Fisheries New Zealand
Tini a Tangaroa

# The 2023 stock assessment of ling (*Genypterus blacodes*) off the west coast South Island (LIN 7WC)

New Zealand Fisheries Assessment Report 2024/02

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## Plain language summary

Ling (*Genypterus blacodes*) is an important commercial fish species in New Zealand middle depths waters and is caught mainly by bottom trawls, bottom longlines, and increasingly by potting.

This report summarises the 2023 stock assessment of one of the five main ling stocks managed under the Quota Management System: the ling stock off the west coast of the South Island (LIN 7WC).

A stock assessment model was carried out, based on commercial catches, information from the west coast South Island *Tangaroa* trawl survey biomass series, the commercial longline standardised catch per unit effort (CPUE) from 1991, and the commercial trawl standardised CPUE from 1997.

The initial spawning stock biomass ($B_0$) for both the base case model was estimated to be about 62 200 t and stock status in 2023 was estimated as 51% $B_0$. An investigative model run provided a slightly lower initial biomass and stock status in 2023 of 52%.

Five-year projections were done using the base case model, resampling recruitment from the entire range of the model, and assuming future annual catch equal to the average catch in 2020–2022. Projected stock status in 2028 was expected to be 52% of $B_0$.

The probability that the stock status in 2028 will be above 40% $B_0$ was 97%, and that of being less than 20%, was zero. This assessment was used to inform Fisheries New Zealand’s management of this ling stock.

# EXECUTIVE SUMMARY

**Mormede, S.[1]; Dunn, A.[2]; Webber, D.N.[3] (2024). The 2023 stock assessment of ling (*Genypterus blacodes*) off the west coast of the South Island (LIN 7WC) .**

***New Zealand Fisheries Assessment Report 2024/02.* 23 p.**

Ling (*Genypterus blacodes*) are an important species commercially caught mainly by bottom trawls and bottom longlines, and, increasingly, by pots. They are found throughout the middle depths of New Zealand waters. Ling are managed as eight administrative Quota Management Areas with five of those reporting about 95% of the landings. There are at least five major biological stocks: the Chatham Rise, the Sub-Antarctic (including the Stewart-Snares shelf and Puysegur Bank), the Bounty Plateau, the west coast of the South Island, and Cook Strait. This report summarises the 2023 stock assessment of the ling stock off the west coast of the South Island (LIN 7WC) using data up to the 2022 calendar year.

The indices of abundance provided to the model were the west coast South Island RV *Tangaroa* trawl survey biomass series, the daily longline standardised catch per unit effort (CPUE) from 1991, and the commercial trawl standardised CPUE from 1997. Sensitivities were carried out and included evaluating the effect of alternative values of natural mortality and steepness, and the exclusion of the trawl CPUE series.

The initial spawning stock biomass ($B_0$) for both the base case and the CPUE sensitivity models were higher than those reported by the previous assessment in 2020, driven partly by the addition of Statistical Area 032 to the assessment, a modification in the definition of the age plus group category, and the inclusion of the CPUE indices in the model. For the base case model, $B_0$ was estimated to be about 62 200 t and stock status in 2023 was estimated as 51% $B_0$. The sensitivity run excluding the commercial trawl CPUE series resulted in a lower estimate of $B_0$ of about 59 700 t, slightly different estimates of year class strengths, and a stock status in 2023 of 52% $B_0$.

In the lower steepness sensitivity model, initial biomass was estimated at 66 700 t and stock status in 2023 was estimated at 52% $B_0$. In the low $M$ sensitivity model, stock status in 2023 was estimated at 36% $B_0$ and the probability of the stock status in 2023 being above 40% $B_0$ was estimated to be about 2%. Sensitivity model runs with alternative catch histories (assuming a 5% increase in total catch for years before 1986 and 2% increase in catch thereafter or assuming misreporting in the 1990s) had little effect on estimates of initial spawning stock biomass or stock status from the base case model.

Five-year projections were done using the base case model, resampling year class strengths using the entire range of the model, and assuming future annual catch equal to the average catch in 2020–2022. Projected stock status in 2028 was expected to be 52% of $B_0$. The probability that the stock status in 2028 will be above 40% $B_0$ was 97%, and that of being less than 20% was zero.

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# 1. INTRODUCTION

Ling (*Genypterus blacodes*, LIN) are an important commercially caught species. Adult ling are found throughout the middle depths of the New Zealand Exclusive Economic Zone (EEZ) typically in depths of 100–800 m (Hurst et al. 2000). Ling are caught mainly by deepwater trawlers, often as bycatch in hoki (*Macruronus novaezelandiae*) target fisheries, and by target demersal longliners. Small quantities of ling are also caught by inshore trawls, setnets, and, increasingly, by pots (Mormede et al. 2022).

Ling are managed as eight administrative Quota Management Areas, with five (LIN 3, 4, 5, 6, and 7) reporting about 95% of landings. There are at least five major biological stocks of ling in New Zealand waters (Horn 2005): the Chatham Rise, the Sub-Antarctic (including the Stewart-Snares shelf and Puysegur Bank), the Bounty Plateau, the west coast of the South Island (WCSI), and Cook Strait. Stock assessments have been carried out for assumed biological stocks for ling on the Chatham Rise (LIN 3&4), Sub-Antarctic (including the Campbell Plateau and Stewart-Snares shelf comprising LIN 5 and the part of LIN 6 west of 176º E, labelled LIN 5&6), Bounty Plateau (the part of LIN 6 east of 176º E, labelled LIN 6B), west coast South Island (LIN 7 west of Cape Farewell, labelled LIN 7WC), and Cook Strait (the part of LIN 2 and LIN 7 between latitudes 41º and 42º S and longitudes 174º and 175.4º E, labelled LIN 7CK). An administrative Fishstock (with no recorded landings) is also defined for the Kermadec FMA (LIN 10) (Fisheries New Zealand 2020).

Starting in 2023, the ling stock off the west coast of the South Island (LIN 7WC) was redefined to include Statistical Area (032, which was previously considered part of the Subantarctic stock (LIN 5&6). This decision was based on the continuity of catches of ling in LIN 7WC to Statistical Area 032. The catch for the ling stock off the west coast of the South Island (LIN 7WC) now comprises part of the catch in LIN 5 (Statistical Area 032) and excludes part of LIN 7 that is part of the Cook Strait stock (LIN 7CK).

The last assessment for LIN 7WC was carried out by Kienzle (2021) and the most recent characterisation of ling in LIN 7WC was for the 2022–23 fishing year (Mormede et al. 2023). Kienzle (2021) reported that "The stock assessment estimated an unfished biomass ($B_0$) at 47 000 t (43 700–51 900 t) and the spawning stock biomass (*SSB*) to be above the target reference point (40% $B_0$) in 2020, at 46% (34–59) of $B_0$". The stock size of LIN 7WC was predicted to continue to decline over the next 5 years, to the target level with a reduction in catch to 85% or 90% of the 2020 total allowable commercial catch. Reported catches have increased slightly since 2019.

Because of data limitations and the variability of age compositions between years, the assessment of the ling stock off the west coast of the South Island was historically implemented as single-sex with a mature partition, single area, integrated statistical catch-at-age model (Dunn et al. 2013, Kienzle 2021). The Bayesian stock assessment software CASAL (Bull et al. 2012) had been used for the previous assessments since 2002–03 (Horn & Dunn 2003). The fisheries have been defined as trawl and longline using observations from commercial catch-at-age, CPUE indices (as a sensitivity), and resource survey biomass and age compositions.

This report fulfils Specific Objective 2 of Project LIN2022-01. The overall Objective was "To carry out stock assessments of ling (*Genypterus blacodes*) from the west coast of the South Island including estimating biomass and sustainable yields" and Specific Objective 2 was "To complete a stock assessment for LIN 7 including estimates of current biomass and yields, the status of the stock in relation to management reference points, and future projections of stock status as required to support management".

# 2. METHODS

## 2.1 Model structure

An age-based statistical catch-at-age stock assessment was carried out for LIN 7WC (west coast of the South Island) using the stock assessment program Casal2 v23.04 (2023-04-12) (Casal2 Development Team 2023). The stock assessment model assumed a Beverton-Holt stock-recruit relationship with ages 1–28, with the oldest age a plus group. The model structure was incrementally changed from the previous assessment model, that used CASAL (Bull et al. 2012) and was a single-sex with a mature partition model, to the current model that was two-sex without a mature partition (see below). Age composition observations were provided as unsexed observations to the model and sexed observations were tested in a sensitivity run (see below).

To align more closely with the spawning season (September to December), to the seasons of the target fisheries (particularly in the early years) and allow a single model year for all ling stocks, the model year was set as the calendar year (January to December) rather than the fishing year (October to September). In this document, ‘year’ always refers to the model year unless specifically otherwise stated. The model time steps were simplified to fit to the new model year, with a single time step from January to December. The model’s annual cycle is described in Table 1.

**Table 1: LIN 7WC annual cycle of the stock model, showing the processes taking place at each time step, their sequence within each time step, and the available observations. Fishing and natural mortality that occur within a time step occur after all other processes, with half of the natural mortality for that time step occurring before and half after the fishing mortality.**

| | | | | | Observations | |
|---|---|---|---|---|---|---|
| Step | Period | Processes | *M** | Age† | Description | %*Z*‡ |
| 1 | Jan-Dec | Recruitment | 1.0 | 0.0 | | |
| | | Spawning | | | | |
| | | fishery (longline) | | | Longline catch-at-age | 0.5 |
| | | | | | Longline CPUE | |
| | | fishery (trawl) | | | Trawl catch-at-age | 0.5 |
| | | | | | Trawl CPUE | |
| | | | | | *Tangaroa* Trawl survey biomass and catch-at-age | |
| 2 | End of Dec | Increment ages | 0.0 | 1.0 | | |

* *M* is the proportion of natural mortality that was assumed to have occurred in that time step.
† Age is the age fraction, used for determining length-at-age, that was assumed to occur in that time step.
‡ %*Z* is the percentage of the total mortality in the step that was assumed to have taken place at the time each observation was made.

## 2.2 Inputs

The updated catch histories, daily commercial longline fishery CPUE, commercial trawl fishery CPUE, age compositions, and estimates of biological parameters are described by Mormede et al. (2023). Both CPUE series were included in the base case model as they represented spatially different fisheries with potentially different selectivities, and the west coast South Island *Tangaroa* trawl survey only covered a small proportion of the area fished by longliners. Because the trajectory of those two CPUE series differed in the 1990s, a sensitivity model run was carried out excluding the trawl CPUE, as it was less likely to represent ling biomass in the 1990s.

The west coast of the South Island middle-depth trawl survey biomass and age compositions were developed by O’Driscoll & Ballara (2018, 2019) and Devine et al. (2022) and were also summarised in the plenary report (Fisheries New Zealand 2023) in the ling chapter. The trawl survey age composition was provided to the model as ages 1 to 28 (with 28 as a plus group). The trawl and longline age compositions were also provided as ages 1 to 28 (with 28 as a plus group). These were increased from observations at ages 4–21 used in the previous analysis (Kienzle 2021) to reduce the effect of the plus group on the model outcomes. All age compositions were provided unsexed in the final models due to the high levels of variability in the sex ratio between ages and years. The inshore trawl survey off the west coast South Island was not used as estimates of ling biomass and age compositions were highly variable between years and were not likely to be an indicator of ling biomass (MacGibbon et al. 2022). A summary of all observations used in the assessment models and the associated time series is given in Table 2. The input parameters used are summarised in Table 3 and Table 4. Recruitment variability was reduced from 0.7 to 0.6 and ageing error from 0.1 to 0.05 to be consistent with the values used other ling stock assessments (Fisheries New Zealand 2023). The model outcomes were not sensitive to these changes.

A lognormal distribution was assumed for all relative biomass observations (i.e., the trawl survey and CPUE indices). The coefficients of variation (CVs) available for the observations of relative abundance allowed for sampling error only. Process error, assumed to arise from differences between model simplifications and real-world variation, was added to the sampling variance, initially estimated during modelling (see below), and eventually arbitrarily set by the Fisheries New Zealand Deepwater Working Group at 0.1 for the trawl survey and 0.2 for the CPUE indices following the values used by Kienzle (2021). Multinomial errors were assumed for all age composition observations. The effective sample sizes for the composition samples were estimated following the method TA1.8 described in appendix A of Francis (2011).

**Table 2: Observations used in the ling stock models for the west coast of the South Island (LIN 7WC), including source years.**

| Data series | Years |
|---|---|
| Commercial trawl CPUE | 1997–2022 |
| Commercial trawl proportion-at-age (Jun–Sep) | 1991, 1994–2008, 2012–2022 |
| Commercial longline CPUE (aggregated) | 1991–2022 |
| Commercial longline proportion-at-age (May–Aug, Oct–Dec for 2021) | 2003, 2006, 2007, 2012, 2015, 2021 |
| Trawl survey biomass (*Tangaroa*, Jul) | 2000, 2012–13, 2016, 2018, 2021 |
| Trawl survey age data | 2000, 2012–13, 2016, 2018, 2021 |

**Table 3: Input parameters used in the ling stock models for the west coast of the South Island (LIN 7WC).**

| Relationship | Reference | Parameter (units) | Value<br>Both | <br>Male | <br>Female |
|---|---|---|---|---|---|
| von Bertalanffy growth | (Mormede et al. 2023) | $t_0$ (y) | | -1.08 | -0.86 |
| | | $k$ ($y^{-1}$) | | 0.08 | 0.08 |
| | | $L_\infty$ (cm) | | 140.0 | 164.1 |
| | | CV | | 0.08 | 0.08 |
| Length-weight | (Mormede et al. 2023) | $a$ ($g.cm^{-1}$) | | $1.31e^{-9}$ | $0.98e^{-9}$ |
| | | $b$ | | 3.292 | 3.362 |
| Stock recruitment relationship | | | | | |
| Stock recruitment steepness | (Kienzle 2021) | $h$ | 0.84 | | |
| Recruitment variability | (Fisheries New Zealand 2023) | $\sigma_R$ | 0.6 | | |
| Ageing error | (Fisheries New Zealand 2023) | CV | 0.05 | | |
| Proportion male at birth | | | 0.5 | | |
| Proportion of mature that spawn | | | 1.0 | | |
| Maximum exploitation rate ($U_{max}$) | | | 0.6 | | |

**Table 4: Maturity-at-age used in the ling stock models for the west coast of the South Island (LIN 7WC) (from Horn 2005).**

| Age | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|---|---|---|---|
| Male | 0.0 | 0.015 | 0.095 | 0.39 | 0.77 | 0.94 | 1.00 | 1.00 | 1.00 | 1.00 |
| Female | 0.0 | 0.004 | 0.017 | 0.06 | 0.18 | 0.39 | 0.65 | 0.85 | 0.94 | 1.00 |

## 2.3 Estimation of parameters

The initial spawning stock biomass ($B_0$) was estimated in the model as a log transformation; recruitment multipliers were estimated as simplex transformations. The trawl and longline fisheries and research survey selectivity ogives were estimated and assumed to be logistic curves; an investigation of the scaled age compositions confirmed that a logistic selectivity ogive for the trawl fishery and research survey was adequate. Because of the highly variable sex ratio in the age compositions between years, selectivities were assumed identical between males and females and age composition data were provided unsexed. Estimated parameters are summarised in Table 5.

**Table 5: Parameters estimated in the ling stock models for the west coast of the South Island (LIN 7WC).**

| Parameter description | Distribution | Initial value | Parameters | | Bounds | |
|---|---|---|---|---|---|---|
| $B_0$ | uniform-log | 200 000 | – | – | 10 000 | 500 000 |
| Year class strength multipliers | lognormal | 1 | 1.0 | 0.6 | 0.01 | 100 |
| *Tangaroa* survey $q$ | lognormal | 0.3 | 0.07 | 0.70 | 0.001 | 1 |
| Trawl CPUE $q$ | uniform-log | 0.5 | – | – | 0.4 | 3 |
| Longline CPUE $q$ | uniform-log | 0.5 | – | – | 0.01 | 3 |
| Trawl fishery selectivity $a_{50}$ (logistic) | uniform | 13 | – | – | 1 | 30 |
| Trawl fishery selectivity $a_{to95}$ (logistic) | uniform | 7 | – | – | 1 | 30 |
| Trawl survey selectivity $a_{50}$ (logistic) | uniform | 13 | – | – | 1 | 50 |
| Trawl survey selectivity $a_{to95}$ (logistic) | uniform | 7 | – | – | 1 | 100 |
| Longline fishery selectivity $a_{50}$ (logistic) | uniform | 13 | – | – | 1 | 60 |
| Longline fishery selectivity $a_{to95}$ (logistic) | uniform | 4 | | | 1 | 200 |

* A range of maximum values was used for the upper bound.

Because no potting trip has been observed in LIN 7WC, the potting fishery was assumed to have the same selectivity as the longline fishery following the analysis carried out for LIN 3&4 (Mormede et al. 2022). Selectivities were assumed constant over all years in each of the fisheries and for the survey. Instantaneous natural mortality ($M$) was assumed at 0.18 $y^{-1}$ for both sexes and to be constant at age in the model (Horn 2008).

Most of the priors were assumed to be relatively uninformative (i.e., uniform or uniform-log) and were specified with wide bounds. The exceptions were the choice of informative prior for the trawl survey catchability $q$, which was assumed lognormal with $\mu$ of 0.07 and CV of 0.7. A sensitivity run was carried out with an alternative prior with $\mu$ of 0.043 and CV of 0.7 and provided identical results to the base case model. In all models, the catchability coefficients ($q$s) for either the survey or the CPUE index were estimated as free parameters.

Annual recruitments were modelled as a recruitment multiplier (i.e., year class strengths) with a lognormal distribution using the simplex method (aka a broken stock approach). The simplex method rescales $n$ parameters as $n$-1 parameters with the constraint that they average one, making it a natural transformation for the estimation of annual recruitment multipliers with the constraint that they have mean one over some year range.

Penalty functions were used to constrain the model so that any combination of parameters that did not allow the historical catch to be taken was penalised. In the models that did not use the simplex method to constrain annual recruitment multipliers, a small penalty was applied to the estimates to encourage estimates that averaged one.

Maximum Posterior Density (MPD) estimates were used to compare diagnostics and fits between models. For final runs, the full posterior distribution was sampled using Markov chain Monte Carlo (MCMC), based on the Metropolis-Hastings algorithm. MCMC chains with a total length of $4\times10^6$ iterations were constructed. A burn-in length of $1\times10^6$ iterations was used, with every 1000th sample taken from the final $3\times10^6$ iterations (i.e., a final sample of length 3000 was sampled from the posterior).

## 3. RESULTS

### 3.1 Model steps from the 2020 base case

The 2020 base case (Kienzle 2021) was used as the starting point for model development. The 2023 initial model was developed by making incremental changes to the 2020 base case, including updating to Casal2 (Casal2 Development Team 2023) the model structure, catches, biological parameters, and observations. Reweighting of the data was only done once the final data and model structure had been updated, to allow comparison of the models throughout this process. Details of the steps are given in Table 6.

The update of the age composition data was the most influential to the model. Further investigations attributed this large change to a misspecification in the 2020 model: age composition data were provided without a plus group but defined within the model as having a plus group. This effect was compounded by the relatively low maximum age of these age compositions, set at 21. The maximum age for the current model was increased to age 28, with the age composition observations using a plus group also at age 28. The update of the catch history to include Statistical Area 032 had a more moderate effect on model outcomes.

Once the data were re-weighted, the 2023 initial case had a higher estimate of initial biomass and status in 2022 (Table 7).

**Table 6: Incremental model build from the 2020 base case to the 2023 initial model run at MPD level. The data were not re-weighted between models. AF = age composition. Objective function values that are not comparable due to changes in data inputs are given in grey.**

| Run | Model description | Objective function | $B_0$ (t) | $SSB_{2020}$ (t) | $SSB_{2020}$ (%) |
|---|---|---|---|---|---|
| R0.0 | Casal 2020 base | 817 | 46 766 | 21 497 | 46.0 |
| R0.1 | Casal2 2020 base | 816 | 47 176 | 21 283 | 45.1 |
| R0.2 | Clean up | 958 | 47 422 | 21 455 | 45.2 |
| R0.3 | Update timing | 960 | 47 094 | 20 918 | 44.4 |
| R0.4 | Update biologicals sexed | 959 | 45 621 | 20 524 | 45.0 |
| R0.5 | Update catches | 961 | 48 938 | 21 308 | 43.5 |
| R0.51 | Original AFs no plus group | 949 | 58 537 | 32 450 | 55.4 |
| R0.5aa | Update AFs (with plus group) | 958 | 54 564 | 27 376 | 50.2 |
| R0.5a | Update AFs and age extent | 1 066 | 56 689 | 29 037 | 51.2 |
| R0.6 | Update to 2023 | 1 181 | 61 456 | 35 573 | 57.9 |

**Table 7: 2020 base and 2023 initial model MPD estimates, once data were re-weighted. Objective function values that are not comparable due to changes in data inputs are given in grey.**

| Run | Model description | Objective function | $B_0$ (t) | $SSB_{2020}$ (t) | $SSB_{2020}$ (%) |
|---|---|---|---|---|---|
| R0.0 | Casal 2020 base | 817 | 46 766 | 21 497 | 46.0 |
| R0.1 | Casal2 2020 base | 816 | 47 176 | 21 283 | 45.1 |
| R1.02 | Initial | 924 | 59 181 | 31 702 | 53.6 |

## 3.2 Developing the base case model

Further modifications were applied to the initial model and are detailed below: the mature partition was removed, ageing error was reduced from 0.1 to 0.05 in line with values used in the other ling stocks (Fisheries New Zealand 2023), process errors were arbitrarily fixed at 0.1 for the survey biomass and 0.2 for the CPUE series, and both the longline and trawl fisheries CPUE were included in the model.

A mature partition had been added to the model in the past in an attempt to better fit the survey composition data at low ages (Dunn et al. 2013). However, this partition resulted in a highly uncertain immature selectivity, unstable MCMC, and little improvement in the fits to the compositional data (Figure 1). Therefore, it was removed from the model.

Ageing error had been set at 0.1 for this model, when it was fixed at 0.05 in other ling models (Fisheries New Zealand 2023). This value was updated to 0.05 for the base case model to test if this might be the cause of the uncertain estimates of selectivity. The main effect was the reduction in the uncertainty around the year class strength estimations at MCMC level. Other parameter estimates were similar, as were the fits to the data.

Process error for the survey biomass and CPUE series had previously been fixed for this model. Various options were evaluated as part of the 2023 investigation. Process error was estimated at MPD level as was done for other ling stocks (e.g., Mormede et al. 2021); it was estimated close to zero for all three abundance indices. As an alternative run, process error was estimated at MCMC level, which resulted in a very low value with a long tail for the survey index, and a near-normal distribution centred at 0.1 for the CPUE indices. As these assumptions had a moderate effect on the model outcome, the Fisheries New Zealand Deepwater Working Group decided to fix process errors at 0.1 for the survey biomass index and 0.2 for the CPUE indices, following Kienzle (2021).

Finally, the initial model was updated to include both CPUE indices. This allowed the model to account for the difference in trend between those two indices in the 1997–2000 period, when there was no survey biomass trend available. A sensitivity was carried out where the trawl CPUE was excluded (see below).

The observation data included in the base case model and their associated error values are detailed in Figure 2. An MPD profile was also carried out on $B_0$ (Figure 3). The upper limit of the initial biomass was most informed by the commercial trawl composition data and CPUE.

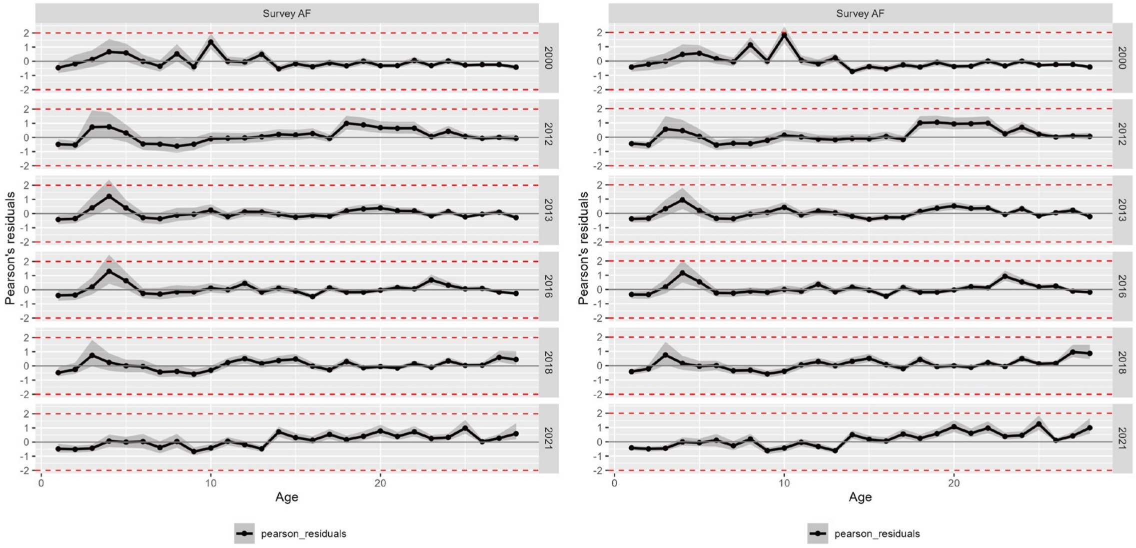

**Figure 1:** Pearson residuals to the survey age composition (AF) data at MCMC level for the model with immature partition and selectivity (left) and without (right).

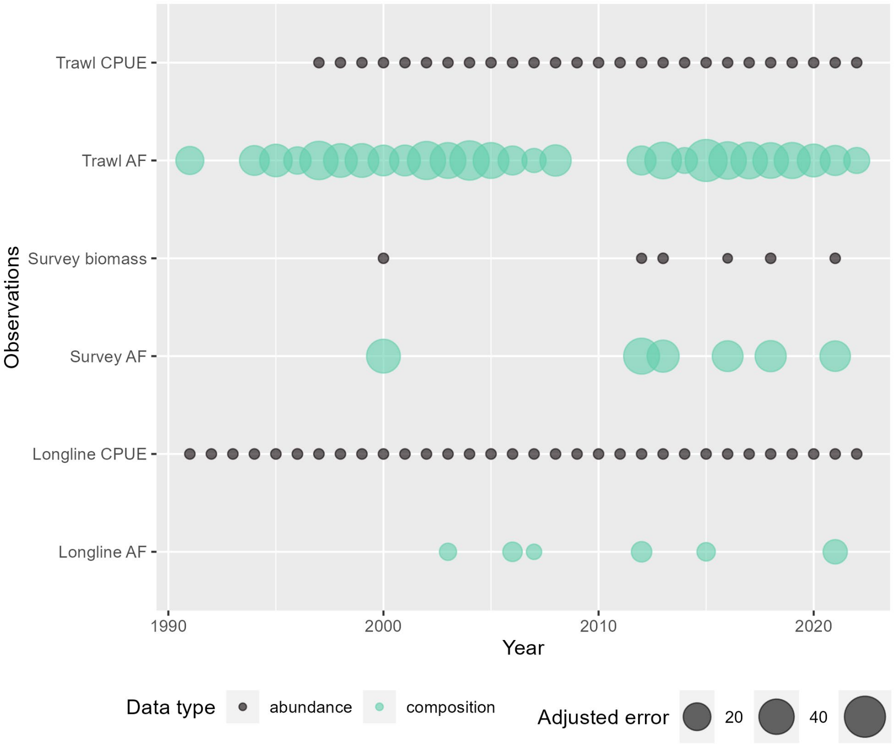

**Figure 2:** Observations included in the base case model and their adjusted error (CV and additional process error combined). The adjusted errors of abundance and age composition data are not comparable and plotted as different colours.

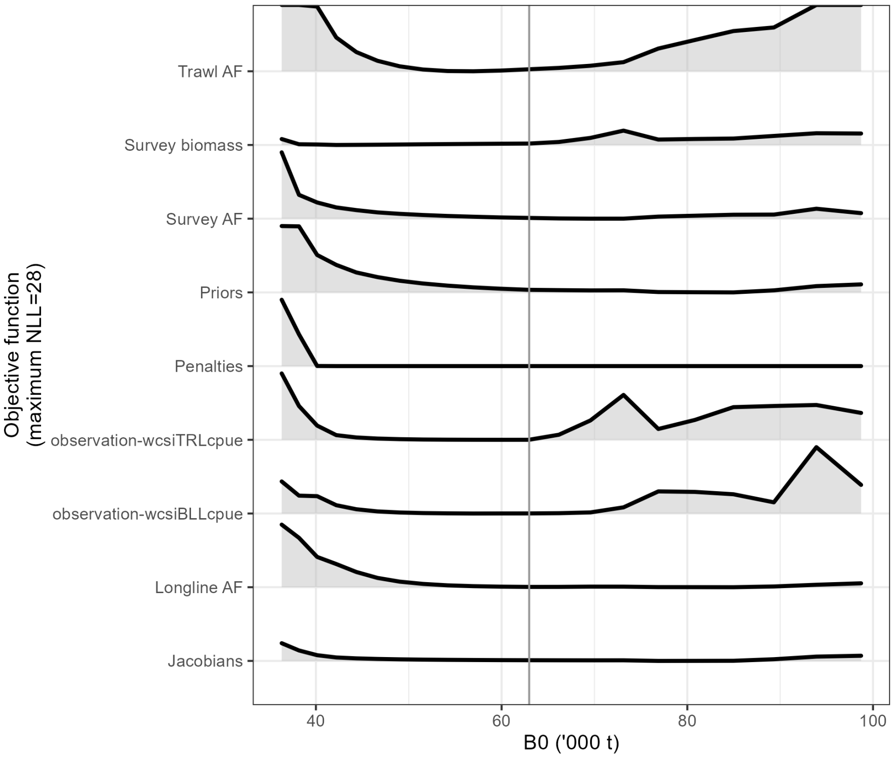

**Figure 3: MPD profile on $B_0$. NLL = negative log likelihood, AF = age composition data, wcsiTRL = west coast South Island trawl survey, and BLL = bottom longline.**

## 3.3 Sensitivity runs

Several sensitivity runs were carried out to investigate the effects of model assumptions and choices of different data or observations.

The 2023 initial model was updated to a sex-specific model to capture the differences in growth between males and females and this structure was carried through to the base case model. A sensitivity run was carried out where age composition data were provided by sex and selectivities were estimated for males and females separately. However, these selectivities were poorly estimated due to the high variability of the sex ratio in the composition data between ages and years. The models using sex-specific age composition data were not considered further.

The main sensitivities carried forward were as follows: the exclusion of the trawl CPUE series to test the effect of the different trend between the two CPUE indices in the late 1990s, reducing steepness from $h$=0.84 to $h$=0.6 (following the recommendation of Horn 2022), and the effect of alternative values of natural mortality.

Natural mortality was not estimated in this model as MPD profiles showed there was no information in the data to estimate natural mortality reliably (not shown). This was not surprising given the variability in the age composition and uncertainty around selectivities. Natural mortality in the base case was fixed at 0.18 $y^{-1}$ which is the average natural mortality of ling over all New Zealand stocks following Horn (2008). Sensitivities were carried out with natural mortality fixed at 0.15 $y^{-1}$ following Edwards (2017) and at 0.21 $y^{-1}$ as there was some evidence that it could be potentially higher for ling off the west coast of the South Island (Horn 2008).

## 3.4 Bayesian model results

Base case estimates indicated that $B_0$ was about 62 000 t for this stock, and that biomass for 2023 was about 51% of $B_0$. The 95% credible interval of stock status estimates for 2023 from the base case and all sensitivity runs were in the range of 36–66% of $B_0$. The probability of the 2023 status being above 40% $B_0$ ranged from 2.5 to 100%, and the probability of it being below 20% $B_0$ was less than 1% in all instances. Removing the trawl survey biomass index reduced the initial biomass by about 2600 t and did not change the 2023 stock status, from an average of 51.1% $B_0$ in the base case to 51.8% $B_0$ (Table 8). Reducing steepness from 0.84 to 0.6 increased initial biomass by about 4500 t and status by about one percentage point compared with the base case model. The model outcomes were most sensitive to alternative values of natural mortality, assuming a lower natural mortality had the most effect on the biomass status in 2023, reducing it from 51% $B_0$ to about 36% $B_0$.

**Table 8: LIN 7WC Bayesian median and 95% credible intervals (in parentheses) of $B_0$ and $B_{2023}$ (in tonnes and as a percentage of $B_0$), and the probability that $B_{2023}$ is above 40% of $B_0$ or below 20% of $B_0$.**

| Model run | $B_0$ | $B_{2023}$ | $B_{2023}$ (% $B_0$) | $P$(>40% $B_0$) | $P$(<20% $B_0$) |
|---|---|---|---|---|---|
| Base case | 62 168 (55 007–74 122) | 34 265 (25 711–47 751) | 51.1 (38.2–63.5) | 0.953 | 0.000 |
| No trawl CPUE (R2) | 59 725 (53 183–70 139) | 30 970 (23 237–42 440) | 51.8 (43.2–61.8) | 0.996 | 0.000 |
| $h = 0.6$ (R3) | 66 716 (59 468–78 689) | 34 803 (26 105–48 449) | 52.1 (43.5–62.1) | 0.998 | 0.000 |
| $M = 0.15$ (R4) | 58 067 (54 568–62 211) | 20 776 (17 255–24 804) | 35.8 (31.5–40.0) | 0.025 | 0.000 |
| $M = 0.21$ (R5) | 72 175 (59 611–96 155) | 47 907 (34 186–72 670) | 66.1 (56.0–77.8) | 1.000 | 0.000 |

Biomass estimates for the stock declined to 1990, remained variable and generally increased until 2012, and have been declining since then (Figure 4). Posterior distributions of year class strength from the base case model are showed in Figure 5; the patterns of strong and weak year classes differed little between the base case model and the sensitivity models. Year classes were generally uncertain for the entire series and followed a pattern of periods of high then low recruitment. Annual exploitation rates have been generally increasing over time for bottom longlines and were highly variable for bottom trawl (Figure 6).

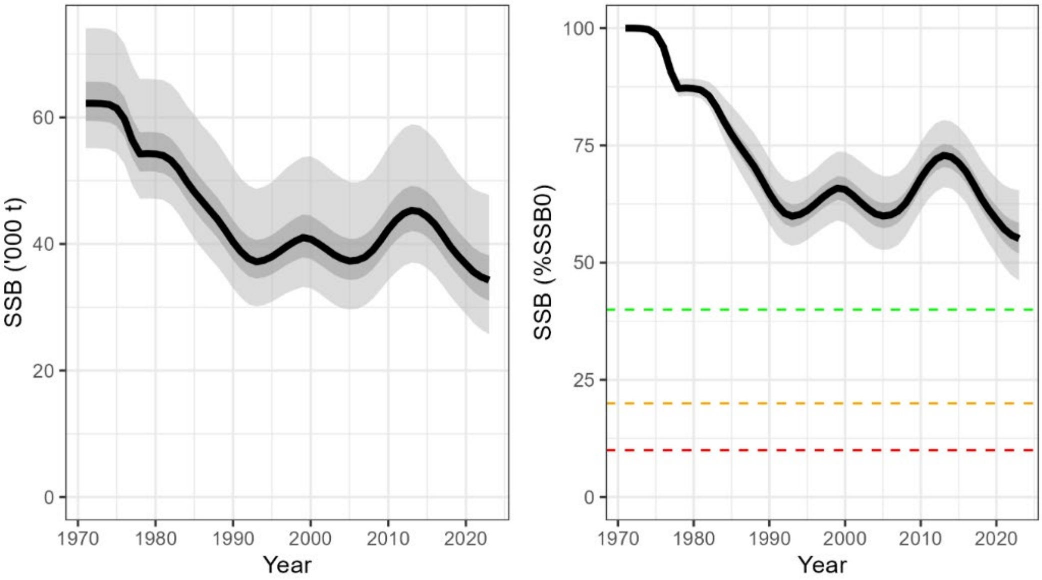

**Figure 4:** LIN 7WC estimated posterior distribution of the spawning stock biomass (*SSB* in tonnes, left) and of the proportion of initial spawning biomass (% $SSB_0$, right) trajectory with estimated initial spawning stock biomass reference points (40%, 20%, and 10% $B_0$) for the base case model. The solid black line represents the median values, the dark grey shading indicates the interquartile range, and light shading indicates the 95% credible interval.

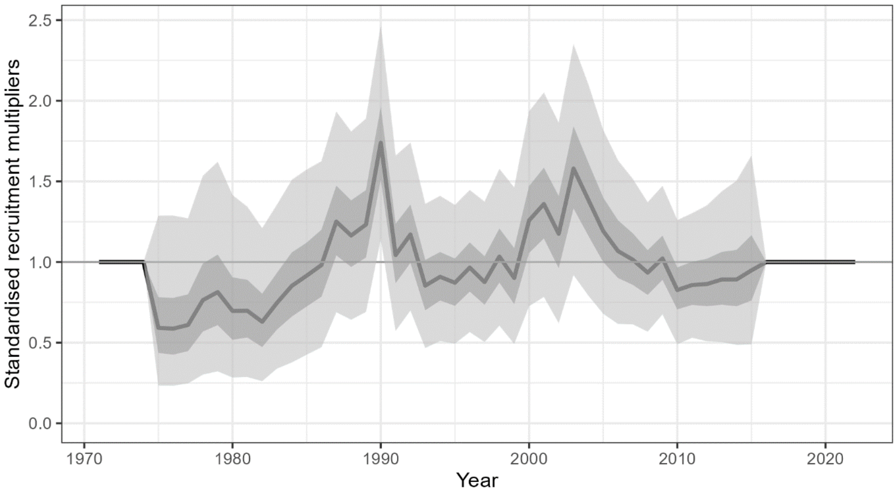

**Figure 5:** LIN 7WC estimated posterior distributions for standardised recruitment multipliers from the base case run, with median (line), the interquartile range (dark grey), and 95% credible interval (light grey). The horizontal line indicates a recruitment multiplier value of one.

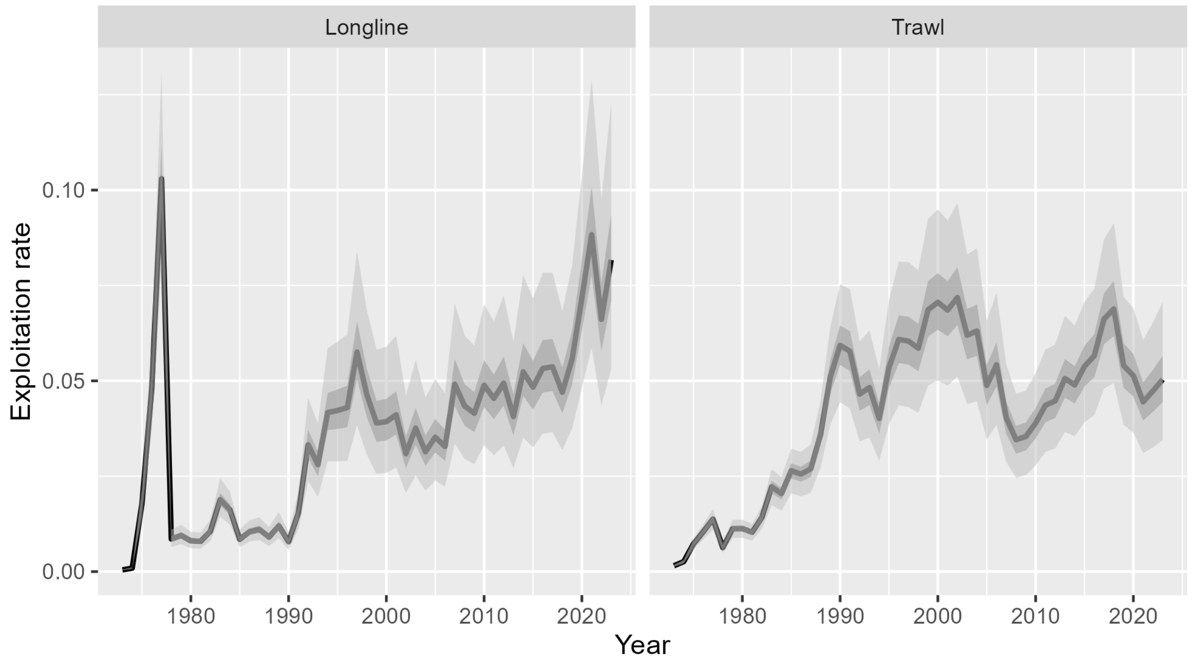

**Figure 6: LIN 7WC base model exploitation rates for the longline (left) and trawl fisheries (right), with the interquartile range (dark grey) and 95% credible interval (light grey).**

Selectivities were estimated with relatively narrow credible intervals (Figure A.1 of Appendix A for the base case) and were virtually identical between model runs (not shown). The ling selectivities in LIN 7WC were unusual in that the survey selected older fish than the commercial trawl fishery. The commercial longline fishery selected older fish than both the survey and commercial trawl. Fits to the observed data were adequate (Figure A.2 and Figure A.3 for the base case), and almost identical between model runs (not shown). The estimated commercial fisheries selectivities were to the right of the maturity ogive, leading to a small proportion of the spawning stock biomass being not vulnerable to fishing (about 10% at $B_0$ for the base case). Fits to the abundance indices generally captured the trends over time within the confidence bounds of each individual series, although the model could not fit to the initial decline in commercial trawl CPUE (Figure A.4 for the base case).

There was no evidence of lack of convergence of the MCMCs (Figure A.5 and Figure A.6). Trace plots showed no evidence of failure to converge for the base case model (Figure A.7) or the sensitivity models (not shown). Multichain diagnostic using approximate $\hat{r}$ statistics (Vehtari et al. 2017) did not suggest any evidence of non-convergence (Figure A.6).

### 3.5 Alternative catch histories

Two alternative catch histories were constructed. In the first scenario, 5% additional fishery mortality for years before the introduction of the QMS (1986) and 2% thereafter was assumed to include the possibility of unreported catches, discards, and mortality of uncaught small fish going through the nets. In the second scenario, catches were modified to account for potential reporting issues of ling between stocks (Dunn 2003). Both those scenarios resulted in very similar estimates of initial biomass and stock status in 2023 to the base case (not shown), and a very similar biomass trajectory. Projections were not run on these models but would be expected to have very similar outcomes to the base case model.

### 3.6 Projections

Because of the high uncertainty on year class strengths, projections were carried out by resampling the full range of year class strengths. Furthermore, because LIN 7WC covers part of LIN 5 but not all of LIN 7, predictions were carried out using the average of the 2020 to 2022 model year catches only, keeping the ratio of catches between the fisheries to that of the 2020–22 fisheries (46% trawl and 54% longline/pot combined).

Using the base case model and the above assumptions, the stock size in LIN 7WC is likely to reduce by about 6% from 2023 levels. The probability of the biomass in 2028 being above 40% $B_0$ is 0.97 and the probability of being below the soft limit (i.e., 20% $B_0$) is zero (Table 9 and Figure 7).

**Table 9: LIN 7WC. Bayesian median and 95% credible intervals (in parentheses) of projected $B_{2028}$, $B_{2028}$ as a percentage of $B_0$, and $B_{2028}/B_{2023}$ (%) for the base case model run. The probability of $B_{2028}$ being above 40% $B_0$ ($p_{40}$) and of $B_{2028}$ being below 20% $B_0$ ($p_{20}$) are also reported.**

| YCS range | Catch range | Future catch (t) Trawl | Future catch (t) Line/Pot | $B_{2028}$ (t) | $B_{2028}$ (% $B_0$) | $B_{2028}$ (% $B_{2023}$) | $p_{40}$ | $p_{20}$ |
|---|---|---|---|---|---|---|---|---|
| All | 2020 –2022 | 1 511 | 1 758 | 32 550<br>(22 128–48 238) | 52 (39–69) | 94 (78–117) | 0.97 | 0.00 |

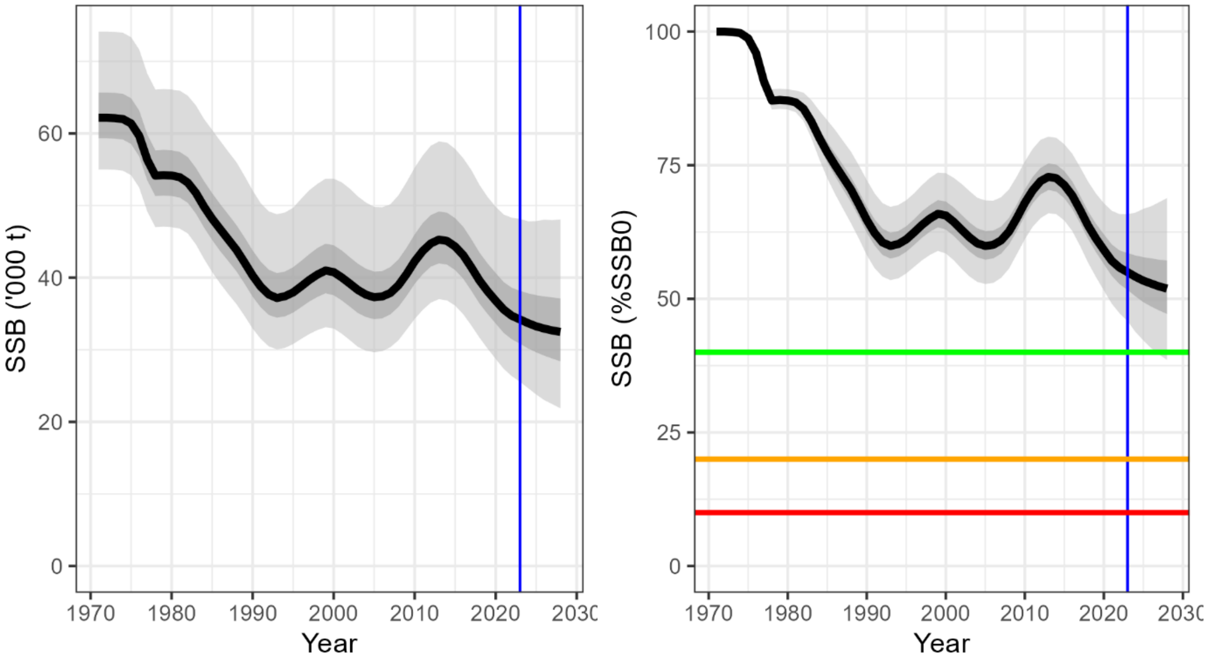

**Figure 7: Trajectory over time of relative spawning biomass (with interquartile range in dark grey and 95% credible intervals in light grey) for the base case model for the WCSI ling stock from the start of the assessment period in 1972 to the most recent assessment in 2023 (vertical blue line) and projected to 2028 with future catches as the average of the catch from 2020-2023 (3269 t) and resampling all year class strengths. Years on the x-axis are calendar years. Biomass estimates are based on MCMC results. The red horizontal line at 10% $B_0$ represents the hard limit, the orange line at 20% $B_0$ is the soft limit, and green line is the %$B_0$ target (40% $B_0$).**

## 4. DISCUSSION

The stock assessment model for ling off the west coast of the South Island (LIN 7WC) updated the 2020 assessment (Kienzle 2021). Several changes were implemented, the most influential ones to stock size and status being the implementation of a plus-group in the composition data and the change in stock boundary. These resulted in a higher initial spawning stock biomass and stock status compared with the 2020 stock assessment. For the base case model, $B_0$ was estimated to be about 62 200 t and stock status in 2023 was estimated as 51% $B_0$.

The model trajectory was consistent with all three abundance indices; not only the survey biomass index but also the longline and trawl CPUE series, although the initial high values of the trawl CPUE could not be fitted in the model. The base case included all three indices.

All selectivities were estimated slightly to the right of the assumed maturity ogive, leading to about 10% of $B_0$ being not vulnerable to fishing. Maturity should be investigated in future assessments to ensure the ogive used (Horn 2005) is adequate for this stock.

Agreed reference points for ling off the west coast of the South Island include a management target of 40% $B_0$, a soft limit of 20% $B_0$, and a hard limit of 10% $B_0$. $B_{2023}$ was estimated to be very likely to be above the target for the base case model and exceptionally unlikely to be below the soft or hard limit (Figure 8).

Based on the projection carried out, the projected stock biomass was likely to reduce slightly over the 2023–2028 period at recent catch levels but remain well over the target.

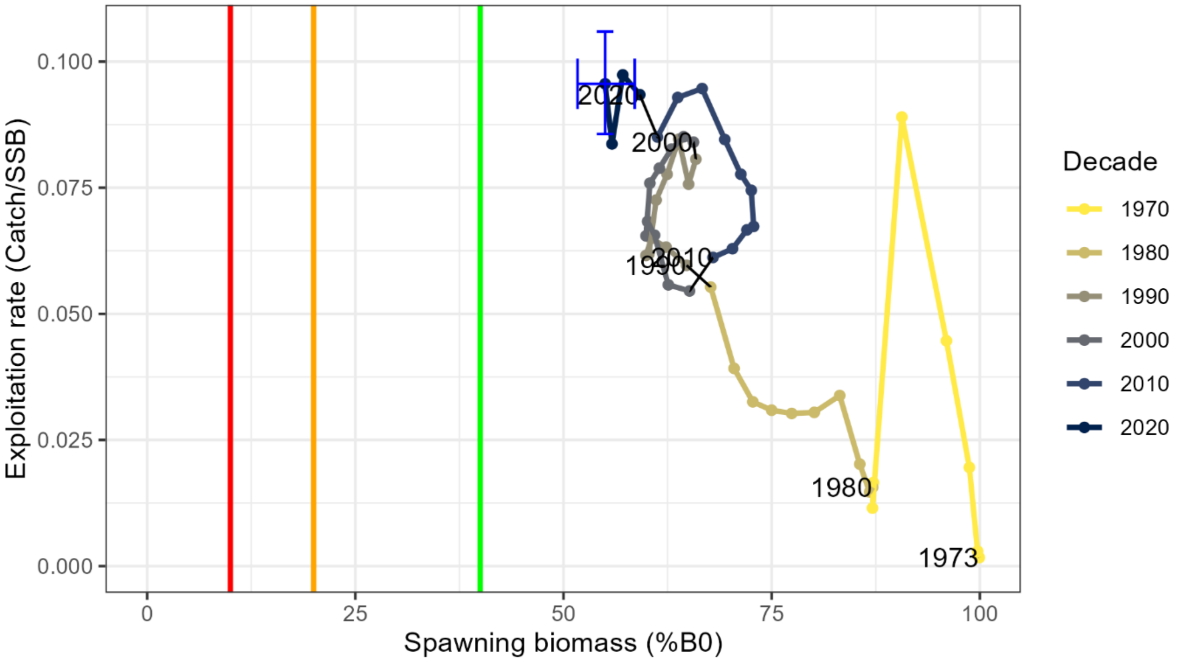

**Figure 8: Trajectory over time of exploitation rate (catch/*SSB*) and spawning biomass (% $B_0$), for the LIN 7WC base model from the start of the assessment period in 1973 to 2023. The red vertical line at 10% $B_0$ represents the hard limit, the orange line at 20% $B_0$ is the soft limit, and green line is the % $B_0$ target (40% $B_0$). Biomass and exploitation rate estimates are medians from MCMC posteriors for the base model. The blue cross represents the limits of the 95% credible intervals of the estimated ratio of the *SSB* to $B_0$ and exploitation rate in 2023.**

## 5. FULFILLMENT OF BROADER OUTCOMES

Whakapapa links all people back to the land, sea, and sky, and our obligations to respect the physical world. This research aims to ensure the long-term sustainability of ling stocks, for the good of the wider community (including stakeholders and the public) and the marine ecosystems that ling inhabit. This project supports Māori and regional businesses, diversity and inclusion, and our research is inextricably linked to the moana from the work it carries out and the tangata whenua it supports.

As part of this project, the team has continued to build capacity and capability in fisheries science and stock assessment, its commitment to zero waste and carbon neutrality, environmental stewardship and social responsibility.

## 6. ACKNOWLEDGEMENTS

We thank the Fisheries New Zealand Data Management Team for the data extracts used in these analyses and the additional assistance and information on interpretation. We also thank Matt Dunn (NIWA) for comments and advice, and members of the Deepwater Fisheries Assessment Working Group for their discussions on this work. This work was funded by Fisheries New Zealand under Objective 2 of project LIN2022-01.

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## 8. Appendix A – Model and diagnostic plots for the base case model

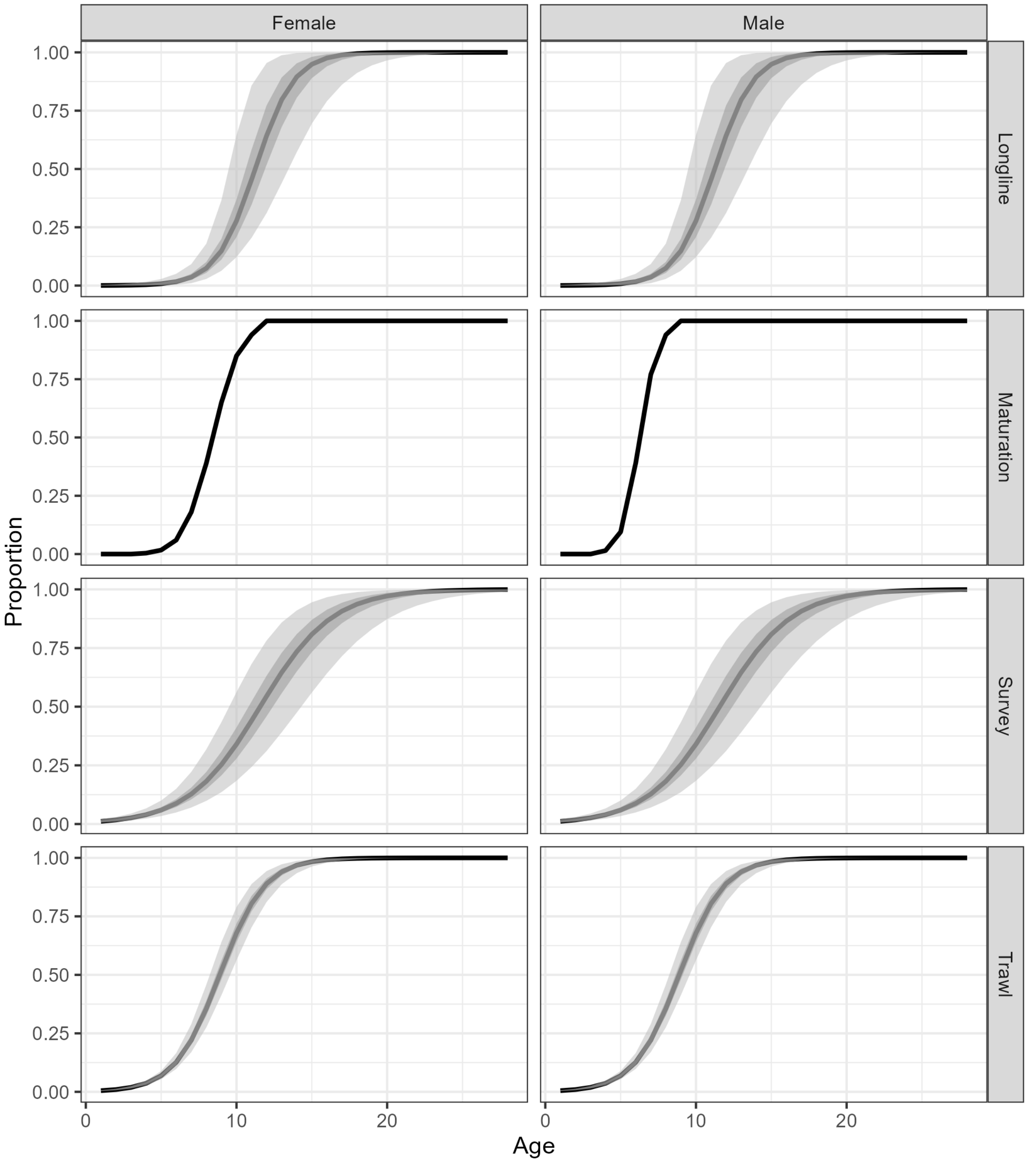

**Figure A.1: Selectivity estimates with the interquartile range (dark grey) and 95% credible interval (light grey). Maturation was fixed in the model and is plotted for comparison.**

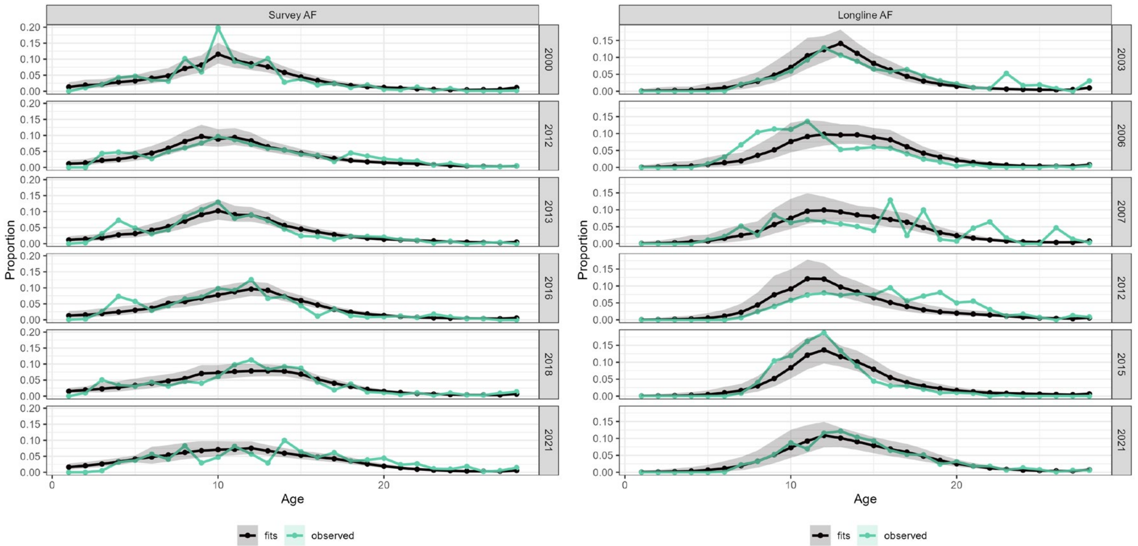

**Figure A.2: Fits to the age composition (AF) data for the survey (left) and the longline fishery (right) with the 95% credible interval (light grey).**

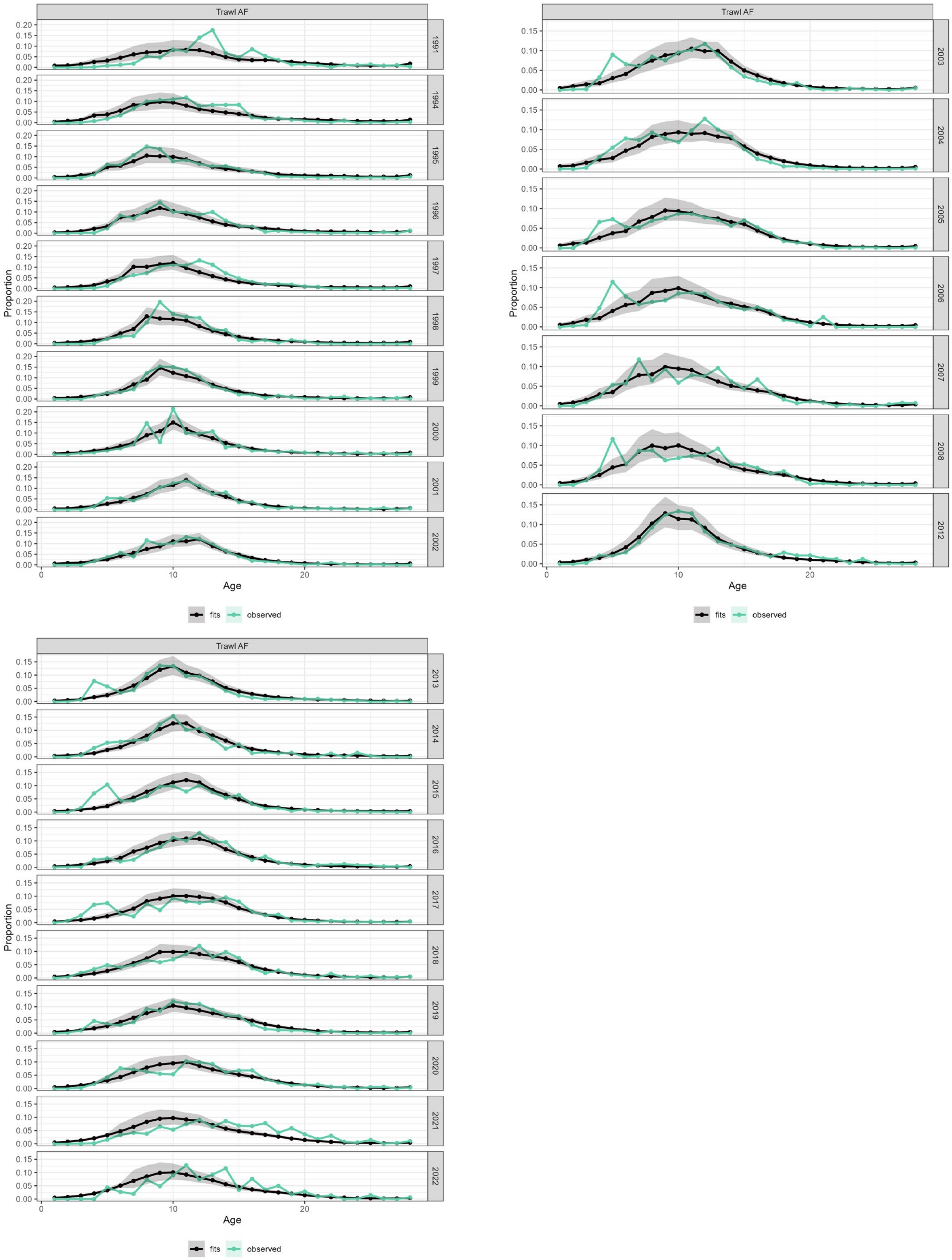

**Figure A.3: Fits to the age composition (AF) data for the trawl fishery with the 95% credible interval (light grey).**

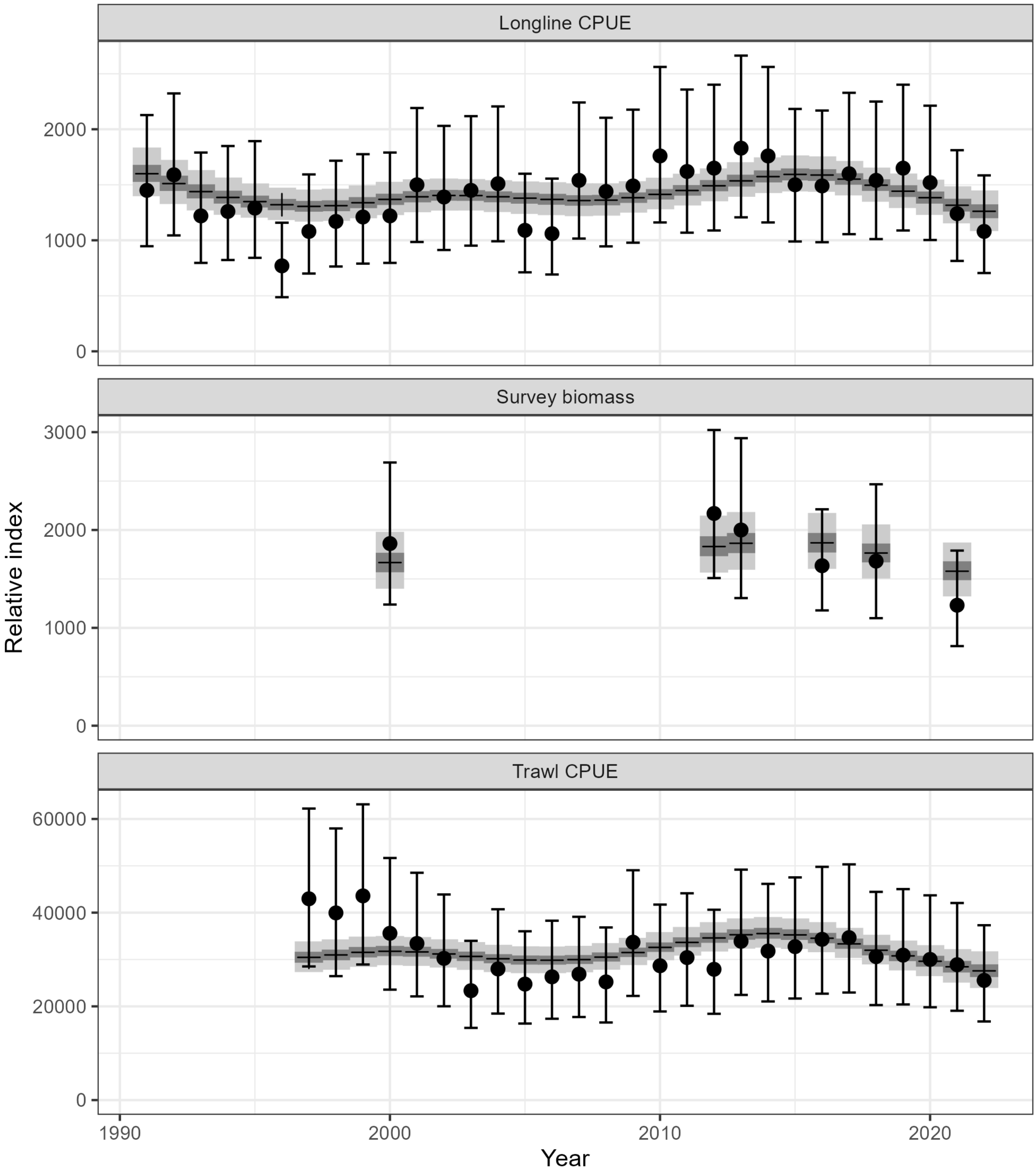

**Figure A.4: Fits to the abundance indices with the interquartile range (dark grey) and 95% credible interval (light grey).**

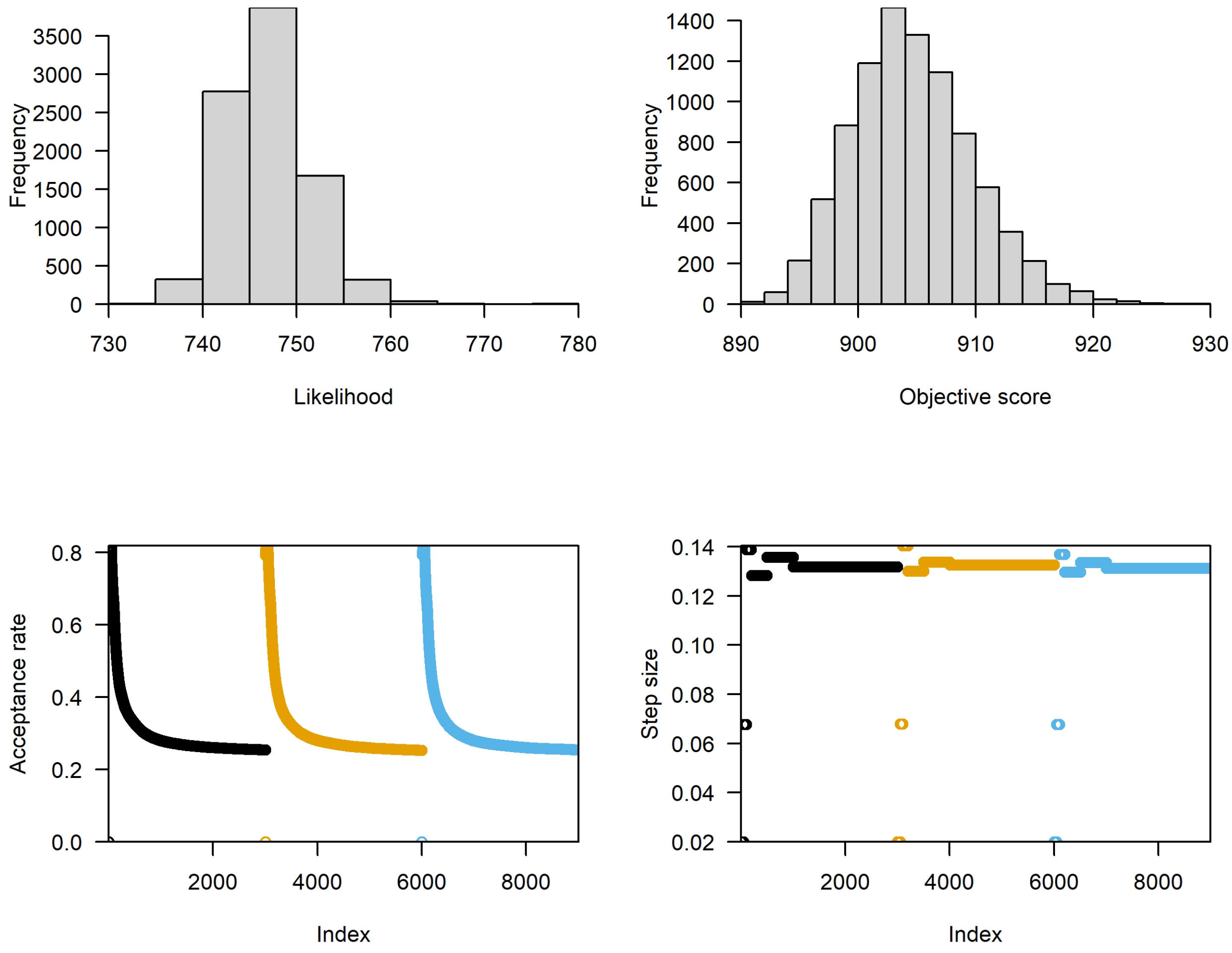

**Figure A.5: MCMC diagnostic plots, showing the distribution of the likelihood of the objective function (top left), the distribution of the objective score (top right), the acceptance rate for each chain (bottom left) and the adaptive step size for each chain (bottom right).**

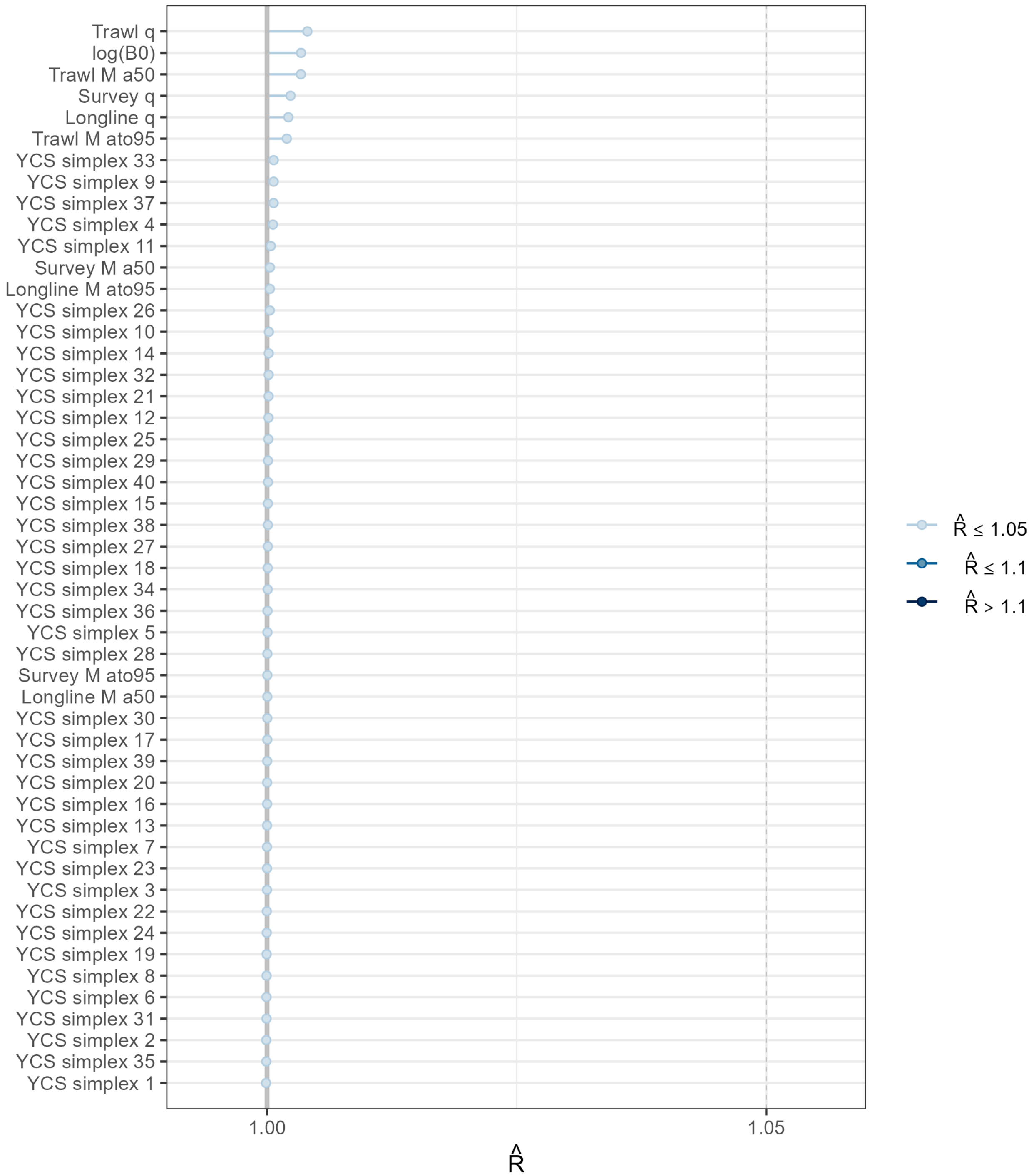

**Figure A.6: MCMC Rhat values for all parameters.**

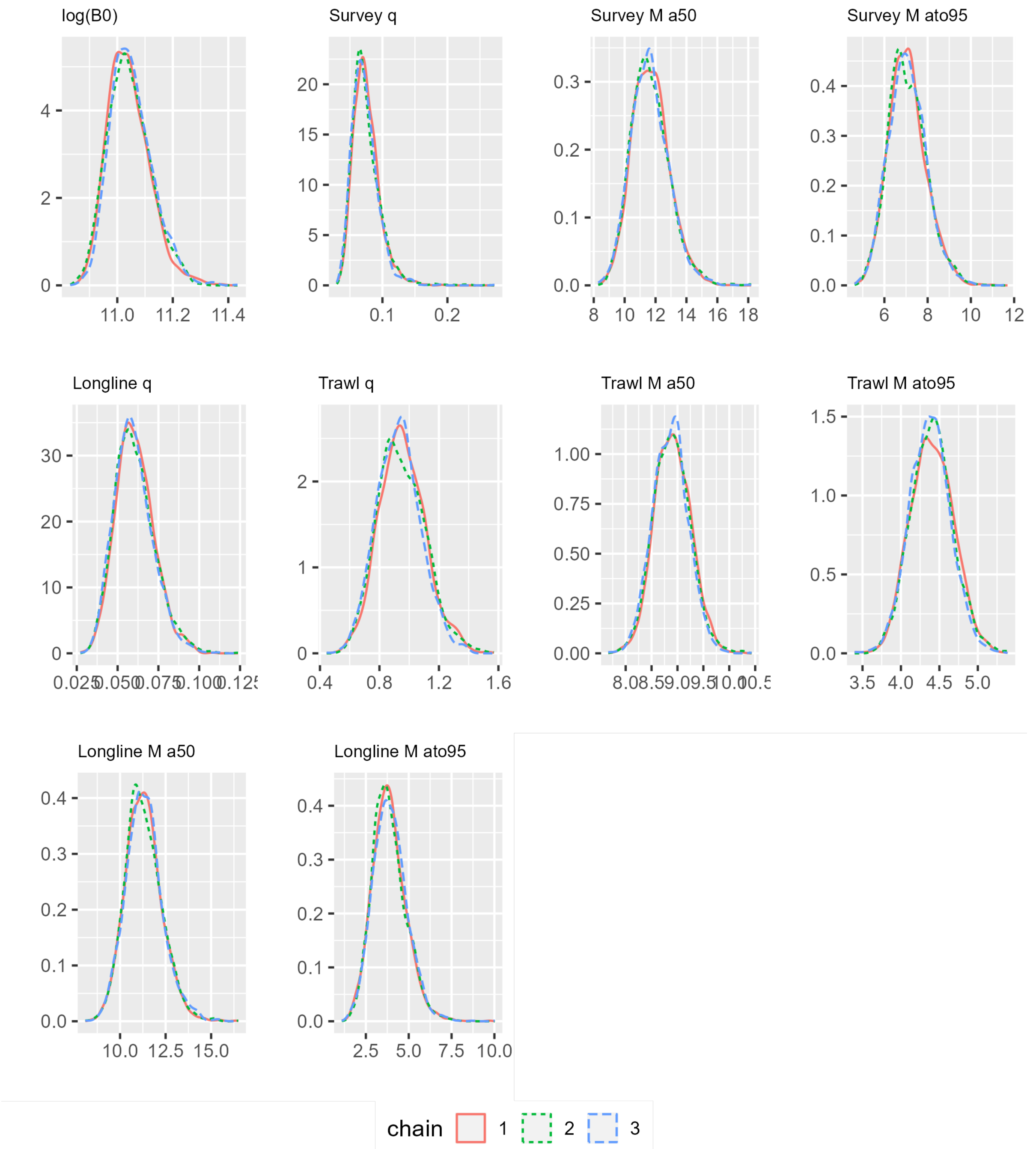

**Figure A.7: MCMC chains density plots for the estimated parameters (excluding year class strength), plotted separately for each chain.**