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The 2024 stock assessment of ling (*Genypterus blacodes*) in the Sub-Antarctic (LIN 5&6 and LIN 6B)

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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 2024 stock assessment of one of the five main ling stocks managed under the Quota Management System: the Sub-Antarctic ling stock, defined as LIN 5&6 and including LIN 6B for the first time.

A stock assessment model was carried out, informed by commercial catches, commercial age compositions, and information from the Sub-Antarctic Tangaroa trawl survey biomass series.

The initial spawning stock biomass (B_0) for both the base case model was estimated to be about 204 630 t and stock status in 2024 was estimated at 66% B_0.

Five-year projections were done using the base case model, assuming various future recruitment and annual catch options. Projected stock status in 2029 was expected to be above the target of 40% B_0 in all instances, however the exploitation rate in LIN 5 was expected to exceed the target exploitation rate if the catch in LIN 5 was increased by more than 20%.

EXECUTIVE SUMMARY

Mormede, S.[1]; Dunn, A.[2]; Webber, D.N.[3] (2024). The 2024 stock assessment of ling (*Genypterus blacodes*) in the Sub-Antarctic (LIN 5&6 and LIN 6B).

***New Zealand Fisheries Assessment Report 2024/84.* 28 p.**

Ling (*Genypterus blacodes*) is 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. This report summarises the 2024 stock assessment of the Sub-Antarctic ling stock (LIN 5&6 and LIN 6B) using data up to and including the 2023 calendar year.

The indices of abundance provided to the model were the summer and autumn Sub-Antarctic trawl surveys. Sensitivity analyses were carried out, including evaluating the effect of alternative values of natural mortality and the use of the longline CPUE series.

The main changes implemented in 2024 were the inclusion of LIN 6B and the exclusion of Statistical Area 032 from this stock, and the removal of the bottom longline standardised CPUE index from the model. These resulted in a higher initial spawning stock biomass and stock status compared with the 2021 stock assessment. For the base case model, B_0 was estimated to be about 204 630 t and stock status in 2024 was estimated at 66% B_0.

Five-year projections were done using the base case model, resampling year class strengths using the entire range of estimated year class strengths, or the 2008–2017 year class strengths as they were lower than average, and assuming future annual catch equal to the average catch in 2021–2024 or TACC for LIN 5 and LIN 6 combined, or adding, 10%, 20%, or 30% catches in LIN 5. Projected stock status in 2029 was expected to be above 40% B_0 in all instances, with the probability of being less than 20% B_0 almost zero. Because the majority of the catch is caught in LIN 5 which is likely to represent 25–30% of the total spawning stock biomass, projections were also benchmarked against the projected exploitation rate in LIN 5.The exploitation rate in LIN 5 remained below the target exploitation rate at current catch levels and for up to 20% increases in LIN 5 catches, but exceeded the target exploitation rate beyond this level, including at total LIN 5 and LIN 6 TACC.

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1. INTRODUCTION

Ling (*Genypterus blacodes*) is an important commercial species with adults found throughout the middle depths of the New Zealand Exclusive Economic Zone (EEZ) typically in depths of 100 m to 800 m (Mormede et al. 2021a, 2022, 2023a). Ling are caught mainly by deepwater trawlers, often as bycatch in hoki (*Macruronus novaezelandiae*) target fisheries, by demersal longliners, and more recently by potting.

Ling are managed as eight administrative Quota Management Areas (QMAs), with five of these QMAs (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 Platform, the west coast of the South Island, and the Cook Strait. LIN 5&6 contributes to the highest ling catches, followed by LIN 3&4 then LIN 7WC.

Recent analyses have indicated that the Bounty Platform might be an offshoot of the Sub-Antarctic stock (Horn 2022). The stock structure of Sub-Antarctic ling was further investigated (Mormede et al. 2024b). Based on available catch rate, age structure, and growth information, LIN 6B was considered unlikely to be part of LIN 3&4, with weak evidence that it was part of LIN 5&6. Because of the paucity of data available to assess LIN 6B as a separate stock, and the similarities in the information between LIN 5&6 and LIN 6B, the Fisheries New Zealand Deepwater Working Group decided to include LIN 6B with LIN 5&6 as a single Sub-Antarctic ling stock for the 2024 assessment (Fisheries New Zealand 2024).

In this analysis, catches from Statistical Area 032 were moved from the Sub-Antarctic ling stock to the west coast of the South Island based on the continuity of catches along the depth contour along Statistical Areas 032, 033, and 034 (Mormede et al. 2023a). Based on the difference in ling growth between LIN 7WC and LIN 5&6, this stock boundary was corroborated (Mormede et al. 2024b).

The last assessment for LIN 5&6 was carried out by Mormede et al. (2021b), who reported that the ‘initial biomass for the base case was substantially lower but much more precise than in the previous assessment at about 187 350 t; stock status in 2021 was estimated at 71% B_0.’ The last assessment for LIN 6B was carried out in 2007 (Fisheries New Zealand 2023a), concluding that the estimate of virgin stock size was not well known, at about 13 570 t (95% credible interval: 10 850 – 19 030 t) and stock status in 2006 was about 61% B_0 (95% credible interval 45 – 79%).

This report fulfils Specific Objective 2 of Project LIN2023-01 funded by Fisheries New Zealand. The Overall Objective was ‘to carry out stock assessments of ling (*Genypterus blacodes*) in the Sub-Antarctic (LIN 5, 6, & 6B) including estimating biomass and stock status.’ Specific Objective 2 was ‘To update the stock assessment of the Sub-Antarctic ling stock including estimates of current biomass, 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 Sub-Antarctic ling using the stock assessment program Casal2 v24.02 (2024-02-21) (Casal2 Development Team 2024). The stock assessment model assumed a Beverton-Holt stock-recruit relationship with ages 1–28, with the oldest age a plus group. The model was a two-sex model with a maturity ogive.

The model structure was incrementally changed from the previous assessment model which used CASAL (Bull et al. 2012) and included LIN 5&6 only. LIN 6B was then included as a separate fishery in the model: a single stock was assumed, with LIN 5&6 biological parameters and a single recruitment process.

To align more closely with other ling stocks, model year was set to calendar year (January to December) rather than fishing year (October to September). In this document, 'year' always refers to the model year unless specifically otherwise stated. The model time steps were modified to the new model year. The model's annual cycle is described in Table 1.

Table 1: Sub-Antarctic ling 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–Aug		0.67	0.5	Trawl survey (autumn)	0.5
2	Sep–Dec	Recruitment	0.33	0.0	Longline CPUE	0.5
		Trawl and longline fisheries			Longline catch-at-age	0.5
		Increment ages			Trawl catch-at-age	0.5
					Trawl survey (summer)	0.5
final				0.5		

* *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, commercial longline fishery CPUE series, age compositions, and estimates of biological parameters are described by Mormede et al. (2024a). The age composition data and fisheries CPUE from LIN 6B were deemed too poorly determined to be useful in the stock assessment and were omitted. Although potting is becoming an important part of this fishery, there are no age data available for potting in LIN 5&6 and potting was assumed to have the same selectivity as bottom longline, as assumed in the other ling stocks that include potting catches (Mormede et al. 2023b).

Despite being used in the 2021 base case model (Mormede et al. 2021b), the non-spatially explicit bottom longline CPUE for LIN 5&6 was too variable to be representative of the underlying abundance of ling. There was also a concern that such a long index (1991–2023) might not have captured technological changes, and hence potential changes in catchability, over time adequately (Fisheries New Zealand 2024). Therefore, it was only used in sensitivity analyses for the stock assessment model in 2024. The spatially explicit CPUE index for LIN 5&6 and LIN 6B combined was used for a sensitivity analysis, as it represented the entire stock definition for the Sub-Antarctic ling population models developed; the index started in 2004.

The Sub-Antarctic *Tangaroa* trawl survey index and age compositions were used in all model runs (Stevens et al. 2022). This survey covered most of the LIN 5&6 area where commercial fishing for ling occurs (Mormede et al. 2024a). The trawl survey age composition was provided to the model as sexed observations with ages 3 to 21 (with 21 as a plus group). The trawl and longline age compositions for LIN 5&6 were also provided as sexed ages 3 to 28 (with 28 as a plus group).

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. 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 and estimated during the Maximum Posterior Density (MPD) estimation. 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 Sub-Antarctic ling stock assessment model

Data series	Model years
Trawl survey biomass (*Tangaroa*, Nov–Dec)	1991–93, 2000–09, 2011–12, 2014, 2018, 2020, 2022
Trawl survey proportion at age (*Tangaroa*, Nov–Dec)	1991–93, 2000–09, 2011–12, 2014, 2018, 2020, 2022
Trawl survey biomass (*Tangaroa*, Mar–May)	1992–93, 1996, 1998
Trawl survey proportion at age (*Tangaroa*, Mar–May)	1992–93, 1996, 1998
LIN 5&6 CPUE (longline) -–sensitivity	1991–2023
LIN 5&6 commercial longline proportion-at-age	1996, 1998–2012, 2014, 2016-2020, 2022
LIN 5&6 commercial trawl proportion-at-age	1993, 1996, 1998–2022

Table 3: Input parameters used in the Sub-Antarctic ling stock assessment models.

Relationship	Reference	Parameter (units)	Value Both	Male	Female
von Bertalanffy growth	(Mormede et al. 2021a)	t_0 (y)		-1.16	-1.53
		k (y^{-1})		0.19	0.13
		L_∞ (cm)		91.2	110.6
		CV		0.08	0.08
Length-weight	(Mormede et al. 2021a)	a (g.cm^{-1})		2.13e^{-9}	1.32e^{-9}
		b		3.293	3.293
Stock recruitment relationship					
Stock recruitment steepness		h	0.84		
Recruitment variability		σ_R	0.7		
Ageing error		CV	0.06		
Proportion male at birth			0.5		
Proportion of mature that spawn			1.0		
Maximum exploitation rate (U_{max})			0.6		
Natural mortality (M)	(Horn 2008)		0.18		

Table 4: Maturity-at-age used in the Sub-Antarctic ling stock models (from Mormede et al. 2024a).

Age	3	4	5	6	7	8	9	10	11	12	13
Male	0.0	0.04	0.16	0.41	0.72	0.91	0.98	0.99	1.00	1.00	1.00
Female	0.0	0.01	0.01	0.12	0.28	0.55	0.78	0.91	0.97	0.99	1.00

2.3 Estimation of parameters

The logarithm of initial spawning stock biomass (B_0) was estimated in the model. The longline fisheries and research survey selectivity ogives were estimated and assumed to be logistic curves. The trawl selectivities were assumed double normal with the right-hand fixed at 100 as was used in the 2021 assessment (Mormede et al. 2021b); a sensitivity analysis with logistic selectivity showed that this parameterisation had little effect. Estimated parameters are summarised in Table 5.

Because no potting trips have been observed in LIN 5&6, 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 across 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). An attempt to estimate natural mortality for this stock was unsuccessful in 2021, with the estimation being both highly uncertain and biased (Mormede et al. 2021b). Length-based natural mortality was attempted as a sensitivity analysis.

Most of the priors were assumed to be relatively uninformative (i.e., uniform or uniform-log) and were specified with wide bounds. The exception was the choice of an informative prior for the trawl survey catchability q, which was assumed lognormal with μ of 0.07 and CV of 0.7 in 2021 (2021b). This prior had undue influence in the 2024 model and was therefore changed to a uniform prior (see below). In all models, the catchability coefficients (qs) 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 (also known as a broken stick approach: the sum of the parameters equals 1). 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.

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. Three MCMC chains with a total length of 6×10^6 iterations each were constructed. A burn-in length of 1×10^6 iterations was used, with every 1000th sample taken from the final 5×10^6 iterations (i.e., a final sample of length 5000 was sampled from the posterior for each of the three independent chains).

Table 5: Parameters estimated in the Sub-Antarctic ling stock models.

Parameter	Shape/ transformation	Starting values			Prior distribution	Parameters		Bounds	
B_0	Log transform	200 000			Uniform			10	13
Year class strengths	Simplex transform	1			Lognormal	1	0.7	-10	10
Survey selectivity	Logistic	5	3		Uniform			0.001-1	5–200*
Trawl selectivity	Double normal Right-hand fixed at 100	10	3	100	Uniform			1	5–200*
Lines selectivity	Logistic	11	3		Uniform			1	5–200*
Survey *q* (free)		0.12			Uniform			0.02	4.0
CPUE *q* (free)		0.01			Uniform			0.0001	10
Survey process error~		0.1			Uniform-log			0.001	2
CPUE process error~		0.2			Uniform-log			0.001	2

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

3. RESULTS

3.1 Update of the 2021 model

The 2021 base case (Mormede et al. 2021b) was used as the starting point for model development. The 2024 initial model was developed by making incremental changes to the 2021 base case, including updating to Casal2 (Casal2 Development Team 2024), 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. This excludes estimates process errors, which were still estimated within the model. Details of the steps are given in Table 6.

The update of the observations was the most influential to the model, particularly on the 2021 stock status. The update of the maturity ogive modified the spawning stock biomass as expected but had little effect on stock status. The update of the catch history to exclude Statistical Area 032 had a more moderate effect on spawning stock biomass and no effect on stock status.

Once the data were re-weighted, the 2024 initial case had a similar estimate of initial biomass but lower estimate of status in 2021 as the 2021 base case model (Table 7). The lower stock status in 2021 was driven by low estimates of recent recruitment which were not estimated in the 2021 model (see below).

An initial investigation into this initial model indicated that the survey catchability priors (q) had an undue influence on the model outcomes, influence it did not have in the 2021 assessment. The priors were modified from a logistic prior to a uniform prior. This resulted in a slight drop in initial biomass and stock status, due to a slight drop in the estimated survey catchability coefficients q (Table 7).

Finally, the catches from LIN 6B were added to the model. Initial biomass increased by about 12 400 t and stock status did not change measurably (Table 7). This increase in biomass is consistent with the estimated initial biomass of LIN 6B when it was assessed as a separate stock in 2007: its initial biomass was estimated at 13 570 t with 95% credible interval of 10 850 – 19 030 t (Horn 2008).

Table 6: Incremental model build from the 2021 base case to the 2024 initial model run at MPD level. The data were not re-weighted between models. 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_{2021} (t)	SSB_{2021} (% B_0)
R0.0	Casal 2021 base	2 619	187 350	132 780	70.8
R0.1	Casal2 2021 base	2 618	180 102	126 239	70.1
R0.2	Clean up	2 717	179 930	125 894	70.0
R0.3	Start January	2 680	182 349	127 003	69.6
R0.4	q free	2 677	188 575	133 545	70.8
R0.5	Update catches	2 676	184 980	129 913	70.2
R0.6	Update observations	2 630	190 110	126 709	66.7
R0.7	Update maturity ogive	2 630	182 793	120 777	66.1
R0.8	Update to 2024	2 906	184 914	113 525	61.4

Table 7: 2021 base and 2024 initial models MPD estimates, once data were re-weighted.

Run	Model description	B_0 (t)	SSB_{2021} (t)	SSB_{2021} (% B_0)	SSB_{2024} (t)	SSB_{2024} (% B_0)
R0.0	Casal 2021 base	187 350	132 780	70.8		
R1.0	Initial	183 381	111 059	60.6	111 059	60.6
R1.1	Uniform survey q priors	175 159	103 513	59.1	103 513	59.1
R2.0	Add LIN 6B catches	187 570	111 990	59.7	111 990	59.7

3.2 Investigating CPUE

In 2021, the bottom longline standardised CPUE in LIN 5&6 was assumed to represent the underlying ling abundance and was used in the stock assessment (Mormede et al. 2021b). In the 2024 update, the bottom longline standardised CPUE was more variable than previously estimated, which was thought to be due to a combination of data selection (Statistical Area 032 was removed from LIN 5&6 in 2023) and subsequent different core vessel selection (Mormede et al. 2024a). Furthermore, the standardised CPUE series spans from 1991 to 2023, and there were concerns that the standardisation might not have fully accounted for changes in technology and other changes that might lead to a progressive improvement in catchability over time. An arbitrary 1% annual learning rate (effort creep) has been used in rock lobster stock assessments (Fisheries New Zealand 2023b) to deal with this problem.

On the other hand, a spatial-temporal standardisation of bottom longlines was assumed to not necessarily suffer from the same issues and was approved by the Fisheries New Zealand Deepwater Working Group (DWWG) for use in a sensitivity analysis. This series spans 2004–2023 due to the lack of set-by-set data before then (Mormede et al. 2024a), and includes LIN 5&6 and LIN 6B.

The following sensitivity analyses of CPUE were conducted at MCMC level:

- Use the non-spatial standardised CPUE from 1991 to 2023 as per previous stock assessments.

- Use the non-spatial standardised CPUE from 1991 to 2003 and the spatial standardised CPUE index from 2004 to 2023.
- Exclude all CPUE indices from the model.
- Include the non-spatial standardised CPUE from 1991 to 2023 with an arbitrary 1% annual learning rate.
- Include the non-spatial standardised CPUE from 1991 to 2023 with an arbitrary 0.5% annual learning rate.

Results showed that removing the non-spatial bottom longline CPUE index resulted in a higher estimate of initial biomass (Table 8). This is not surprising as most of the information about the maximum value of initial biomass was contained in the longline CPUE index (Figure 1). The other models had varying levels of initial biomass between those two extremes and are not reported here.

The model was poorly informed on which of these sensitivity runs might be most supported by the remaining data in the model: excluding the CPUE index resulted in an improvement in negative log likelihood (NLL) of only three points, consisting of an improvement of six NLL points to the fits to the summer survey, and a reduction of two NLL points to the commercial age compositions. The DWWG recommended the model excluding CPUE be the base case for this stock assessment, as it led to a small improvement in the fits to the survey data whilst the other models had some arbitrary decisions made on the potential learning rate of the fleet.

Table 8: Results of the model sensitivity runs investigating various treatments of the bottom longline CPUE. CI is the 95% credible interval range of the posterior distribution.

Run	Model description	B_0 (t)	B_0 CI range (t)	SSB_{2024} (% B_0)	SSB_{2024} CI range (% B_0)
R2.0a	Non-spatial CPUE only	182 244	158 594 – 219 454	57.6	51.0 – 65.2
R3.0	Non-spatial and spatial CPUE	200 908	172 508 – 246 076	67.9	61.3 - 75.3
R7.0	no CPUE	205 459	171 639 – 262 863	67.5	58.4 – 77.7
R7.1	CPUE 1% learning rate	199 207	170 151 – 246 659	64.1	56.9 – 71.8
R7.3	CPUE 0.5% learning rate	189 985	163 654 – 230 473	60.7	53.9 – 68.4

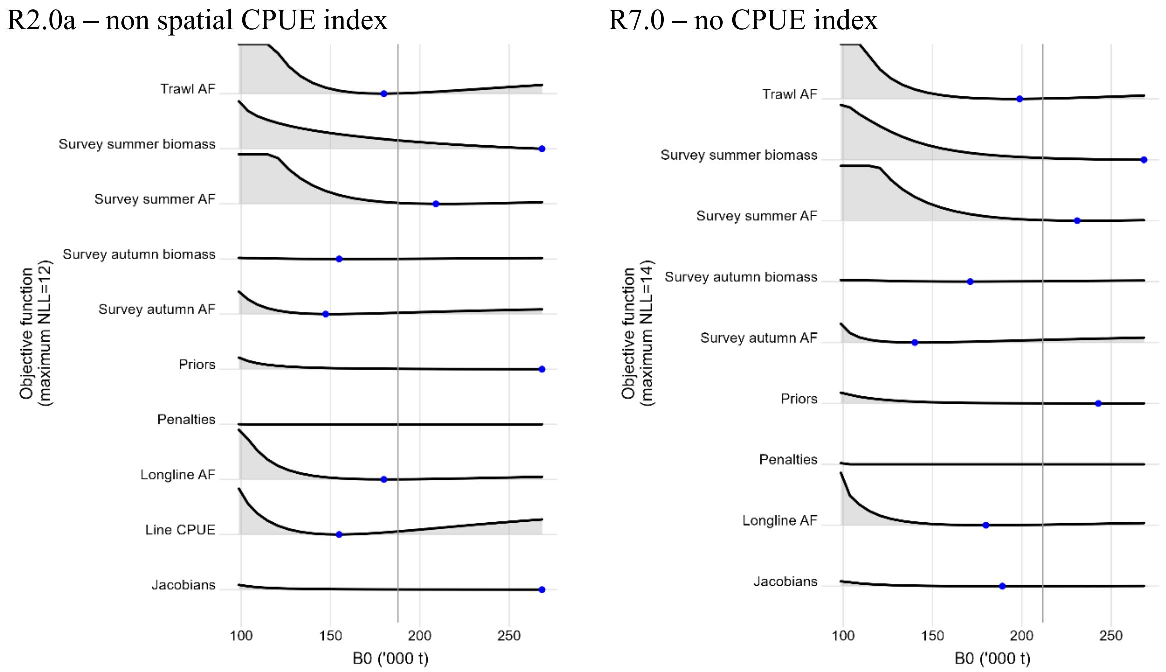

Figure 1: MPD profile on B_0 for the model with non-spatial CPUE (R2.0a, left) or without CPUE (R7.0, right). NLL = negative log likelihood, AF = age composition data.

3.3 Investigating natural mortality

The estimation of natural mortality within the stock assessment model was attempted in 2021 (Mormede et al. 2021a). Natural mortality was estimated at about 0.21 y^{-1} but was not well informed by the data. Furthermore, simulations showed that the estimates were biased high by about 0.02 y^{-1}. Consequently, a fixed natural mortality value of 0.18 y^{-1} was used in the 2021 assessment (as used in the previous assessments and most other ling stock assessments) and as the initial case in the 2024 assessment (Table 3).

Following recent scientific developments (Huynh et al. 2018; Lorenzen et al. 2022; Lorenzen 2022), length-based natural mortality was investigated for ling in the Sub-Antarctic. Natural mortality was applied as a length-based selectivity with the following parameters:

$$selectivity = a \times length^{b}$$
$$natural\ mortality = M \times selectivity,$$

whereby M was fixed at 0.18 y^{-1}, parameter b was set at -1 following recommendations (Huynh et al. 2018; Lorenzen et al. 2022; Lorenzen 2022), and parameter a was estimated with a normal prior with standard deviation (mu = 100, sigma = 100). Chiefly, if $a = 100$, the natural mortality of a fish of length 100 cm would be 0.18 y^{1}.

The estimation of parameter a was successful, with a well-behaved MCMC chain, but was only based on two NLL points due to the lack of young fish caught by the fishery to inform this curve. This parameterisation of natural mortality resulted in a differential mortality at age by sex due to the differences in growth rates of males and females (Figure 2). It also increased initial biomass and biomass range, due to the uncertainty around this parameter. Because length-based natural mortality represents current best practice in stock assessment and captures the differential mortality between males and females, the DWWG recommended that a sensitivity run be carried out on the final model with length-based natural mortality and with its parameter a fixed at 98 cm as per the median of the posterior distribution. Fixing parameter a was deemed important to avoid increasing the uncertainty in the estimate of initial biomass too much. The usual bounding sensitivities of $M = 0.16$ y^{-1} and $M = 0.20$ y^{-1} were also conducted as per previous stock assessments. These are summarised below.

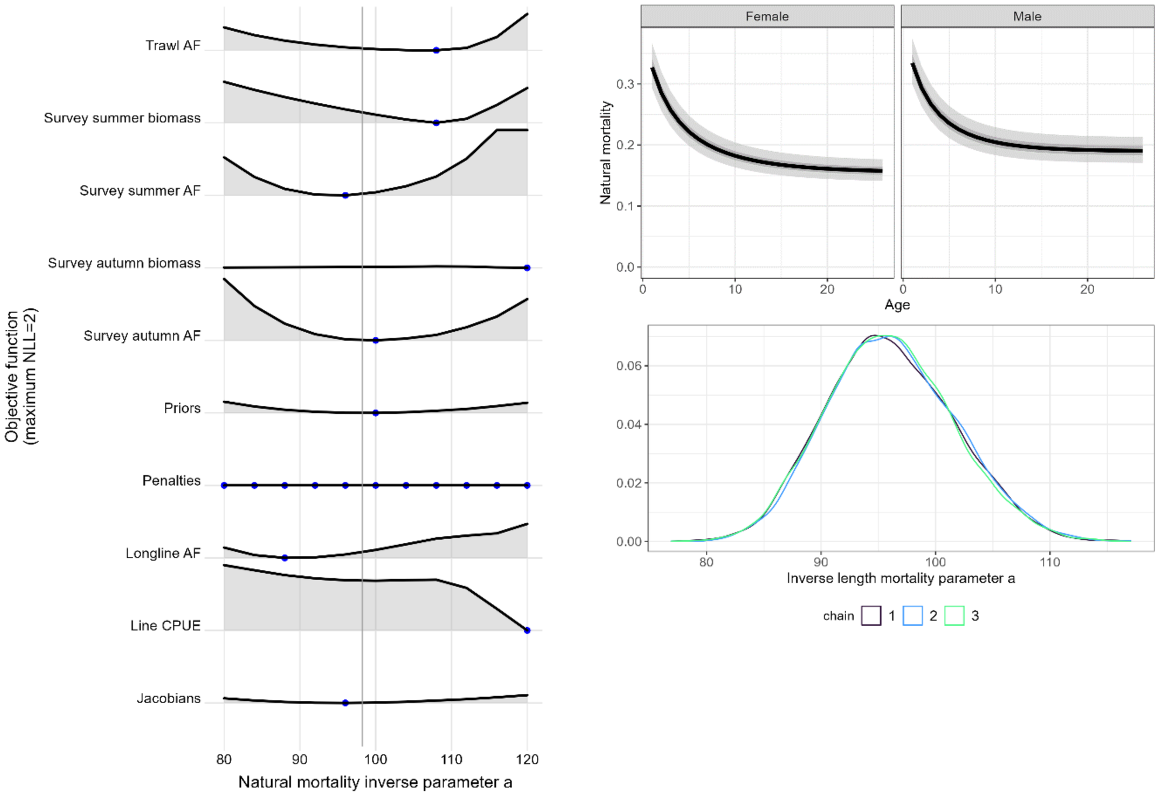

Figure 2: Diagnostics on the estimation of length-based natural mortality. MPD profile on natural mortality parameter *a* (left), resulting mortality at age by sex with 95% credible interval in grey (top right) and posterior distribution of parameter *a* for the three independent chains (bottom right). NLL = negative log likelihood, AF = age composition data.

3.4 Final base case model and sensitivities

The base case of the 2024 stock assessment of Sub-Antarctic ling included LIN 5&6 and LIN 6B catches, the Sub-Antarctic summer and autumn survey biomass indices and age compositions, and the LIN 5&6 commercial bottom longline and bottom trawl age compositions. The observation data included in the base case model and their associated error values are detailed in Figure 3. Natural mortality was fixed at 0.18 y^{-1}.

The following sensitivity runs from the base case model were carried out:

- models with alternative natural mortality values of $M = 0.16$ y^{-1} and $M = 0.20$ y^{-1} were conducted as per previous stock assessments, as well as length-based natural mortality with a = 98 cm (see above),
- a model including the bottom longline non-spatial standardised CPUE,
- a model with a small amount of additional catch to represent potential under-reporting,
- and a model excluding the bottom longline age compositions.

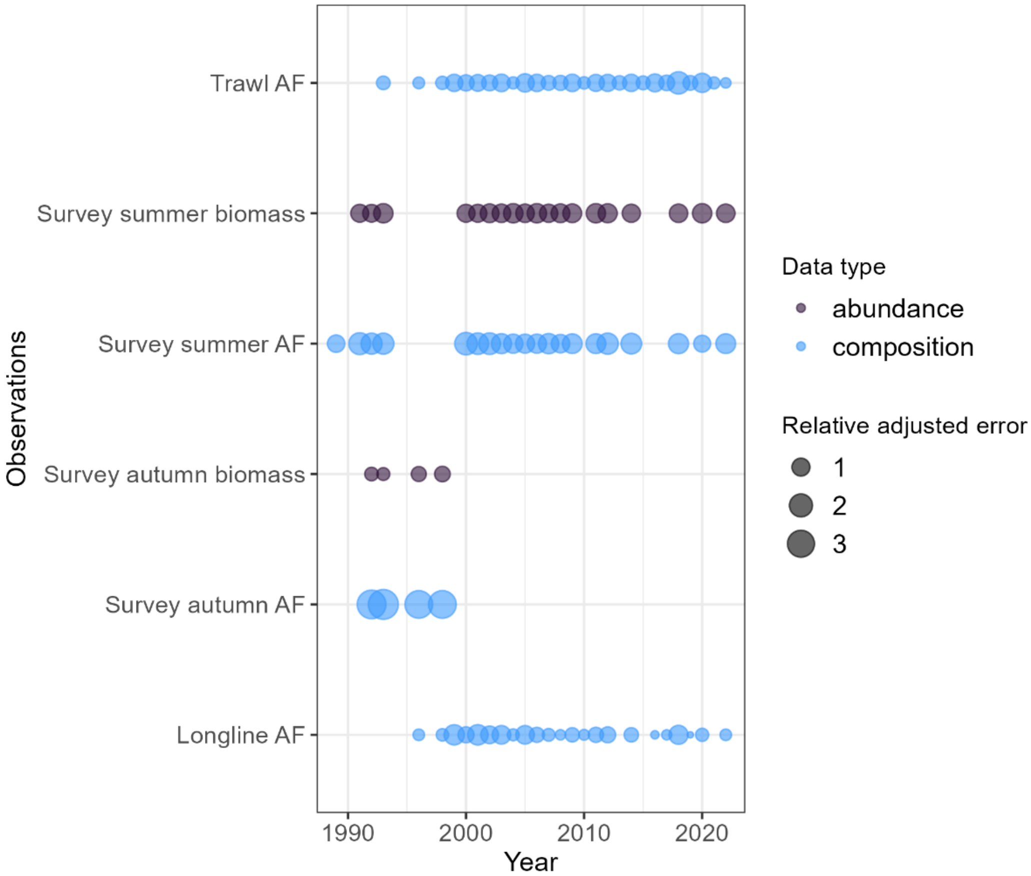

Figure 3: Observations included in the base case model and their relative adjusted error (CV and additional process error combined). The adjusted errors of abundance and age composition data are not comparable and are plotted as different colours. AF represents age compositions.

The base case estimated that B_0 was about 204 630 t for this stock, and that biomass for 2024 was about 66% 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 2024 status being above 40% B_0 was at or above 99.3%, and the probability of it being below 20% B_0 was 0% in all instances.

Adding the CPUE index reduced the initial biomass by about 10% and the 2024 stock status from an average of 66.3% B_0 in the base case to 54.3% B_0 (Table 9). Removing the bottom longline age compositions resulted in a slight increase in initial biomass and stock status in 2024, confirming that it has a limited effect on the model. The model outcomes were most sensitive to alternative values of natural mortality, assuming lower natural mortality had the most effect on the biomass status in 2024, reducing it from 66% B_0 to about 54% B_0. Length-based natural mortality had little effect on initial biomass and resulted in a small reduction in stock status in 2024, possibly due to the resulting differential natural mortality between sexes.

An alternative catch history was constructed: 5% additional fishery mortality for years before the introduction of the QMS (1986) and 2% thereafter to include the possibility of unreported catches, discards, and mortality of uncaught small fish going through the nets. This scenario resulted in a slight increase in initial biomass and equivalent stock status in 2024.

Table 9: LIN 5&6 and LIN 6B. Posterior median and 95% credible intervals (in parentheses) of B_0 (in tonnes), and B_{2024} as a percentage of B_0, and the probability that B_{2024} is above 40% and below 20% of B_0 from the base model and sensitivity runs.

Model run	B_0		B_{2024} (% B_0)		P(>40% B_0)	P(<20% B_0)
Base model	204 628	171 734 – 258 458	66.3	55.3 – 78.3	1.000	0.000
Base + CPUE	180 575	157 476 – 215 386	54.3	45.5 – 64.0	0.999	0.000
Base - BLL AF	212 692	175 995 – 275 733	69.3	57.6 – 82.1	1.000	0.000
M=0.16	158 380	142 888 – 179 277	52.1	42.3 – 62.3	0.993	0.000
M=0.20	304 797	226 047 – 419 980	76.7	65.1 – 88.3	1.000	0.000
length-based M	205 664	174 120 – 255 506	64.5	53.9 – 75.7	1.000	0.000
Additional catch	208 772	175 345 – 262 784	66.3	55.3 – 78.4	1.000	0.000

Biomass estimates for the stock have been variable and generally declining since the start of the model in 1970 (Figure 4). Posterior distributions of year class strength from the base case model are shown 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 more uncertain at the start of the series. They also show continued lower than average recent recruitment, from 2010 to 2017, the last estimated recruitment year in the model. Annual exploitation rates have been generally increasing over time for bottom trawl and were highly variable for bottom longline, with a recent increase in exploitation rate (Figure 6). The overall stock exploitation rate showed an increase to 2000, decline to about 2010, and increase again since then, to near the highest levels seen in the model (Figure 7).

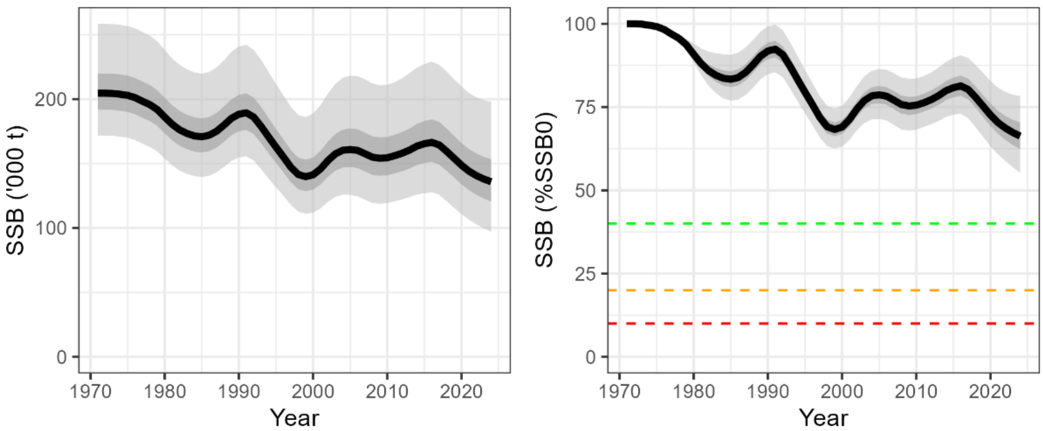

Figure 4: Sub-Antarctic ling estimated posterior distribution of the spawning stock biomass (*SSB* in tonnes, left) and of the proportion of initial spawning biomass (% SSB_0, right) trajectory with estimated initial spawning stock biomass reference points (40%, 20%, and 10% B_0) for the base case model.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

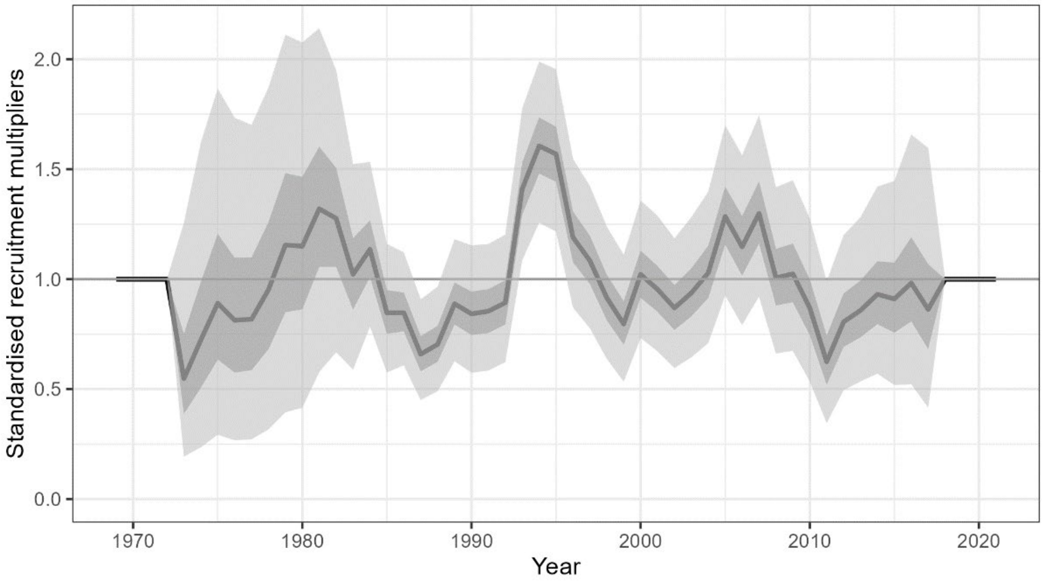

Figure 5: Sub-Antarctic ling estimated posterior distributions for standardised recruitment multipliers from the base case run, with median (line), the interquartile range (dark grey), and 95% credible interval (light grey). The horizontal line indicates a recruitment multiplier value of one.

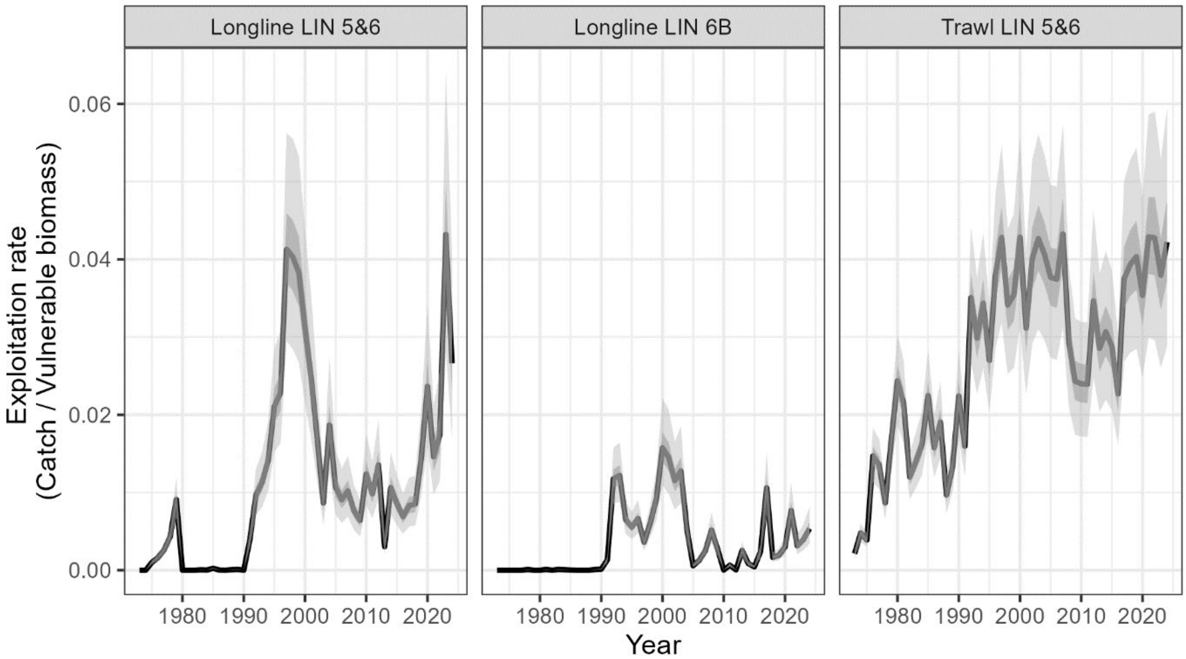

Figure 6: Sub-Antarctic ling base model exploitation rates expressed as catch (in tonnes) divided by vulnerable biomass (in tonnes) by fishery and area with the interquartile range (dark grey) and 95% credible interval (light grey).

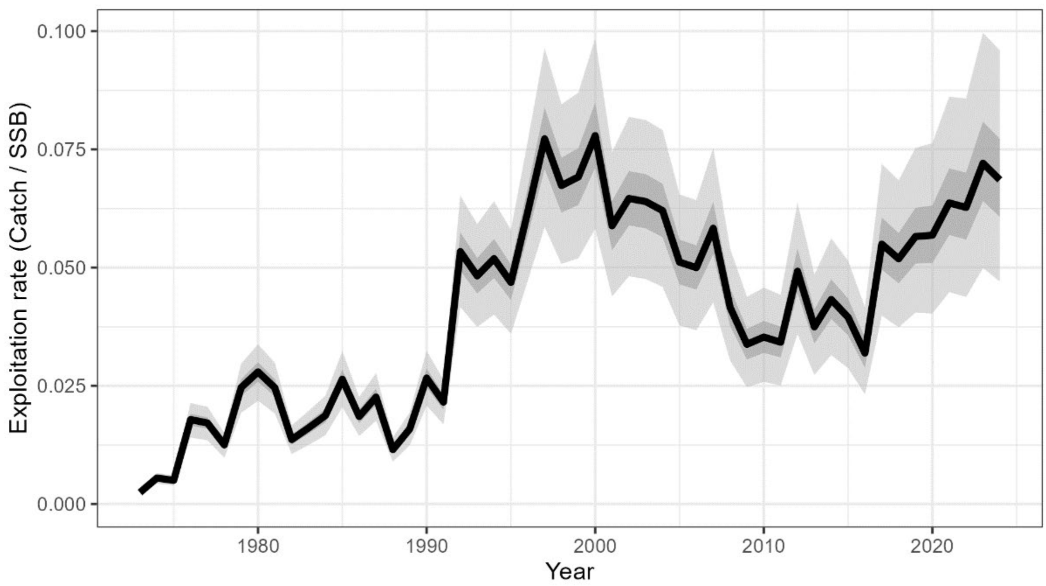

Figure 7: Sub-Antarctic ling base model overall exploitation rate expressed as catch (in tonnes) divided by spawning stock biomass (SSB, in tonnes) with the interquartile range (dark grey) and 95% credible interval (light grey).

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, apart from the model with length-based natural mortality as differential natural mortality between sexes resulted in a slightly different value of parameter alpha for the commercial selectivities (not shown). 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). Fits to the abundance indices generally captured the trends over time within the confidence bounds of each series, although the model could not fit to the scale of the variability of the summer survey biomass index (Figure A.4 for the base case).

There was no evidence of a lack of convergence of the MCMCs (Figure A.5). Multichain diagnostic using approximate $\hat{r}$ statistics (Vehtari et al. 2017) and effective sample size did not suggest any evidence of non-convergence (Figure A.6 and Figure A.7 respectively). Trace plots also showed no evidence of failure to converge for the base case model (Figure A.8 and Figure A.9) or the sensitivity models (not shown).

Because the Sub-Antarctic stock status is expected to still be high, at about 66% of initial biomass, the model has no information on what the stock recruitment relationship might be (Figure 8), and an assumed steepness of 0.84 was maintained in this assessment as per previous assessments (Mormede et al. 2021b).

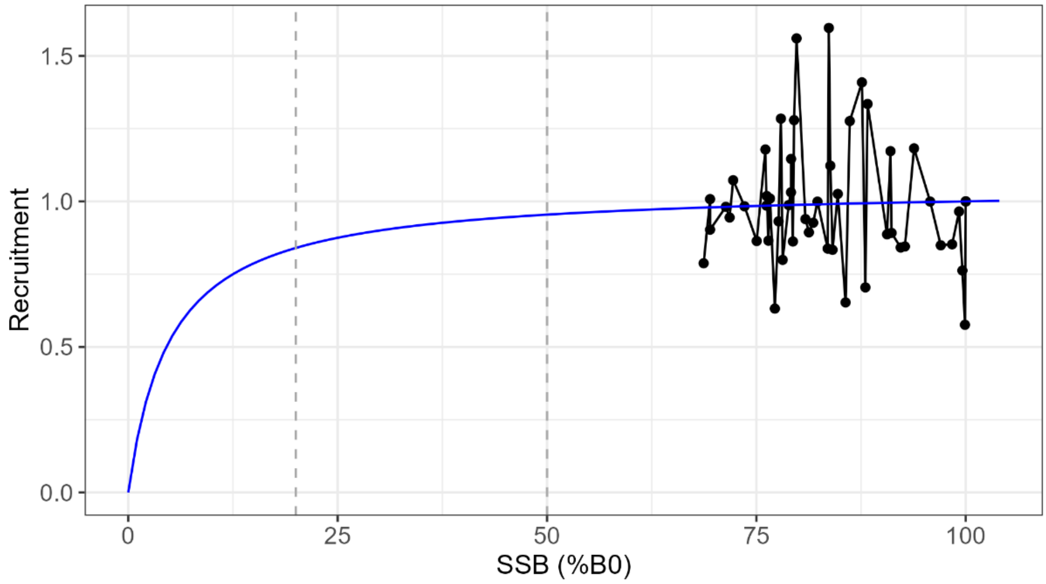

Figure 8: Sub-Antarctic ling stock recruit relationship, with spawning stock biomass (SSB) as a proportion of initial spawning stock biomass (B0) is plotted against recruitment strength for each year of the model. The assumed stock recruit relationship with steepness of 0.84 is plotted as a blue line.

3.5 Projections

Projected stock status

Because recent recruitment has been lower than average (Figure 5), projections were carried out by either resampling the full range of estimated year class strengths, or the last ten estimated years. They were also carried out using either the average of the 2020–23 catches, or the TACC for LIN 5 and LIN 6 combined, noting that the ling catch in LIN 6 has been well below the TACC since 2003 (Fisheries New Zealand 2024). All projections were carried out using the base case model.

For LIN 5&6 and LIN 6B, the probability of B_{2029} being below 40% of B_0 was very small when assuming either one of two future annual catch scenarios (the average catch from 2020–2023, or the TACC apportioned to the 2020–2023 catches between the fisheries) and long term (1973–2017) or recent (2008–2017) recruitment (Table 10 and Figure 9).

Additional projections were carried out whereby the LIN 5 catch limit was increased by 10, 20, or 30%. These projections assumed recent recruitment (2008–2017), and that the catch split between trawl and longline remained the same as the 2020–2023 average. The probability of B_{2029} being below 40% of B_0 was very small in those instances as well.

Table 10: LIN 5&6 and LIN 6B. Posterior median and 95% credible intervals (range) of projected B_{2029}, B_{2029} as a percentage of B_0, B_{2029}/B_{2024} (%) and probability of B_{2029} being over 40% B_0 in 2029 (pab40) for the base case run and different recruitment and future catch split options. YCS range is the range of years where recruitment was resampled for the projections and catch range is the basis of future catches (either 2020–23 or TACC). Future catch is also reported for the LIN 5&6 trawl fishery (trawl), LIN 5&6 longline fishery (line) and LIN 6B fishery (6B).

YCS range	Catch range	Future catch (t) trawl	line	6B	B_{2029} (t)	B_{2029} (t) range	B_{2029} (% B_{2024})	B_{2029} (% B_{2024}) range	B_{2029} (% B_0)	B_{2029} (% B_0) Range	pab40
1973–2017	2020–23	6 954	1 967	396	133 874	95 594 – 194 403	98.4	91.9 - 106.4	65.3	54.3 – 77.4	1.000
2008–2017	2020–23	6 954	1 967	396	132 208	93 368 – 194 186	97.2	91.4 - 104.1	64.5	53.2 – 77.3	1.000
1973–2017	TACC	10 235	2 895	583	119 754	81 531 – 180 217	88.0	80.5 - 96.1	58.4	46.5 – 71.4	0.999
2008–2017	TACC	10 235	2 895	583	118 044	79 315 – 179 991	86.8	79.4 - 94.5	57.6	45.3 – 71.5	0.998
2008–2017	LIN5+10	7 360	2 082	396	130 530	91 691 – 192 494	95.9	90.0 - 102.9	63.6	52.2 – 76.6	1.000
2008–2017	LIN5+20	7 766	2 197	396	128 852	90005 – 190 803	94.7	88.7 - 101.6	62.8	51.3 – 75.9	1.000
2008–2017	LIN5+30	8 172	2 311	396	127 174	88 327 – 189 116	93.4	87.4 - 100.5	62.0	50.3 – 75.2	1.000

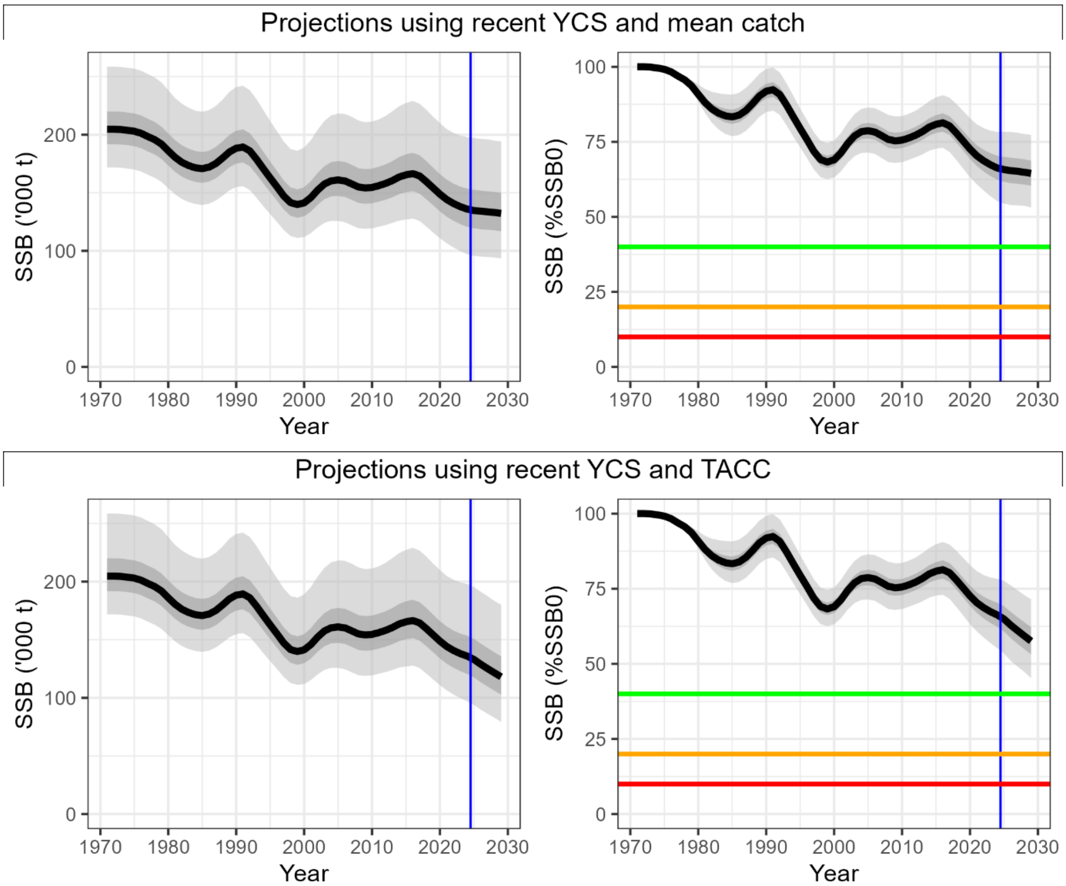

Figure 9: Trajectory over time of relative spawning biomass (with interquartile range in dark grey and 95% credible intervals in light grey) for the LIN 5&6 and LIN 6B base model from the start of the assessment period in 1973 to the most recent assessment in 2024 (vertical blue line) and projected to 2029 with future catches as either the average of the catch from 2020–2023 (9317 t) (top row) or TACC (13 713 t) (bottom row). Years on the x-axis are calendar year. 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). Projections were undertaken by resampling recent year class strengths (2008–2017).

Projected LIN 5 exploitation rate

The fishery in the Sub-Antarctic stock has been disproportionately concentrated on the LIN 5 FMA whereby the catch is at the TACC in LIN 5 but not in LIN 6. Increasing catch limits without considering the relative exploitation rates in the two FMAs risks localised overexploitation even within acceptable stock status. A projected relative exploitation rate for LIN 5 FMA was calculated for the various projections carried out. When projecting at the TACC, the catch in LIN 5 was assumed to increase in both LIN 5 and LIN 6 FMAs proportionally to the total increase.

The LIN 5 exploitation rate was estimated as the ratio of LIN 5 catch by the proportion of the total stock SSB expected to be in LIN 5 (Table 11, Figure 10). This proportion was assumed to be either 25% based on the results of the spatial CPUE analysis (Mormede et al. 2024a) or 30% based on the 2010 ratio of TAC between the two FMAs as this ratio was set up based on expected population split (K. Sullivan, pers. comm., Plenary meeting 14th May 2024). A proportion of about 20% based on the Sub-Antarctic trawl survey was deemed unrealistically low; it was both highly variable and did not sample LIN 6B, therefore not used here.

The probability of the LIN 5 exploitation rate being below the target exploitation rate (*U_{40}*) was over 50% for all projections at current catches, indicating that the exploitation rate was below the target exploitation rate under those assumptions.

If the LIN 5 SSB was assumed to be 25% of the total stock SSB, the exploitation rate in LIN 5 in 2029 was expected to exceed the target exploitation rate more than 50% of the time for catch increases in LIN 5 of 20% upwards. A 10% increase in the LIN 5 TACC would increase the LIN 5 exploitation rate to about target exploitation rate. If the LIN 5 SSB was assumed to be 30% of the total SSB, the exploitation rate in LIN 5 in 2029 was expected to exceed target exploitation rate more than 50% of the time for catch increases of 30% upwards (Table 11).

Table 11: LIN 5&6 and LIN 6B. Posterior median and 95% credible intervals (range) of projected B_{2029}, B_{2029} as a percentage of B_0, and probability of the LIN 5 exploitation rate being over U_{40} (of 0.176) in 2029 (pLIN5 < U40) under the assumption of LIN 5 being 30% or 25% of the total stock *SSB* for the base case run and different recruitment and future catch split options. YCS range is the range of years where recruitment is resampled for the projections and catch range the basis of future catches (2020–23 or TACC). Future catch is also reported for the LIN 5&6 trawl fishery (trawl), LIN 5&6 longline fishery (line) and LIN 6B fishery (6B).

YCS range	Catch range	Future catch (t)			B_{2029} (t)	B_{2029} (t) range	B_{2029}	B_{2029} (%B_0)	pab40	pLIN 5 < U40	
		trawl	line	6B			(%B_0)	Range		30% SSB	25% SSB
1973–2017	2020–23	6 954	1 967	396	133 874	95 594 – 194 403	65.3	54.3 – 77.4	1.000	0.96	0.76
2008–2017	2020–23	6 954	1 967	396	132 208	93 368 – 194 186	64.5	53.2 – 77.3	1.000	0.95	0.73
1973–2017	TACC	10 235	2 895	583	119 754	81 531 – 180 217	58.4	46.5 – 71.4	0.999	0.17	0.04
2008–2017	TACC	10 235	2 895	583	118 044	79 315 – 179 991	57.6	45.3 – 71.5	0.998	0.16	0.03
2008–2017	LIN5+10	7 360	2 082	396	130 530	91 691 – 192 494	63.6	52.2 – 76.6	1.000	0.84	0.51
2008–2017	LIN5+20	7 766	2 197	396	128 852	90005 – 190 803	62.8	51.3 – 75.9	1.000	0.68	0.30
2008–2017	LIN5+30	8 172	2 311	396	127 174	88 327 – 189 116	62.0	50.3 – 75.2	1.000	0.48	0.16

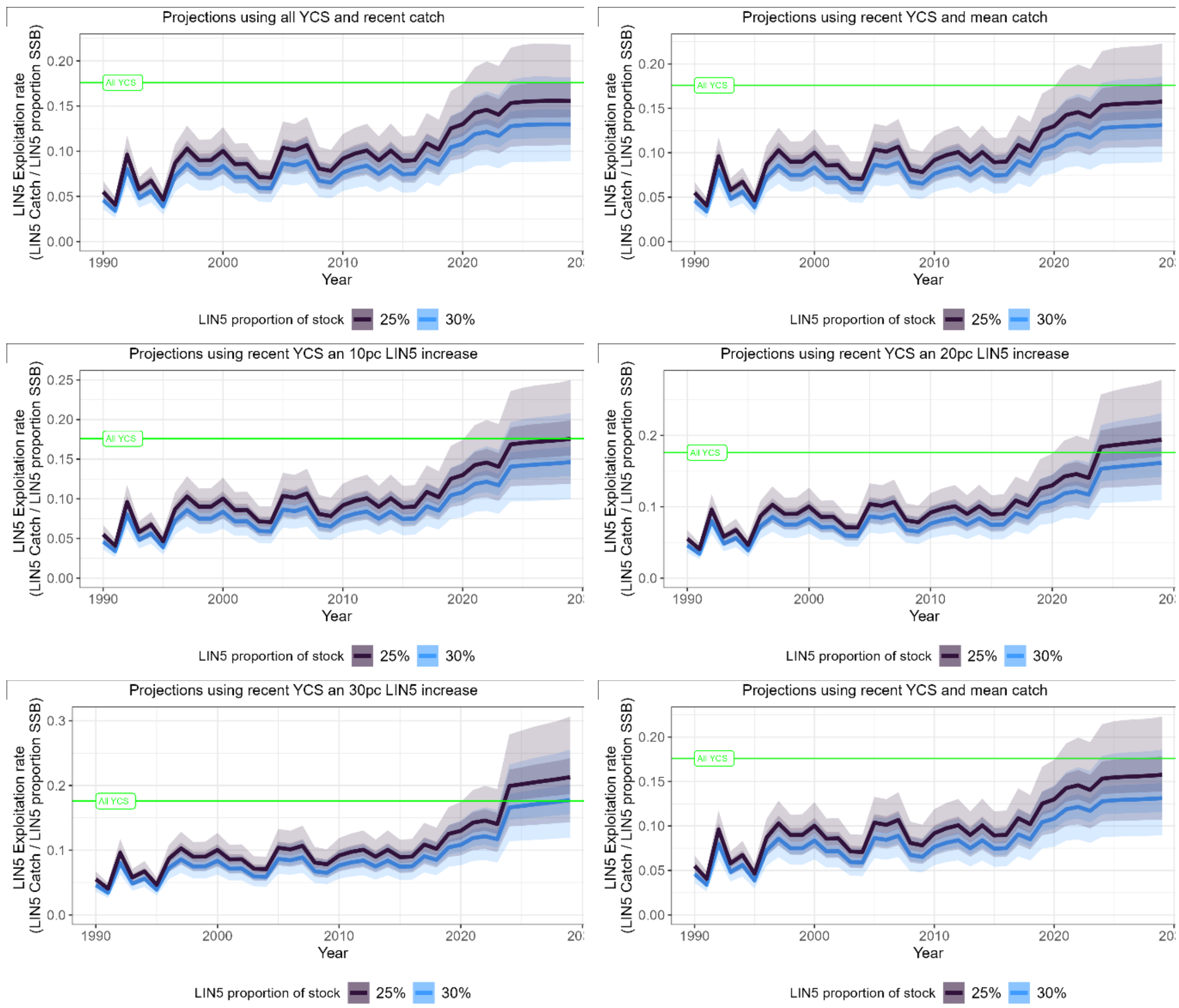

Figure 10: LIN 5&6 and LIN 6B base model: LIN 5 projected exploitation rate (Catch / SSB) with interquartile range shown as dark shading and 95% credible interval as light shading. The horizontal line is the exploitation rate U40 (catch divided by SSB U40 = 0.176 under average recruitment assumptions). Two assumptions are shown on each plot: LIN 5 being 25% or 30% of the total stock SSB. Each plot represents one of the projection options (not all options are shown).

4. DISCUSSION

The stock assessment model for Sub-Antarctic ling (LIN 5&6 and LIN 6B) updated the 2021 assessment (Mormede et al. 2021b). The main changes implemented were the inclusion of LIN 6B and the exclusion of Statistical Area 032 to this stock, and the removal of the bottom longline standardised CPUE index. These changes resulted in a higher initial spawning stock biomass and stock status compared with the 2021 stock assessment. For the base case model, B_0 was estimated to be about 204 630 t and stock status in 2024 was estimated as 66% B_0.

The model trajectory was generally consistent with the survey biomass indices. Including the bottom longline CPUE resulted in a slightly lower initial biomass and stock status.

Agreed reference points for Sub-Antarctic ling include a management target of 40% B_0, a soft limit of 20% B_0, and a hard limit of 10% B_0. B_{2024} 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 11).

Based on the projections carried out, the projected stock biomass was likely to decline over the 2025–2029 period at recent catch levels, or at TACC levels, but remain well over the target. Because most of the catch is caught in LIN 5 which is likely to represent 25–30% of the total stock spawning stock biomass, projections were also benchmarked against the projected exploitation rate in LIN 5 to avoid the risk of overexploitation of part of the stock. The exploitation rate in LIN 5 remained below the target exploitation rate at current catch levels and up to 20% increases in LIN 5 catches, but exceeded the target exploitation rate beyond this level, including at total LIN 5 and LIN 6 TACC.

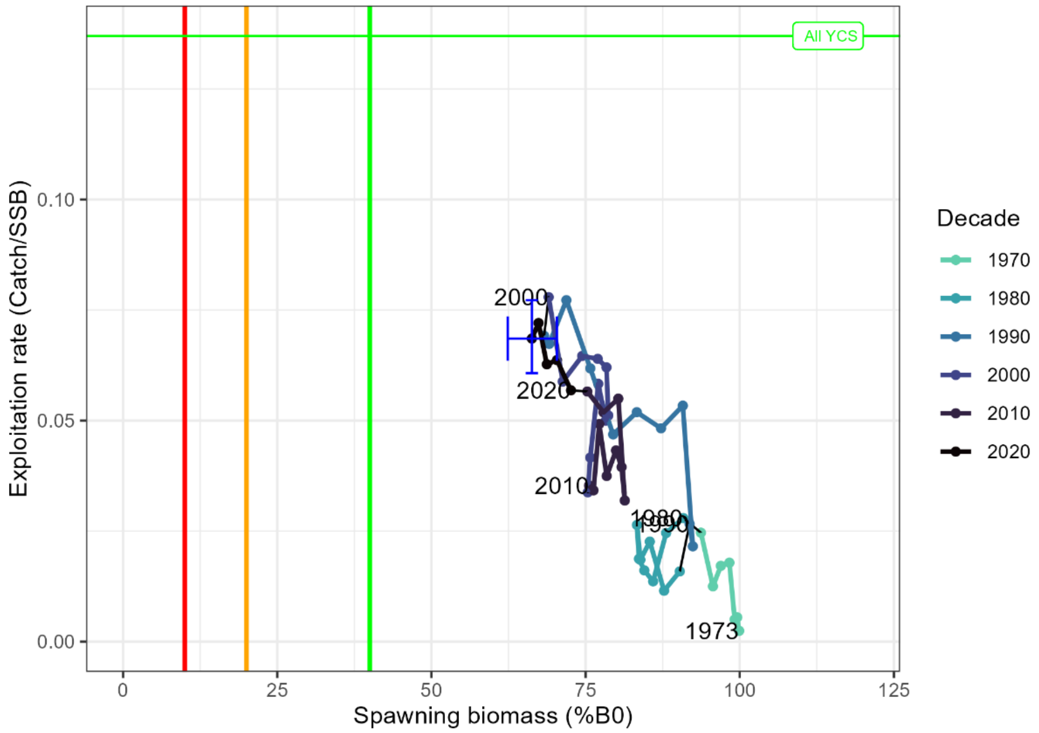

Figure 11: Trajectory over time of exploitation rate (catch/SSB) and spawning biomass (% B_0), for the Sub-Antarctic ling base model from the start of the assessment period in 1973 to 2024. The red vertical line at 10% B_0 represents the hard limit, the orange line at 20% B_0 is the soft limit, and green lines are the % B_0 target (40% B_0) and the corresponding exploitation rate (catch divided by SSB U_{40} = 0.176 under average recruitment assumptions). Biomass and exploitation rate estimates are medians from posterior distributions 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. FULFILMENT OF BROADER OUTCOMES

As required under Government Procurement rules[4], Fisheries New Zealand considered broader outcomes (secondary benefits such as environmental, social, economic or cultural benefits) that would be generated by this project. The following broader outcomes were delivered.

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.

[4] https://www.procurement.govt.nz/procurement/principles-charter-and-rules/government-procurement-rules/planning-your-procurement/broader-outcomes/

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 Project Scientist Gretchen Skea for facilitating the project and reviewing this document. 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 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 LIN2023-01.

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

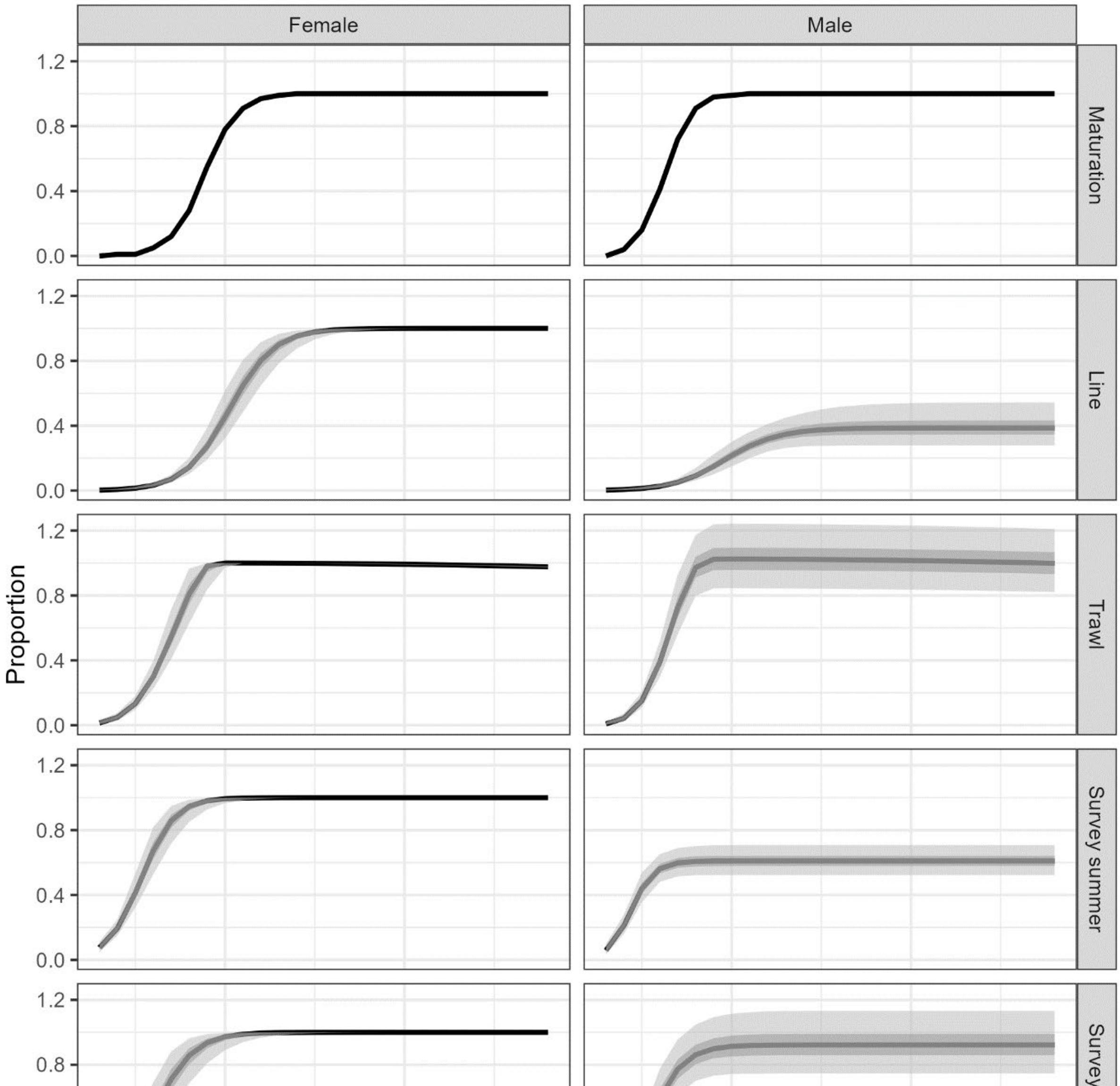

Figure A.1: Selectivity estimates with the interquartile range (dark grey) and 95% credible interval (light grey). Maturation was fixed in the model and is plotted for comparison.

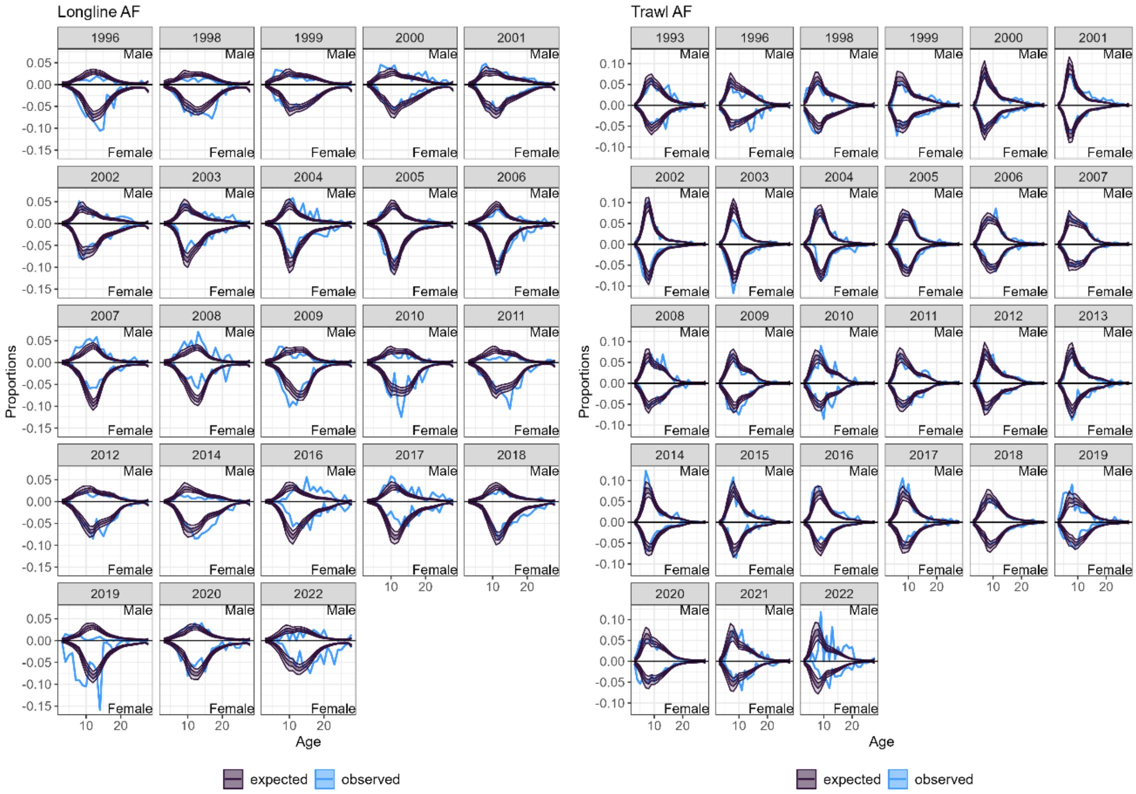

Figure A.2: Fits to the age composition (AF) data for the LIN 5&6 bottom longline fishery (left) and the LIN 5&6 bottom trawl fishery (right) with the interquartile range (dark purple) and 95% credible interval (light purple).

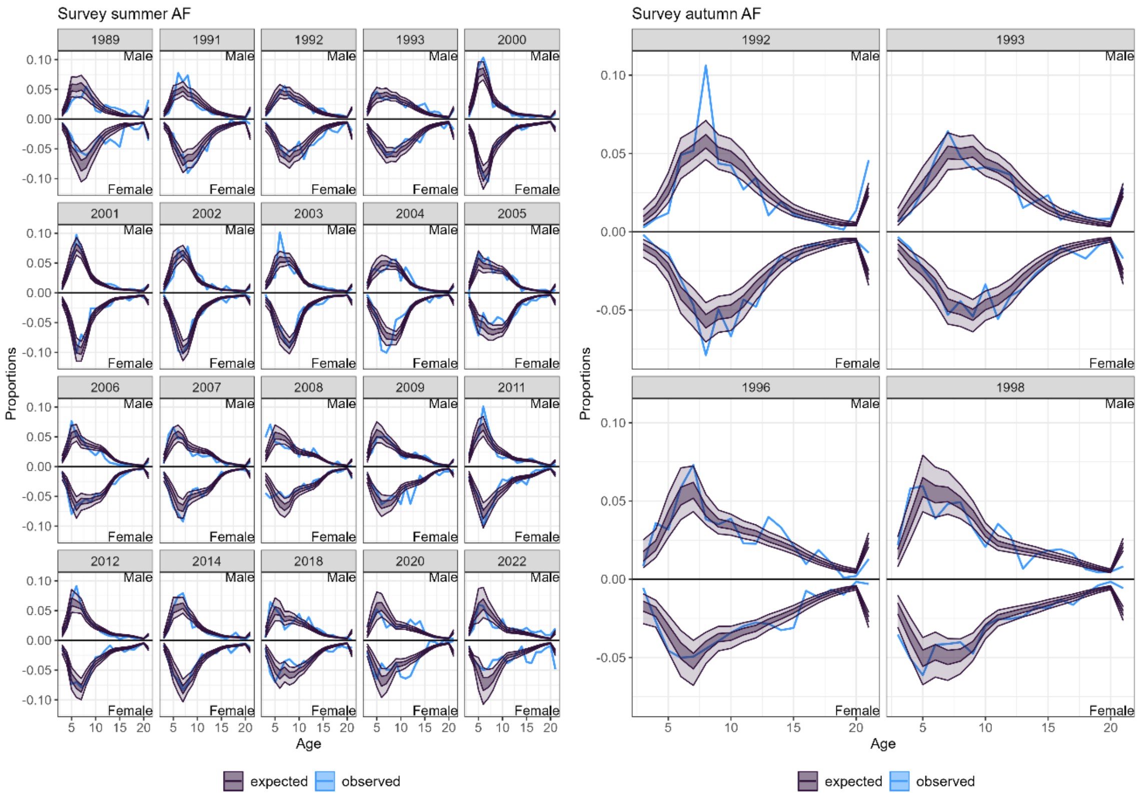

Figure A.3: Fits to the age composition (AF) data for the summer survey (left) and autumn survey (right) with the interquartile range (dark purple) and 95% credible interval (light purple).

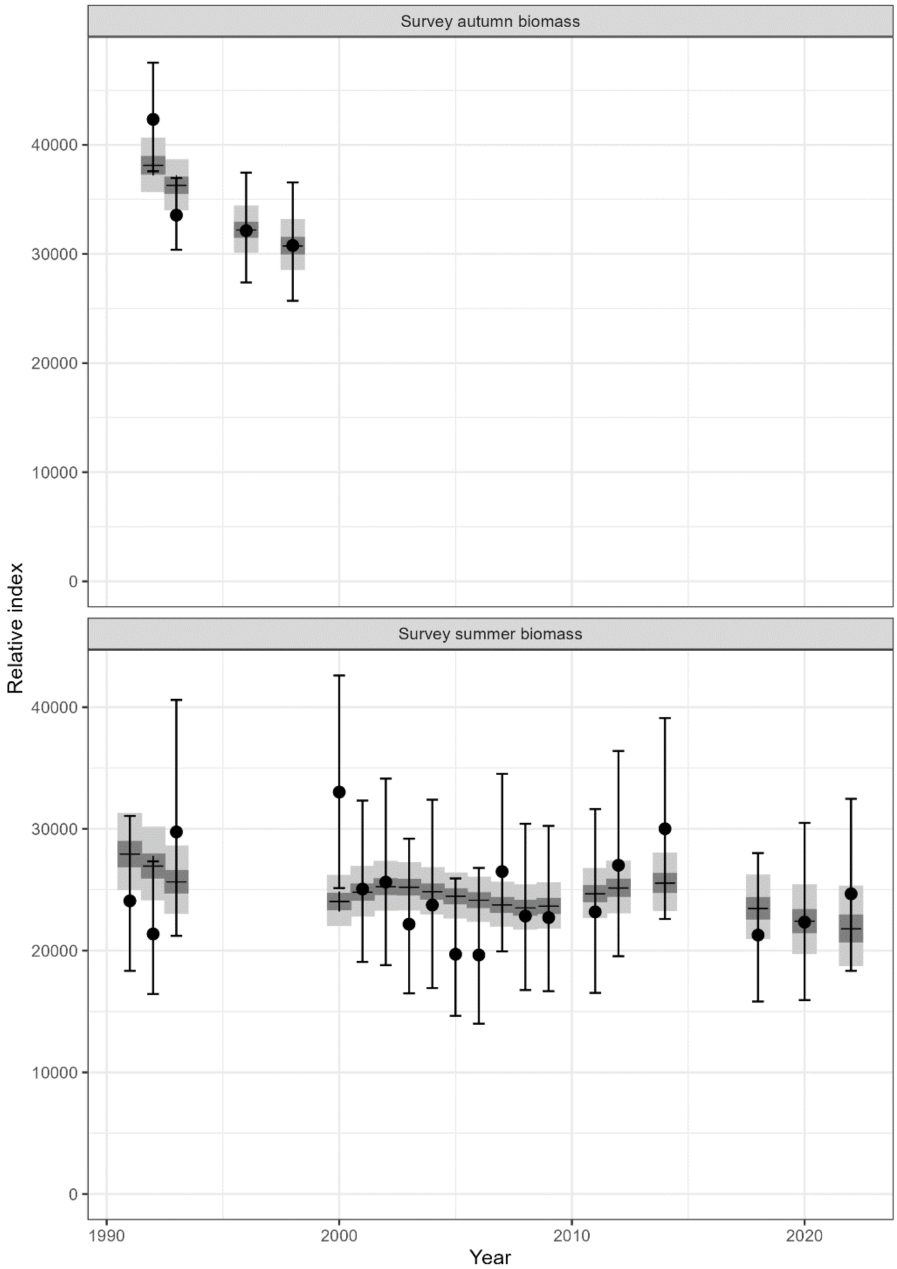

Figure A.4: Fits to the abundance indices with the interquartile range (dark grey) and 95% credible interval (light grey).

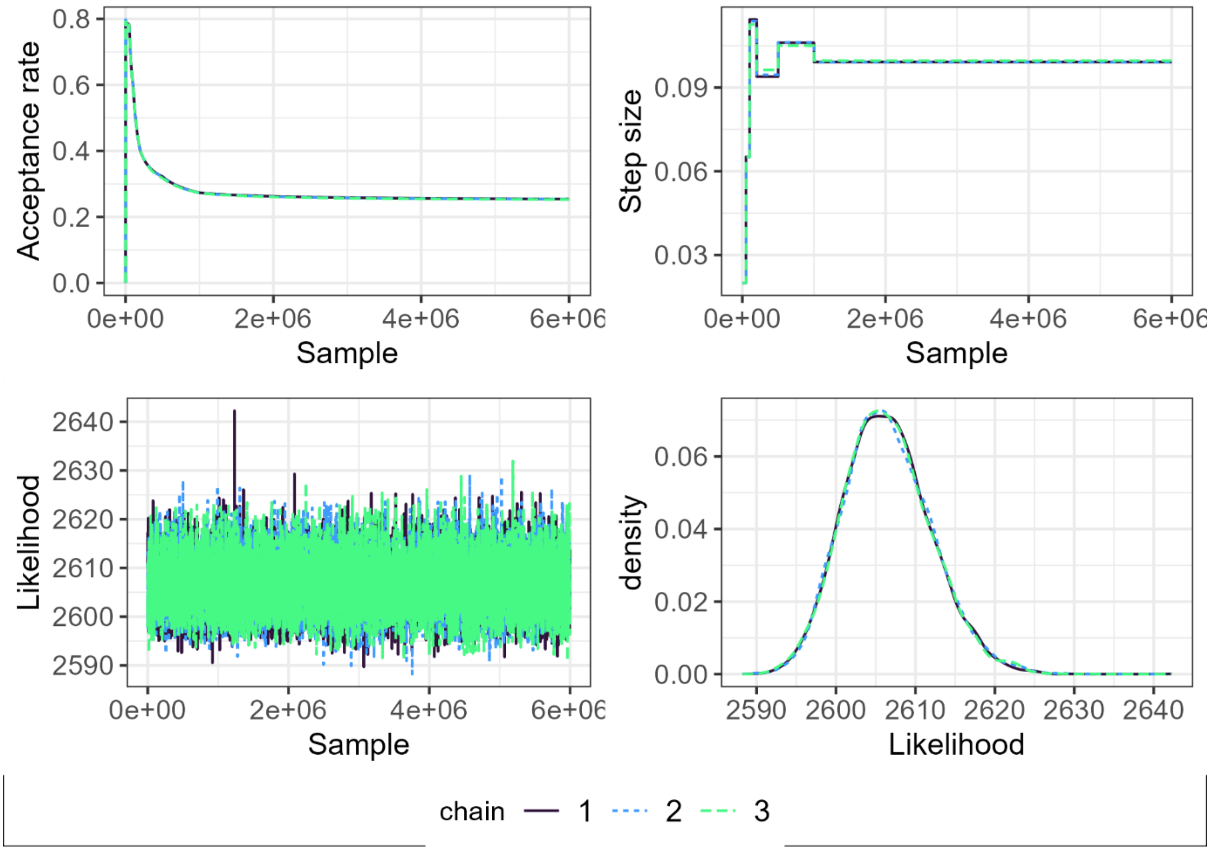

Figure A.5: MCMC diagnostic plots, showing the acceptance rate for each chain (top left), the adaptive step size for each chain (top right), the likelihood of the objective function as a function of the chain number (bottom left) and as a density distribution (bottom right).

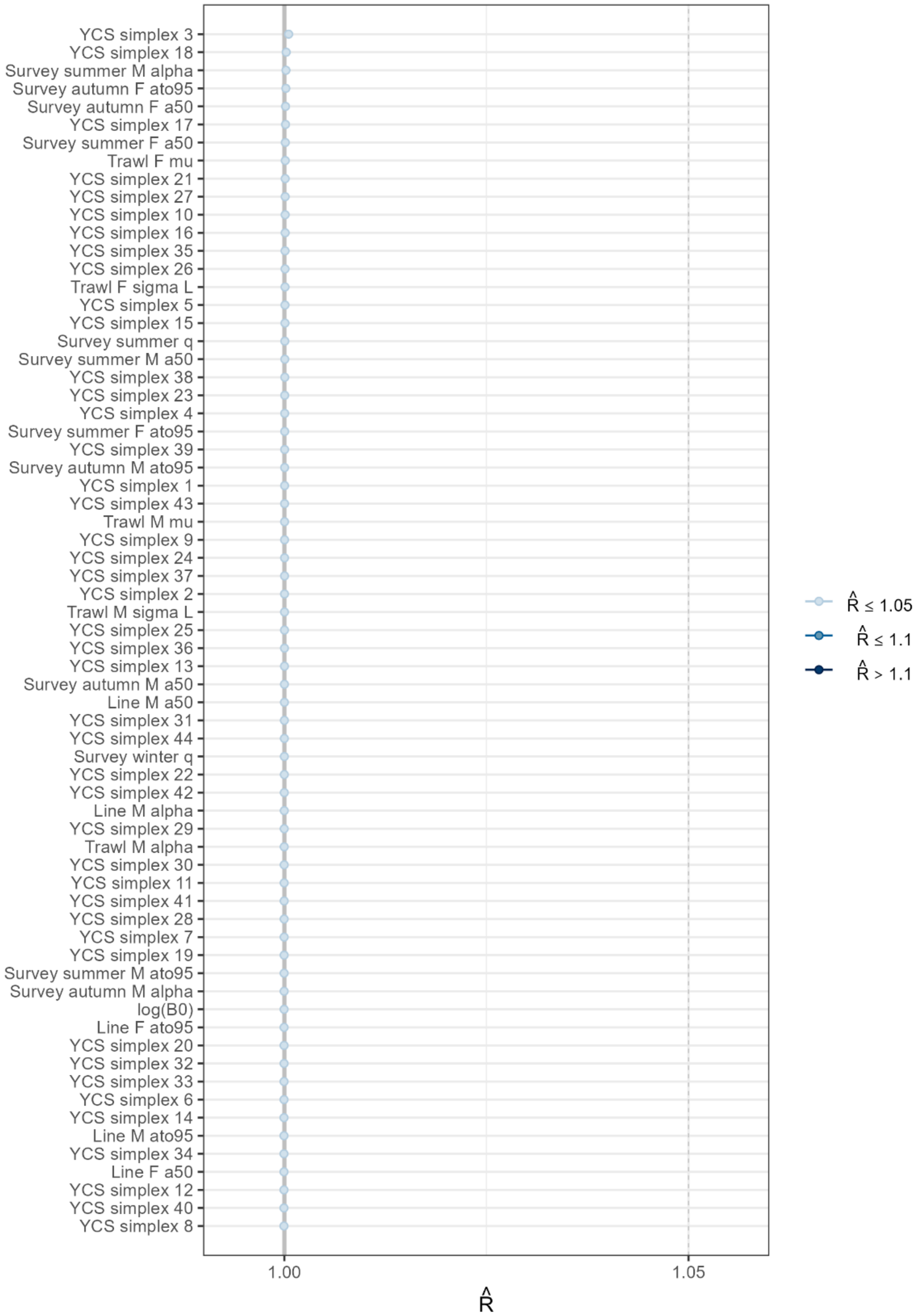

Figure A.6: MCMC r̂ values for all parameters, ordered from highest to lowest value.

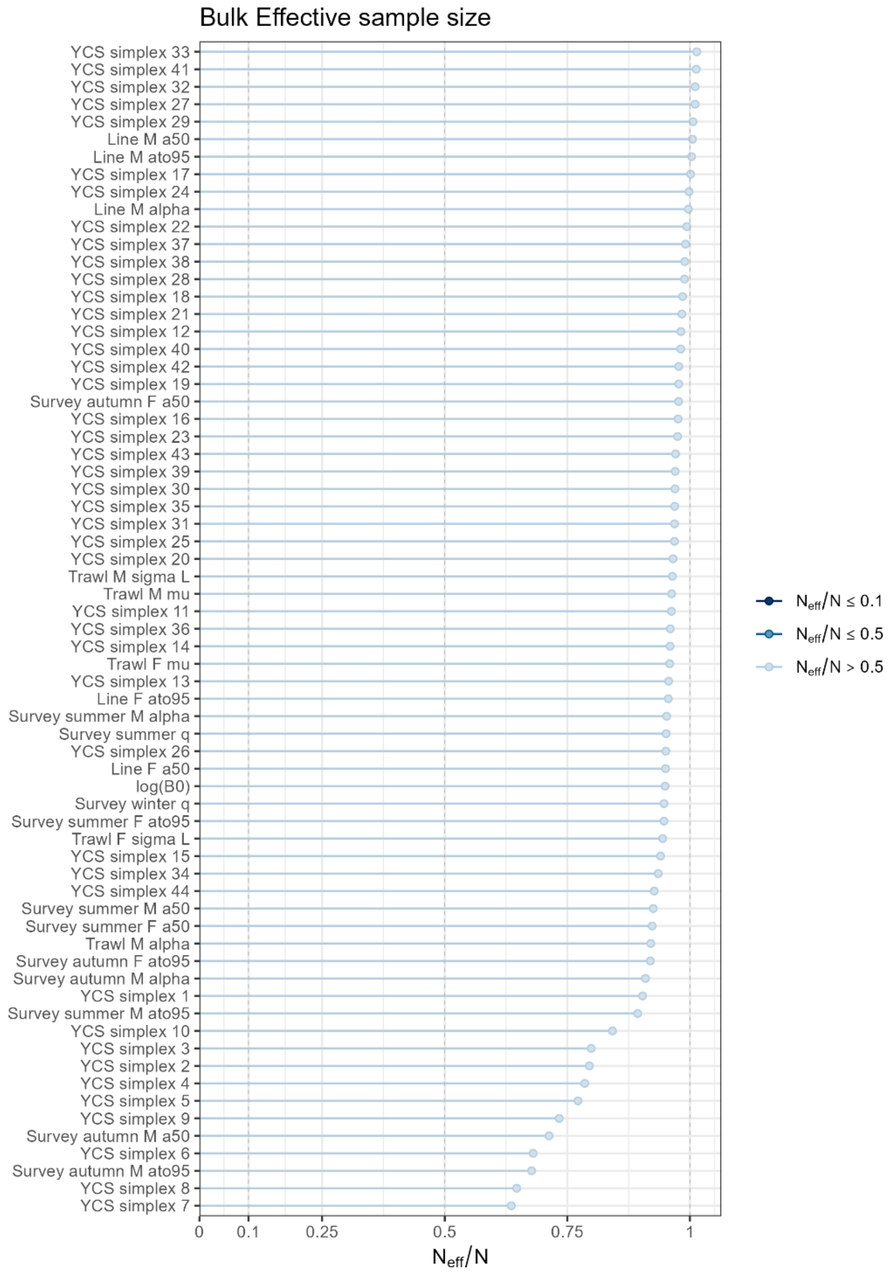

Figure A.7: MCMC bulk effective sample size values for all parameters, ordered from highest to lowest value.

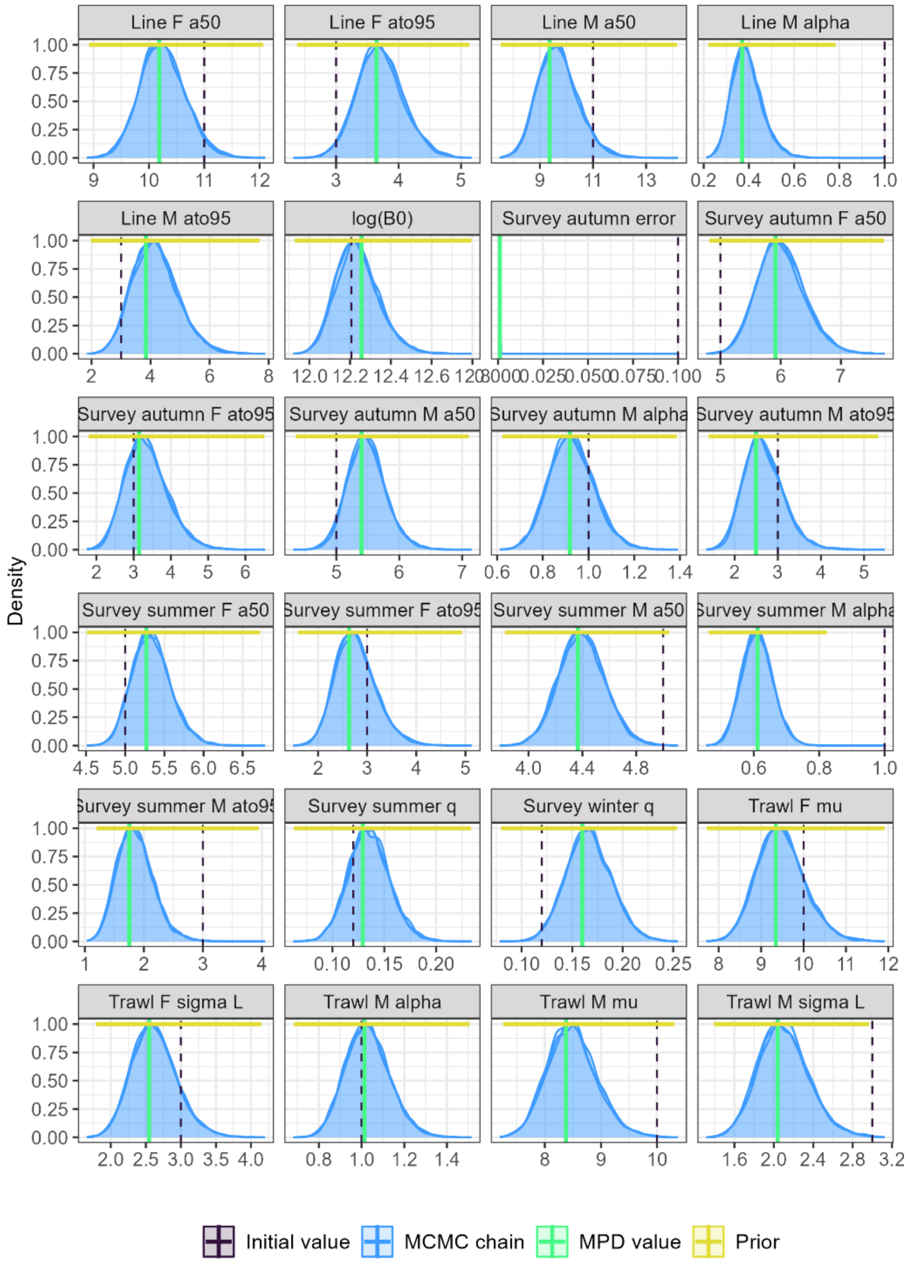

Figure A.8: Posterior density plots for the estimated parameters (excluding year class strength), plotted separately for each chain. The prior, initial value, and MPD value are also plotted.

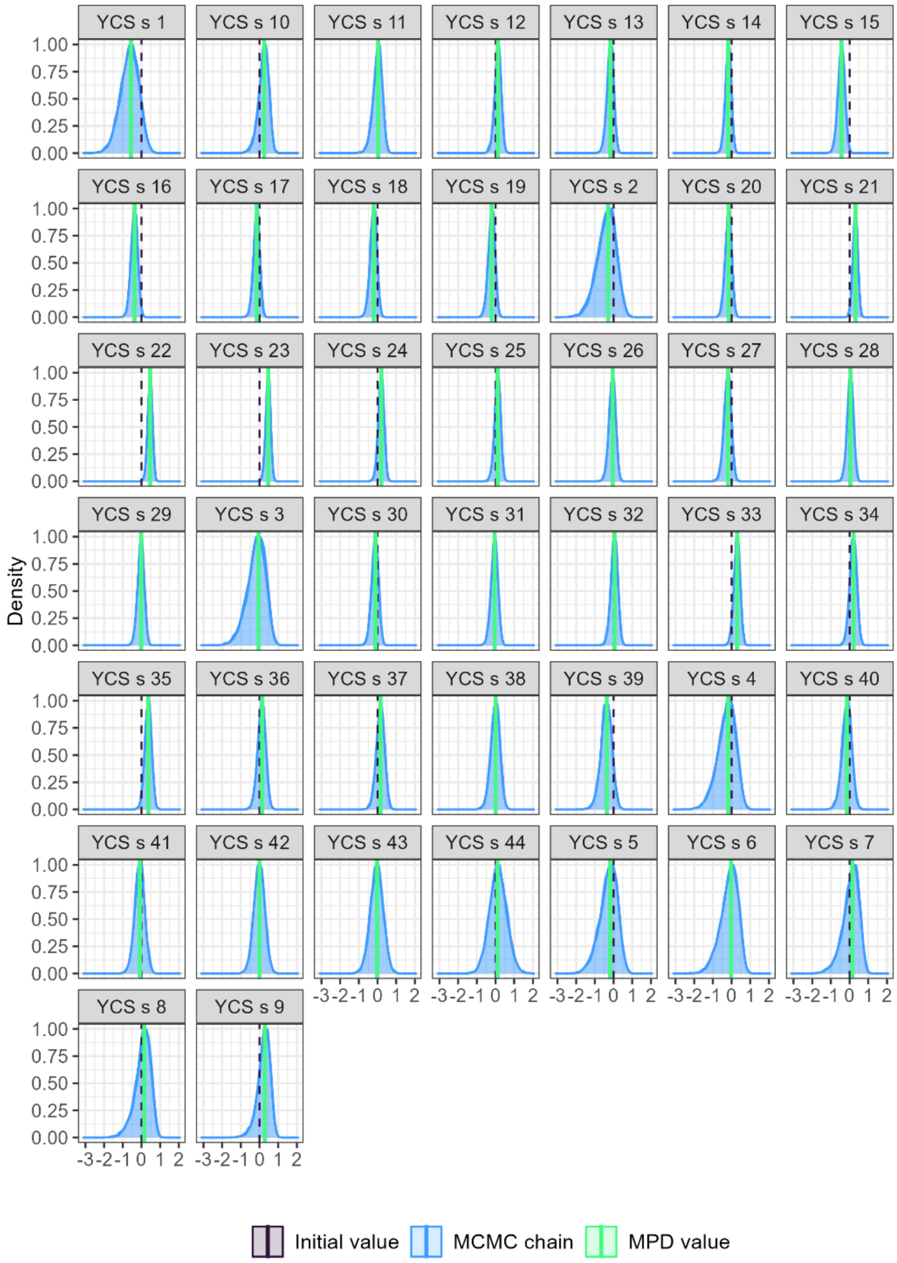

Figure A.9: MCMC chains density plots for the estimated year class strength parameters, plotted separately for each chain. The initial value, and MPD value are also plotted.