 95% CI) (Figure 3.12).

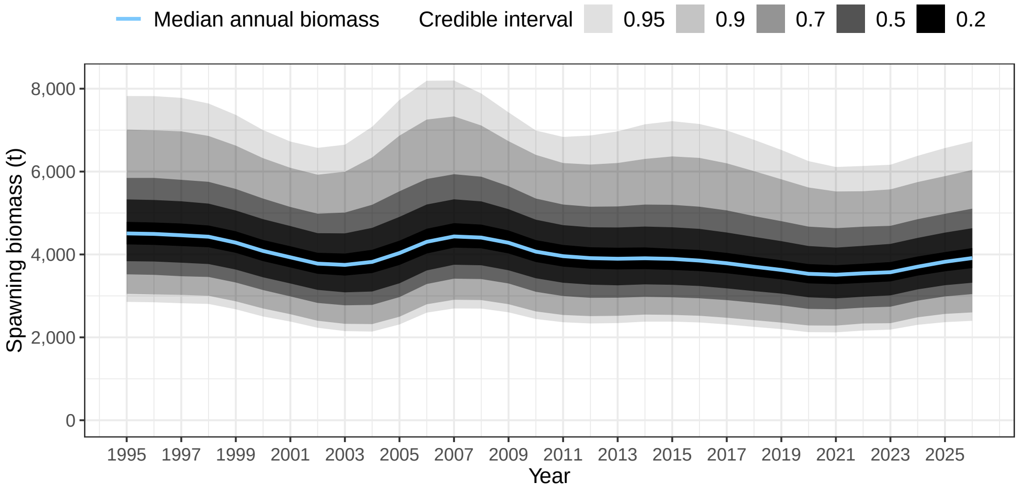


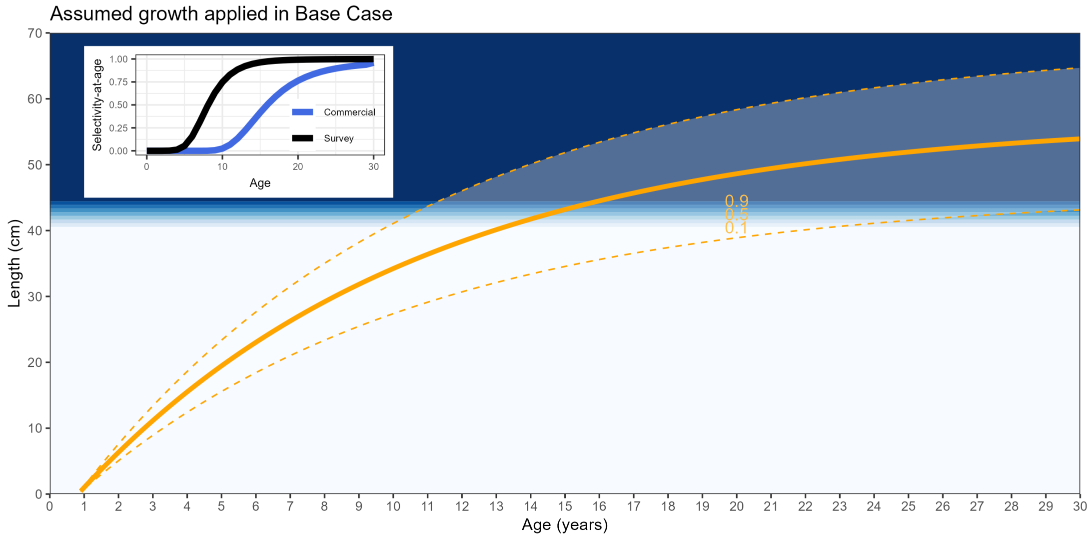
Figure 3.12: Estimated absolute spawning biomass for white teatfish in Queensland, from MCMC ensemble scenarios

3.2.5 Alternative growth parameters

The growth parameters included in the stock assessment model affected the population scale parameters (i.e., R_0, virgin biomass; Table 3.1). When the growth parameters estimated by Purcell et al. (2025) were used in scenario 7, the median virgin biomass was estimated as 13,752 t, which was larger than the range of virgin biomass from the scenarios included in the ensemble (2,894 – 7,445 t).

This result occurred as the small L_∞ (41.3 cm) estimated by Purcell et al. (2025) is only marginally larger than the 40 cm MLS. Therefore, it creates a growth trajectory where only a very small percentage of the population is above the legal size. This is demonstrated in Figure 3.13 which shows the growth trajectory of the assumed growth parameters used in the base case and those of Purcell et al. (2025). As selectivity is length-based, the selectivity-at-age within the stock assessment model is converted from length. This creates an additional issue for scenario 7 which determined that individuals would not grow above the MLS until their mid-20's and at 30 years old, only 4% of individuals would be above the MLS (Figure 3.13). As selectivity is based on length, the model can only accommodate catches from such a small percentage of the population by estimating a large 'cryptic biomass', hence why the virgin biomass estimates are so much larger than the other seven scenarios (Appendix D).

The use of assumed parameters that match the sizes of white teatfish harvested in Queensland provides a growth trajectory that allows a larger percentage of the population to be above legal size. Therefore, the other scenarios do not need to estimate cryptic biomass to account for issues with selectivity.


Assumed growth applied in Base Case

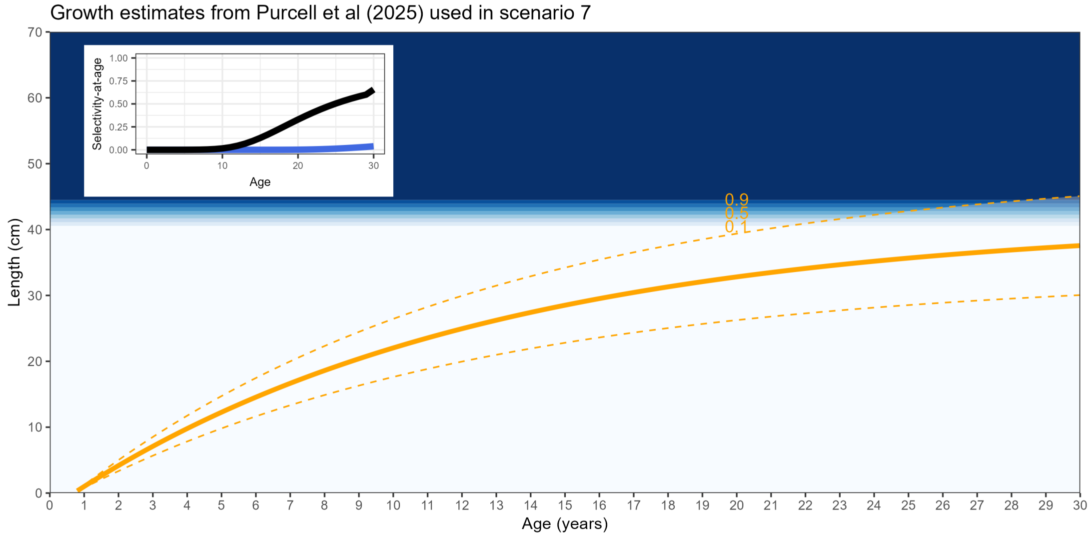

Growth estimates from Purcell et al (2025) used in scenario 7

Figure 3.13: Comparison of growth profiles used in the base case (top) and Scenario 7 (bottom). The blue shading shows the selectivity-at-length for the commercial fleet with an MLS of 40 cm, based on the selectivity ogive with progressively darker shades showing the proportion of individuals at a given length that are available for capture. The inset plots in the top left corner show the converted selectivity-at-age for the survey fleet and the commercial fleet.

4 Discussion

4.1 Stock status

Stock status for white teatfish at the beginning of 2026 was estimated to be between 67% and 115% of an assumed unfished state in 1995. 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

Three scenarios were excluded from the ensemble with scenario 7 discussed in Section 4.3.1. Scenario 10 was not included as it was a sensitivity scenario designed to examine the effect of scaling the survey biomass estimates. Lastly, scenario 5 was not included due to poor convergence and model performance. The seven model scenarios included in the ensemble accounted for uncertainty in key parameters such as h, σ_R and M as well as uncertainty in growth. The consistency between scenarios was driven by the models being conditioned on the large biomass estimate from the 2024 and 2025 surveys (Koopman et al. unpublished; Koopman and Knuckey unpublished) 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 white 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:

- The present assessment was performed using Stock Synthesis whereas the previous assessment was performed using an age-structured surplus production model (ASPM).
- The biological parameters have been updated to values provided in Purcell et al. (2025), or with more conservative assumed values. Uncertainty in these values was addressed through the ensemble modelling approach applied.
- The current assessment used whole wet weight units for catch, whereas the previous assessment used landed (i.e. salted) weight for catch units.
- The present assessment included surveyed estimates of biomass (Koopman et al. unpublished; Koopman and Knuckey unpublished) that were not available when the previous assessment was undertaken. These were used to condition the model on estimates of absolute biomass in specific years.

The previous assessment estimated stock status in 2021 for the whole GBR as 78% relative to 1995 (Helidoniotis 2021). This was consistent with the present assessment, which estimated relative spawning biomass to be 78% in 2021 based on the ensemble model.

4.3 Key considerations

4.3.1 Alternative growth parameters

Until recently, no growth information was available for white teatfish, leading to assumed values being required for assessment (Helidoniotis 2021). However, von Bertalanffy growth parameters were recently estimated for white teatfish from New Caledonia (Purcell et al. 2025), which provided an opportunity to better inform the model on population biology. Unfortunately, early attempts to include these estimates were unsuccessful due to the small L_∞ (41.3 cm) estimated for the New Caledonian population (Purcell et al. 2025). This resulted in issues within the stock assessment model, as very few individuals within the numbers-at-age matrix would grow above the MLS of 40 cm. This caused the stock assessment model to estimate a large 'cryptic biomass' as the fishery catches could only account for a small portion of the stock. This is a selectivity issue that needs to be avoided as the model is estimating a large biomass through the absence of information, rather than evidence that a large population exists.

Given this discrepancy, industry members were contacted to determine whether this growth profile from New Caledonia (Purcell et al. 2025) was applicable to the white teatfish population on the GBR. Fishers stated that the maximum length of white teatfish is highly plastic and location specific. Populations in the northern GBR grow very large ($>$ 50 cm) and a large proportion of white teatfish encountered are above the 40 cm MLS. However, fishers also stated that in other regions, such as the Swains in the southern GBR, white teatfish do not grow as large and it is common for only a small percentage to be larger than 40 cm. This matches the spatial distribution of catches with most white teatfish harvested in Zone 1 (north of 19° S). Therefore, it is most likely that the growth estimated by Purcell et al. (2025) for white teatfish from New Caledonia aligns with the slower and shorter growing populations of the southern GBR, rather than populations in the north (where most catches occur). As a result, assumed growth parameters (L_∞ = 57 cm, k = 0.1yr^{-1}) were used in the stock assessment model, with the results of Purcell et al. (2025) used in a sensitivity scenario. These assumed growth parameters represent a population that grows slowly but still reaches large sizes, and are consistent with a long lived species such as white teatfish.

This highlights the uncertainty regarding how growth should be specified for sea cucumbers within stock assessment models. Evidence of spatially variable growth further leads to the need to account for reef-level population dynamics to accurately model stocks. However, the data needed to undertake a model of this complexity is rarely available for even the most well studied fish stocks, let alone sea cucumbers which are often data poor. The approaches taken in this assessment were to 1) explore the impact of growth parameters on the model, 2) determine sensible values based on population biology and the fishery dynamics, and 3) incorporate uncertainty in these values through an ensemble modelling approach. Three sets of growth parameters, termed 'slow', 'moderate' and 'fast', were included in model scenarios and all three sets of parameters provided consistent estimates of stock status. Therefore, while the growth dynamics of white teatfish on the GBR remain highly uncertain, the stock assessment model was not compromised by this.

The 'slow' growth scenario that used the parameters from Purcell et al. (2025) was not included in the ensemble model due to the large cryptic biomass that was estimated.

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). However, this was not possible at a reef scale with the current data and information available for species caught in the QSCF, including white teatfish. From the information available, it is likely that white teatfish populations are reasonably well mixed and could be considered as a single population on the GBR (Skewes 2024). 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 white 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 white 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, the surveyed biomass estimates for white teatfish have been scaled up to available halimeda bioherm habitat across the GBRMP, which includes green zones (Koopman et al. unpublished; Koopman and Knuckey unpublished). Therefore, these biomass estimates do provide an indication of stock size in both blue and green zones, although this is not differentiated. Given that catches have been small and stock depletion minimal, the white teatfish assessment therefore provides results representative of the whole population.

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 model does not differentiate between open and closed areas, the management implications of marine park zoning have been considered through MSE (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, rainfall, and tides 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 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 CPUE 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 white 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, 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 CPUE 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 CPUE will 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 absolute biomass level at a known point in time 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. This white teatfish stock assessment differs from other assessments (Smart et al. 2024b) as it had two years of surveyed biomass estimates rather than one. These estimates had high variability across both surveys which was smoothed out by the model that fit between one estimate that was likely biased high and a second that was biased low. The availability of both estimates therefore limits the risk that a single and uncertain estimate can have a large influence on the model outcomes. Currently, selectivity is estimated from two years of length frequency data with limited samples and there will be some bias introduced depending on how much recent recruitment has influenced population length structure at the time of the surveys. 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).

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.

4.5.4 Management

The QSCF harvest strategy (Fisheries Queensland 2021) states that all sea cucumber species must be maintained at, or returned to, a target exploitable biomass level that achieves maximum economic yield, defined as 60% virgin biomass.

4.6 Conclusions

This stock assessment was commissioned to establish the status of white teatfish stock and inform the management of the QSCF. The biomass was estimated to be between 67% and 115% at the beginning of 2026, relative to an assumed unfished state in 1995. This interval was generated over an ensemble of seven scenarios.

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A Diagnostics for standardised indices of abundance

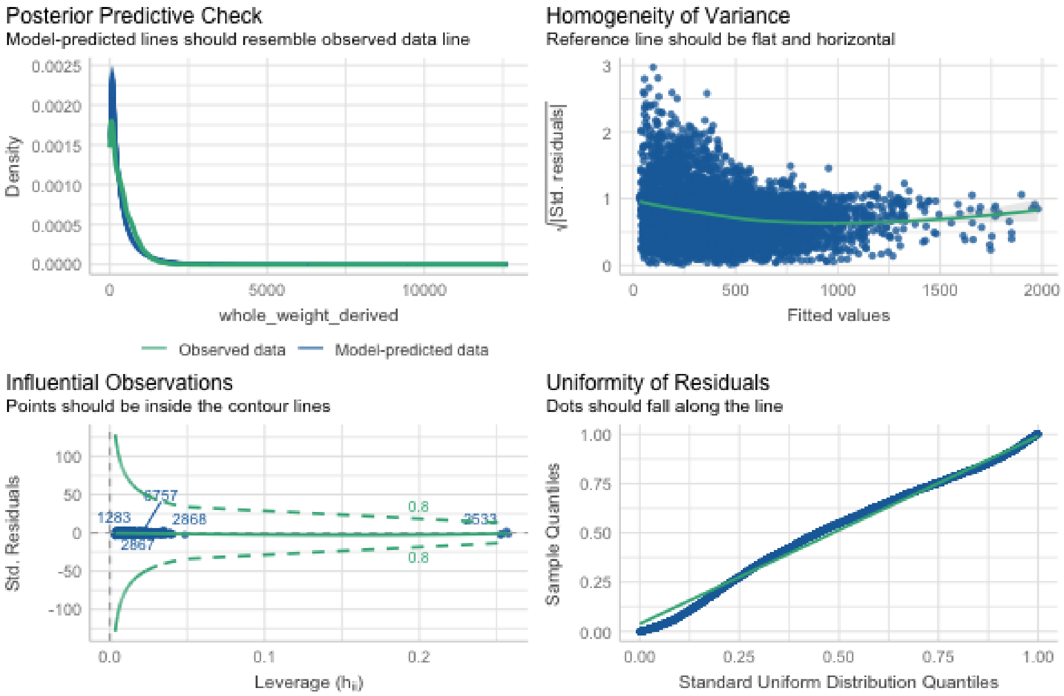

Figure A.1: GLM diagnostics

B Model inputs

B.1 Biological data

B.1.1 Weight and length

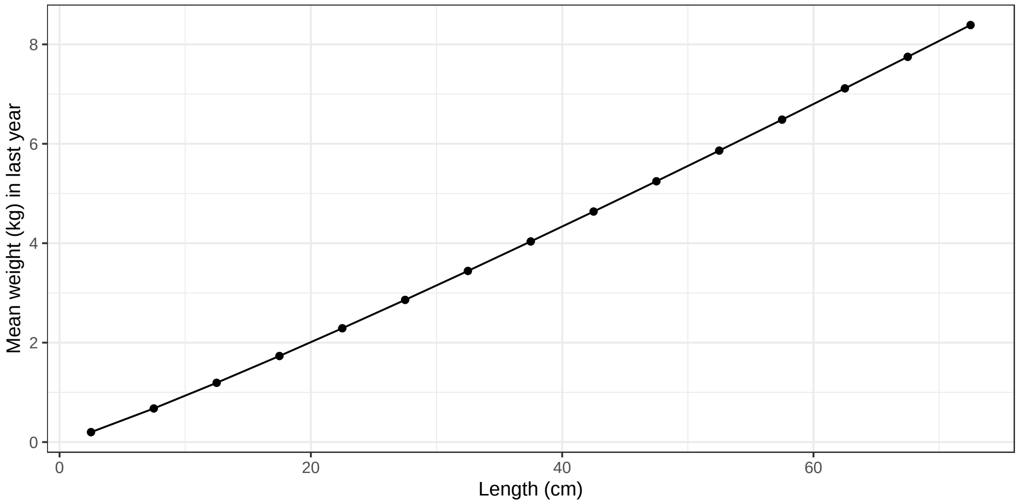

Figure B.1: Weight–length relationship for white teatfish in Queensland

B.1.2 Fecundity and maturity

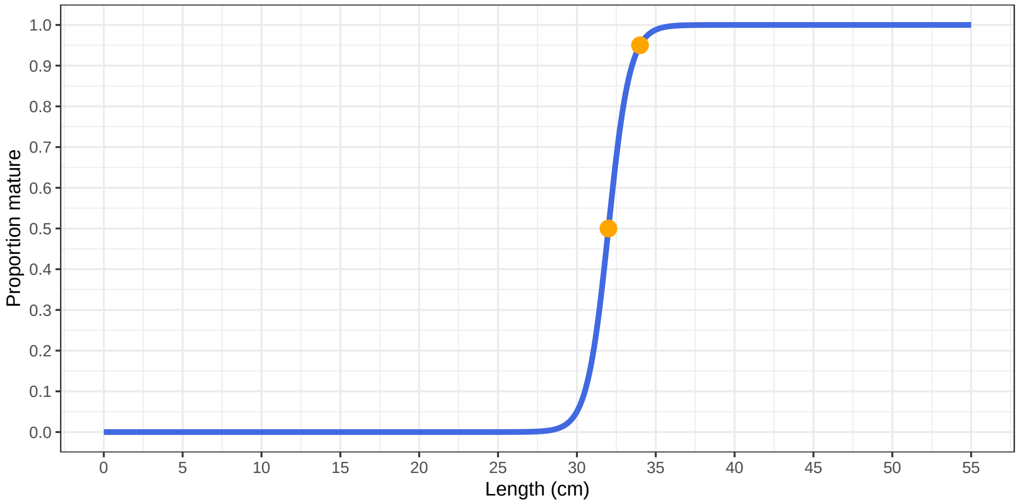

Figure B.2: Length-at-maturity. Orange points show the length-at-50% maturity and 95% maturity.

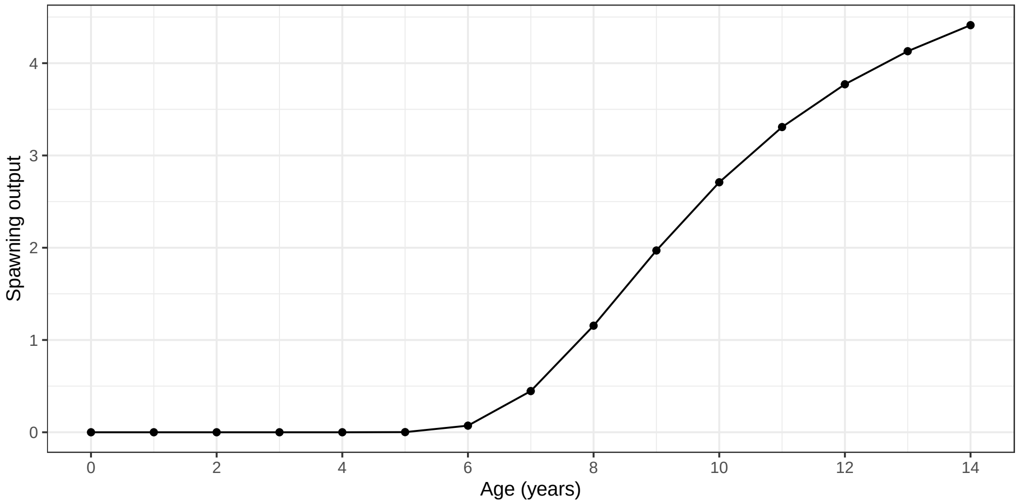

Figure B.3: Spawning-output-at-age (maturity multiplied by fecundity).

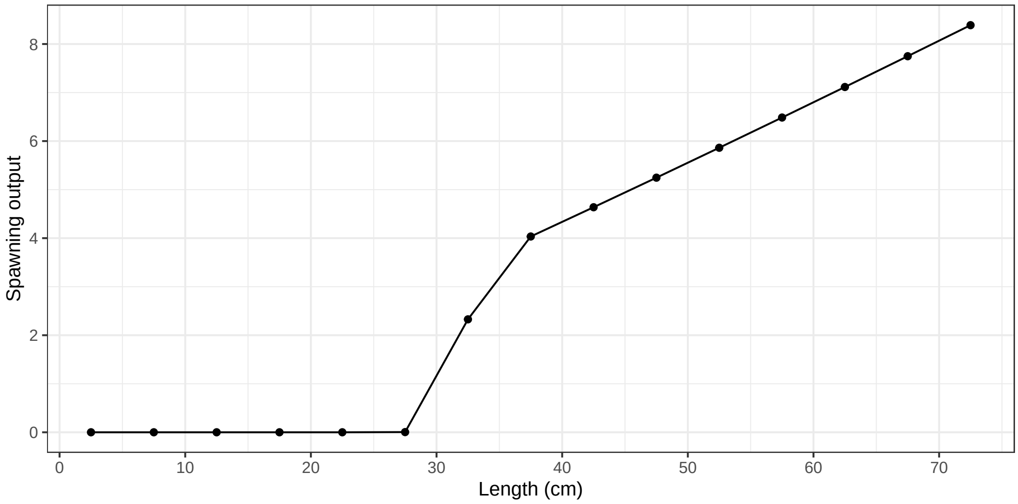

Figure B.4: Spawning-output-at-length (maturity multiplied by fecundity).

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.

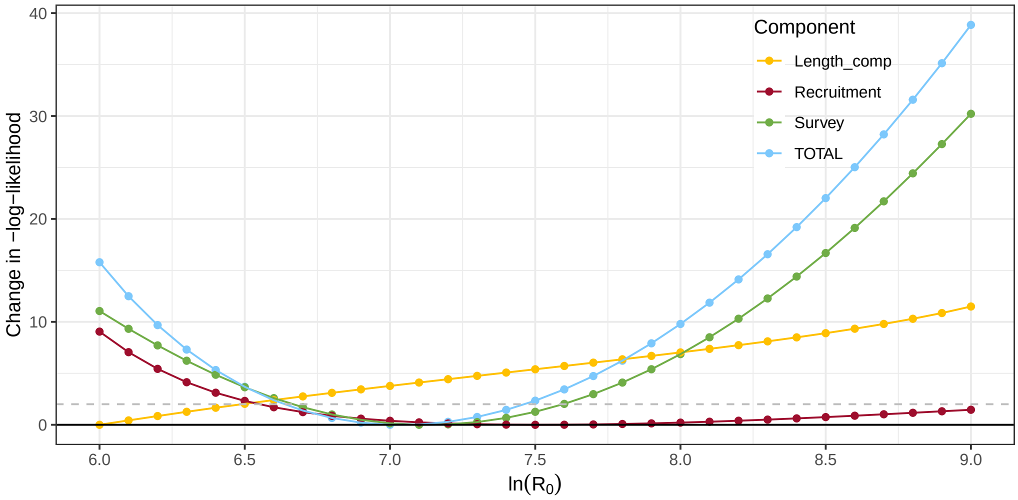

Figure C.1: Likelihood profile for $\ln(R_0)$. Dashed grey line shows the cut-off for a difference of 1.98 likelihood points. Values within this range are considered to have equal model support.

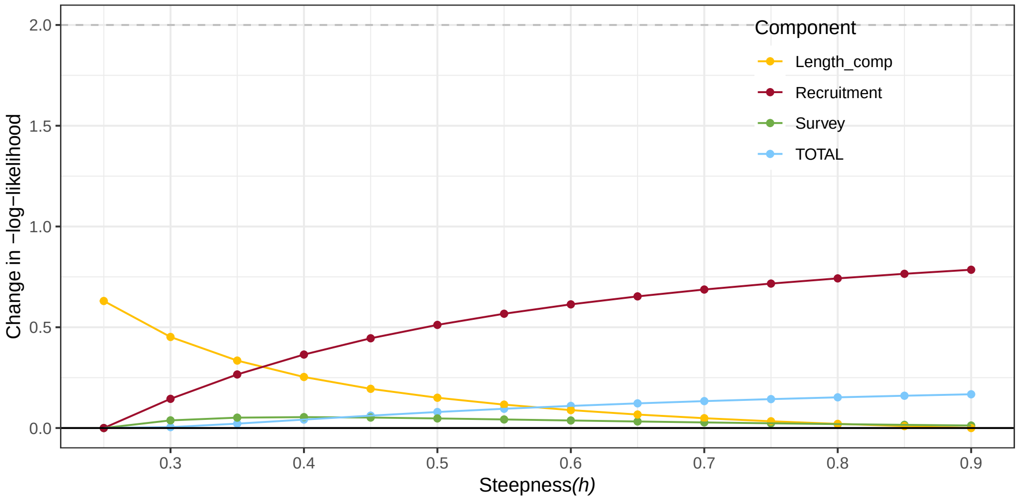

Figure C.2: Likelihood profile for steepness (h). Dashed grey line shows the cut-off for a difference of 1.98 likelihood points. Values within this range are considered to have equal model support.

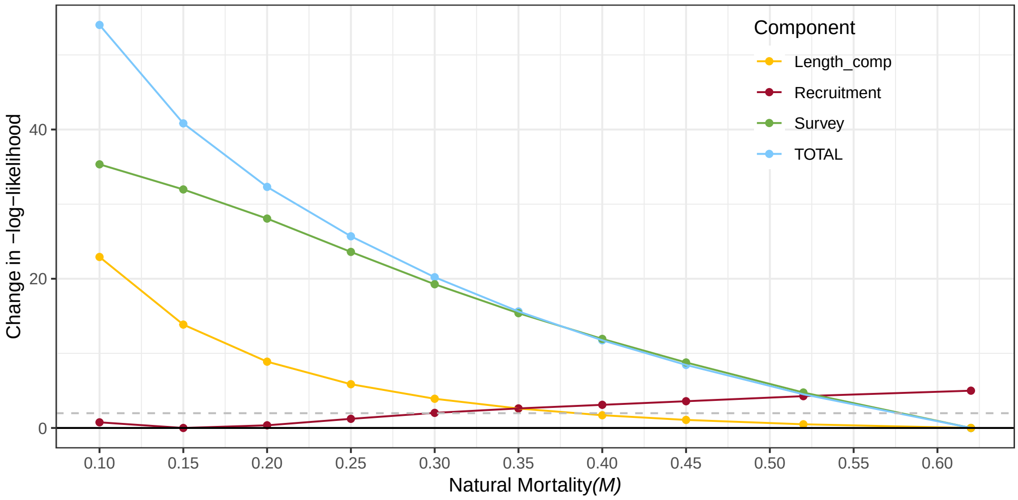

Figure C.3: Likelihood profile for natural mortality (M). Dashed grey line shows the cut-off for a difference of 1.98 likelihood points. Values within this range are considered to have equal model support.

C.2 Other outputs

C.2.1 Stock-recruit curve

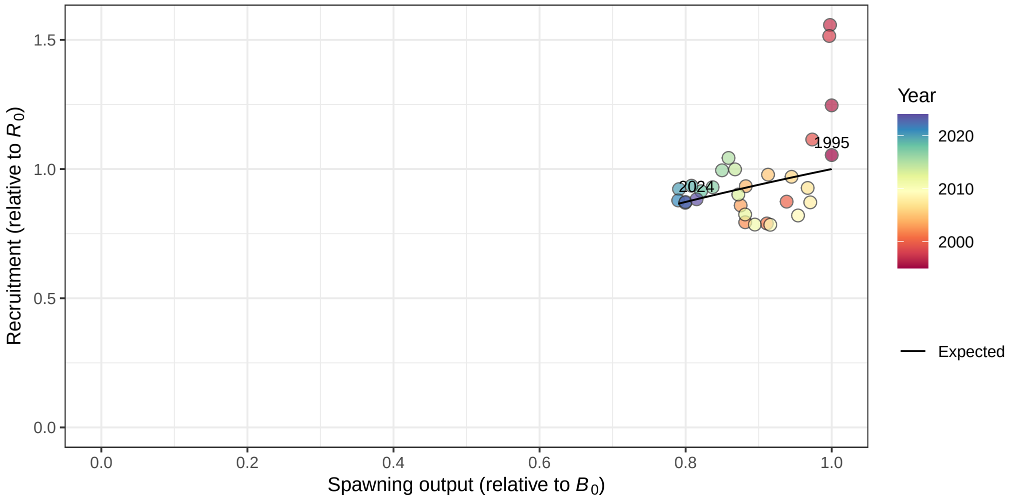

Figure C.4: Stock-recruitment curve based on the base case scenarios. Point colors indicate year, with warmer colors indicating earlier years and cooler colors in showing later years

C.2.2 Fishing mortality

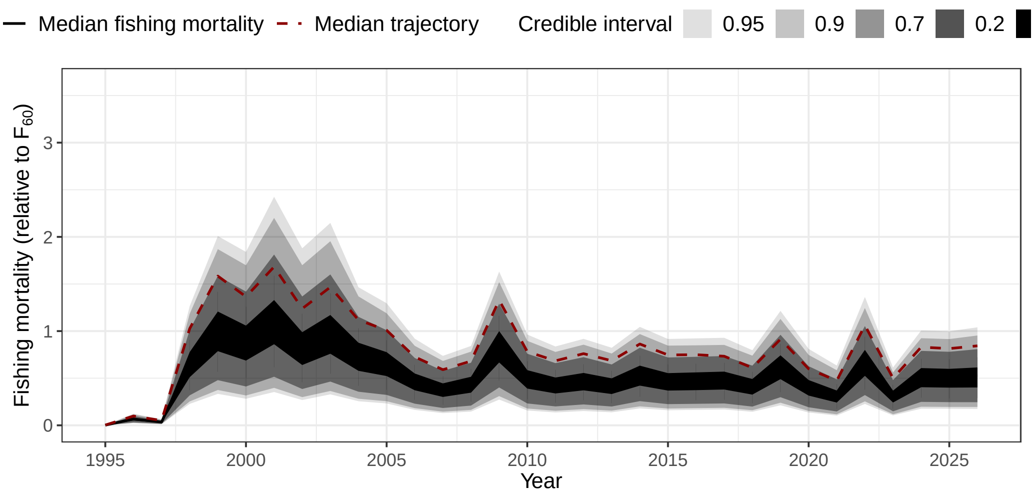

Figure C.5: Time series of fishing mortality ratio (F/F_{60}) from the ensemble model

C.2.3 Recruitment deviations

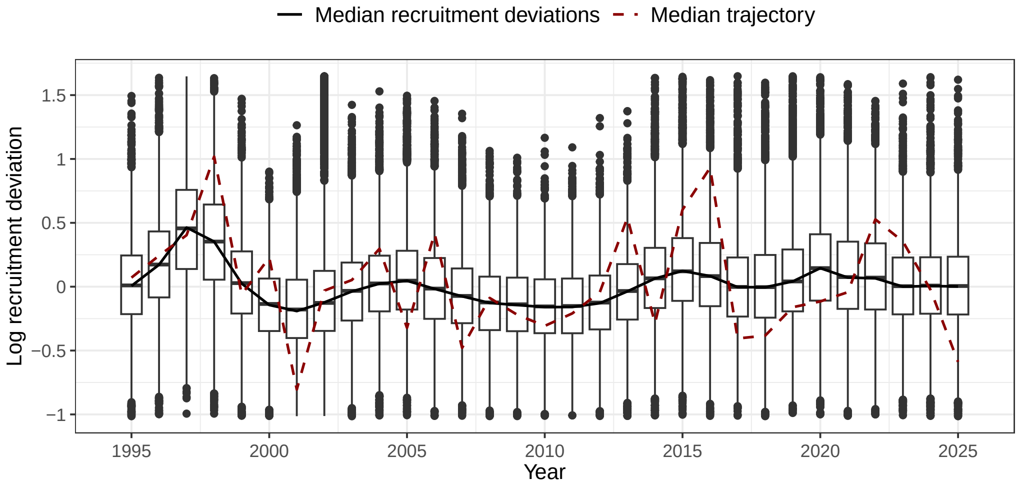

Figure C.6: Recruitment deviations from the ensemble model—whiskers represent 95% credible intervals, boxes represent 50% credible intervals, horizontal bars represent medians, and the points represent outliers

C.2.4 Sensitivity: parameter estimates and derived quantities

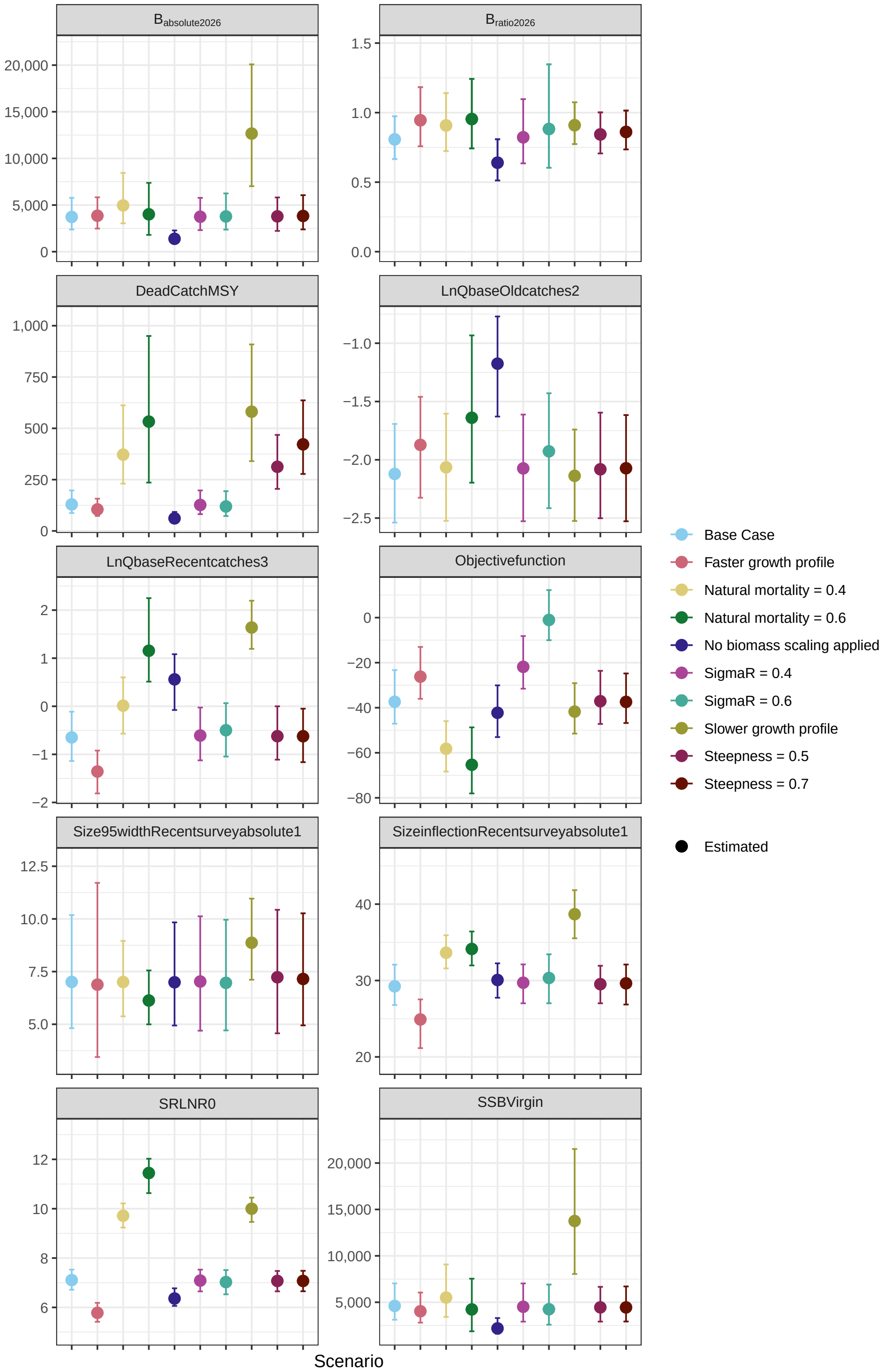

Figure C.7: Comparison of parameter estimates and derived quantities among the Ten scenarios included in the ensemble model

D Detailed model outputs

D.1 Base Case

This section presents results for the Base Case scenario.

Table D.1: Summary of parameter estimates for white 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)	7.1	6.7	7.5
SSB_Virgin	4603.8	3115.6	7035.1
SSB_2026	3723.07	2376.89	5775.42
Bratio_2026	0.8	0.7	1
LnQ_base_Old_catches(2)	-2.1	-2.5	-1.7
LnQ_base_Recent_catches(3)	-0.65	-1.14	-0.11
Size_inflection_Recent_survey_absolute(1)	29.2	26.8	32.1
Size_95%width_Recent_survey_absolute(1)	7	4.8	10.2

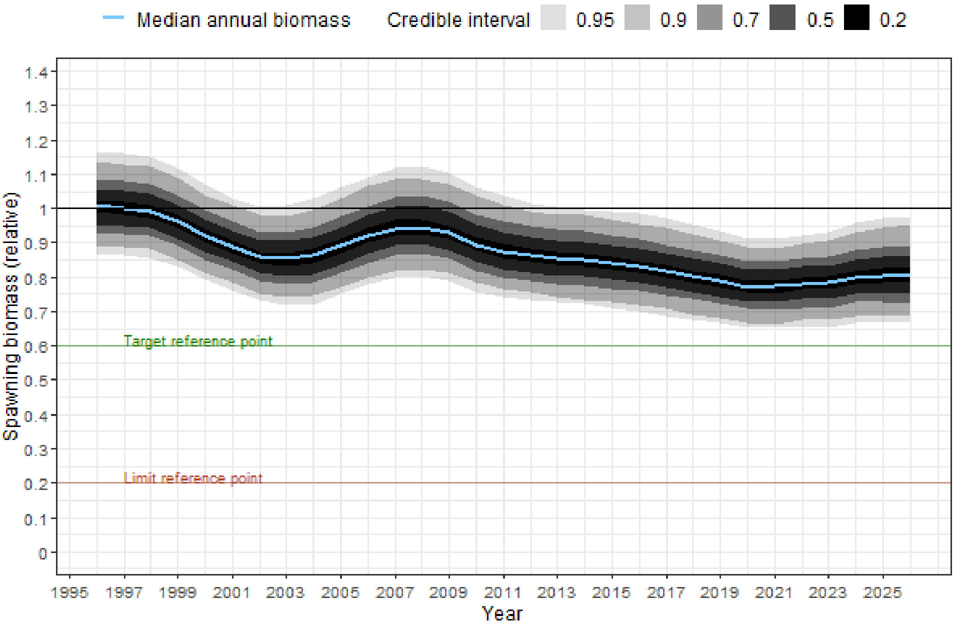

Figure D.1: Relative spawning biomass for the Base Case scenario

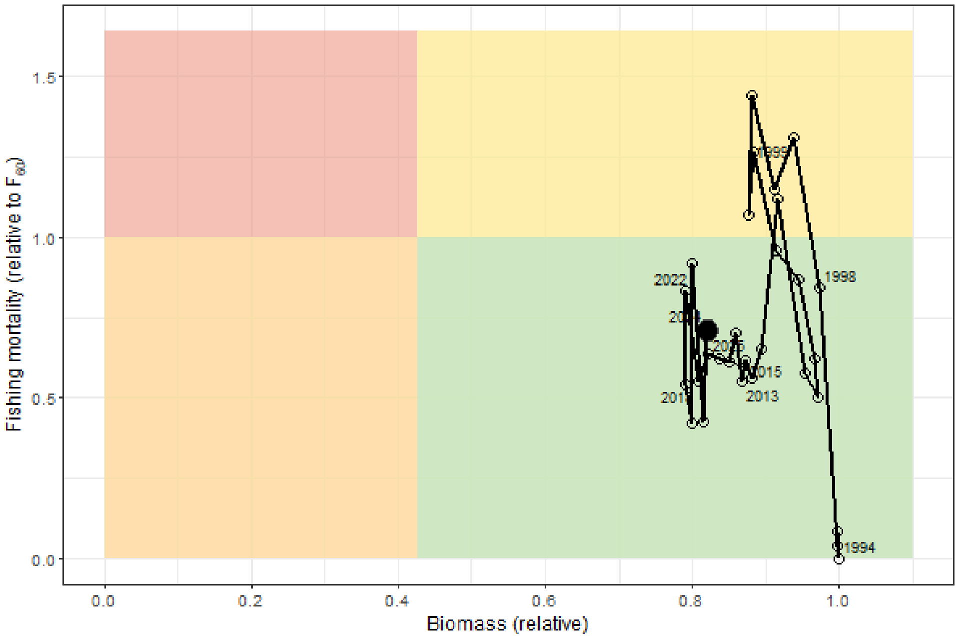

Figure D.2: Phase plot for the Base Case scenario

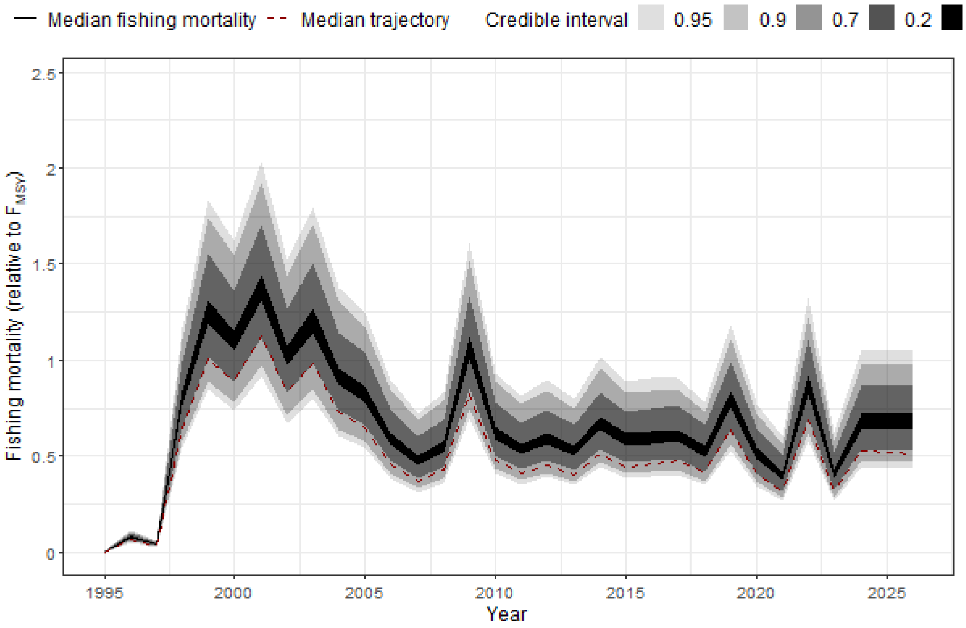

Figure D.3: Fishing mortality for the Base Case scenario

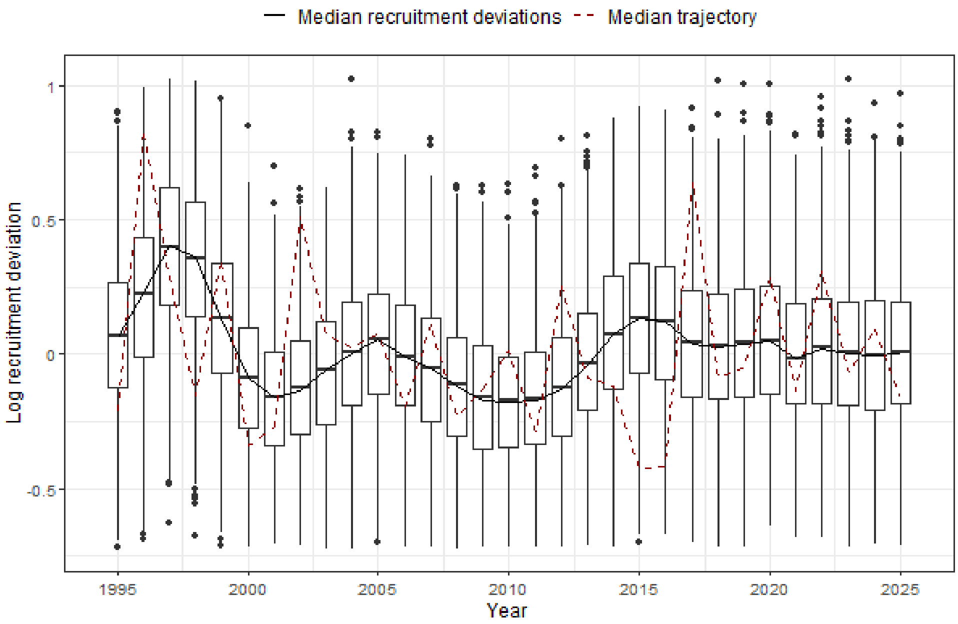

Figure D.4: Recruitment deviations for the Base Case scenario

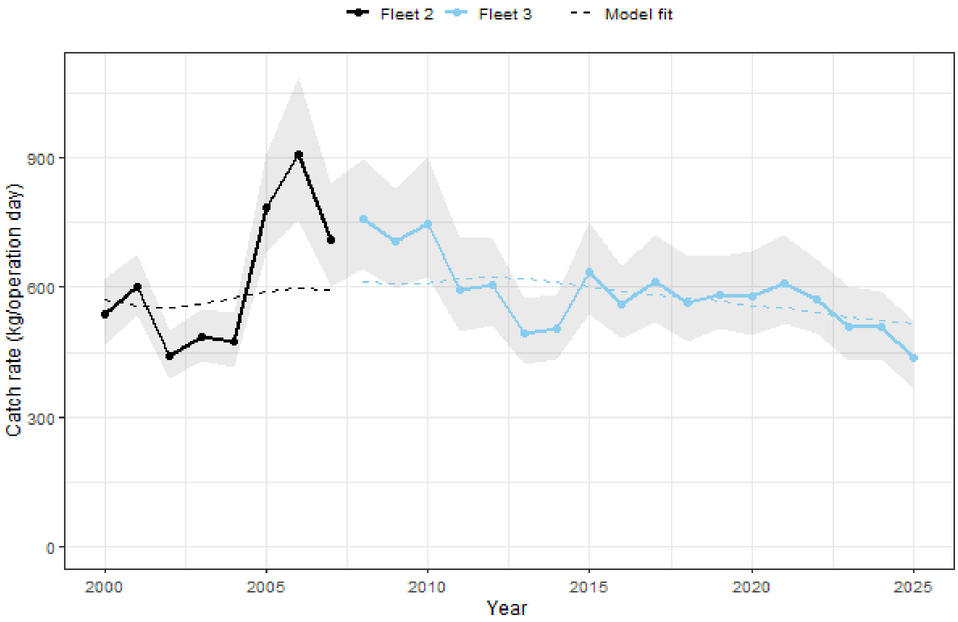

Figure D.5: CPUE fit for the Base Case scenario

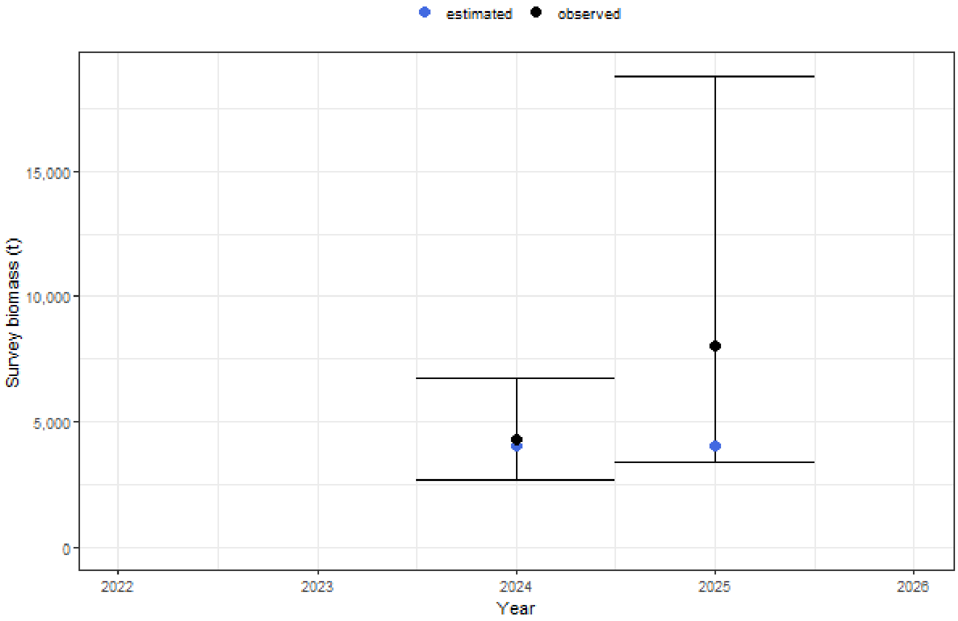

Figure D.6: Surveyed biomass fit for the Base Case scenario

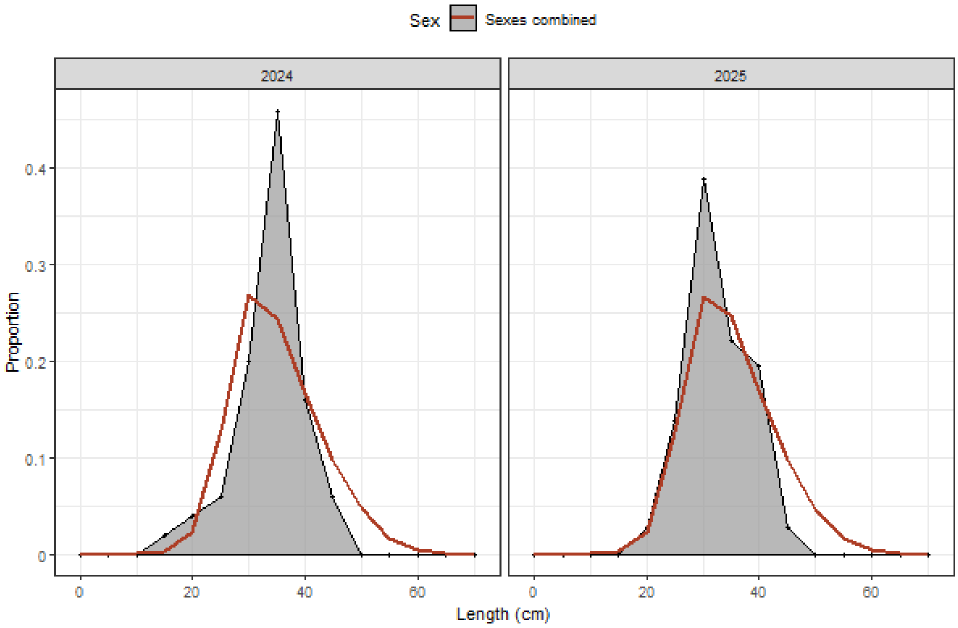

Figure D.7: Length composition fit for the Base Case scenario

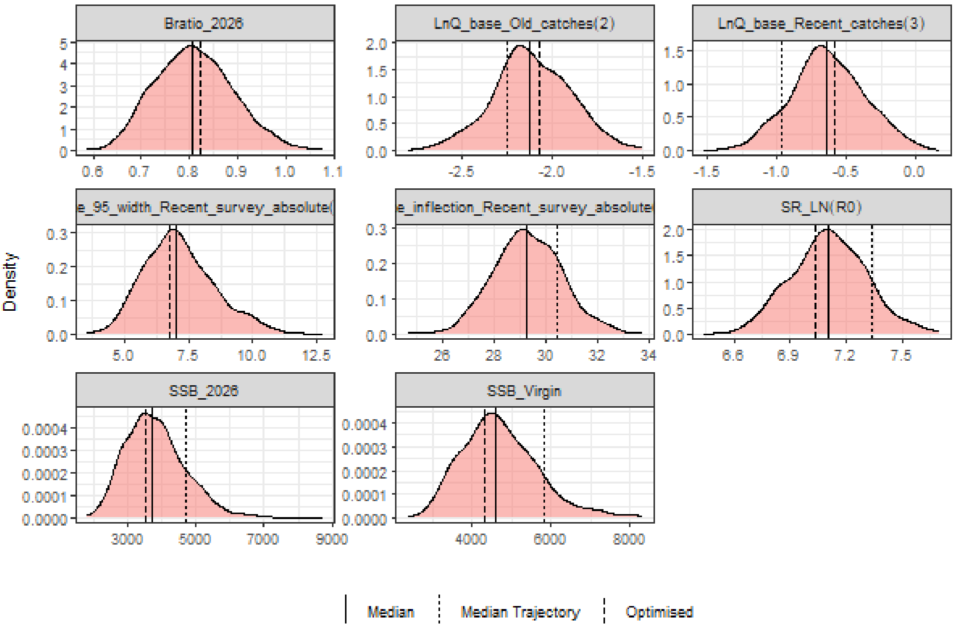

Figure D.8: MCMC parameter posterior densities for the Base Case scenario

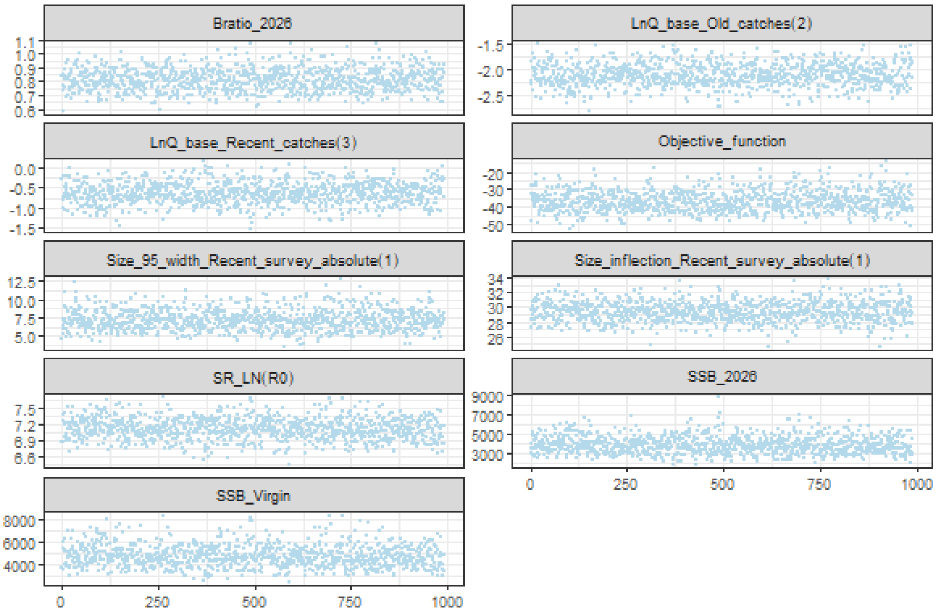

Figure D.9: MCMC trace plots for the Base Case scenario

D.2 Steepness = 0.5

This section presents results for the Steepness = 0.5 scenario.

Table D.2: Summary of parameter estimates for white 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)	7.1	6.7	7.5
SSB_Virgin	4449.5	2916.3	6658.9
SSB_2026	3788.41	2226.76	5812.76
Bratio_2026	0.8	0.7	1
LnQ_base_Old_catches(2)	-2.1	-2.5	-1.6
LnQ_base_Recent_catches(3)	-0.62	-1.11	0
Size_inflection_Recent_survey_absolute(1)	29.5	27	31.9
Size_95%width_Recent_survey_absolute(1)	7.2	4.6	10.4

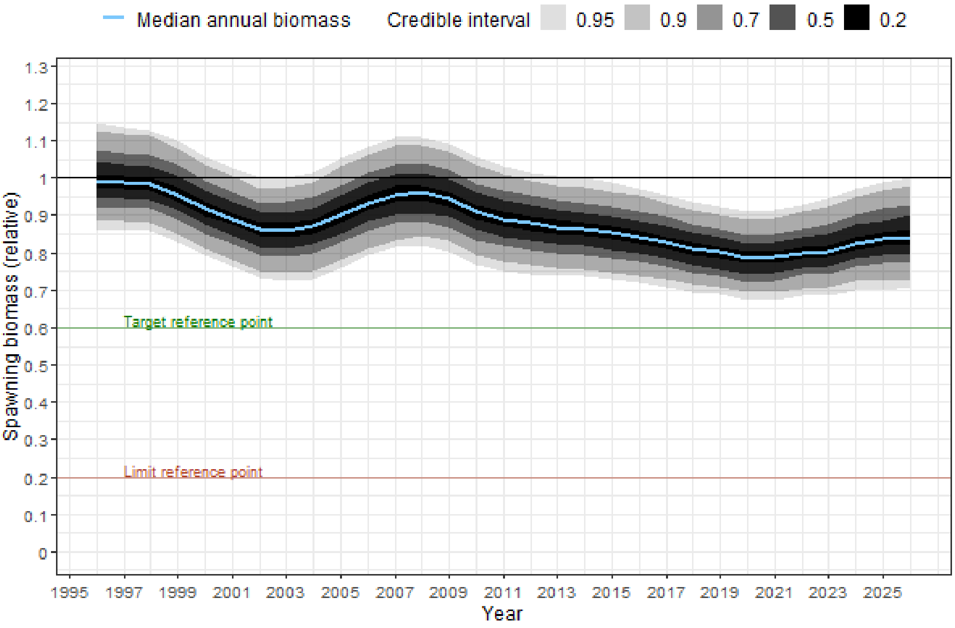

Figure D.10: Relative spawning biomass for the Steepness = 0.5 scenario

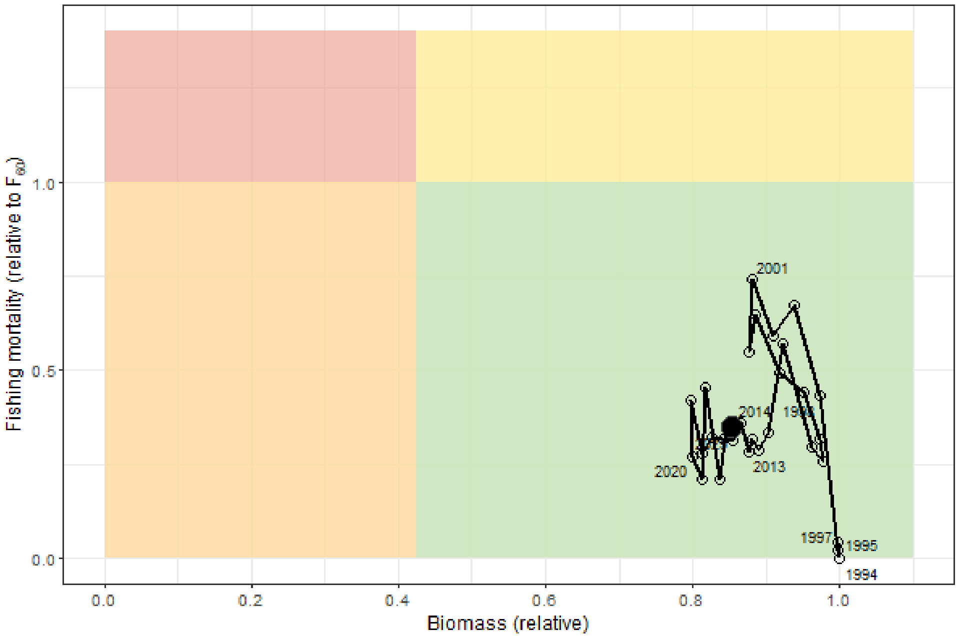

Figure D.11: Phase plot for the Steepness = 0.5 scenario

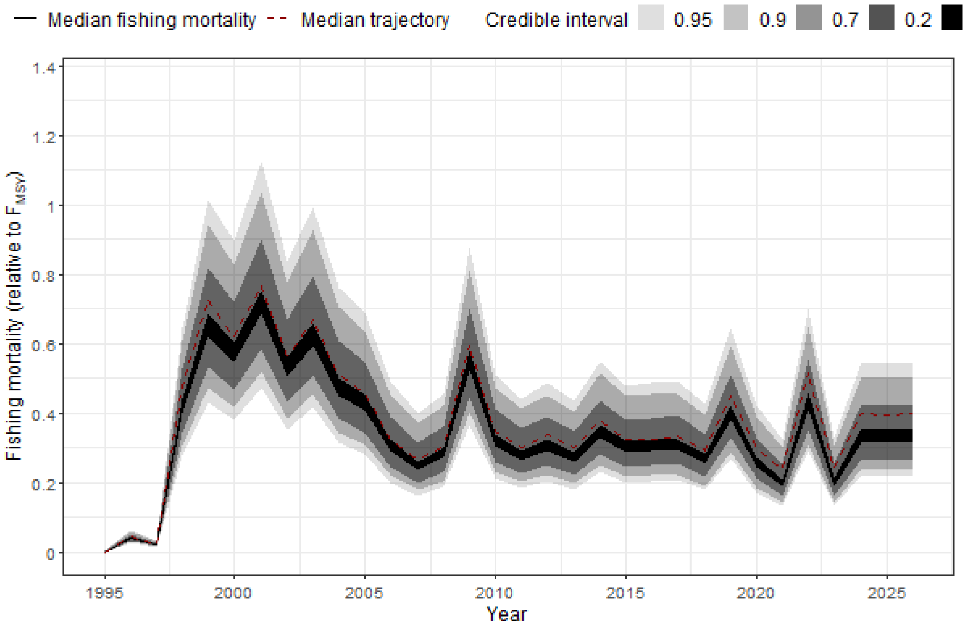

Figure D.12: Fishing mortality for the Steepness = 0.5 scenario

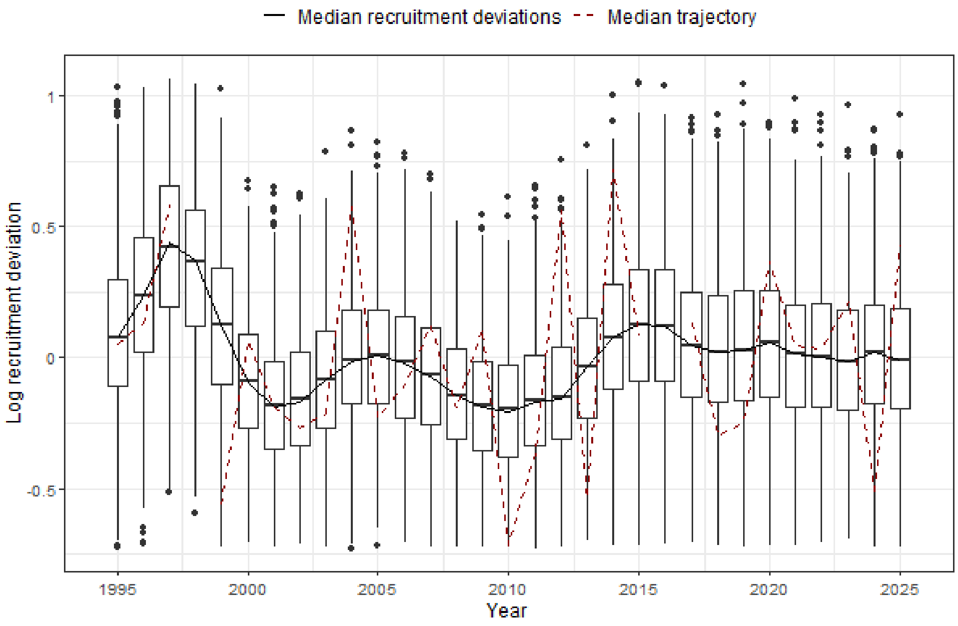

Figure D.13: Recruitment deviations for the Steepness = 0.5 scenario

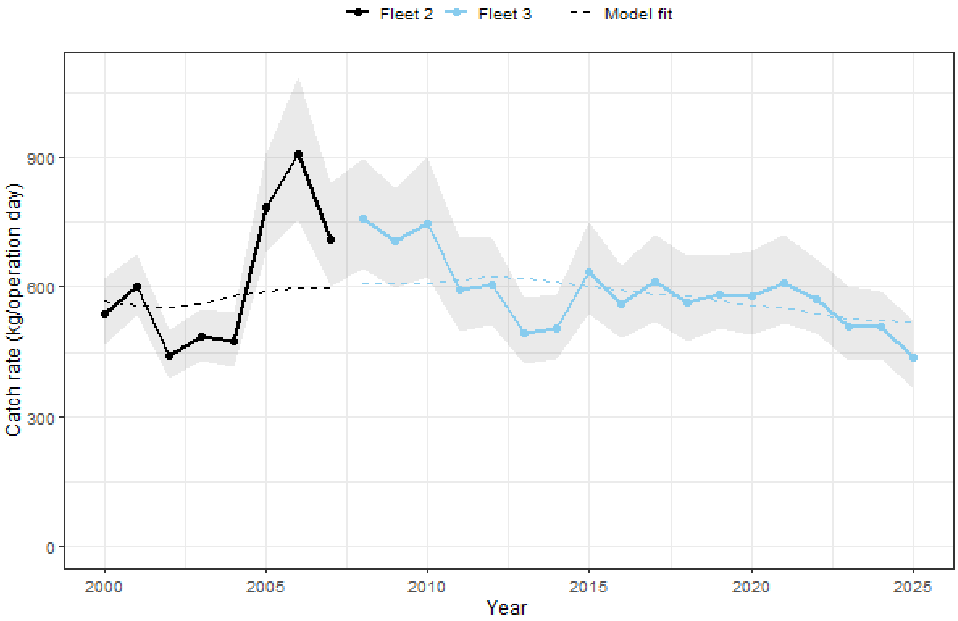

Figure D.14: CPUE fit for the Steepness = 0.5 scenario

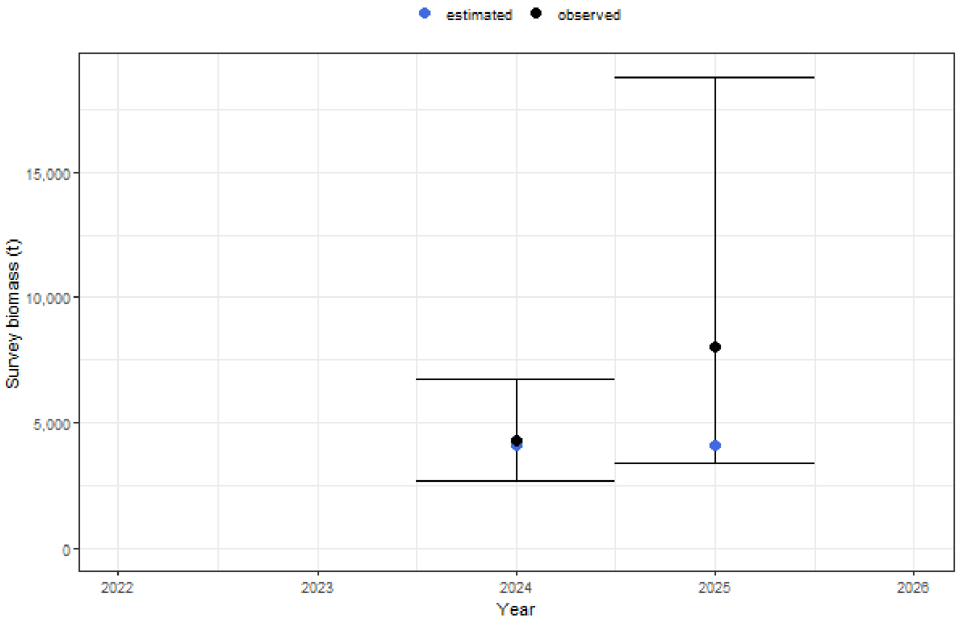

Figure D.15: Surveyed biomass fit for the Steepness = 0.5 scenario

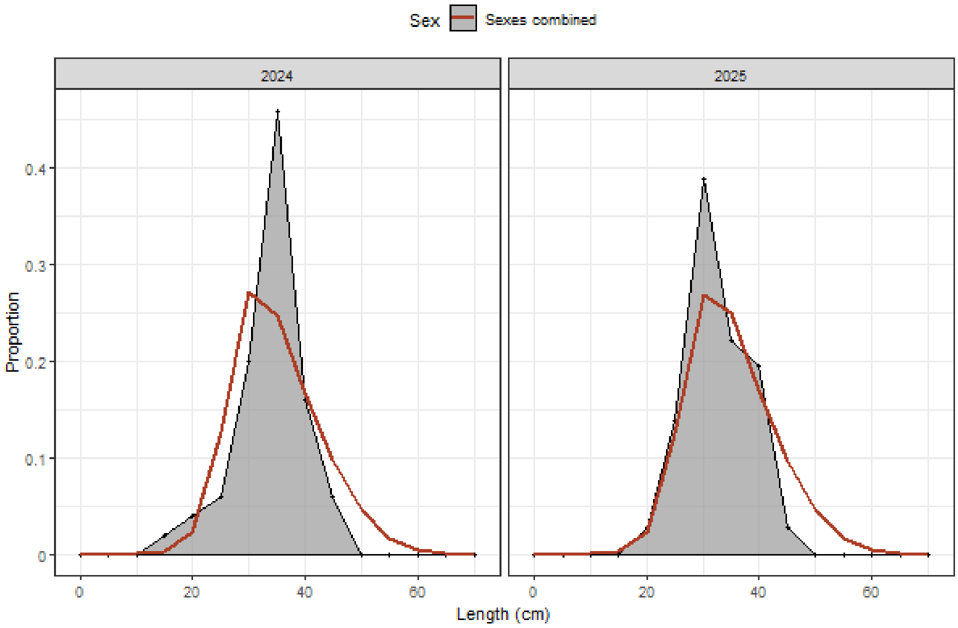

Figure D.16: Length composition fit for the Steepness = 0.5 scenario

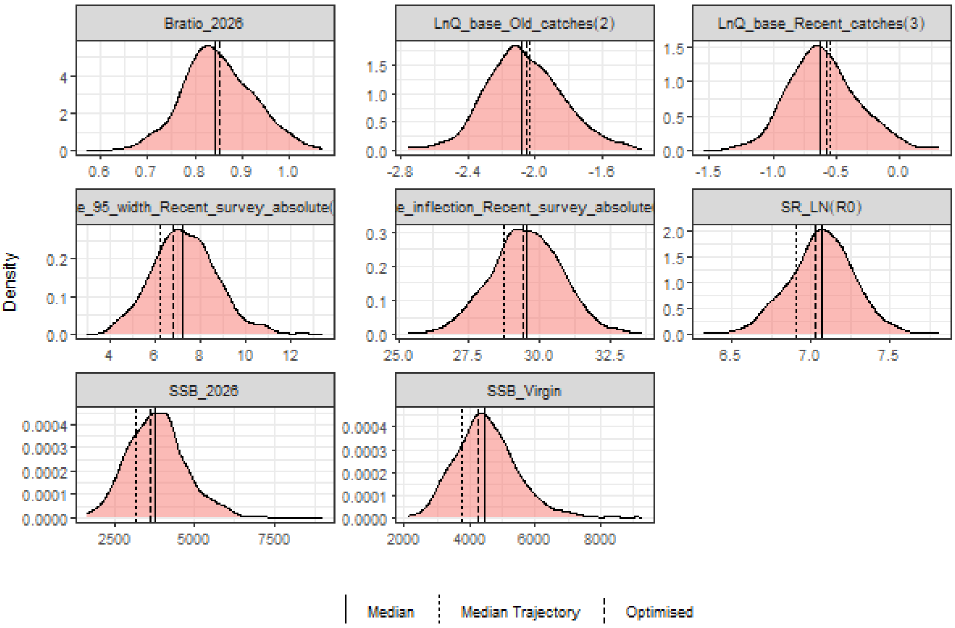

Figure D.17: MCMC parameter posterior densities for the Steepness = 0.5 scenario

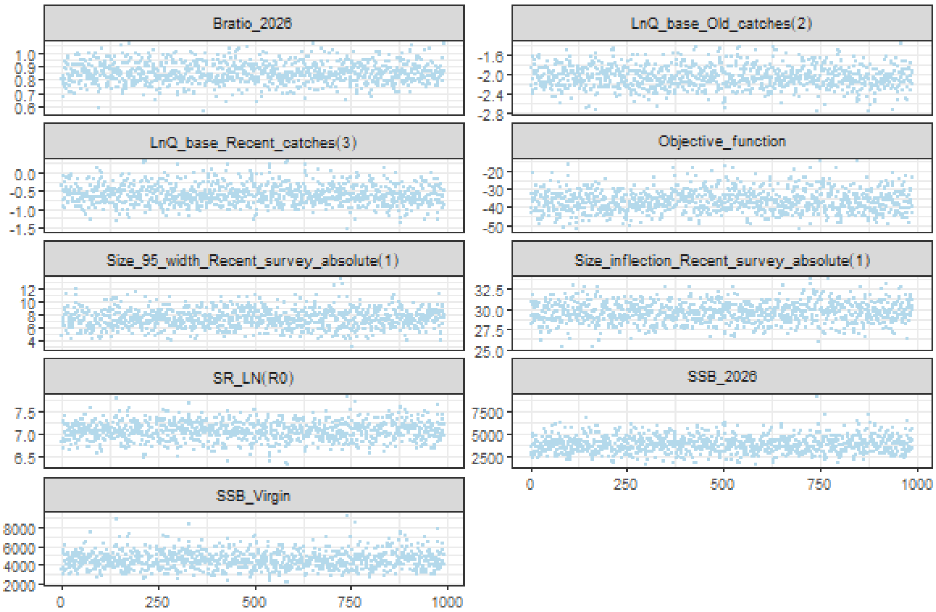

Figure D.18: MCMC trace plots for the Steepness = 0.5 scenario

D.3 Steepness = 0.7

This section presents results for the Steepness = 0.7 scenario.

Table D.3: Summary of parameter estimates for white 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)	7.1	6.7	7.5
SSB_Virgin	4445.1	2925.5	6703.8
SSB_2026	3830.84	2389.54	6058.57
Bratio_2026	0.9	0.7	1
LnQ_base_Old_catches(2)	-2.1	-2.5	-1.6
LnQ_base_Recent_catches(3)	-0.62	-1.16	-0.05
Size_inflection_Recent_survey_absolute(1)	29.6	26.9	32.1
Size_95%width_Recent_survey_absolute(1)	7.1	4.9	10.3

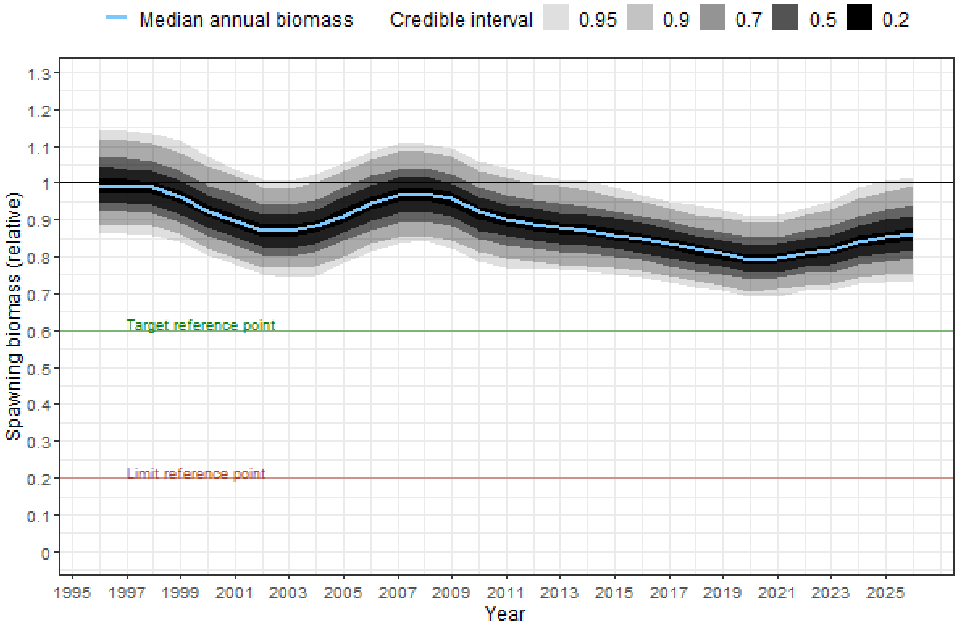

Figure D.19: Relative spawning biomass for the Steepness = 0.7 scenario

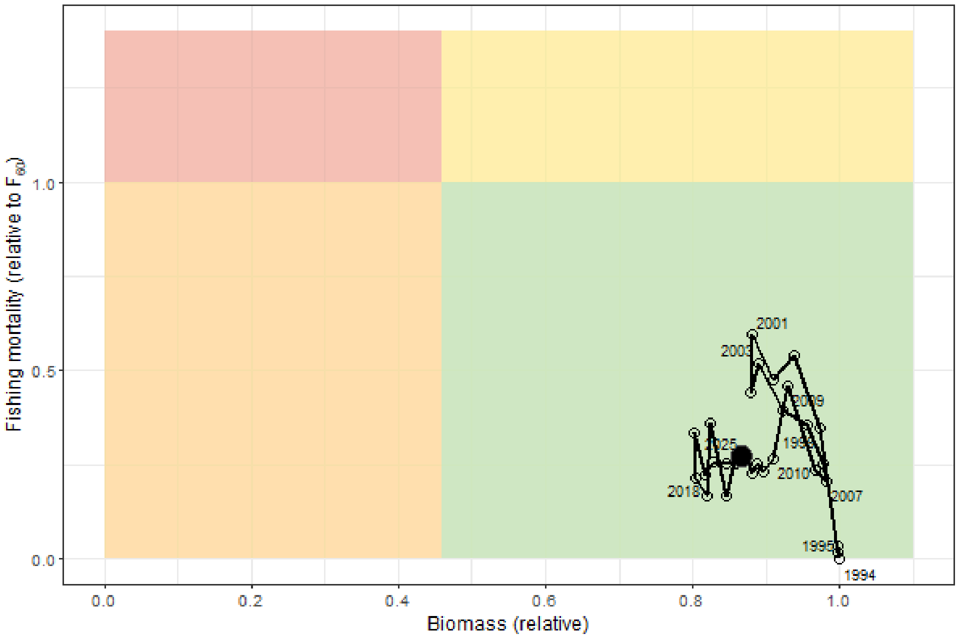

Figure D.20: Phase plot for the Steepness = 0.7 scenario

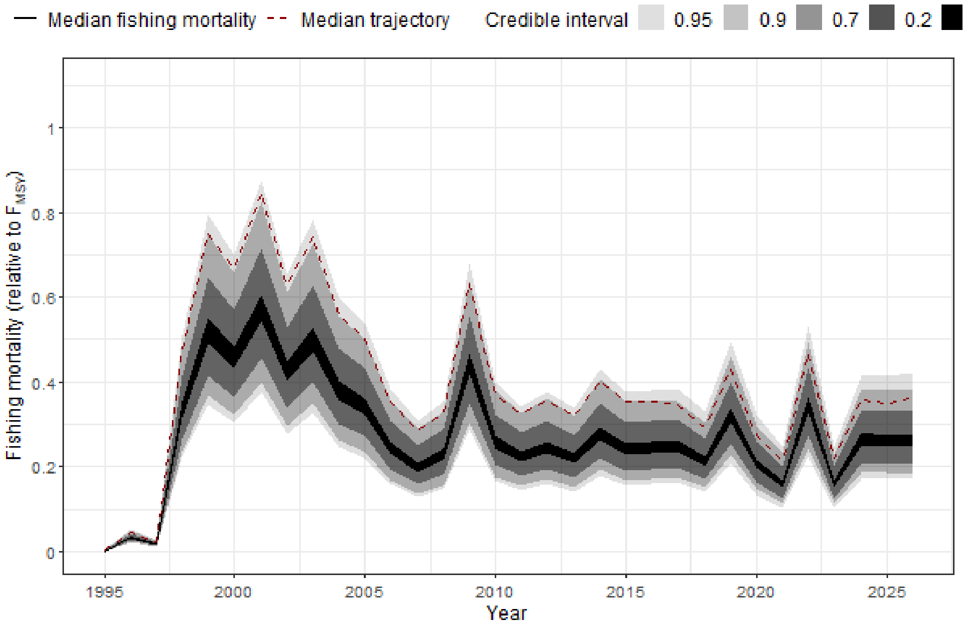

Figure D.21: Fishing mortality for the Steepness = 0.7 scenario

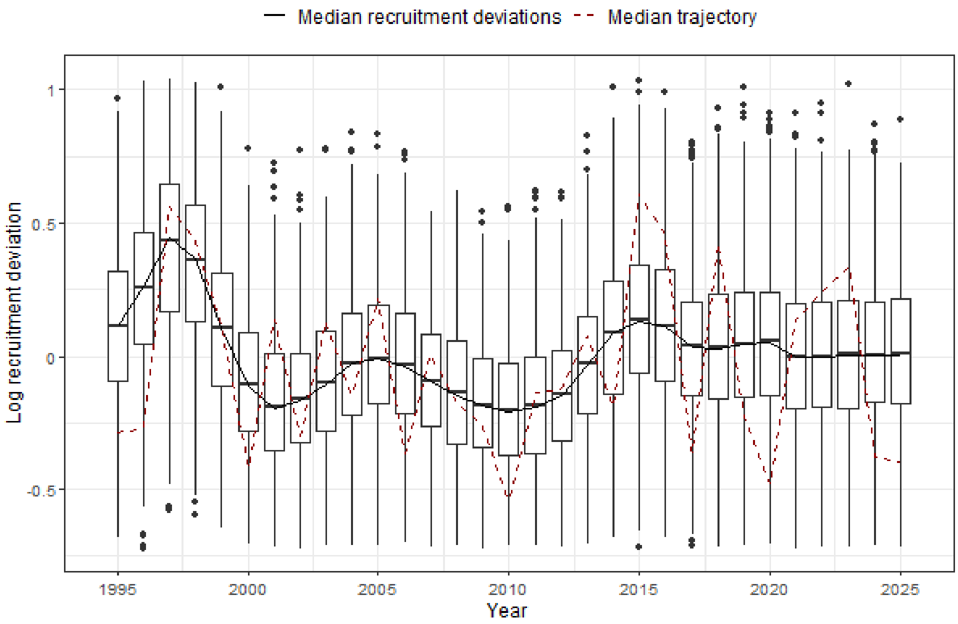

Figure D.22: Recruitment deviations for the Steepness = 0.7 scenario

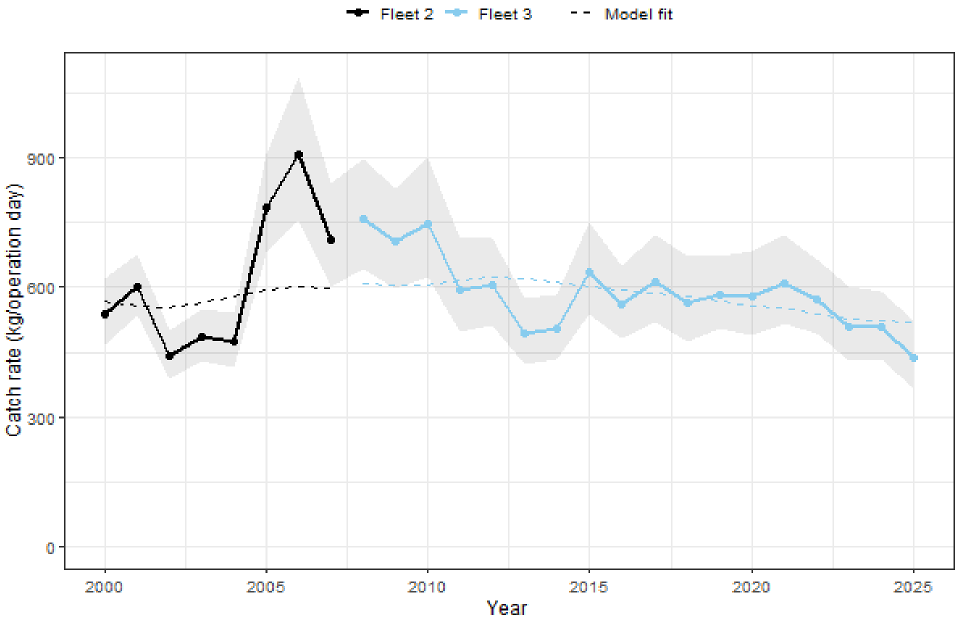

Figure D.23: CPUE fit for the Steepness = 0.7 scenario

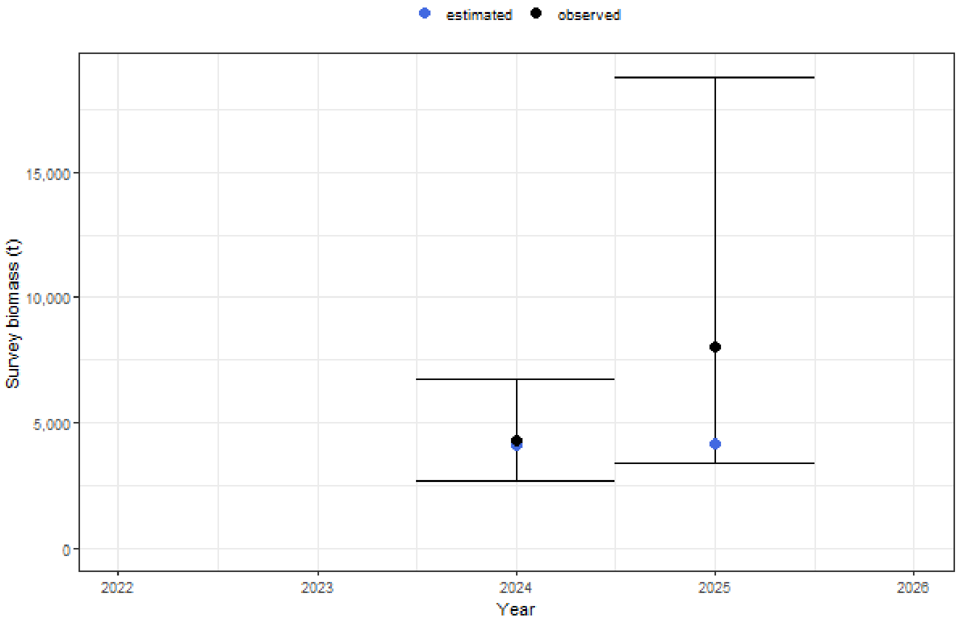

Figure D.24: Surveyed biomass fit for the Steepness = 0.7 scenario

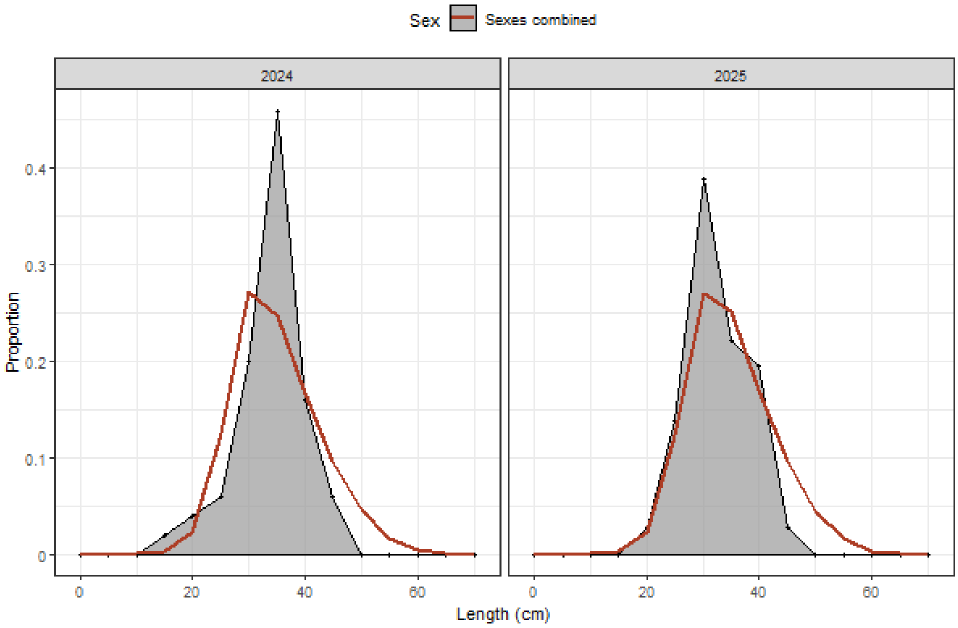

Figure D.25: Length composition fit for the Steepness = 0.7 scenario

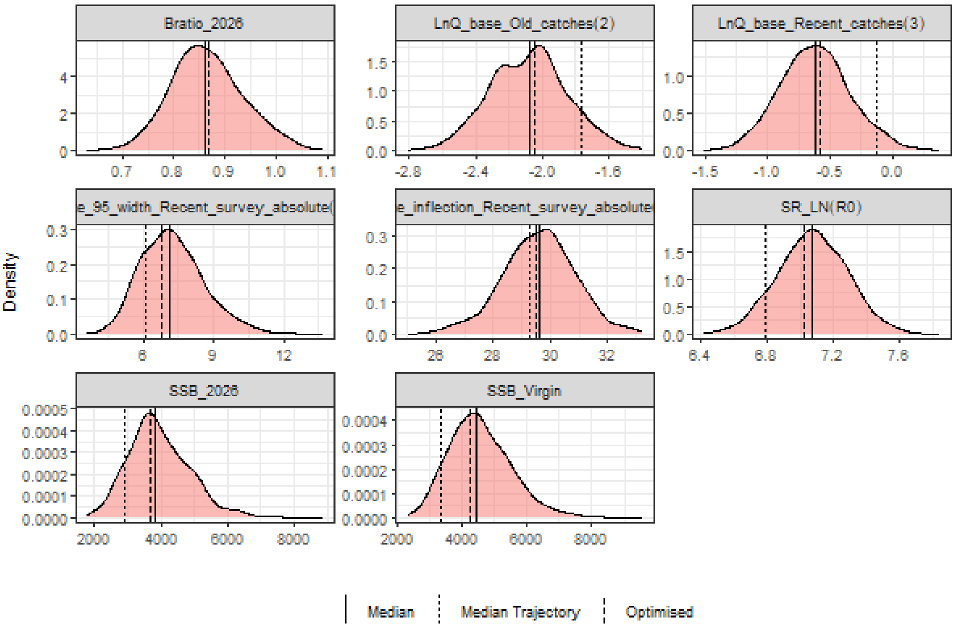

Figure D.26: MCMC parameter posterior densities for the Steepness = 0.7 scenario

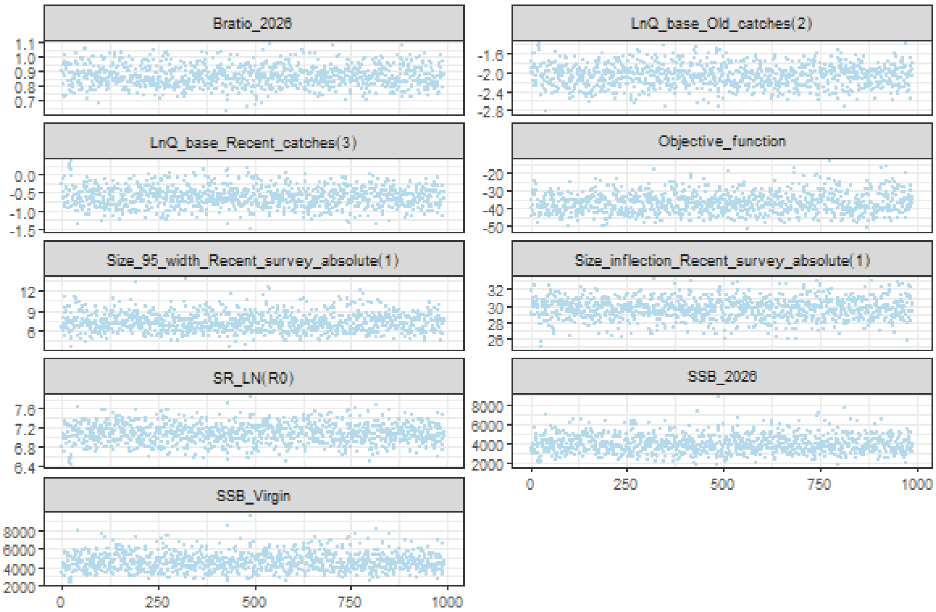

Figure D.27: MCMC trace plots for the Steepness = 0.7 scenario

D.4 Natural mortality = 0.4

This section presents results for the Natural mortality = 0.4 scenario.

Table D.4: Summary of parameter estimates for white teatfish the Natural mortality = 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)	9.7	9.2	10.2
SSB_Virgin	5507.1	3416.9	9069.2
SSB_2026	4960.65	3037.85	8448.86
Bratio_2026	0.9	0.7	1.1
LnQ_base_Old_catches(2)	-2.1	-2.5	-1.6
LnQ_base_Recent_catches(3)	0.01	-0.57	0.6
Size_inflection_Recent_survey_absolute(1)	33.6	31.6	35.9
Size_95%width_Recent_survey_absolute(1)	7	5.4	9

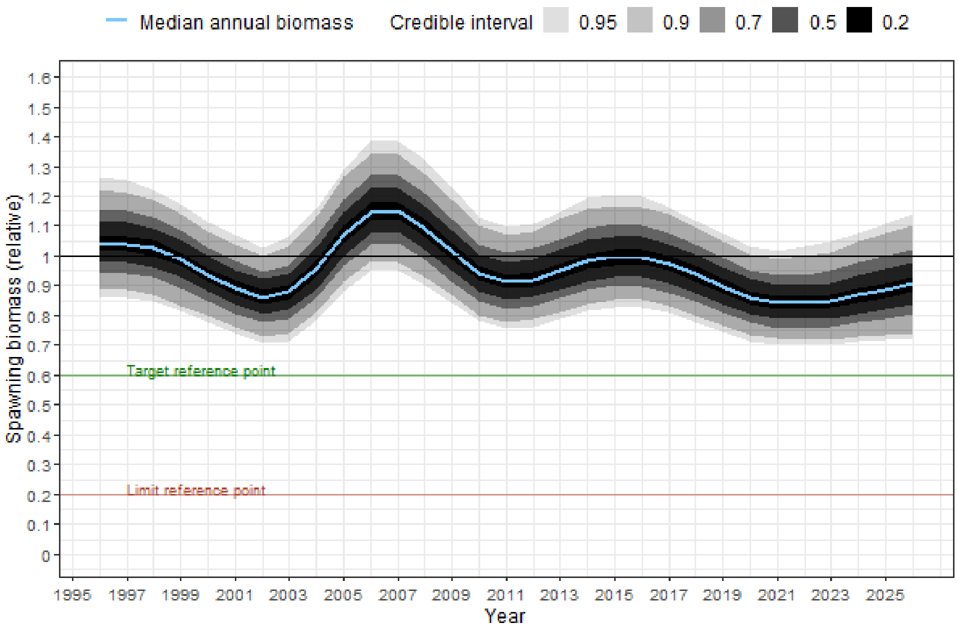

Figure D.28: Relative spawning biomass for the Natural mortality = 0.4 scenario

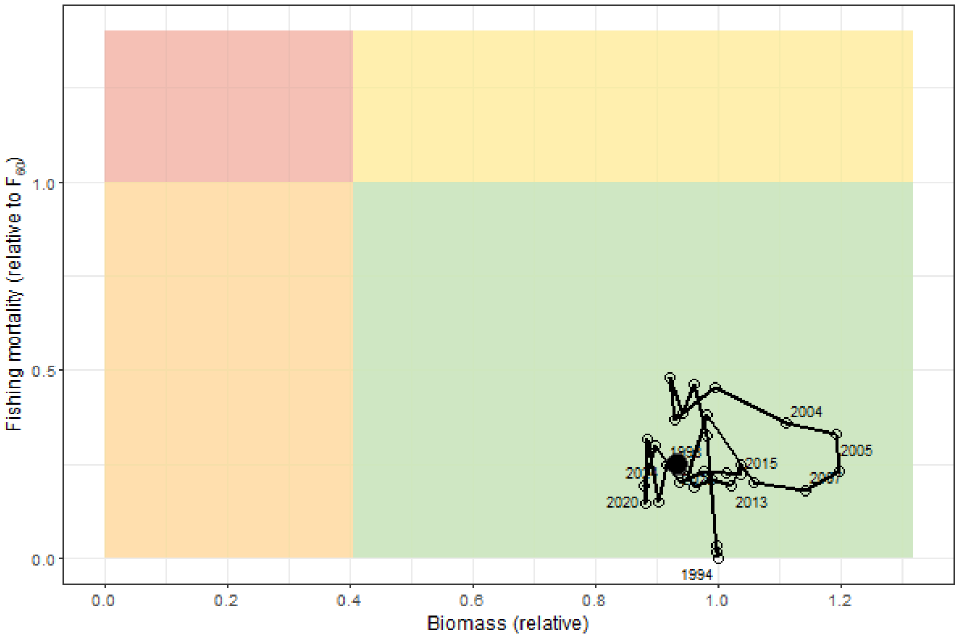

Figure D.29: Phase plot for the Natural mortality = 0.4 scenario

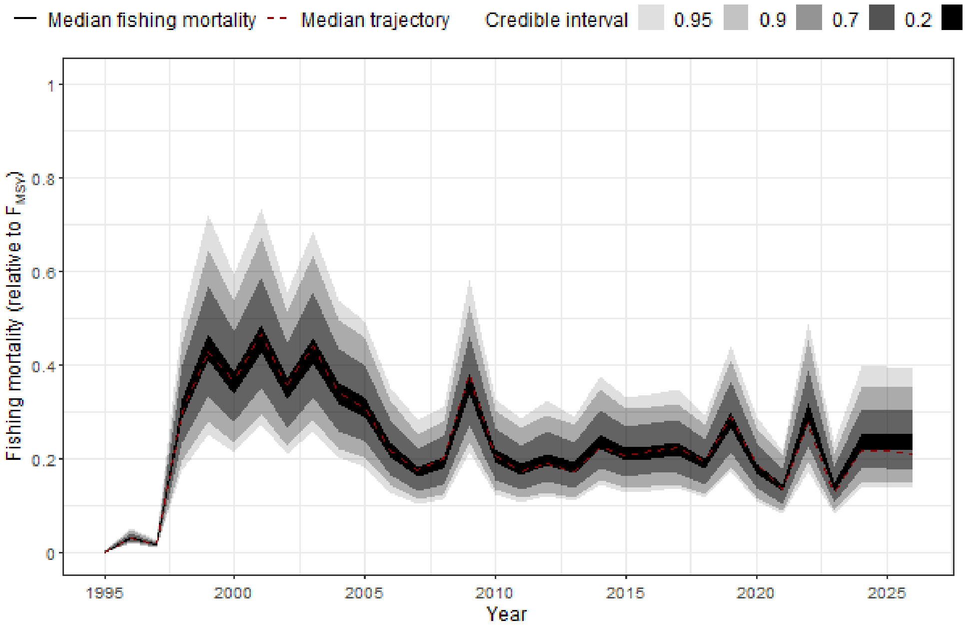

Figure D.30: Fishing mortality for the Natural mortality = 0.4 scenario

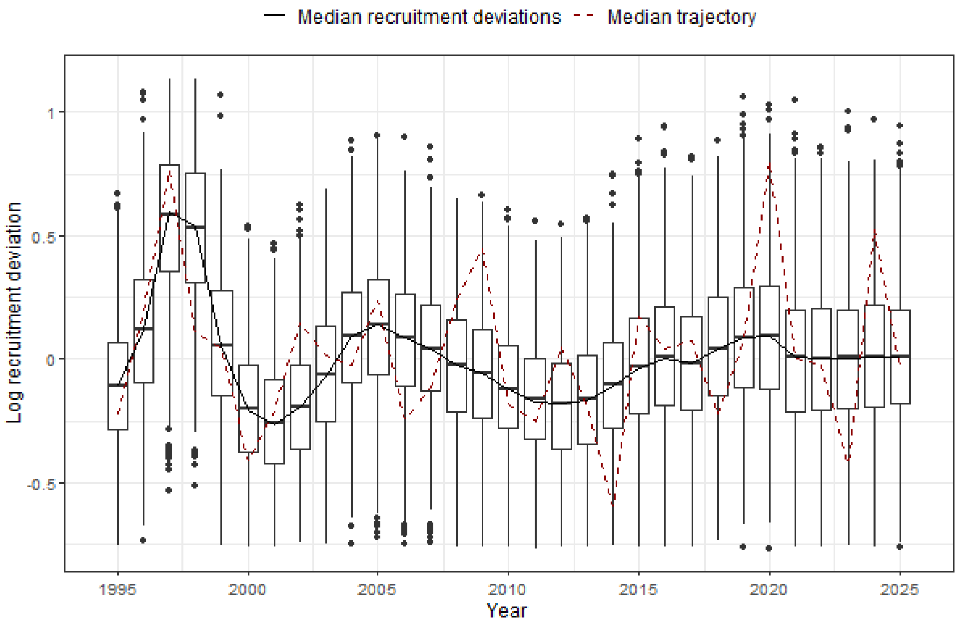

Figure D.31: Recruitment deviations for the Natural mortality = 0.4 scenario

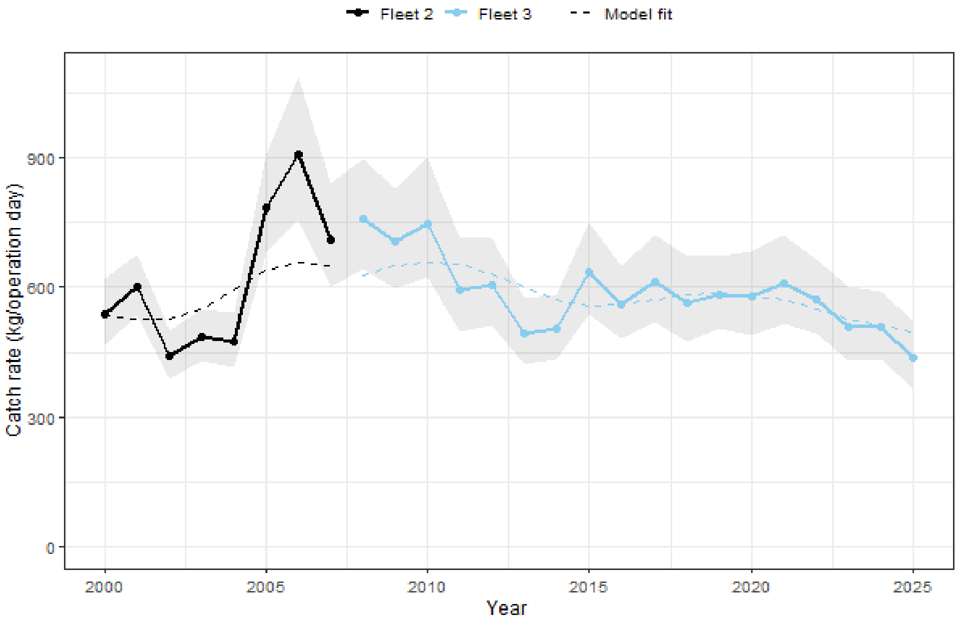

Figure D.32: CPUE fit for the Natural mortality = 0.4 scenario

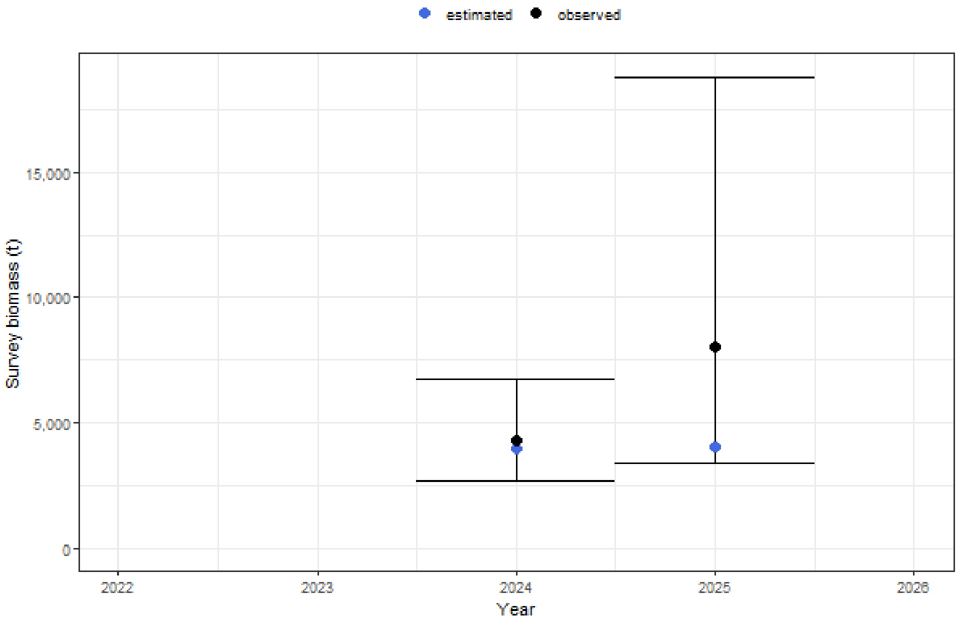

Figure D.33: Surveyed biomass fit for the Natural mortality = 0.4 scenario

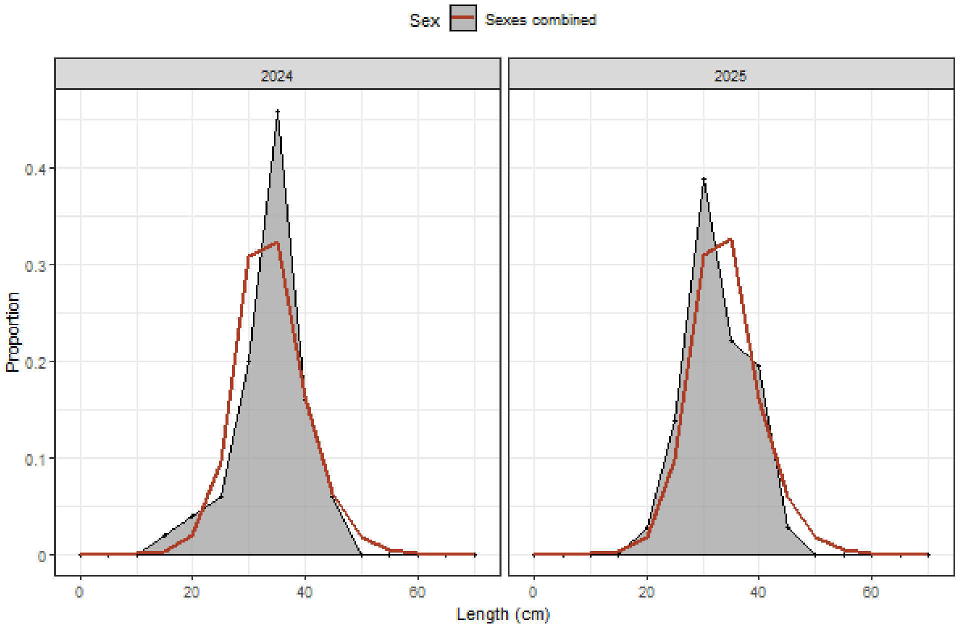

Figure D.34: Length composition fit for the Natural mortality = 0.4 scenario

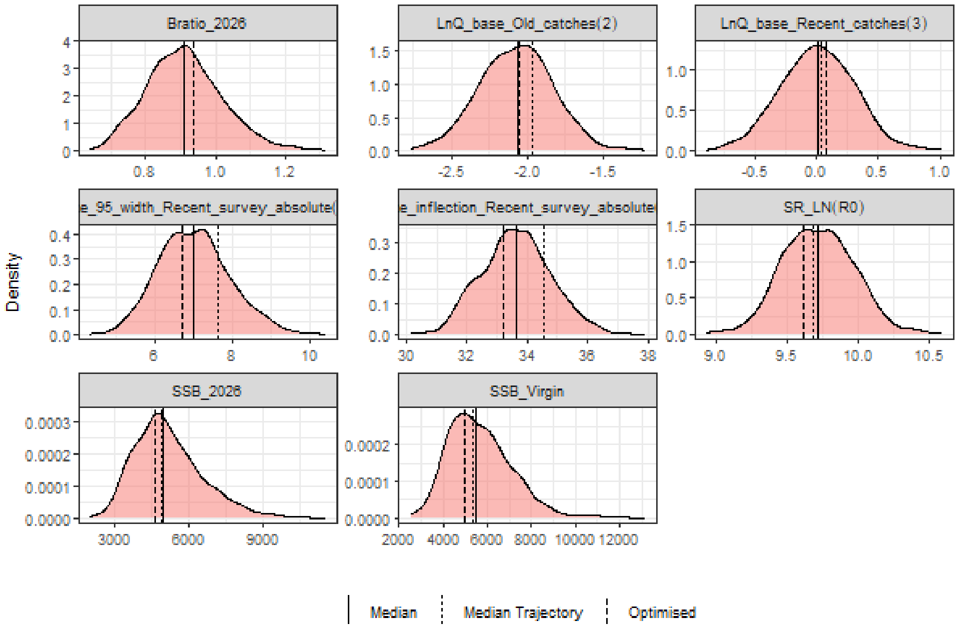

Figure D.35: MCMC parameter posterior densities for the Natural mortality = 0.4 scenario

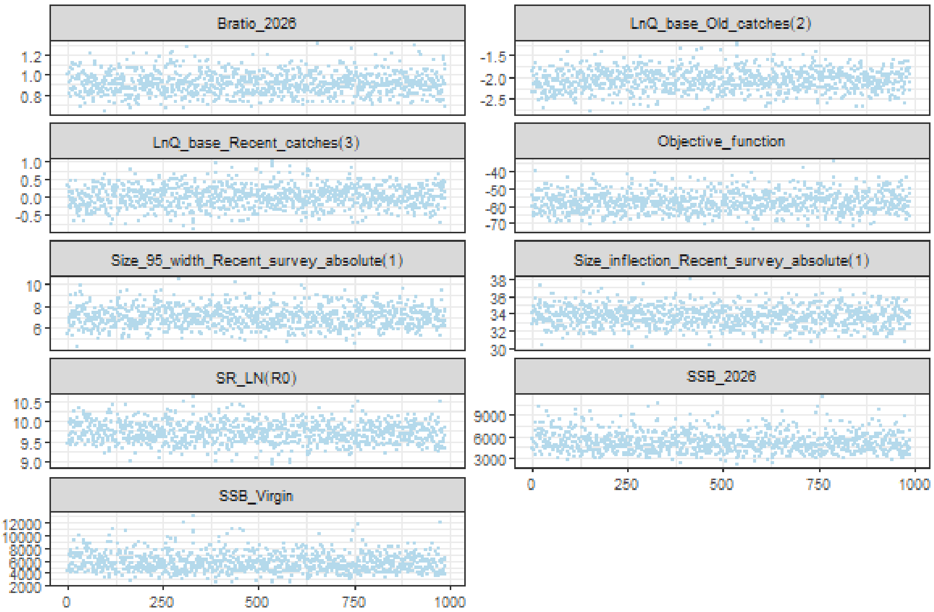

Figure D.36: MCMC trace plots for the Natural mortality = 0.4 scenario

D.5 Natural mortality = 0.6

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

Table D.5: Summary of parameter estimates for white 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)	11.4	10.6	12
SSB_Virgin	4228.1	1871.3	7539.2
SSB_2026	4008.96	1801.13	7379.82
Bratio_2026	1	0.7	1.2
LnQ_base_Old_catches(2)	-1.6	-2.2	-0.9
LnQ_base_Recent_catches(3)	1.15	0.51	2.25
Size_inflection_Recent_survey_absolute(1)	34.1	32	36.4
Size_95%width_Recent_survey_absolute(1)	6.1	5	7.6

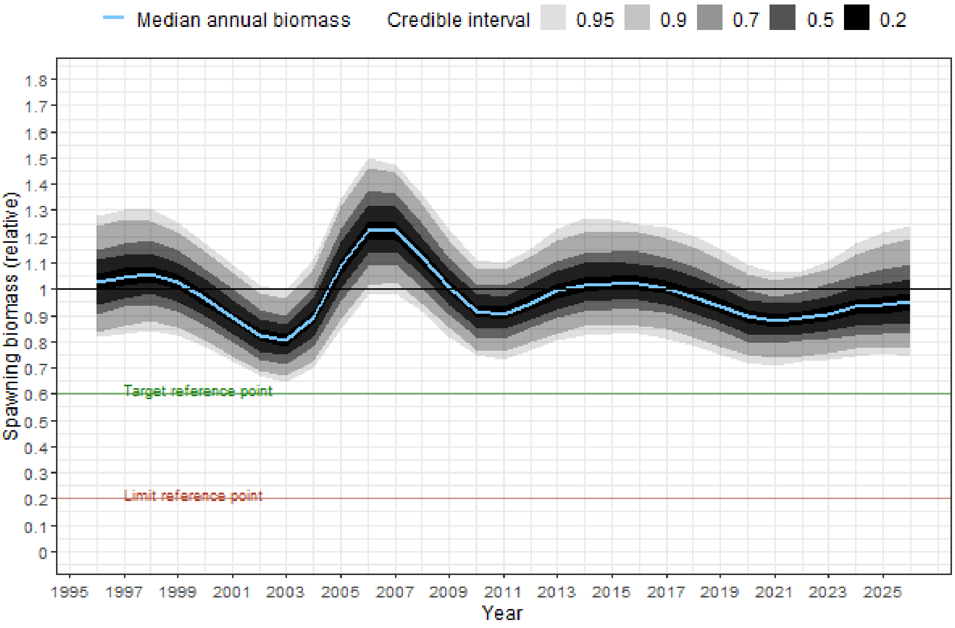

Figure D.37: Relative spawning biomass for the Natural mortality = 0.6 scenario

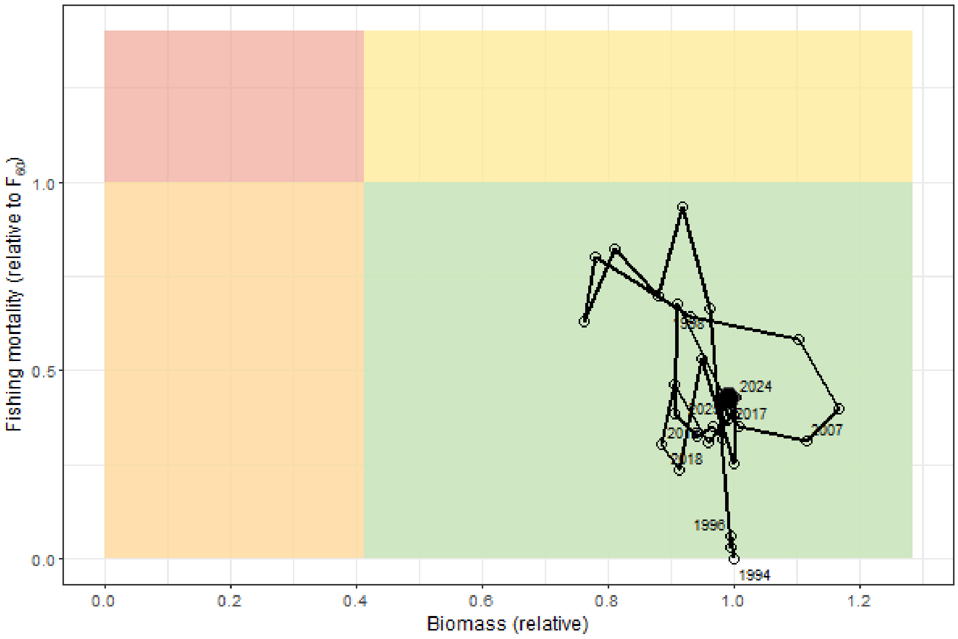

Figure D.38: Phase plot for the Natural mortality = 0.6 scenario

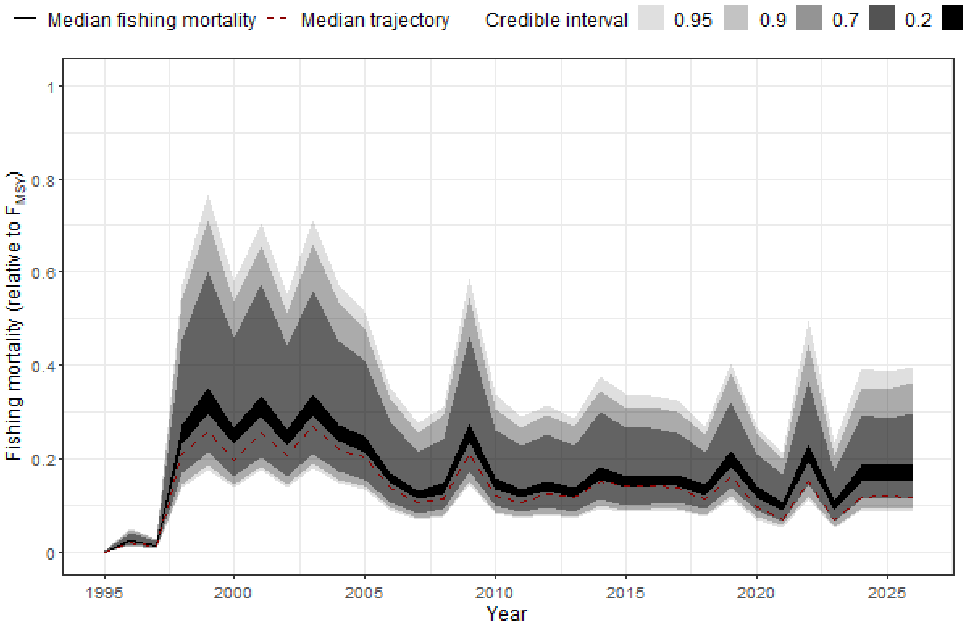

Figure D.39: Fishing mortality for the Natural mortality = 0.6 scenario

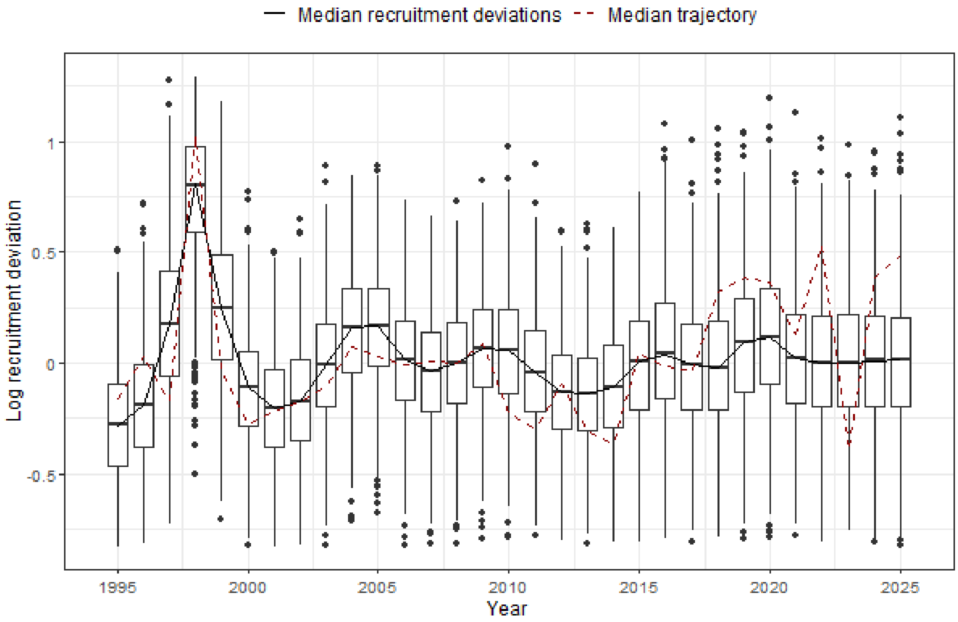

Figure D.40: Recruitment deviations for the Natural mortality = 0.6 scenario

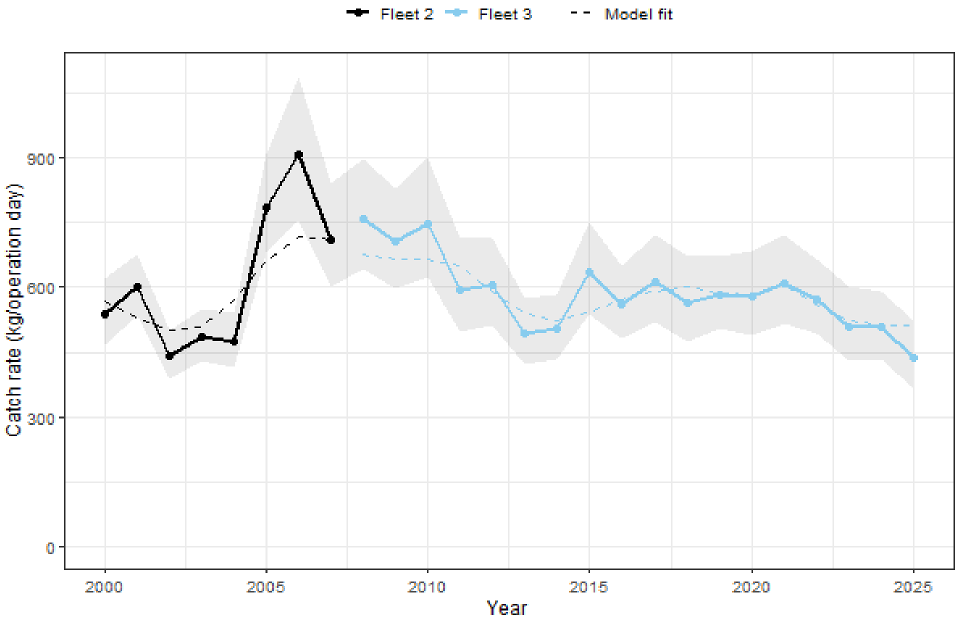

Figure D.41: CPUE fit for the Natural mortality = 0.6 scenario

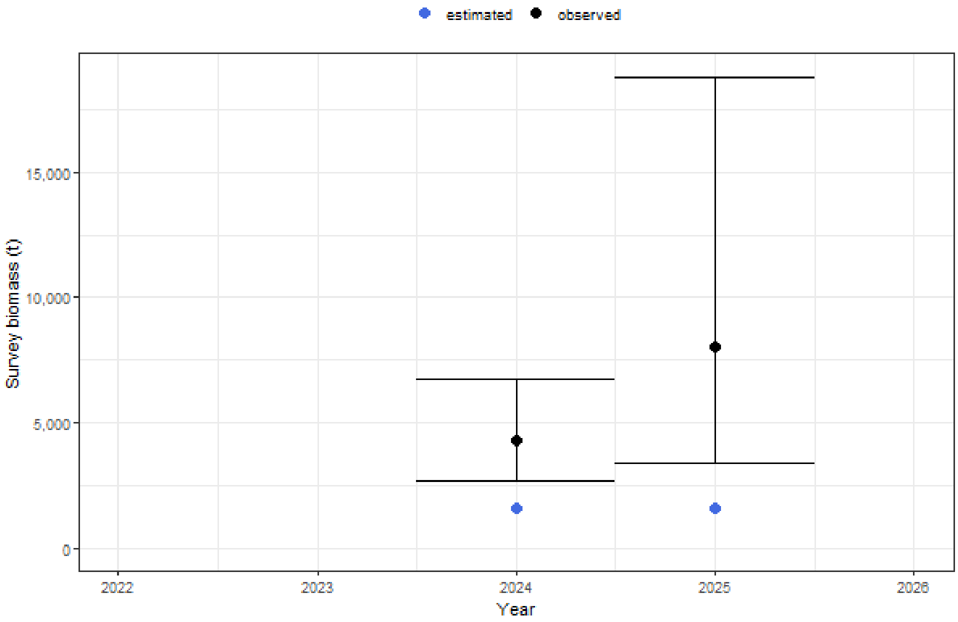

Figure D.42: Surveyed biomass fit for the Natural mortality = 0.6 scenario

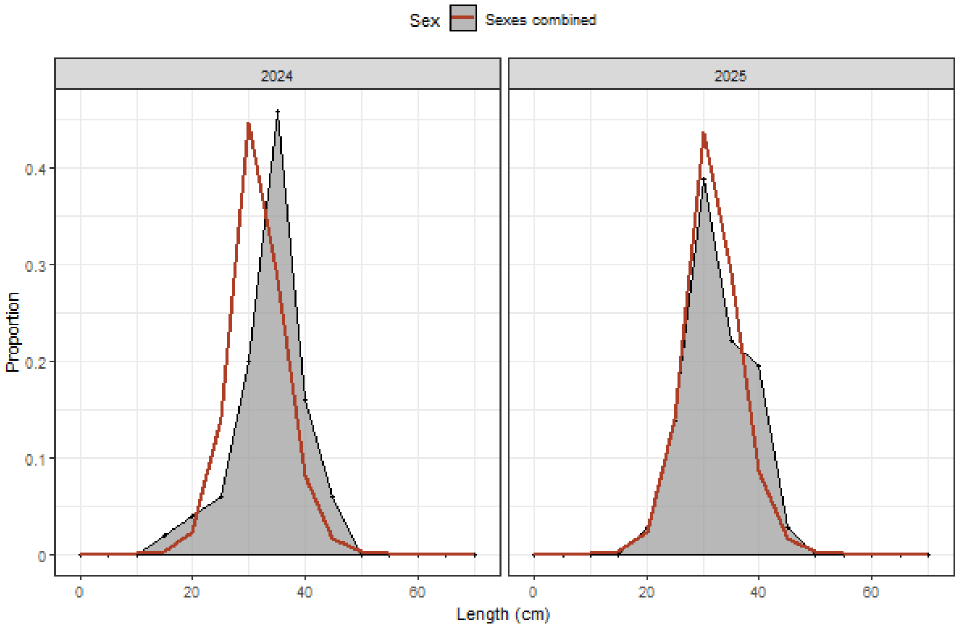

Figure D.43: Length composition fit for the Natural mortality = 0.6 scenario

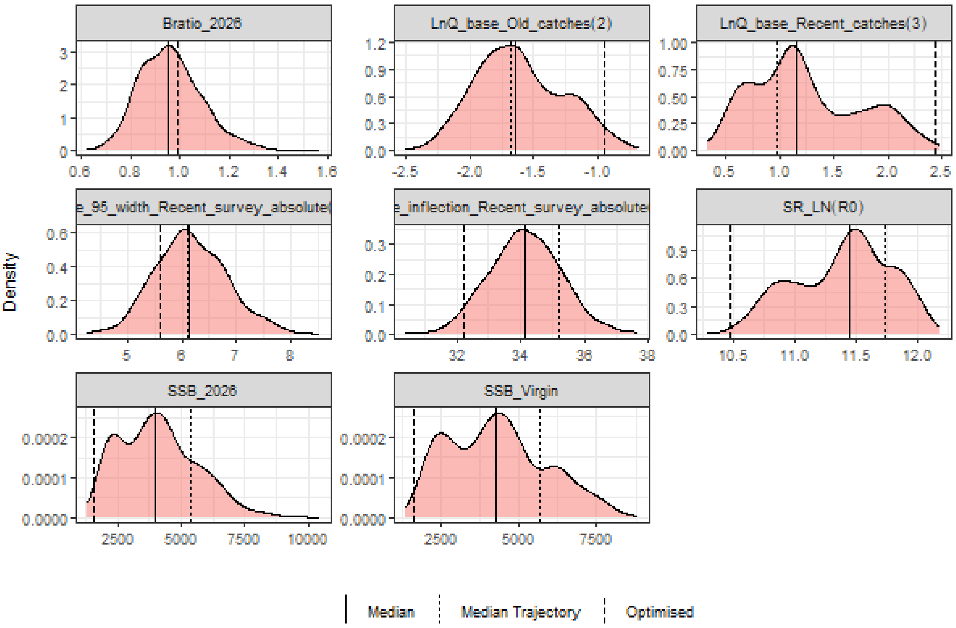

Figure D.44: MCMC parameter posterior densities for the Natural mortality = 0.6 scenario

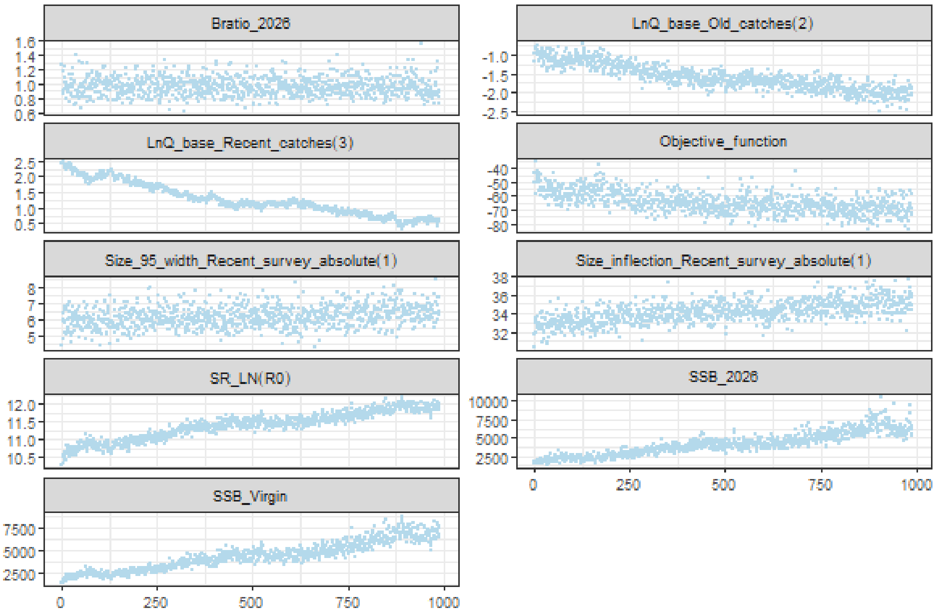

Figure D.45: MCMC trace plots for the Natural mortality = 0.6 scenario

D.6 Faster growth profile

This section presents results for the Faster growth profile scenario.

Table D.6: Summary of parameter estimates for white 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)	5.8	5.4	6.2
SSB_Virgin	4031.6	2808.6	6046.1
SSB_2026	3854.27	2477.82	5830.16
Bratio_2026	0.9	0.8	1.2
LnQ_base_Old_catches(2)	-1.9	-2.3	-1.5
LnQ_base_Recent_catches(3)	-1.36	-1.81	-0.92
Size_inflection_Recent_survey_absolute(1)	24.9	21.2	27.5
Size_95%width_Recent_survey_absolute(1)	6.9	3.4	11.7

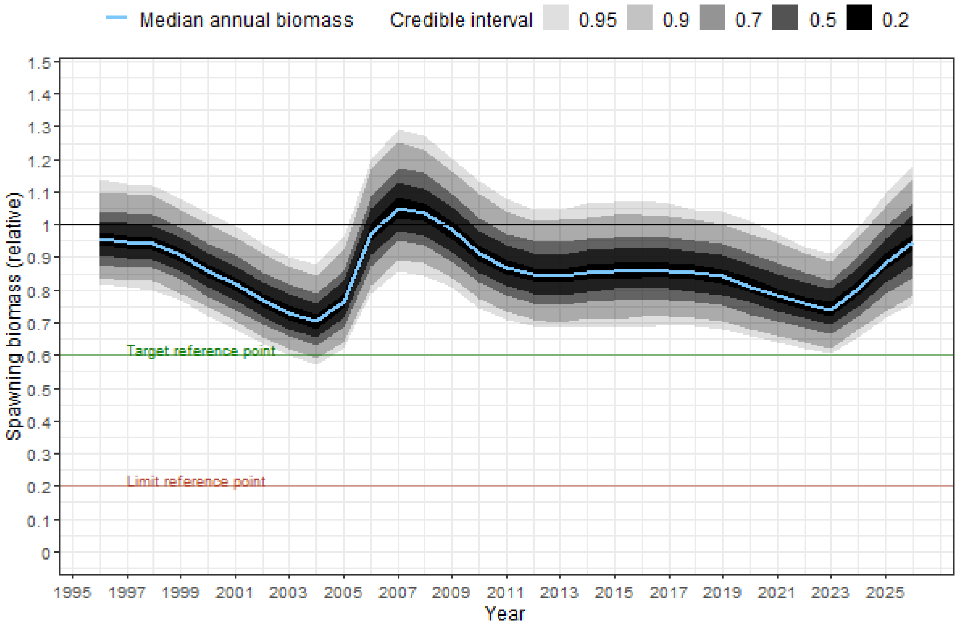

Figure D.46: Relative spawning biomass for the Faster growth profile scenario

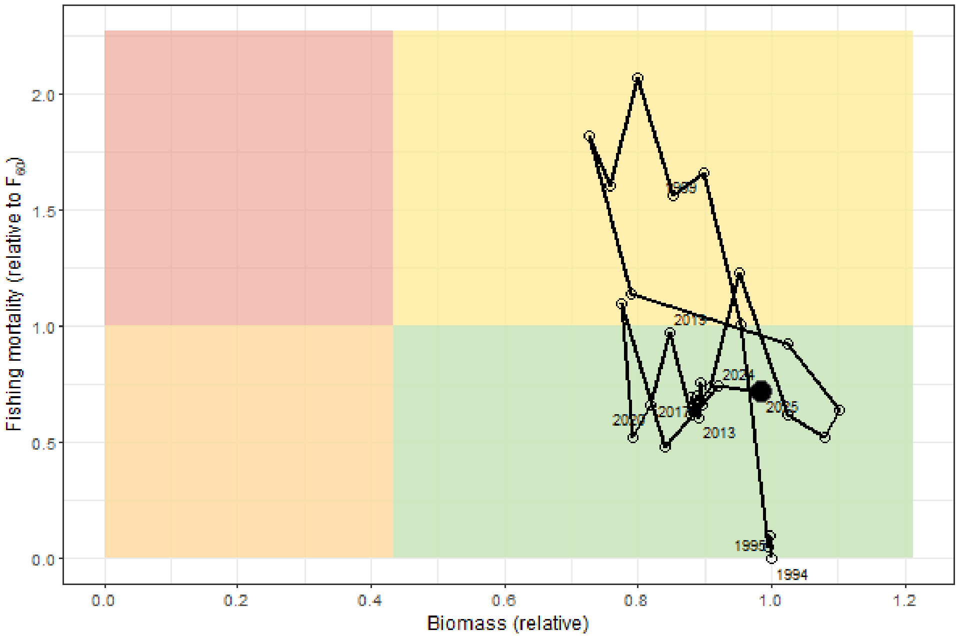

Figure D.47: Phase plot for the Faster growth profile scenario

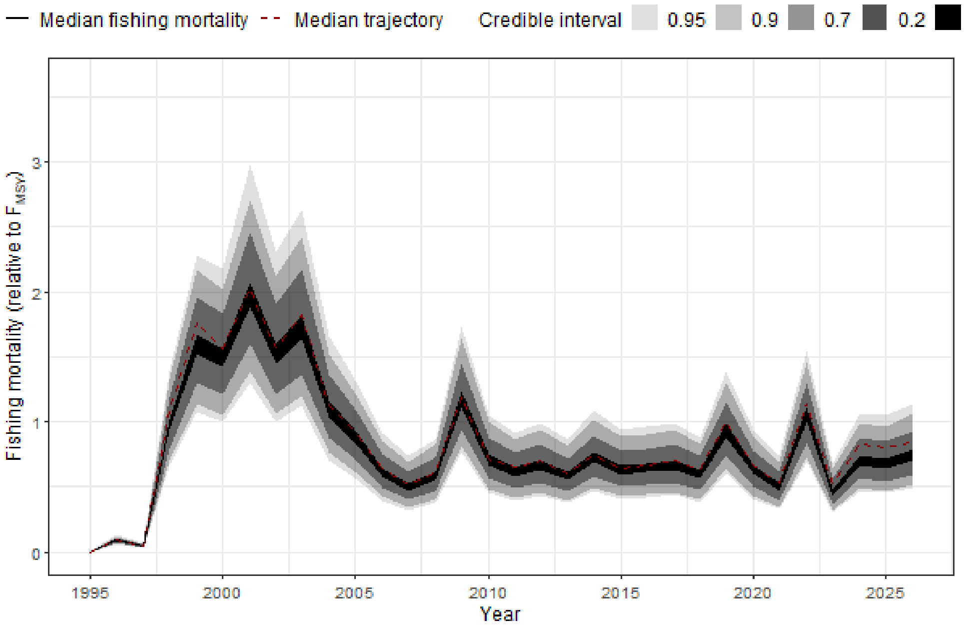

Figure D.48: Fishing mortality for the Faster growth profile scenario

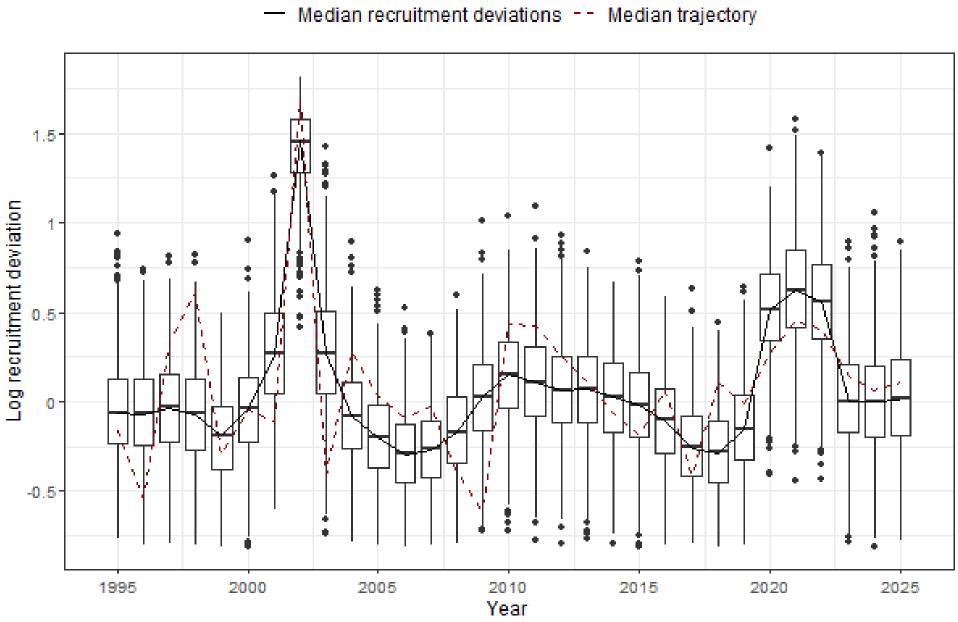

Figure D.49: Recruitment deviations for the Faster growth profile scenario

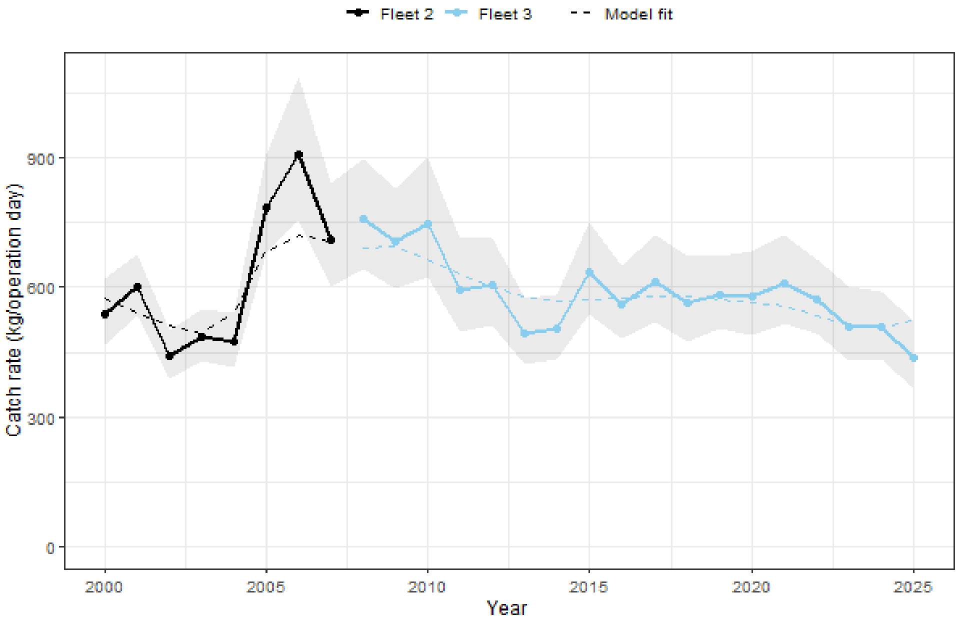

Figure D.50: CPUE fit for the Faster growth profile scenario

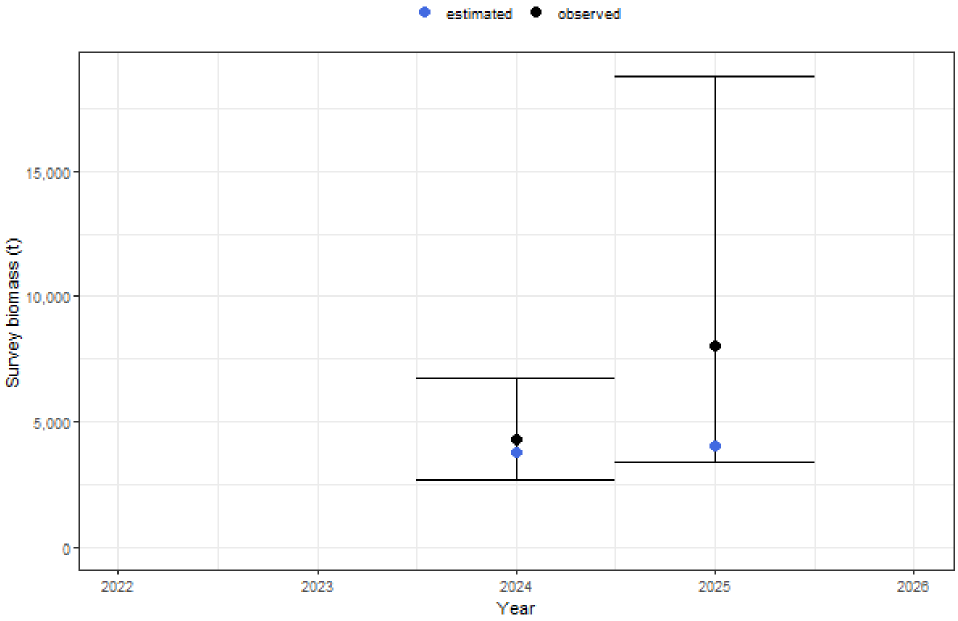

Figure D.51: Surveyed biomass fit for the Faster growth profile scenario

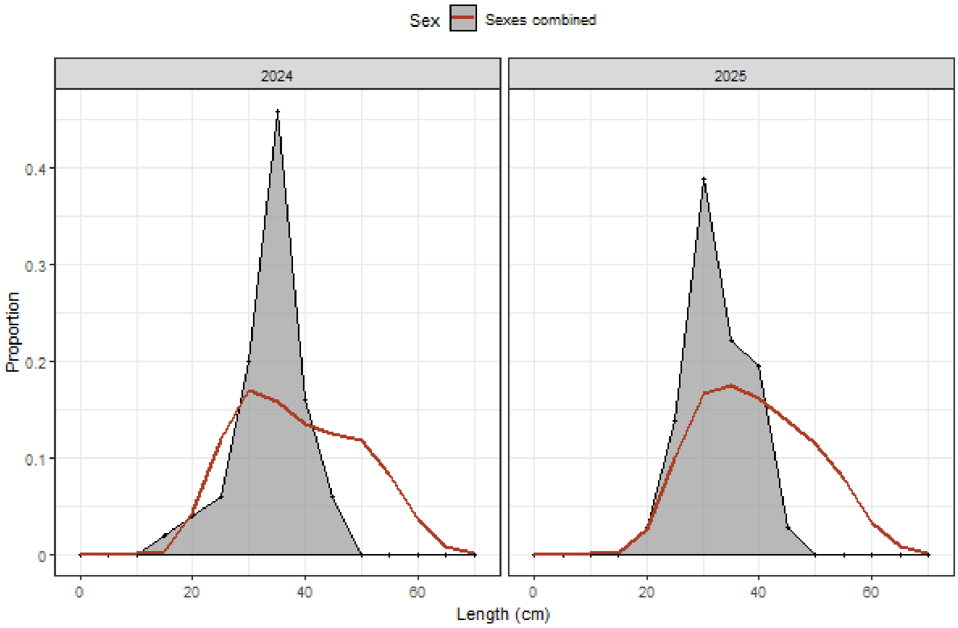

Figure D.52: Length composition fit for the Faster growth profile scenario

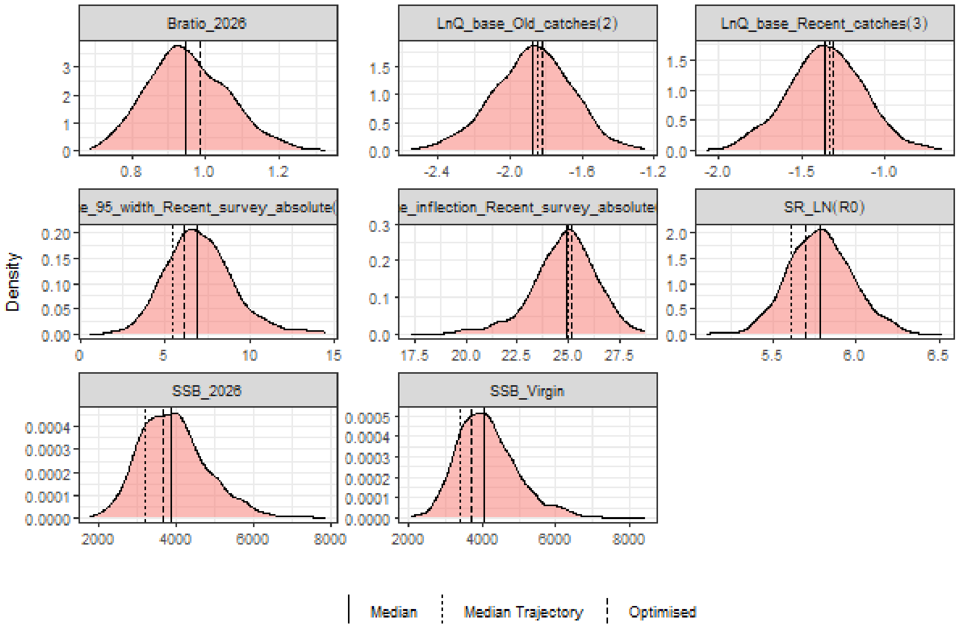

Figure D.53: MCMC parameter posterior densities for the Faster growth profile scenario

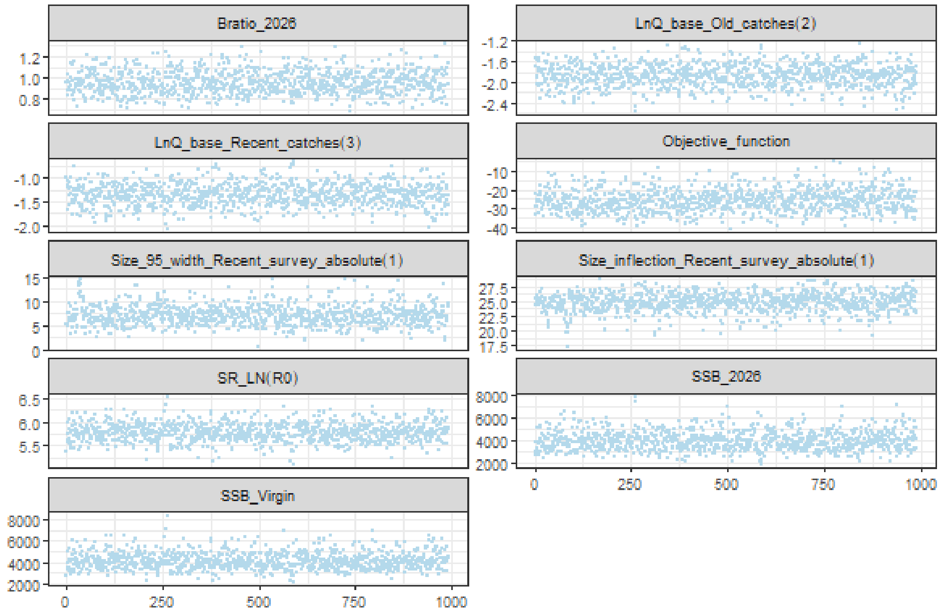

Figure D.54: MCMC trace plots for the Faster growth profile scenario

D.7 Slower growth profile

This section presents results for the Slower growth profile scenario.

Table D.7: Summary of parameter estimates for white 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)	10	9.5	10.4
SSB_Virgin	13752.5	8048.8	21508.6
SSB_2026	12664.9	7020.78	20084.54
Bratio_2026	0.9	0.8	1.1
LnQ_base_Old_catches(2)	-2.1	-2.5	-1.7
LnQ_base_Recent_catches(3)	1.64	1.19	2.2
Size_inflection_Recent_survey_absolute(1)	38.7	35.5	41.8
Size_95%width_Recent_survey_absolute(1)	8.9	7.1	11

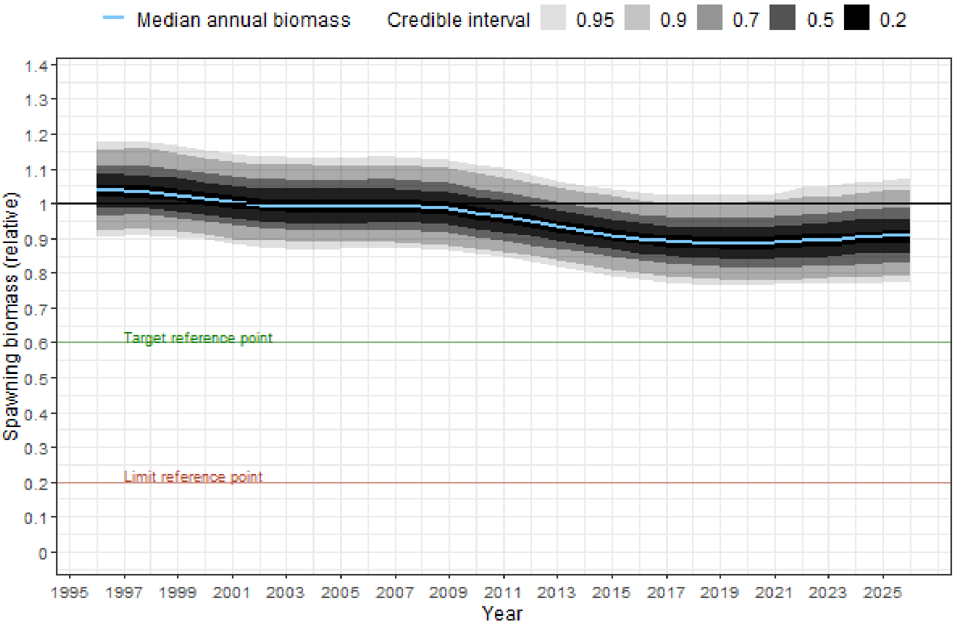

Figure D.55: Relative spawning biomass for the Slower growth profile scenario

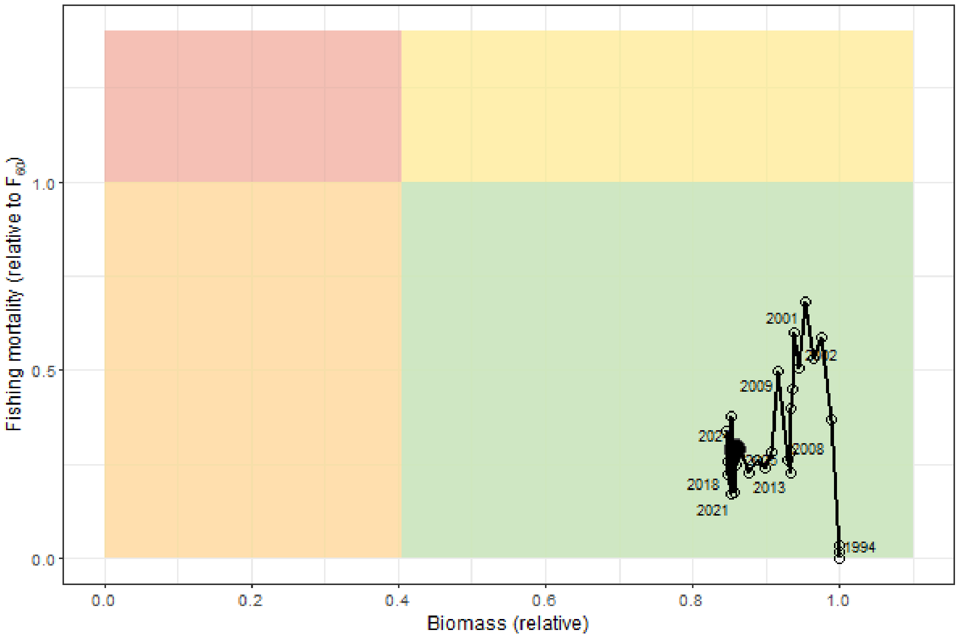

Figure D.56: Phase plot for the Slower growth profile scenario

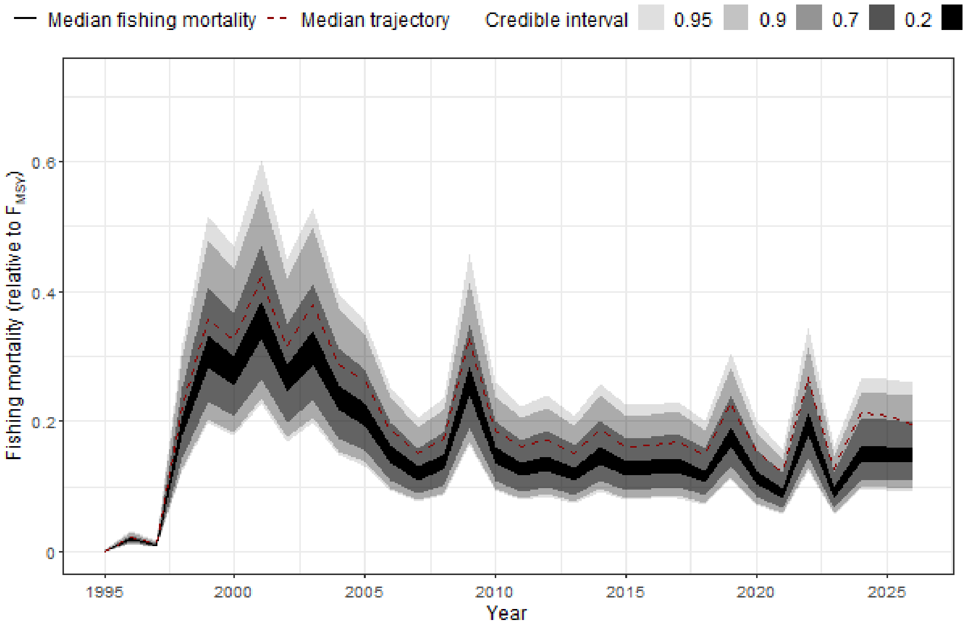

Figure D.57: Fishing mortality for the Slower growth profile scenario

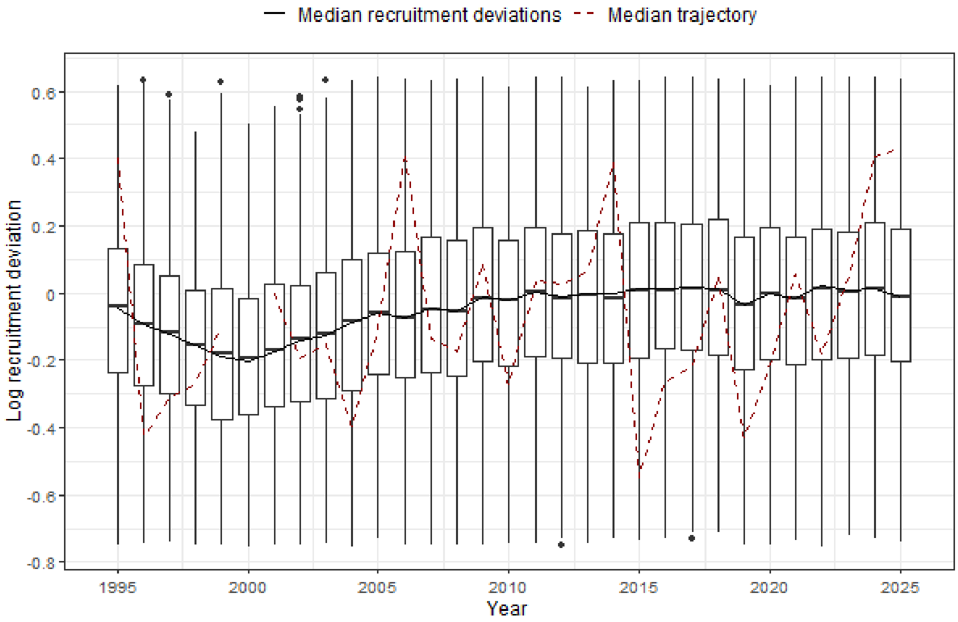

Figure D.58: Recruitment deviations for the Slower growth profile scenario

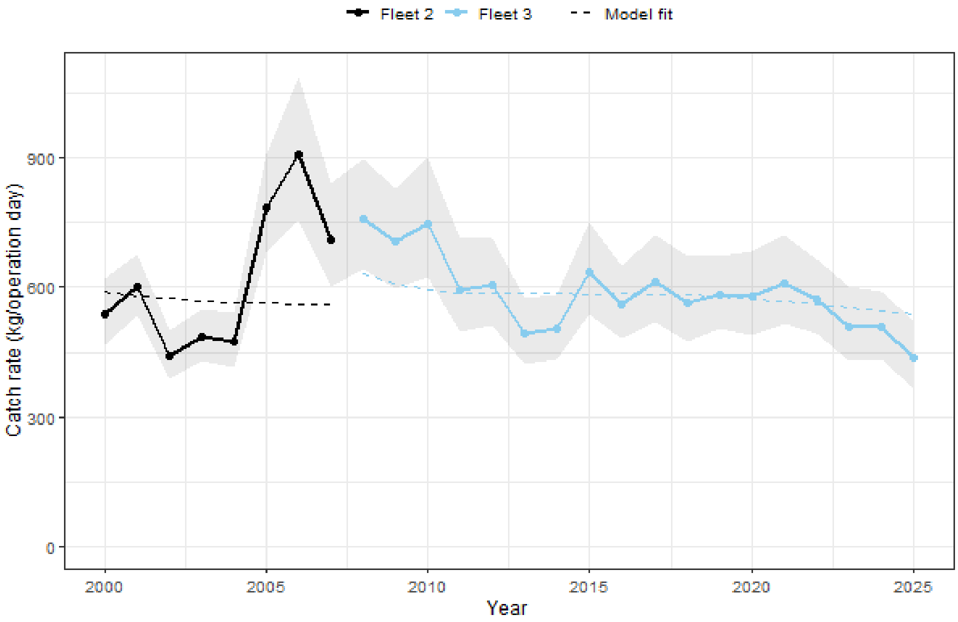

Figure D.59: CPUE fit for the Slower growth profile scenario

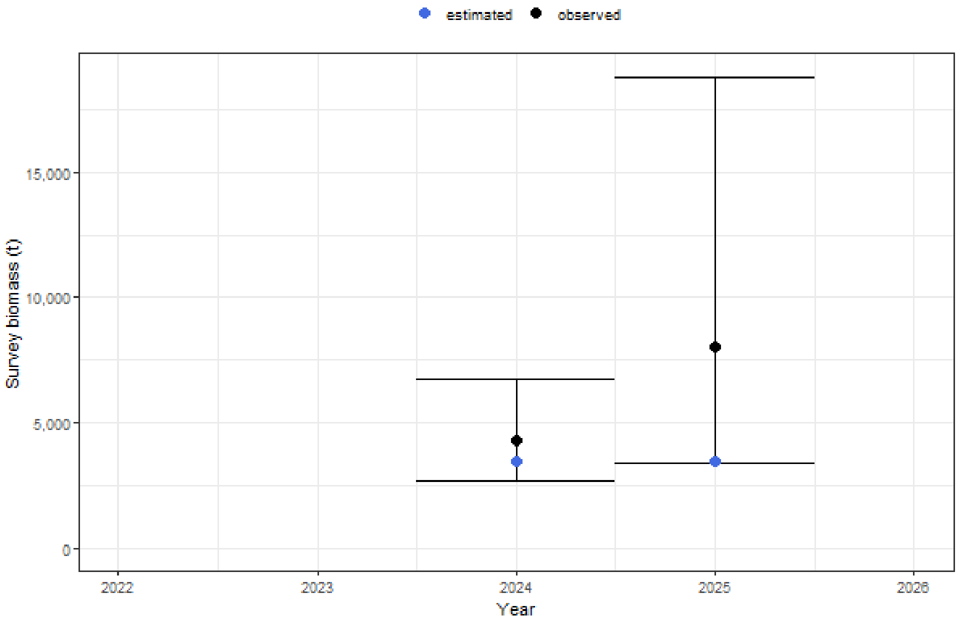

Figure D.60: Surveyed biomass fit for the Slower growth profile scenario

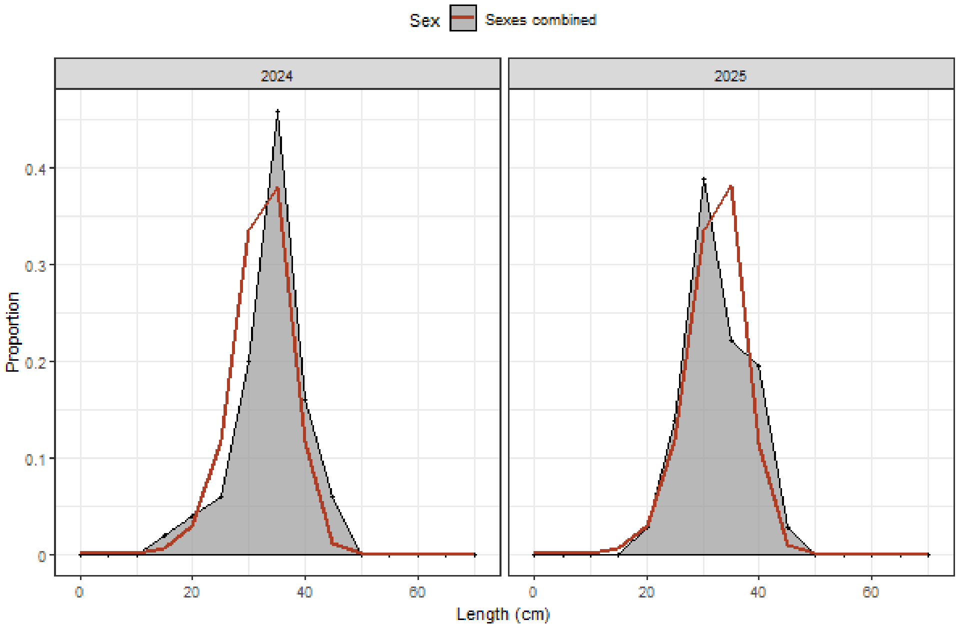

Figure D.61: Length composition fit for the Slower growth profile scenario

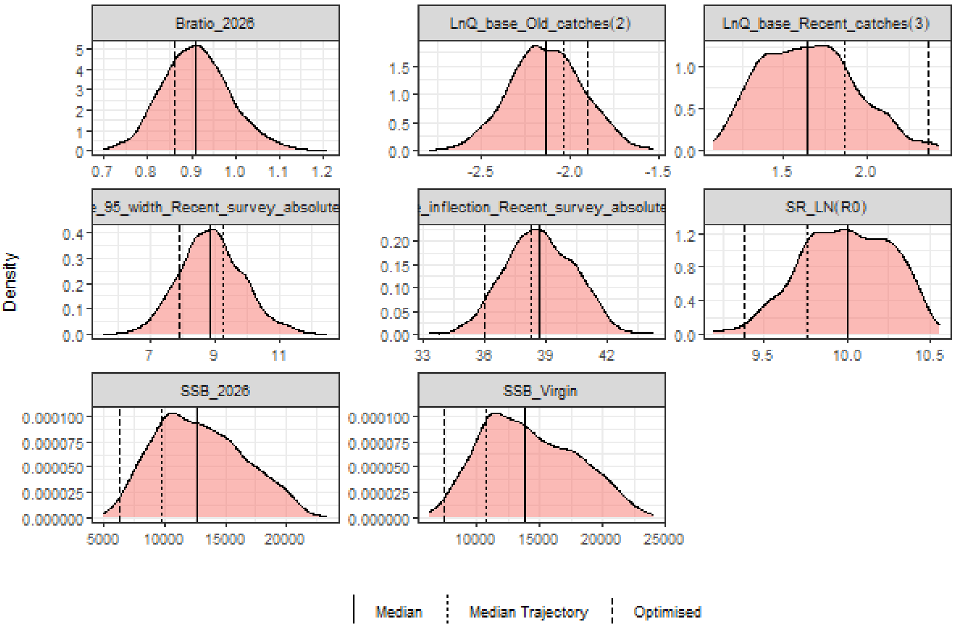

Figure D.62: MCMC parameter posterior densities for the Slower growth profile scenario

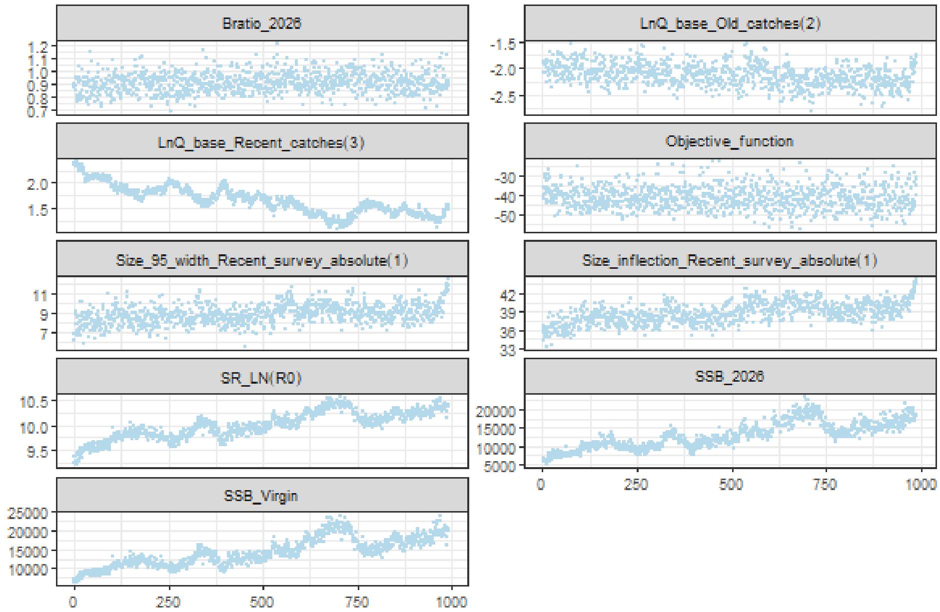

Figure D.63: MCMC trace plots for the Slower growth profile scenario

D.8 SigmaR = 0.4

This section presents results for the SigmaR = 0.4 scenario.

Table D.8: Summary of parameter estimates for white 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	6.6	7.5
SSB_Virgin	4513.7	2912	7028.6
SSB_2026	3748.04	2309.08	5771.26
Bratio_2026	0.8	0.6	1.1
LnQ_base_Old_catches(2)	-2.1	-2.5	-1.6
LnQ_base_Recent_catches(3)	-0.61	-1.12	-0.03
Size_inflection_Recent_survey_absolute(1)	29.7	27	32.1
Size_95%width_Recent_survey_absolute(1)	7	4.7	10.1

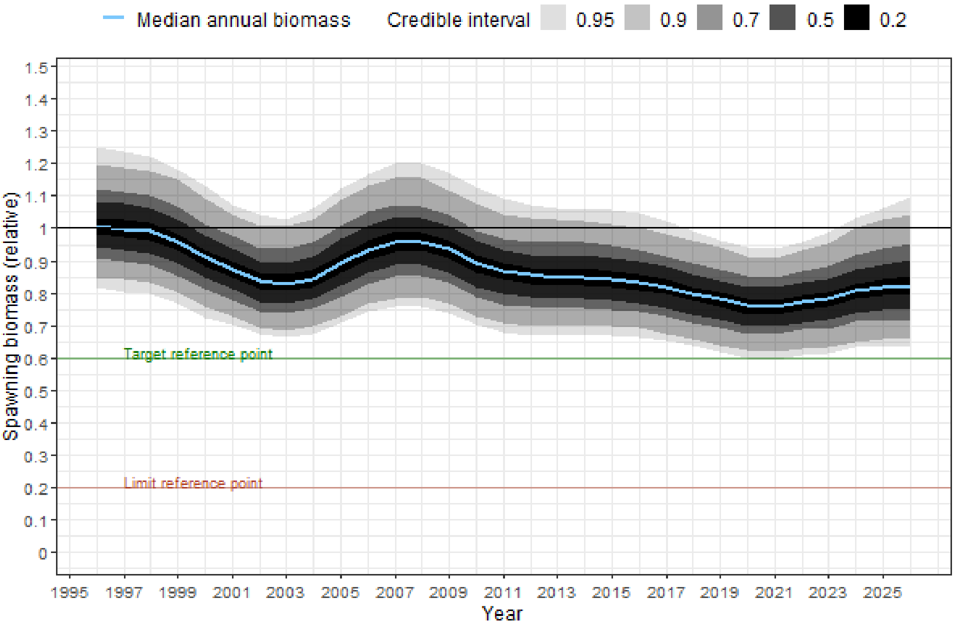

Figure D.64: Relative spawning biomass for the SigmaR = 0.4 scenario

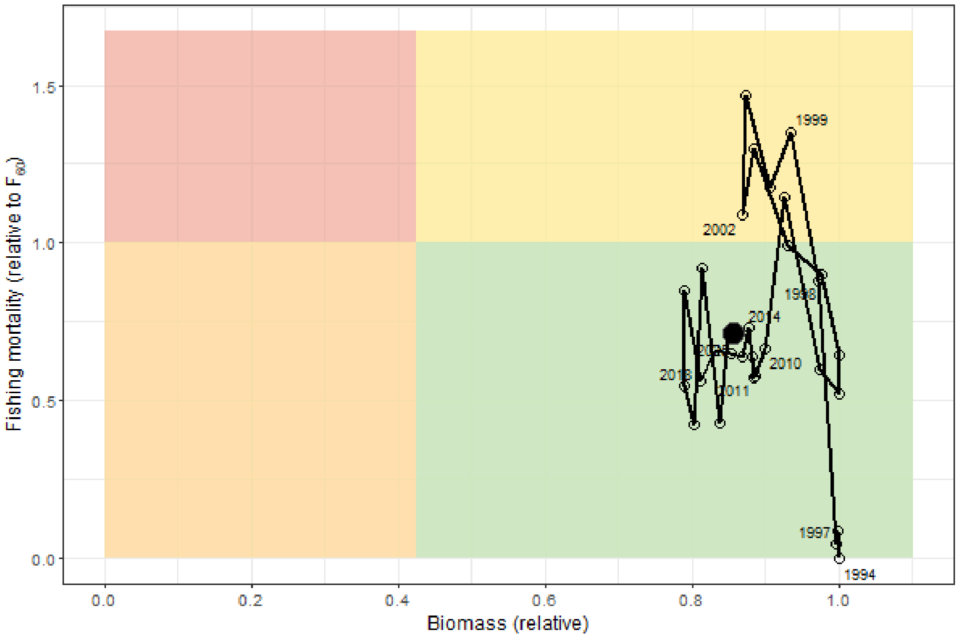

Figure D.65: Phase plot for the SigmaR = 0.4 scenario

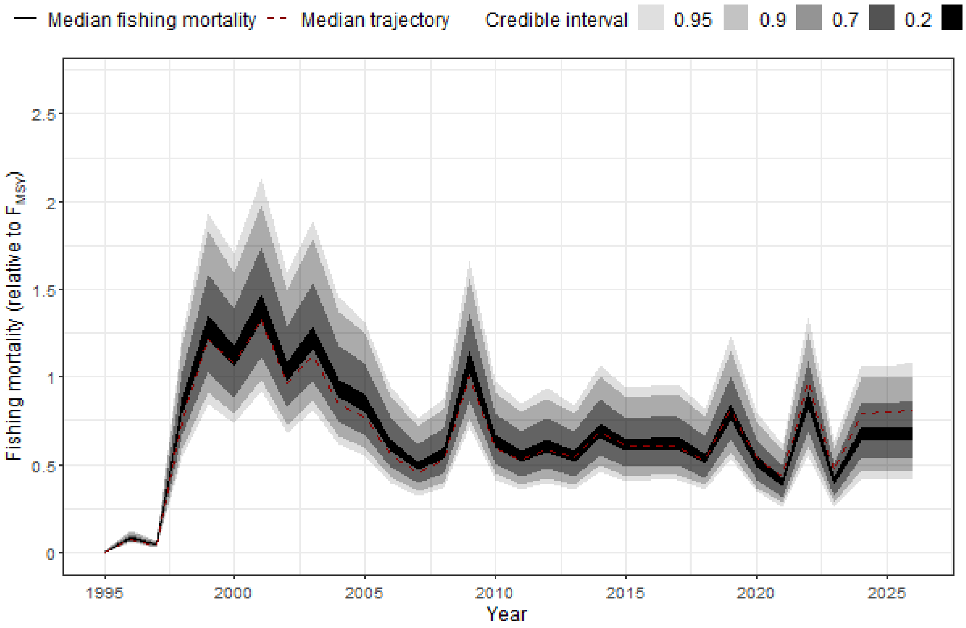

Figure D.66: Fishing mortality for the SigmaR = 0.4 scenario

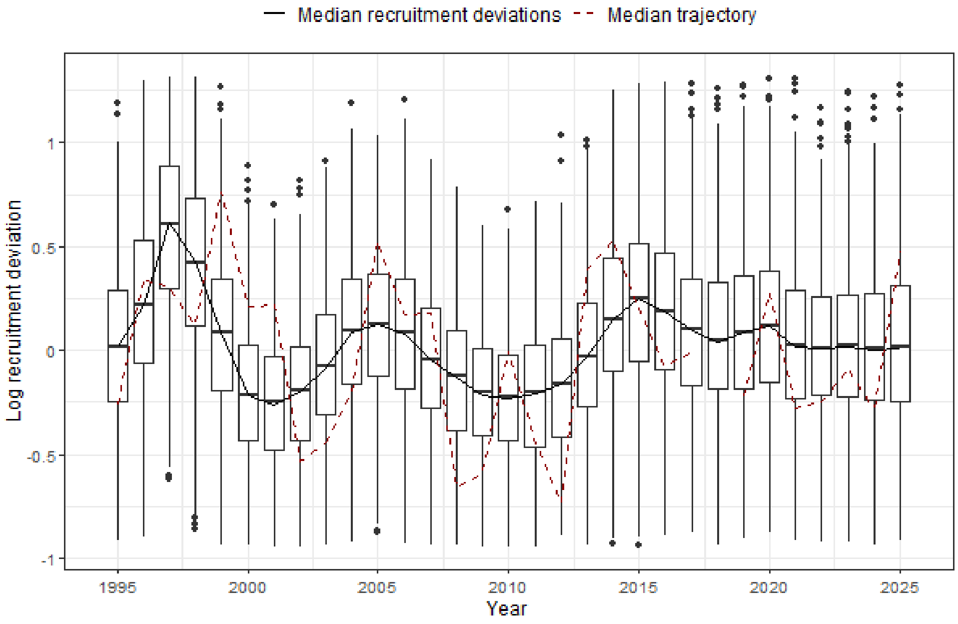

Figure D.67: Recruitment deviations for the SigmaR = 0.4 scenario

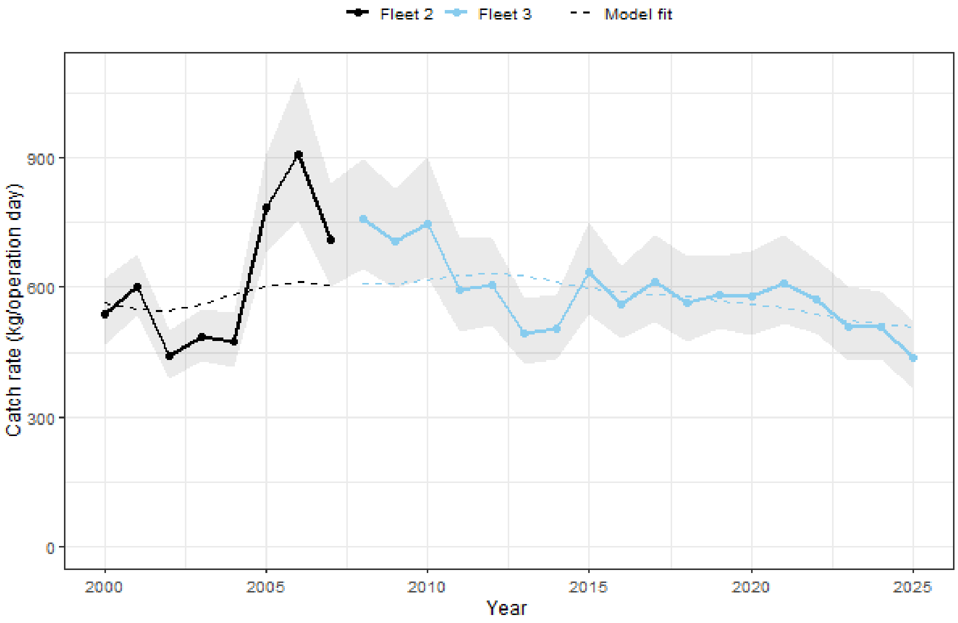

Figure D.68: CPUE fit for the SigmaR = 0.4 scenario

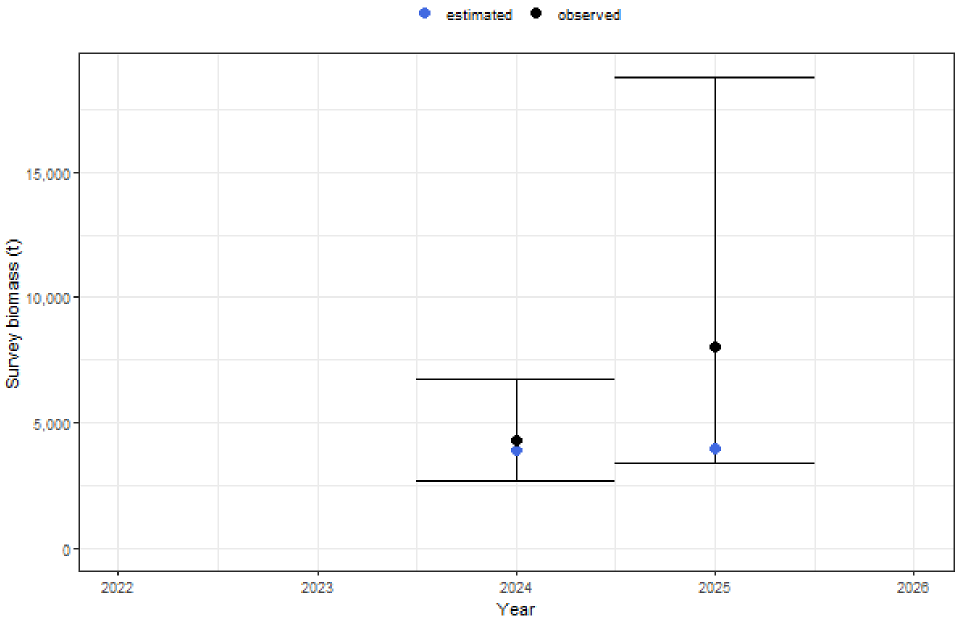

Figure D.69: Surveyed biomass fit for the SigmaR = 0.4 scenario

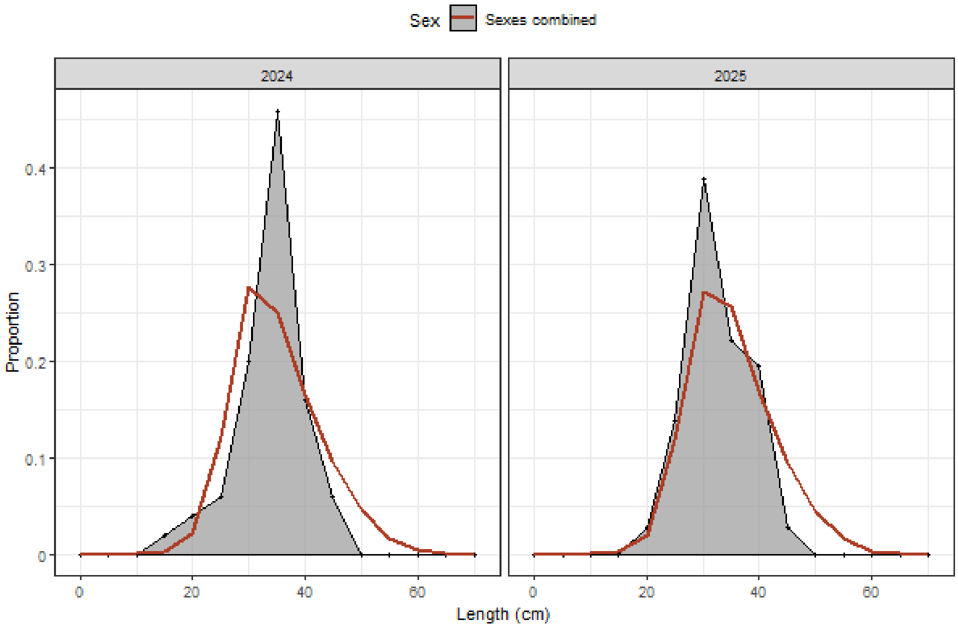

Figure D.70: Length composition fit for the SigmaR = 0.4 scenario

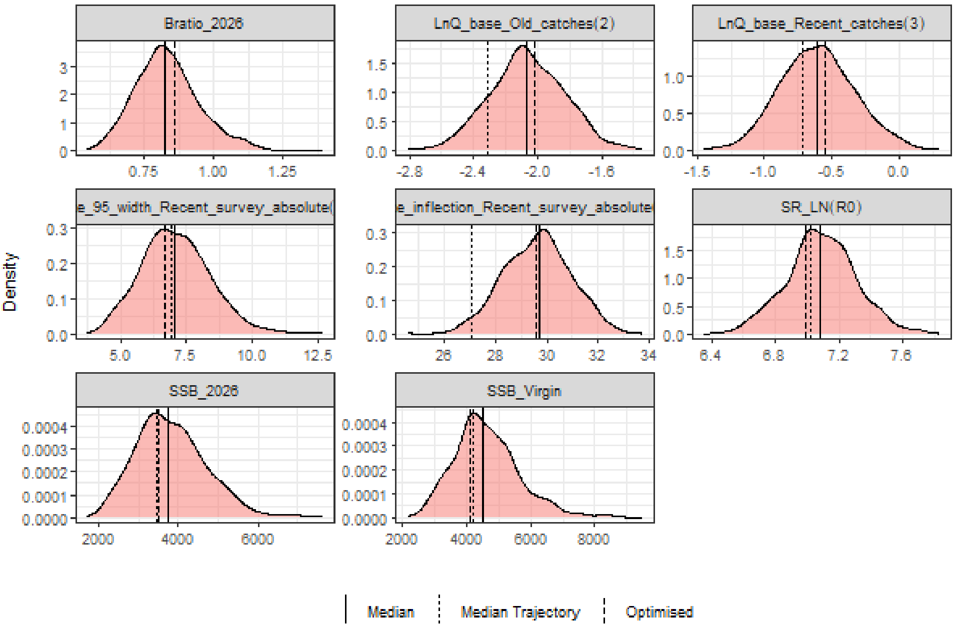

Figure D.71: MCMC parameter posterior densities for the SigmaR = 0.4 scenario

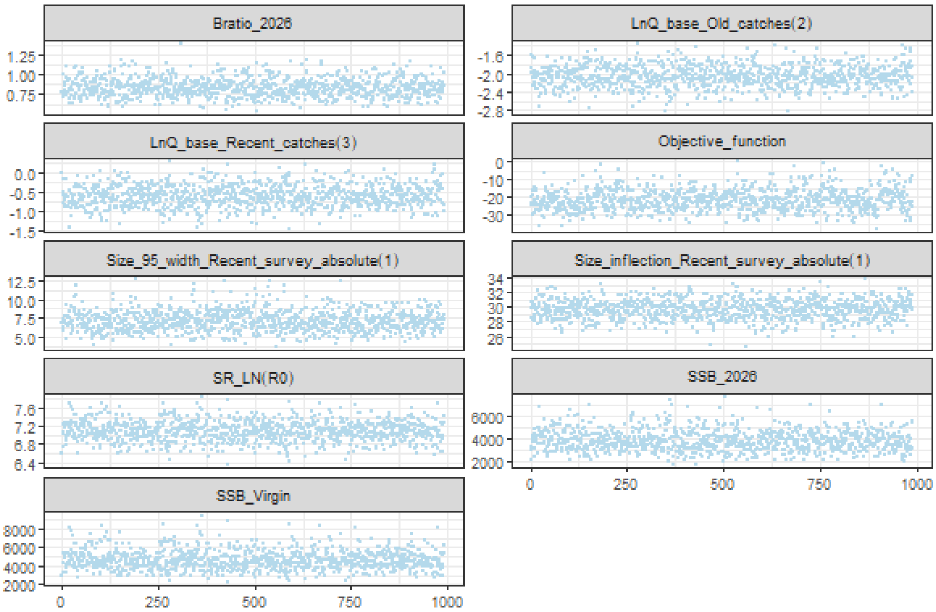

Figure D.72: MCMC trace plots for the SigmaR = 0.4 scenario

D.9 SigmaR = 0.6

This section presents results for the SigmaR = 0.6 scenario.

Table D.9: Summary of parameter estimates for white 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	6.5	7.5
SSB_Virgin	4247.8	2585.9	6908.4
SSB_2026	3780.02	2369.53	6245.19
Bratio_2026	0.9	0.6	1.3
LnQ_base_Old_catches(2)	-1.9	-2.4	-1.4
LnQ_base_Recent_catches(3)	-0.5	-1.05	0.06
Size_inflection_Recent_survey_absolute(1)	30.3	27	33.4
Size_95%width_Recent_survey_absolute(1)	7	4.7	10

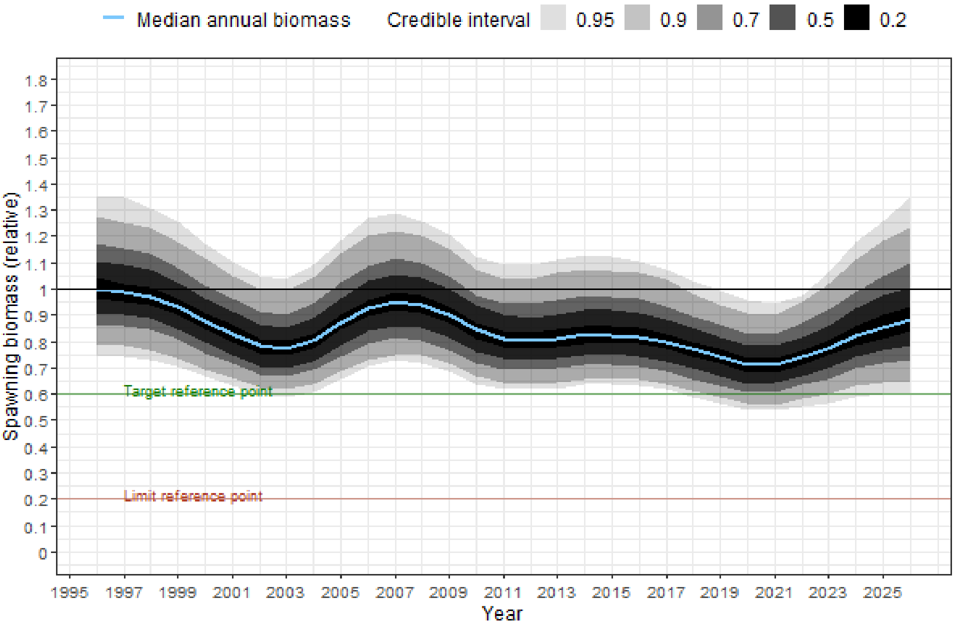

Figure D.73: Relative spawning biomass for the SigmaR = 0.6 scenario

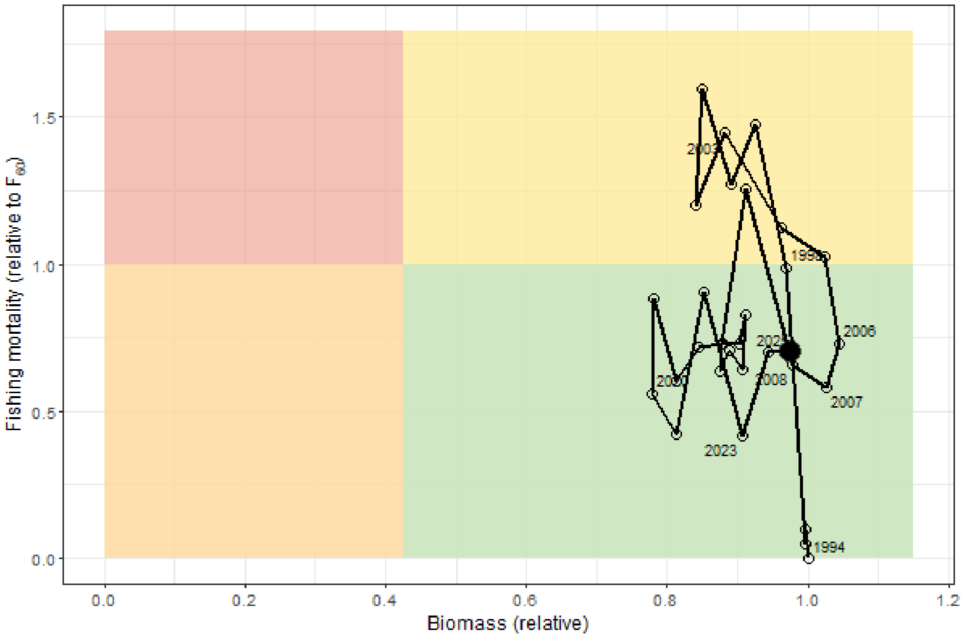

Figure D.74: Phase plot for the SigmaR = 0.6 scenario

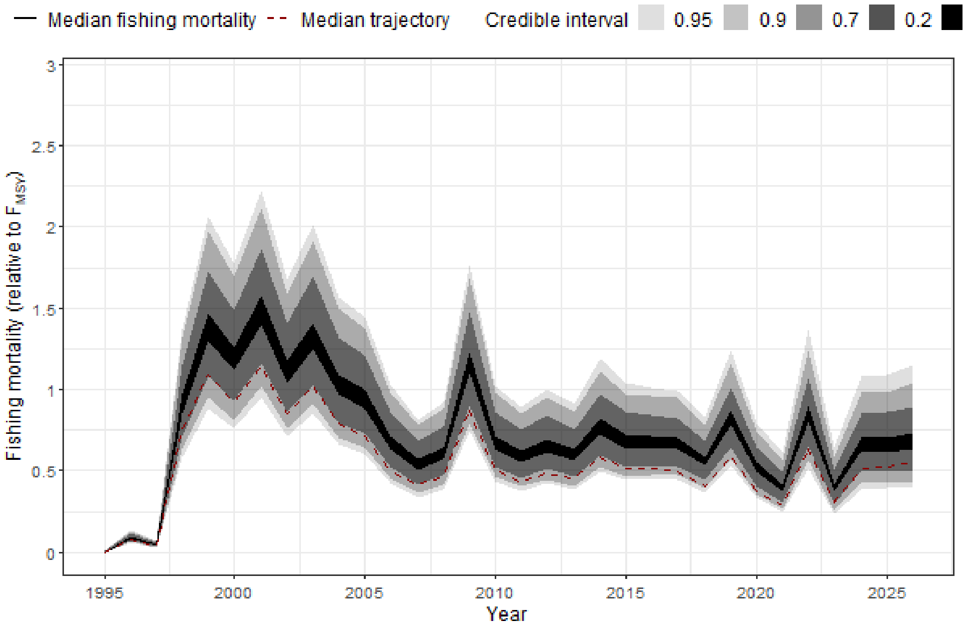

Figure D.75: Fishing mortality for the SigmaR = 0.6 scenario

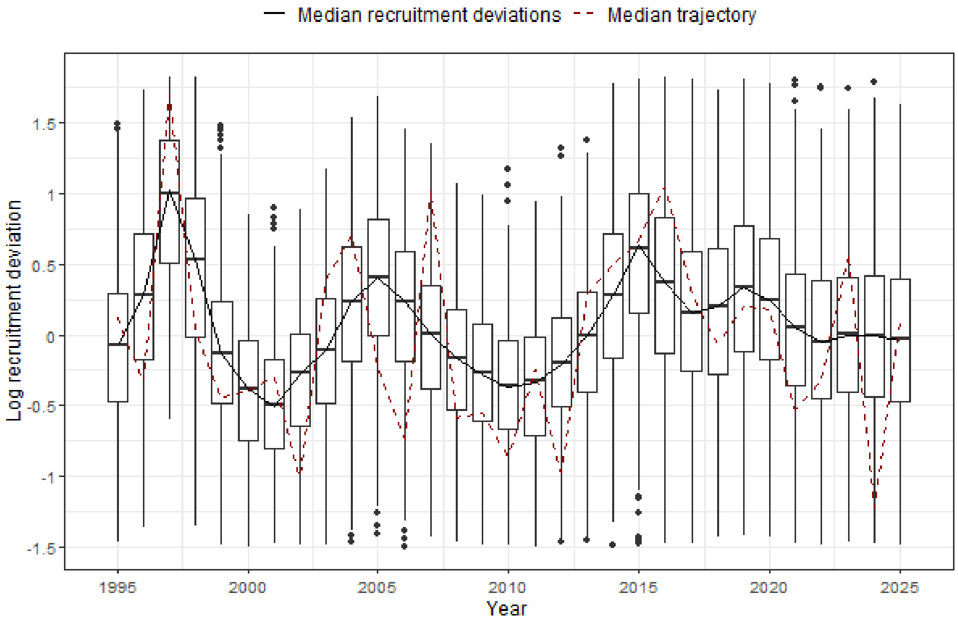

Figure D.76: Recruitment deviations for the SigmaR = 0.6 scenario

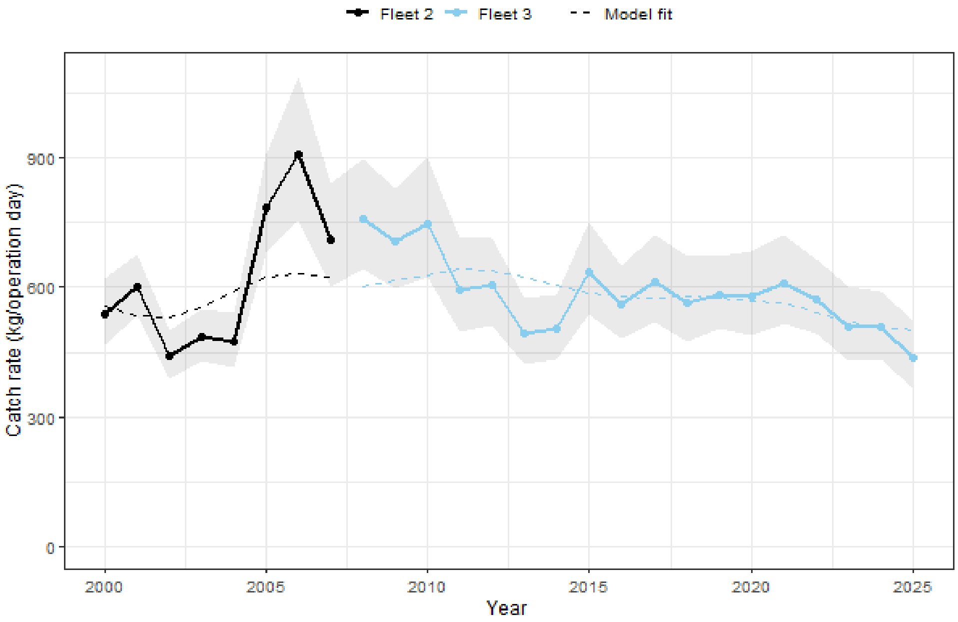

Figure D.77: CPUE fit for the SigmaR = 0.6 scenario

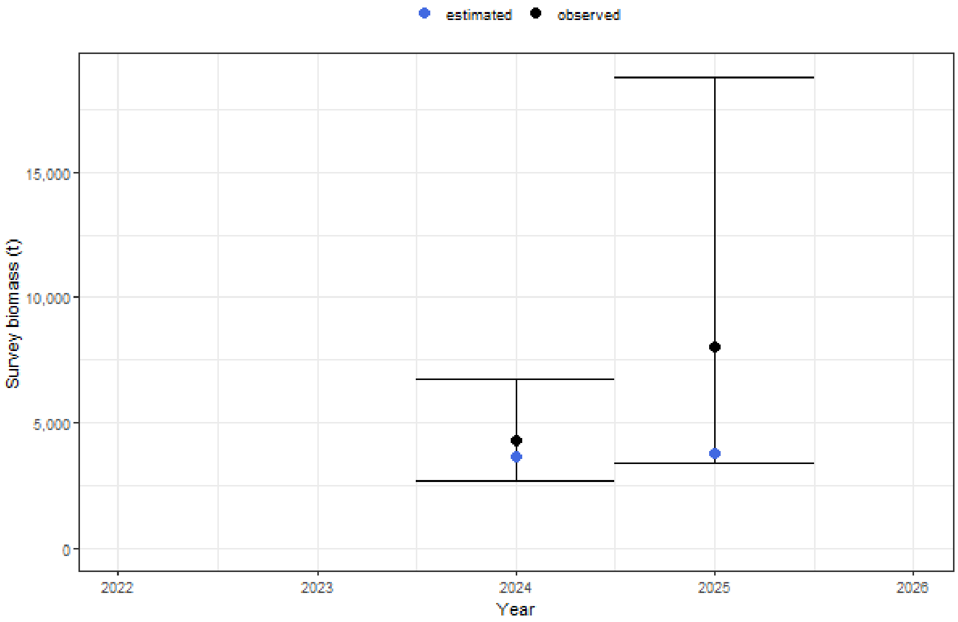

Figure D.78: Surveyed biomass fit for the SigmaR = 0.6 scenario

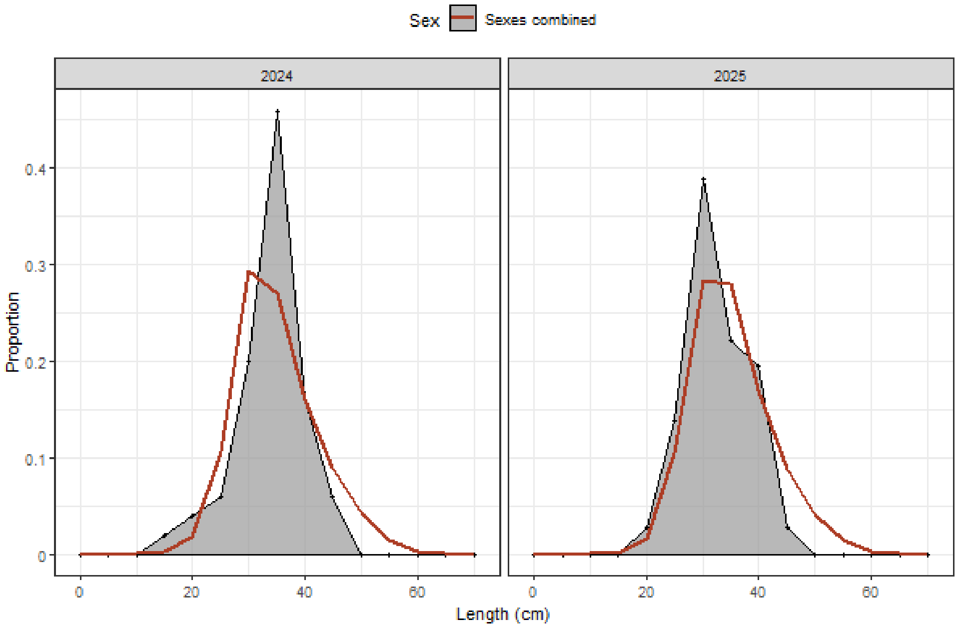

Figure D.79: Length composition fit for the SigmaR = 0.6 scenario

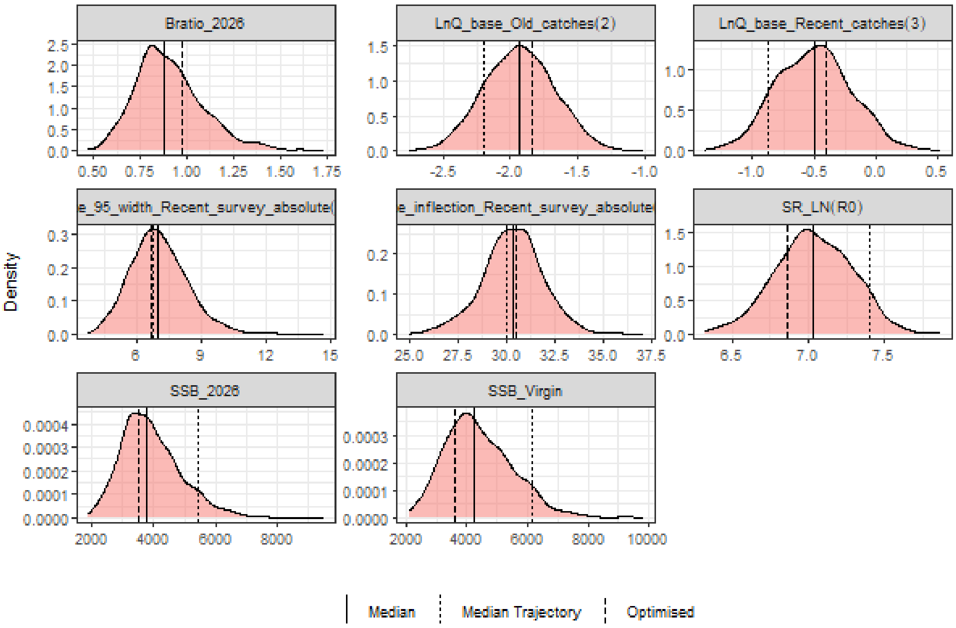

Figure D.80: MCMC parameter posterior densities for the SigmaR = 0.6 scenario

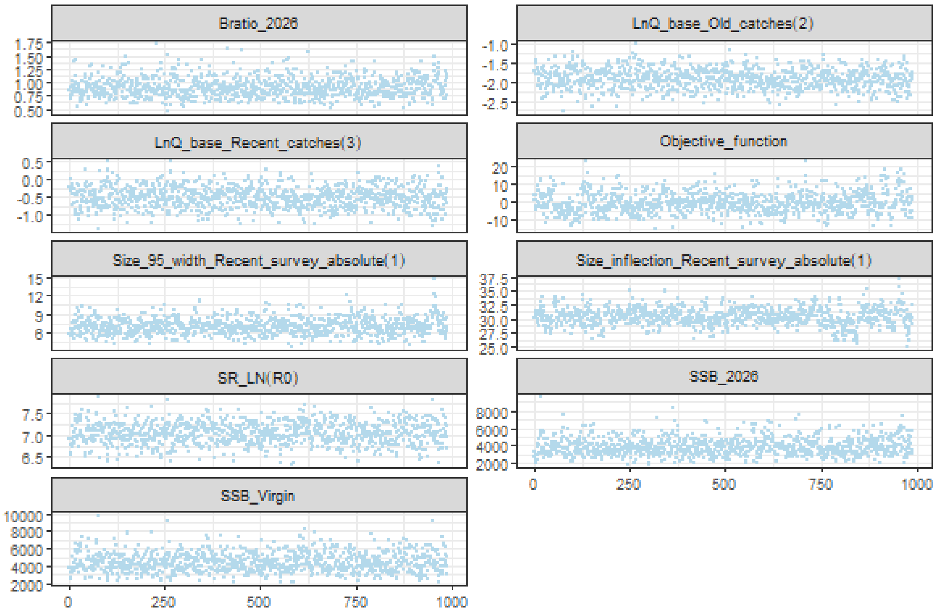

Figure D.81: MCMC trace plots for the SigmaR = 0.6 scenario

D.10 No biomass scaling applied

This section presents results for the No biomass scaling applied scenario.

Table D.10: Summary of parameter estimates for white teatfish the No biomass scaling 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)	6.4	6.1	6.8
SSB_Virgin	2182.2	1618.4	3297.8
SSB_2026	1381.91	951.94	2276.78
Bratio_2026	0.6	0.5	0.8
LnQ_base_Old_catches(2)	-1.2	-1.6	-0.8
LnQ_base_Recent_catches(3)	0.56	-0.08	1.08
Size_inflection_Recent_survey_absolute(1)	30.1	27.7	32.2
Size_95%width_Recent_survey_absolute(1)	7	4.9	9.8

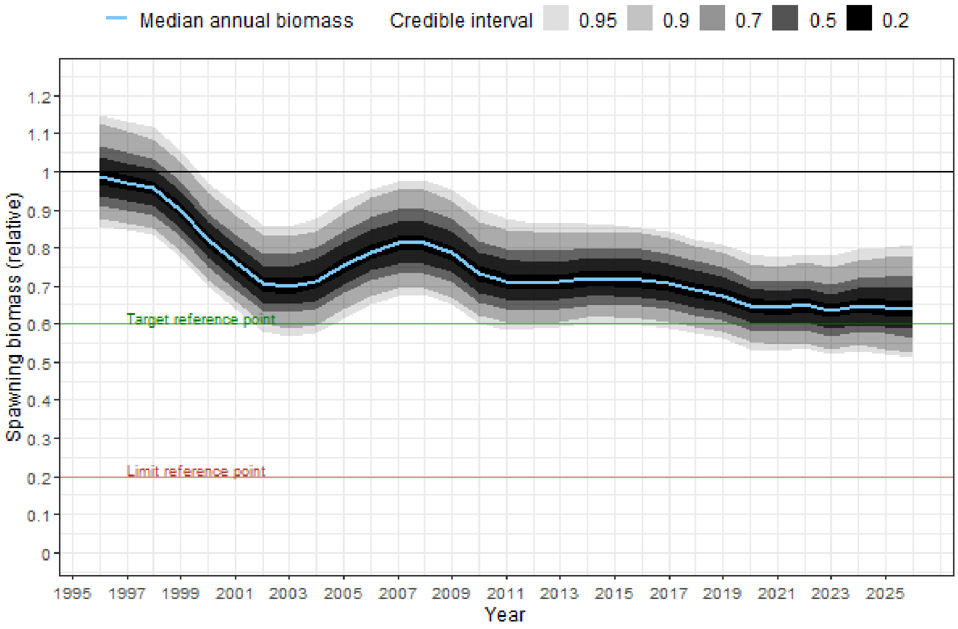

Figure D.82: Relative spawning biomass for the No biomass scaling applied scenario

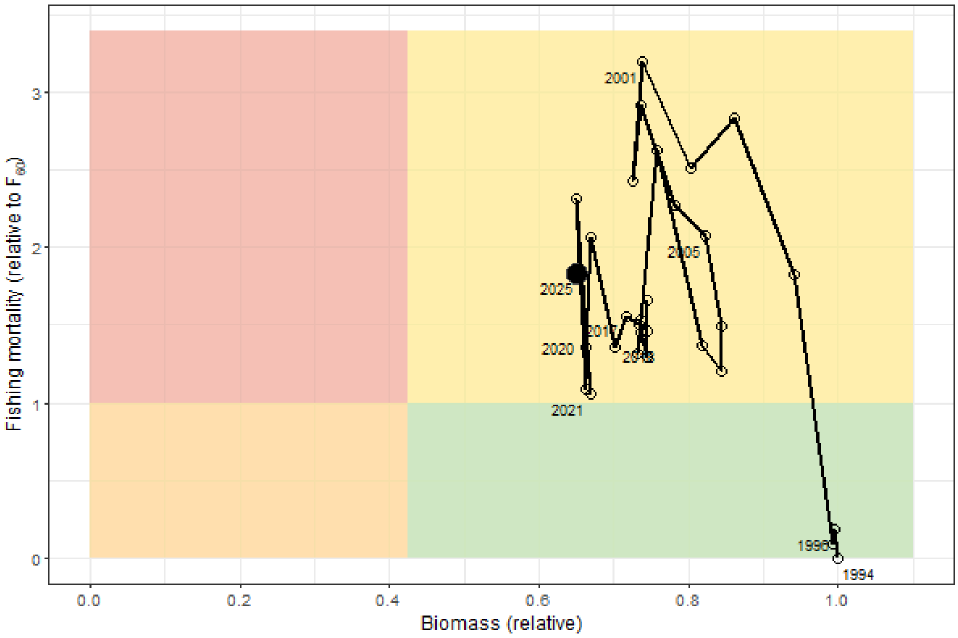

Figure D.83: Phase plot for the No biomass scaling applied scenario

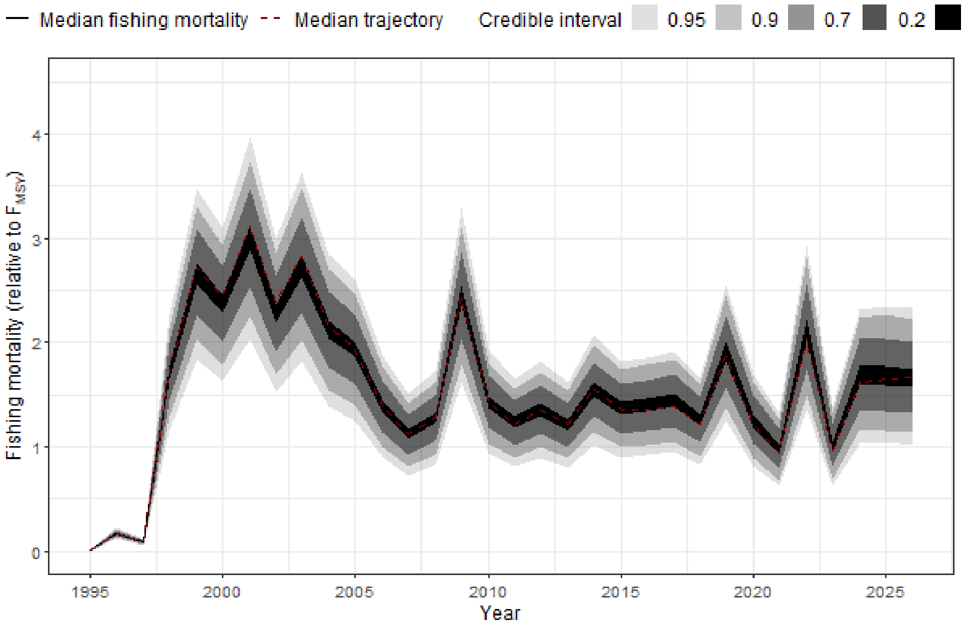

Figure D.84: Fishing mortality for the No biomass scaling applied scenario

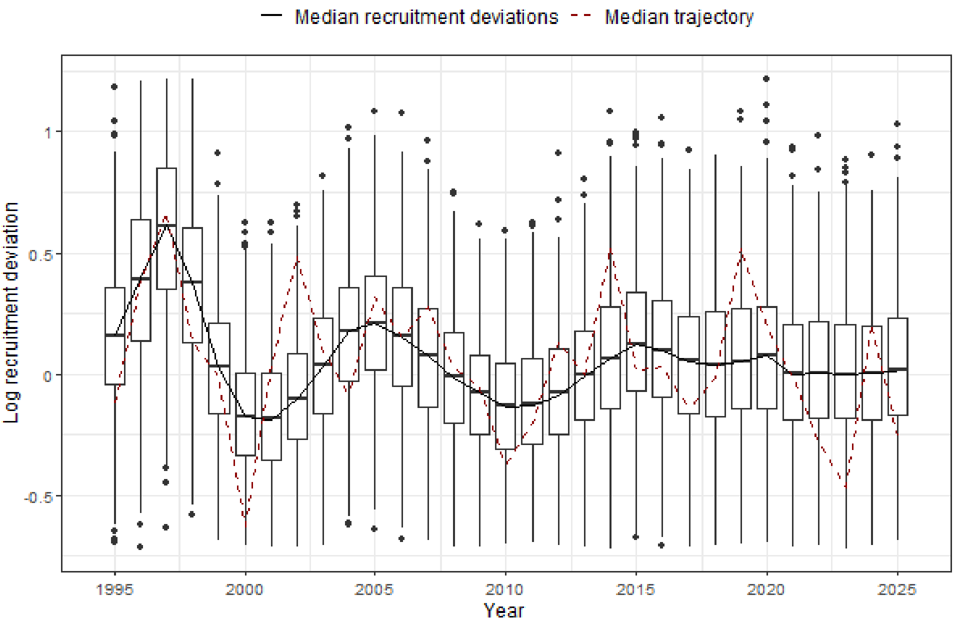

Figure D.85: Recruitment deviations for the No biomass scaling applied scenario

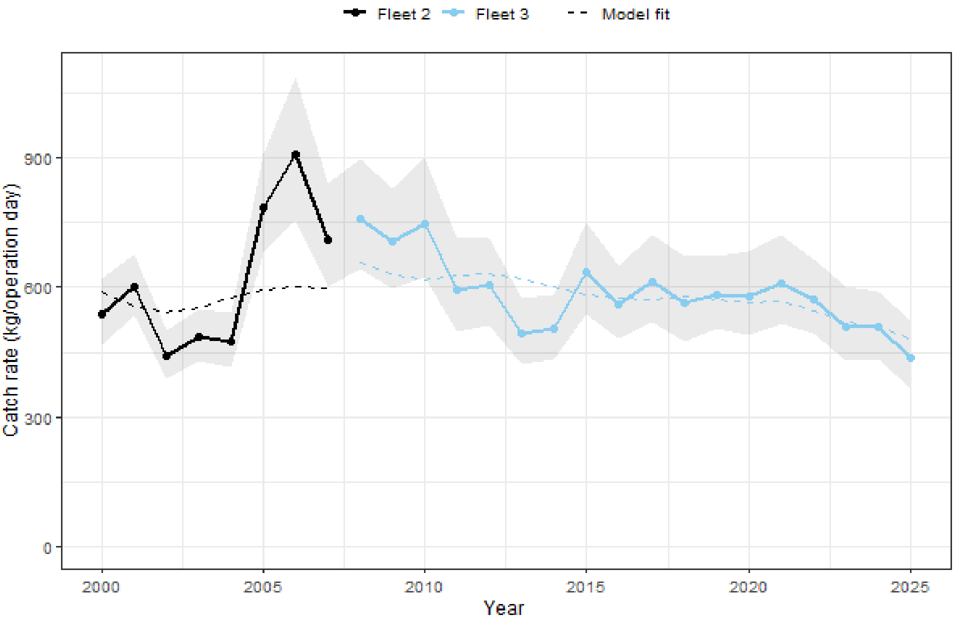

Figure D.86: CPUE fit for the No biomass scaling applied scenario

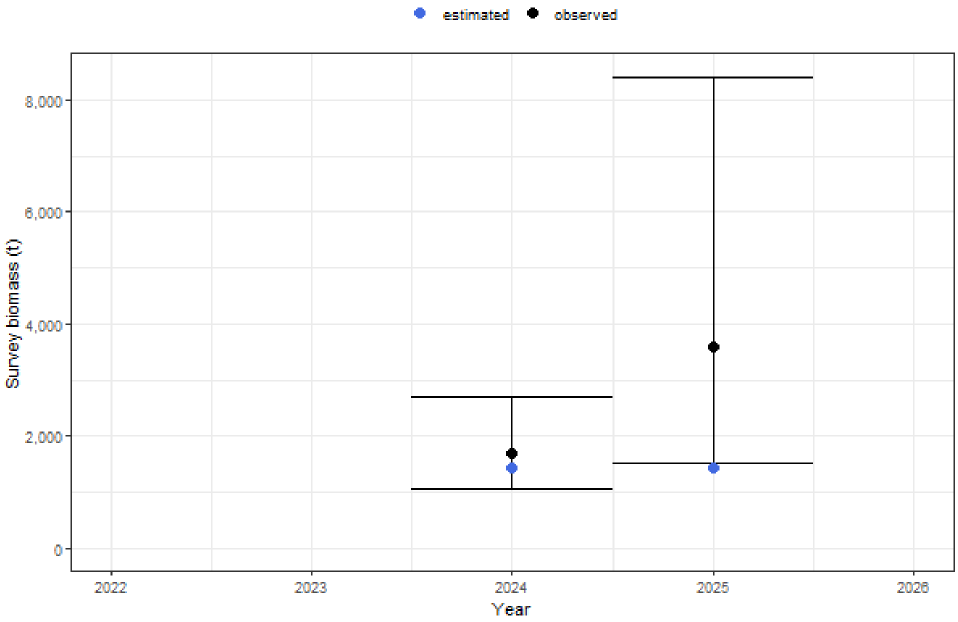

Figure D.87: Surveyed biomass fit for the No biomass scaling applied scenario

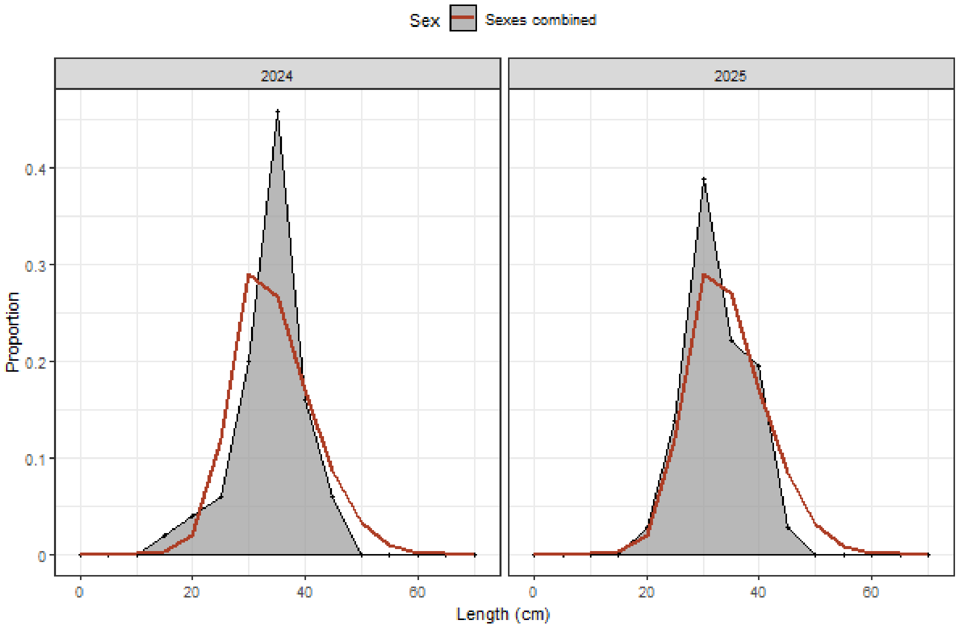

Figure D.88: Length composition fit for the No biomass scaling applied scenario

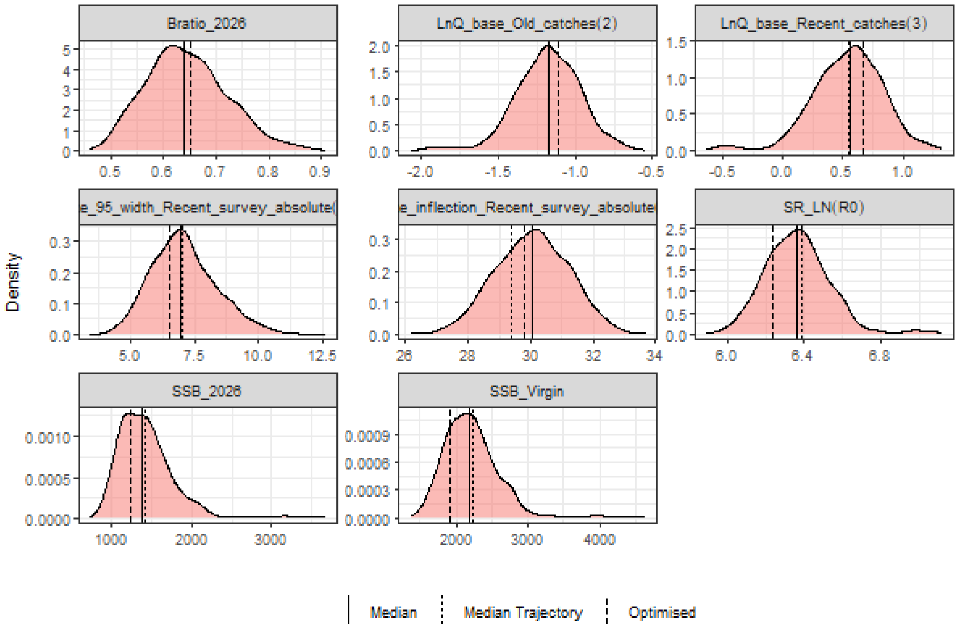

Figure D.89: MCMC parameter posterior densities for the No biomass scaling applied scenario

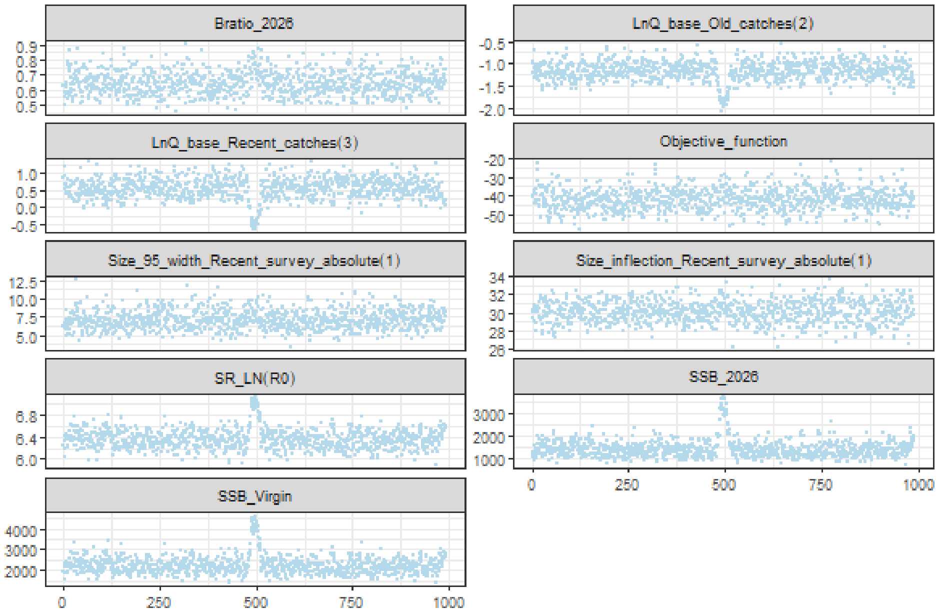

Figure D.90: MCMC trace plots for the No biomass scaling applied scenario