Fisheries New Zealand

Tini a Tangaroa

Stock assessment of ling (*Genypterus blacodes*) in the Sub-Antarctic (LIN 5&6) for the 2020–21 fishing year

New Zealand Fisheries Assessment Report 2021/64

S. Mormede,
A. Dunn,
D.N. Webber

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EXECUTIVE SUMMARY

Mormede, S.[1]; Dunn, A.[2]; Webber, D.N.[3] (2021). Stock assessment of ling (*Genypterus blacodes*) in the Sub-Antarctic (LIN5&6) for the 2020–21 fishing year.

***New Zealand Fisheries Assessment Report 2021/64*. 36 p.**

Ling (*Genypterus blacodes*) are an important species commercially caught mainly by bottom trawls and bottom longlines; they are found throughout the middle depths of New Zealand. Ling are managed as eight administrative quota management areas (QMAs) 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 BountyPlateau, the west coast of the South Island, and Cook Strait. This report summarises a stock assessment of the Sub-Antarctic stock (LIN 5&6, excluding LIN 6B) for the 2020–21 fishing year.

The main indices of abundance provided to the model were the Sub-Antarctic summer and autumn trawl surveys and the commercial longline standardised catch per unit effort (CPUE) series. The latter provided the most information on initial biomass to the model and helped reduce the uncertainty around that parameter. All three indices were fitted adequately within the assessment models.

Natural mortality was shown to be poorly estimated, with bias, and was fixed at 0.18 y^{-1}. Sensitivity runs with natural mortality values of 0.16 y^{-1} and 0.20 y^{-1} were also carried out, as well as a sensitivity run excluding the longline CPUE. Model stability was improved by using nuisance q for catchability of biomass indices, and by fixing the right-hand limb of the trawl selectivity to its median estimated value (of 100).

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. In all sensitivity runs, the probability of the stock status in 2021 being above 40% B_0 was between 67% and 99%, and that of being below 20% B_0 was less than 1%. This was not surprising because the annual exploitation rate was low (less than 0.1) for all years in the base case model. A sensitivity run with alternative catch histories (5% increase pre 1986 and 2% increase thereafter) showed little difference to the base case run.

Five-year projections were carried out using the base case model and various future annual catch: the average of the last five years, the Total Allowable Commercial Catch, a 10% increase in LIN 5 catch, or a 20% increase in LIN 5 catch. Projected stock status in 2026 was expected to be between 58% and 68% of B_0 on average depending on the future annual catch. In all instances the probability that the stock status in 2026 will be above 40% B_0 was greater than 93%, and that of being less than 20% was zero.

[1] SoFish Consulting Ltd., Wellington New Zealand.
[2] Ocean Environmental Ltd., Wellington, New Zealand.
[3] Quantifish Ltd., Tauranga, New Zealand.

1. INTRODUCTION

Ling are an important commercially caught species and are targeted by both bottom trawls and demersal longlines. Adult ling are found throughout the middle depths of the New Zealand exclusive economic zone (EEZ) typically in depths 100–800 m (Hurst et al. 2000). Ling are caught mainly by deepwater trawlers, often as bycatch in hoki target fisheries and by target demersal longliners (Ballara 2019). Small quantities of ling are also caught by inshore trawl, setnets, and potting (Ballara 2019, Mormede et al. 2021).

Ling are managed as eight administrative QMAs, 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, and Cook Strait. Stock assessments have been carried out for ling for biological stocks assumed to be 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).

The most recent assessment for LIN 5&6 was carried out by Masi (2019) and the most recent characterisation of ling in LIN 5&6 was for the 2020–21 fishing year (Mormede et al. 2021). Masi (2019) reported a similar status as the preceding assessment by Roberts (2016), and Masi (2019) reported that the estimated B_0 was "*about 278 000 t and very unlikely to be lower than 186 000 t and* B_{2018} *was approximately 254 000 t (90% of* B_0*)*". B_{2018} was estimated to be between 75% and 101% B_0 and was "virtually certain (> 99%) to be above the target" (Fisheries New Zealand 2020). Although model sensitivity runs gave different estimates of the total stock biomass, they did report similar estimates of stock status. The stock size of LIN 5&6 was predicted to increase slightly over the next 5 years at the recent catch levels.

The ling stock assessments have typically been implemented as single area integrated statistical catch-at-age two-sex models. The Bayesian stock assessment software CASAL (Bull et al. 2012) has been used for all assessments since 2002–03. The fisheries have been defined as trawl, and spawning and non-spawning longlines using observations from commercial catch-at-age, CPUE indices (as a sensitivity), and resource survey biomass and age frequencies (Masi 2019). Natural mortality has been estimated, either as a U-shape or single mortality term.

The 2020 Plenary (Fisheries New Zealand 2020) reported that the major source of uncertainty in the assessment for Sub-Antarctic ling was the lack of contrast in the summer trawl series (the main relative abundance series), and that this made it difficult to accurately estimate the upper bound of past and current biomass. The previous assessment also excluded the CPUE indices because they were deemed to not adequately reflect abundance due to a lack of fit of spawning longline CPUE within the model.

This report fulfils Specific Objective 2 of Project LIN2020-01. The overall Objective was "To carry out stock assessments of ling (*Genypterus blacodes*) in the Sub-Antarctic (LIN 5&6) including estimating biomass and stock status" and 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 two-sex total catch history stock assessment model assuming a Beverton-Holt stock-recruit relationship was carried out for LIN 5&6 (Sub-Antarctic) using the stock assessment program CASAL v2.30 (Bull et al. 2012). The stock assessment model partitions the population into two sexes and age groups 3 to 25 with the oldest age being a plus group. To align more closely with the spawning season (September to December), and to the season of the fishery (particularly in the early years), the model year was set as September to August, rather than the fishing year (October to September). In this document, year always represents model year unless specifically otherwise stated.

The 2021 investigation of the spatial-temporal structure of ling in LIN 5&6 resulted in the revision of the Sub-Antarctic ling stock to two fisheries only: bottom trawl and bottom longline fisheries (Mormede et al. 2021). The model time steps were also modified to represent the fishery more accurately, with a first time step from September to December representing spawning, and a second time step with the rest of the year. The proportional growth in each time step was based on the monotonic growth model (Mormede et al. 2021) which indicates there is virtually no growth in the first time step. The model's annual cycle is described in Table 1. The growth provided to the model was that which has happened half-way through the time step (hence half of the growth in this model happens at year end: between the middle of the second time step and the end of the year).

Table 1: Annual cycle of the stock assessment model of Sub-Antarctic ling (LIN 5&6). The 'X' marks when processes or observations occur in the year, for example recruitment happens in September and is part of timestep 1.

Monthly timing of biological and fisheries processes								Model timing of biological and fisheries processes					
	Recruitment	Maturation and spawning	Trawl catch (%)	Longline catch (%)	Tangaroa resource surveys (biomass and AFs)	Fishery AFs	Fishery CPUE	Model timestep	Ageing	Proportion of growth	Proportion of natural mortality	Trawl catch (%)	Longline catch (%)
								Year start	X				
Sep	X		13	4				1		0.00	0.33	100	100
Oct			28	13									
Nov		X	18	18									
Dec			10	9	19 (Dec 1990 to 2020)	X	X						
Jan			6	6				2		0.50	0.66	0	0
Feb			3	6									
Mar			2	9									
Apr			3	9	4 (Apr 1992 to 1998)								
May			3	8									
Jun			6	7									
Jul			5	6									
Aug			4	5									
								Year end		0.50			

2.2 Inputs

The updated catch histories, longline fishery CPUE, catch-at-age and estimates of biological parameters are described by Mormede et al. (2021). The rolled-up longline standardised CPUE (further referred to as longline CPUE) was deemed a suitable fishery-based index of abundance whereas the bottom trawl standardised CPUE was deemed to represent changes in patterns in the fishery driven by changes in hoki Total Allowable Commercial Catch (TACC) over time (Mormede et al. 2021). The Sub-Antarctic trawl survey biomass and age frequencies were provided through a different project (e.g., Horn & Sutton 2019) and are summarised in the 2021 ling plenary document (Fisheries New Zealand 2021). A summary of all observations used in this assessment and the associated time series is given in Table 2. The input parameters used in the models are summarised in Table 3 and Table 4.

Lognormal errors, with known coefficients of variation (CVs), were assumed for all relative biomass observations. The CVs available for those observations of relative abundance allow for sampling error only. Additional variance, assumed to arise from differences between model simplifications and real-world variation, was added to the sampling variance. The additional variance, termed process error, was estimated in the models at maximum posterior density (MPD) level only. Multinomial errors were assumed for all age composition observations. The effective sample sizes for the composition samples were estimated following method TA1.8 as described in appendix A of Francis (2011).

Table 2: Observations used in the Sub-Antarctic ling stock models (LIN 5&6), including source years.

Data series	Model years
Trawl survey biomass (*Tangaroa*, Nov–Dec)	1992–94, 2001–10, 2012–13, 2015, 2017, 2019, 2021
Trawl survey proportion at age (*Tangaroa*, Nov–Dec)	1992–94, 2001–10, 2012–13, 2015, 2017, 2019
Trawl survey biomass (*Tangaroa*, Mar–May)	1992–93, 1996, 1998
Trawl survey proportion at age (*Tangaroa*, Mar–May)	1992–93, 1996, 1998
CPUE (longline)	1991–2020
Commercial longline proportion-at-age	1994, 1996, 1998-2012, 2014, 2017, 2018
Commercial trawl proportion-at-age	1992, 1994, 1996, 1998-2019

Table 3: Input parameters used in the Sub-Antarctic ling stock models (LIN 5&6).

Relationship	Reference	Parameter		Value	
		(units)	Both	Male	Female
von Bertalanffy growth	Mormede et al. (2021)	t_0 (y)		-0.71	-1.09
		k (y^{-1})		0.14	0.14
		L_∞ (cm)		91.2	111.2
		CV		0.07	0.08
Length-weight	Mormede et al. (2021)	a ($g.cm^{-1}$)		$2.13e^{-9}$	$1.32e^{-9}$
		b		3.179	3.293
Stock recruitment relationship					
Stock recruitment steepness	Masi (2019)	h	0.84		
Recruitment variability		σ_R	0.6		
Ageing error	Masi (2019)	CV	0.06		
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 Sub-Antarctic ling stock models (from Horn 2005).

Age (y)	3	4	5	6	7	8	9	10	11	12
Male	0.0	0.00	0.10	0.30	0.50	0.80	1.00	1.00	1.00	1.00
Female	0.0	0.00	0.05	0.10	0.30	0.50	0.80	1.00	1.00	1.00

2.3 Estimation of parameters

The initial spawning stock biomass (B_0) was estimated in the model, as were year class strengths and fishing selectivity ogives. The trawl fishery selectivity ogives were fitted as double normal curves; the longline fishery and research survey ogives were fitted as logistic curves. Selectivities were assumed constant over all years in each fishery / survey. The parameters estimated, their shape, prior distribution, starting values, and bounds are summarised in Table 5.

Most priors were intended to be relatively uninformed and were specified with wide bounds. The exceptions were the choice of informative priors for the trawl survey catchability q. The priors on q for all the *Tangaroa* trawl surveys were estimated assuming that the catchability constant was a product of areal availability (0.5–1.0), vertical availability (0.5–1.0), and vulnerability between the trawl doors (0.03–0.40). The resulting (approximately lognormal) distribution had mean 0.13 and CV 0.70, with bounds assumed to be 0.02 to 0.30. The updated prior for M was chosen based on a 2017 study of ling mortality (Edwards 2017). The survey q were set as nuisance in 2016 (Roberts 2016) and then changed to free q in 2019 (Masi 2019). Both options were investigated in 2021.

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 strongly penalised. A small penalty was applied to the estimates of year class strengths to encourage estimates that averaged 1.

For final runs, the full posterior distribution was sampled using Markov chain Monte Carlo (MCMC) methods, based on the Metropolis-Hastings algorithm. MCMC chains with a total length of 4×10^6 iterations were constructed. A burn-in length of 1×10^6 iterations was used, with every 1000^{th} sample taken from the final 3×10^6 iterations (i.e., a final sample of length 3000 was taken from the Bayesian posterior).

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

Parameter	Shape	Starting values			Prior distribution	Parameters		Bounds	
B_0		350 000			uniform-log			50 000	800 000
YCS		1			lognormal	1	0.7	0.01	100
survey selectivities	logistic	5	3		uniform			0	20–200
trawl selectivity	double-normal	10	3	25	uniform			0	20–200
line selectivity	logistic	11	3	0.3	uniform			0	20–200
survey q		0.13			lognormal	0.13	0.7	0.02	0.4
survey process error		0.1			uniform-log			0.001	2
CPUE q					uniform-log			$10e^{-6}$	$10e^{-2}$
M (2019)		0.2			uniform			0.01	0.6
M (update)		0.16			lognormal	0.16	0.2	0.05	0.5
M_{diff} (sensitivity)		0			normal	0	0.05	-0.15	0.15

3. RESULTS

3.1 Model steps from the 2018 base case

The 2018 base case (Masi 2019) was used as the start for model development. Changes were made incrementally to reach the 2021 models. Re-weighting of the data was only carried out at the last step to allow comparison between models through this process. Details of the steps are given in Table 6, and the reweighted 2021 initial model and 2018 base model are summarised in Table 7.

Results show that updating the catch age frequencies had the most impact on the unweighted model; in particular, the addition of historic years of catches where age frequencies were not previously available due to the previously used fishery split. However, once all data were re-weighted, the 2018 base case and 2021 initial case were similar in terms of estimation of initial biomass and natural mortality. Adding the longline CPUE index reduced the estimate of initial biomass and 2018 stock status (Table 7). The two datasets with most information on the initial biomass parameter were the longline CPUE and the longline proportions-at-age (Figure 1).

Table 6: Incremental model build from the 2019 base case to the 2021 initial model run, at MPD level. The data were not re-weighted between models. AF = age frequency, LL = longline, BT = bottom trawl, YCS = year class strength.

Model	Description	B_0 (%)	B_{2018}/B_0 (%)	M (y^{-1})	Objective function
R0.1	2018 base	326 604	91.1	0.204	2 383
R0.2	update biological parameters	320 570	91.3	0.204	2 383
R0.3	update timing of surveys	329 030	91.5	0.204	2 383
R0.4	2 fisheries (was 3 fisheries)	319 780	92.0	0.206	2 284
R0.5	update catches	336 014	92.5	0.207	2 283
R0.6	update AFs	358 311	93.2	0.212	2 351
R0.7	add historic AFs (1994, 96, 98 LL and 1999, 2000 BT)	410 861	93.4	0.218	2 554
R0.8	YCS start values 1 everywhere	405 660	90.6	0.218	2 554
R0.9	update to 2021 catches and 2019 AFs	383 413	82.4	0.215	2 666

Table 7: 2018 base and 2021 initial model runs, once data were re-weighted.

Model	Description	B_0 (%)	B_{2018}/B_0 (%)	M (y^{-1})
R0.1	2018 base	326 600	91.1	0.204
R1.0	2021 initial	325 800	88.5	0.207
R2.0	2021 initial with longline CPUE	257 720	80.5	0.203

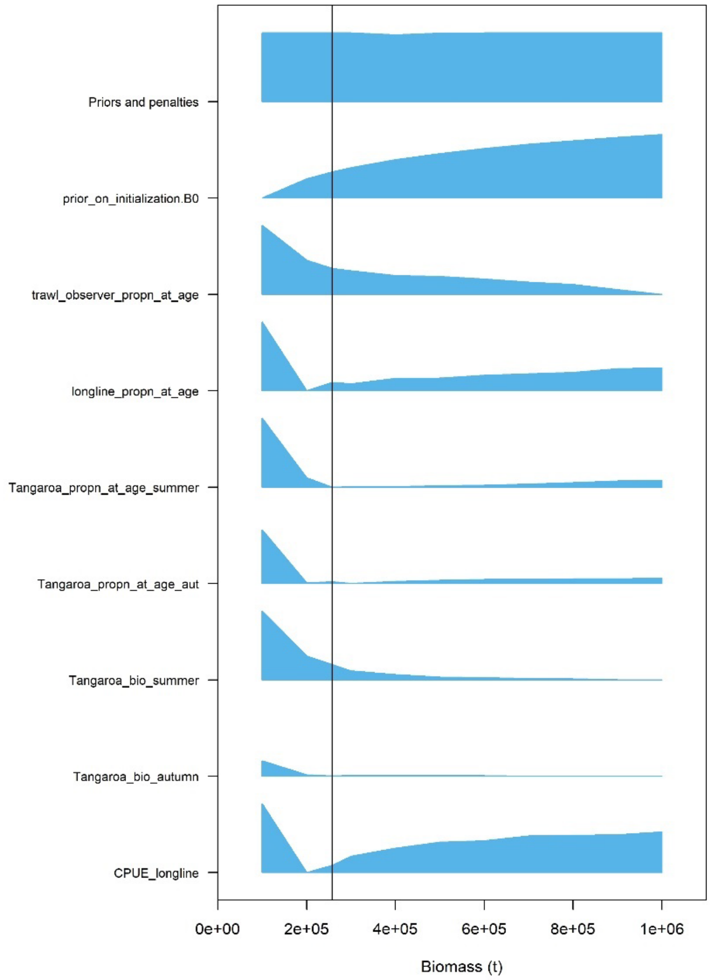


Figure 1: MPD profile on the initial biomass parameter B_0 for model R2.0, expressed for each data series. The maximum possible height of each blue graph represents 10 negative log likelihood (NLL) points.

3.2 Investigating natural mortality

Prior to being estimated within the model (Roberts 2016, Masi 2019), natural mortality was assumed to be 0.18 y^{-1} (Horn 2008). Natural mortality for ling in LIN 5&6 was recently estimated at 0.16 y^{-1} with a CV 0.2 by Edwards (2017), based on life history characteristics.

Models runs were carried out with a low information prior on natural mortality or with the prior recommended by Edwards (2017). Model runs estimated *M* at about 0.21 y^{-1} regardless of the prior on M, with very little difference between males and females (see, for example, model R1.1). Fixing *M* to various values had a strong influence on initial biomass and status as expected. Fitting to data was achieved in the models by giving more weight to the survey age frequency weights as natural mortality was fixed to smaller values (Table 8). MPD profiles of the natural mortality parameter showed it was not well informed by the data available to the model. Figure 2 shows the MPD profile for M for model R1.1; that for model R1.2 was similar.

The ability of the model to estimate natural mortality within the assessment model was investigated using a simulation experiment. An operating model was developed with *M* fixed at 0.17 y^{-1} and then used to simulate observations. A total of 400 observations were simulated based on model parameters fixed at (i) the MPD and (ii) 400 sets of values drawn from the MCMC parameter estimates. These were then used in a MPD estimation for both scenarios using the 400 simulated observations and same model structure, but with M estimated. Results show that the values of natural mortality estimated were similar to that assumed in the operating model but biased slightly high, i.e., it was over-estimated in the model by about 0.02 y^{-1} on average (Figure 3).

Table 8: Model runs at MPD level investigating natural mortality. M_{diff} is the differential natural mortality between males and females, only estimated in R1.2. '*' represents natural mortality values fixed in the model. Only data weighting which changed between models are showed (the other weights were similar between models).

Model	Description	Survey winter weight	Survey summer weight	B_0 (%)	B_{2021}/B_0 (%)	M	M_{diff}
R1.0	2021 initial model	0.154	0.175	325 805	0.80	0.207	-
R1.1	Model with M prior updated	0.167	0.175	314 870	0.80	0.207	
R1.2	Model with M_{avg} and M_{diff}	0.166	0.175	330 346	0.81	0.206	0.014
R1.3	M fixed at 0.14 and reweighted	0.374	0.231	133 094	0.37	0.14*	-
R1.4	M fixed at 0.17 and reweighted	0.235	0.206	170 725	0.62	0.17*	-
R1.5	M fixed at 0.20 and reweighted	0.179	0.183	308 439	0.81	0.20*	-

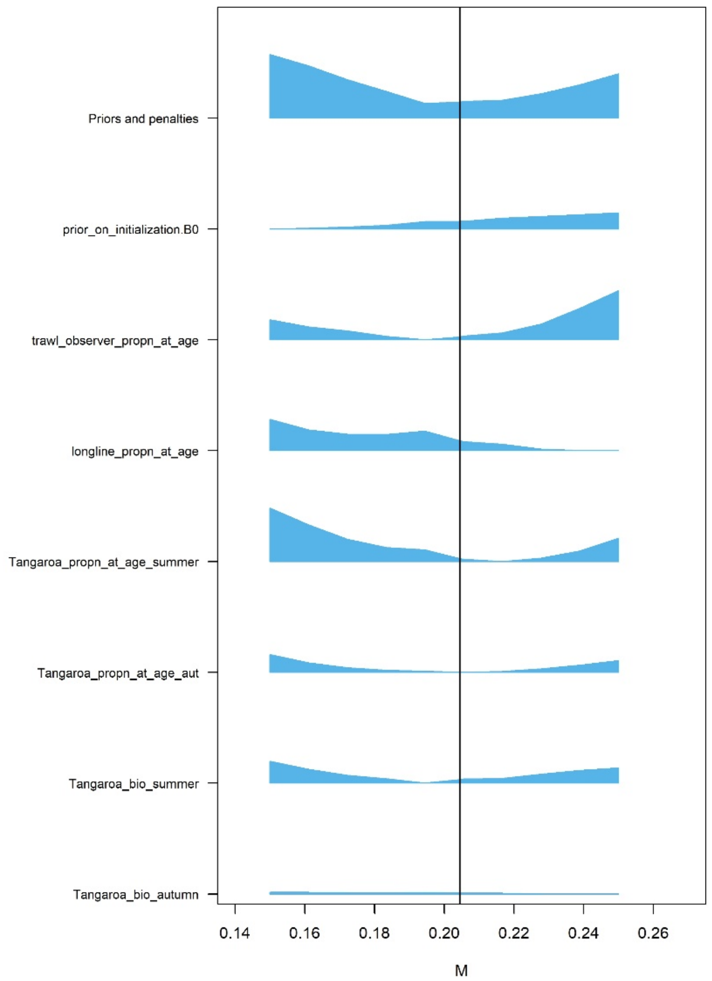


Figure 2: MPD profile on the natural mortality parameter M for model R1.1, expressed for each data series. The maximum height of each blue graph represents 10 negative log likelihood (NLL) points.

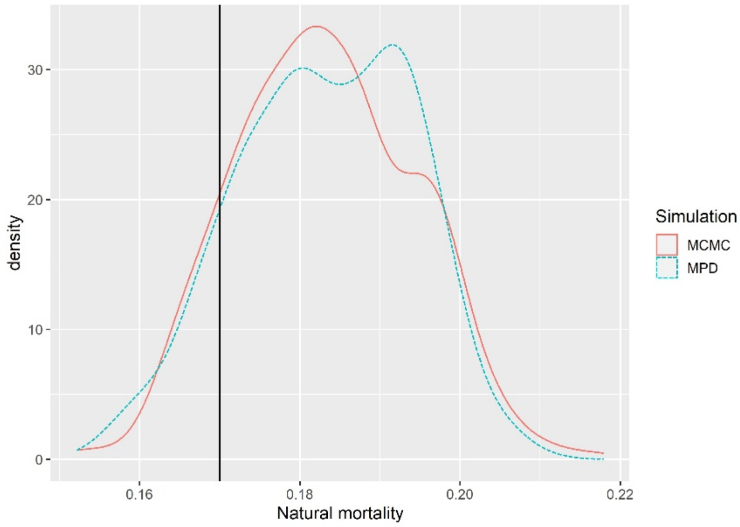
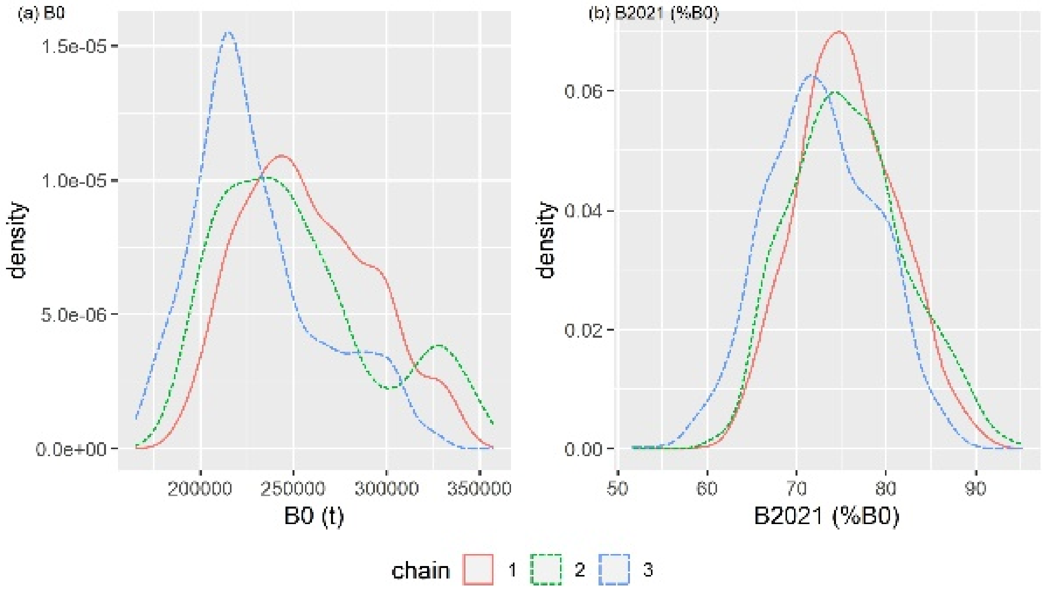


Figure 3: Distribution of natural mortality estimated based on either MPD or MCMC pseudo-observations. The 'true' natural mortality of 0.17 y^{-1} is showed as a black vertical line.

3.3 Model stability

The survey catchability *q* parameters were set as nuisance parameters in 2016 (Roberts 2016) and then changed to free parameters in 2019 (Masi 2019). The initial model with longline CPUE, a constant estimated *M*, and free *q* parameters had poorly behaved MCMC chains on most estimated parameters (R1.0). Using nuisance *q* parameters (R2.1) improved the chains for most of the parameters, but not for B_0. Fixing the right-hand limb trawl selectivity at its median estimated value of 100 (R2.2) improved the stability of the model further but did not significantly improve the chains for B_0. Assuming that the trawl selectivity was logistic did not improve the models (not shown). Removing the CPUE series also did not stabilise the model (not shown). Fixing natural mortality (e.g., R3.0) resulted in the most stable models. Note that fixing mortality with free *q* parameters (not shown) also resulted in a slightly less stable model. The MCMC chains for B_0 and B_{2021} for various models are shown in Figure 4 and Figure 5.

R2.0 Longline CPUE, estimated *M*, free *q*



R2.1 Longline CPUE, estimated *M*, nuisance *q*

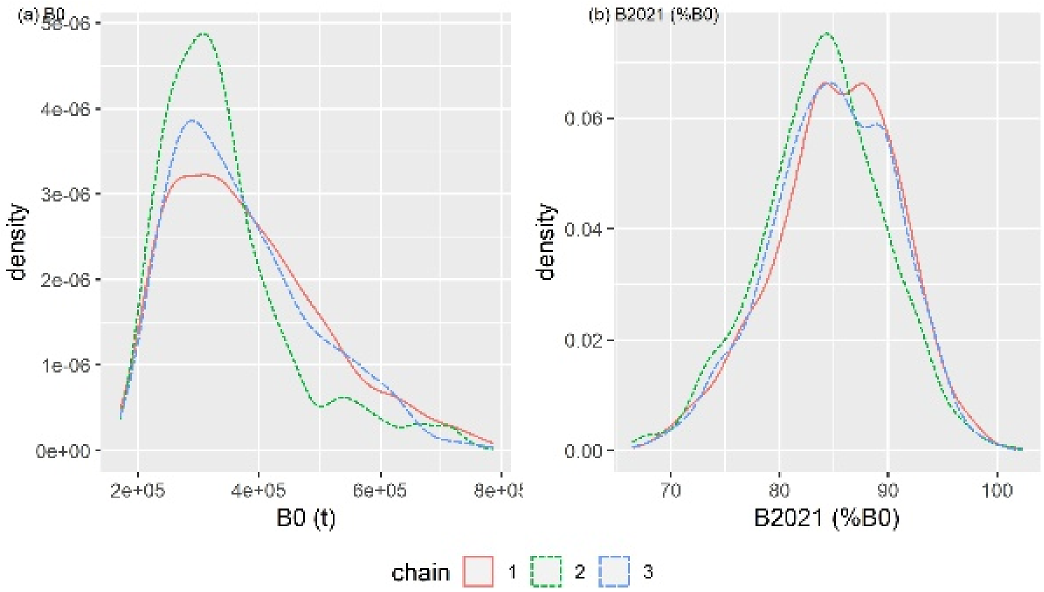
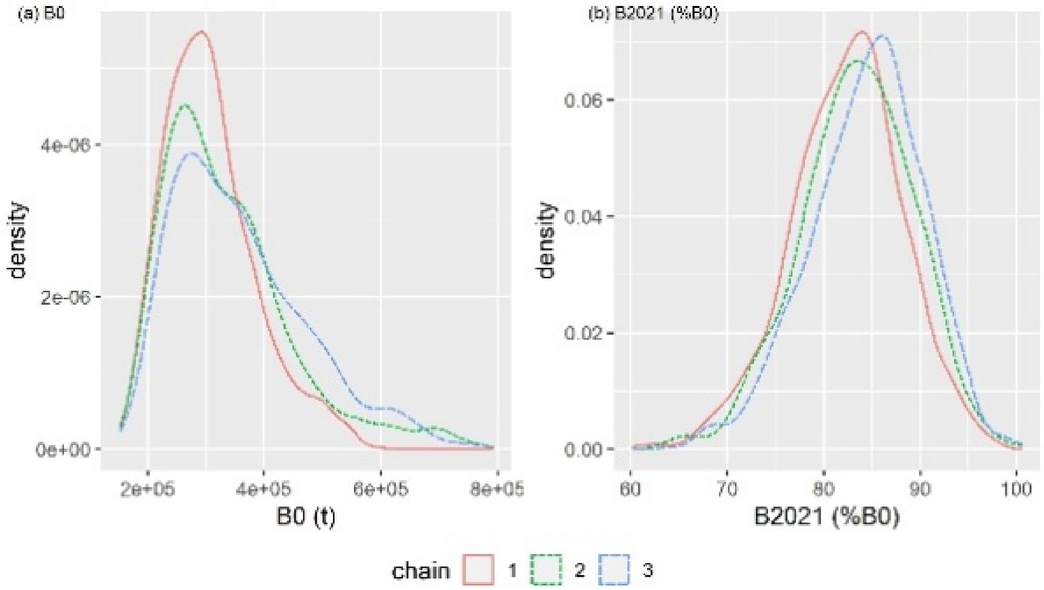


Figure 4: MCMC chains for models investigating the stability of longline models R2.0 and R2.1. A single MCMC was run for each model and the density distribution of its three sections of 1000 values each are plotted on top of each other.

R2.2 Longline CPUE, estimated *M*, nuisance *q*, fixed right-hand limb selectivity



R3.0 Longline CPUE, *M* = 0.18, nuisance *q*, fixed right-hand limb selectivity

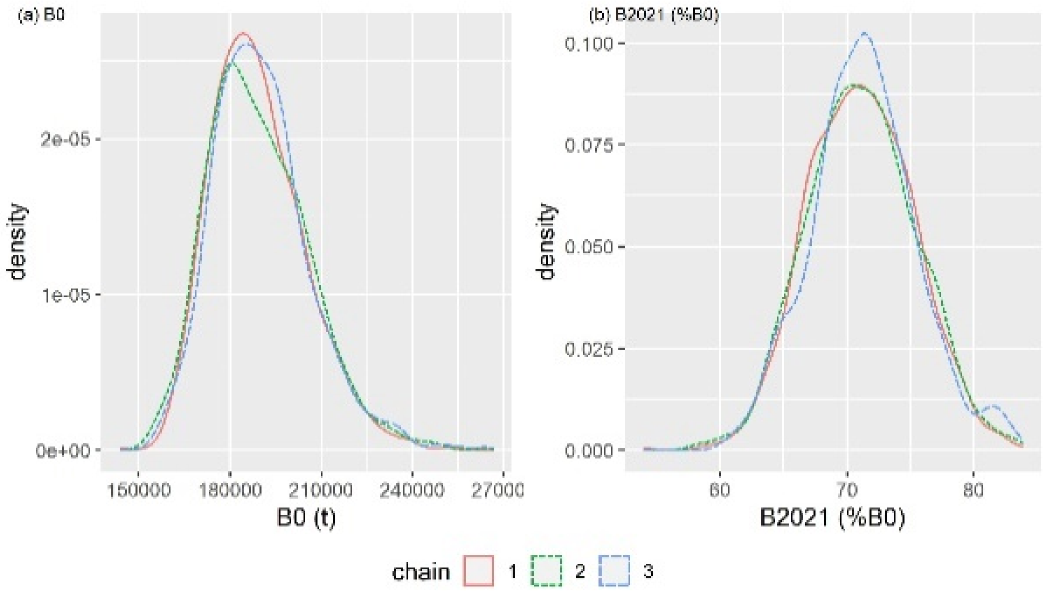


Figure 5: MCMC chains for models investigating the stability of longline models R2.2 and R3.0. A single MCMC was run for each model and the density distribution of its three sections of 1000 values each are plotted on top of each other.

3.4 Final model runs

The only models deemed acceptable in terms of MCMC chain convergence had a fixed natural mortality value, nuisance *q* parameters, and fixed right-hand limb of trawl selectivities. The base case was chosen with $M = 0.18$ y^{-1} because it was the value assumed in assessments from before when *M* was estimated. In addition, when *M* was estimated, it was estimated at about 0.20 y^{-1}, however, the simulation experiment suggested that it may be typically over-estimated by about 0.02 y^{-1}. Hence, a value of 0.18 y^{-1} was assumed in these models. Three sensitivities were carried out: fixing *M* at 0.16 y^{-1}, at 0.20 y^{-1}, and excluding the longline CPUE series.

Stock status estimates for 2021 from these models were between 61–80% of B_0. The probability of the 2021 status being above 40% B_0 ranged from 67 to 99%, and the probability of it being below 20% B_0

was less than 1% in all instances. As expected, reducing *M* reduced both the initial biomass and stock status in 2021, and conversely increasing *M* increased both the initial biomass and the stock status in 2021. Removing the longline CPUE index increased the initial biomass and the stock status in 2021 slightly (Table 9).

Table 9: LIN 5&6 Bayesian median and 95% credible intervals (in parentheses) of B_0 and B_{2021} (in tonnes), and B_{2021} as a percentage of B_0, and the probability that B_{2021} is above 40% and below 20% of B_0 from the base model and sensitivity runs.

Model run	B_0	B_{2021}	B_{2021} (% B_0)	P(>40% B_0)	P(<20% B_0)
Base case model	187 350 (163 190 – 226 090)	132 780 (104 630 – 177 230)	70.8 (63.1 – 79.3)	0.934	0.000
$M = 0.16\ y^{-1}$	157 800 (144 500 – 175 820)	96 520 (79 080 – 119 840)	61.2 (54.1 – 69.1)	0.671	0.008
$M = 0.20\ y^{-1}$	258 770 (203 270 – 361 080)	208 840 (150 460 – 318 790)	80.6 (72.2 – 89.7)	0.995	0.000
$M = 0.18\ y^{-1}$ and no CPUE	197 130 (166 520 –246 370)	147 690 (109 610 –209 350)	75.0 (64.8 –86.0)	0.962	0.000

Biomass estimates for the stock declined through the 1990s but have been stable since the early 2000s (Figure 6 for the base case). Posterior distributions of year class strength estimates from the base case model run are shown in Figure 7; the distribution from the base case model differed little from the sensitivity models. Year classes were generally weak from 1985 to 1992, strong from 1994 to 1996 and 2005 to 2010, and average since then. Overall, estimated year class strengths were not widely variable, with all medians being between 0.5 and 1.5. Annual exploitation rates (catch over vulnerable biomass) were low (less than 0.1, Figure 7).

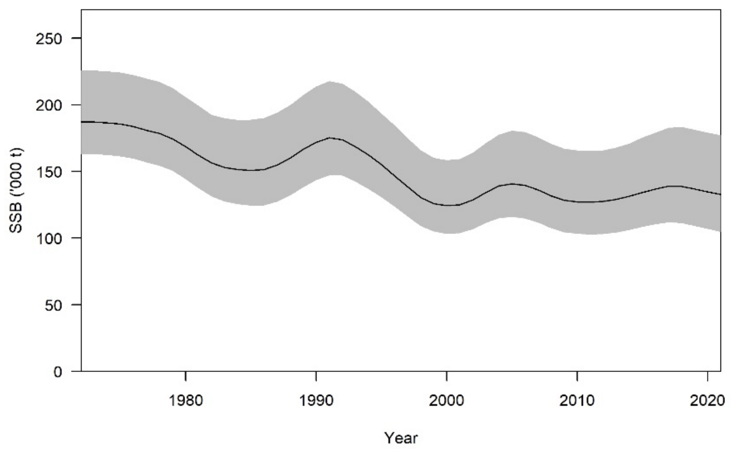


Figure 6: Biomass trajectory of the base case model for Sub-Antarctic ling, with 95% credible interval.

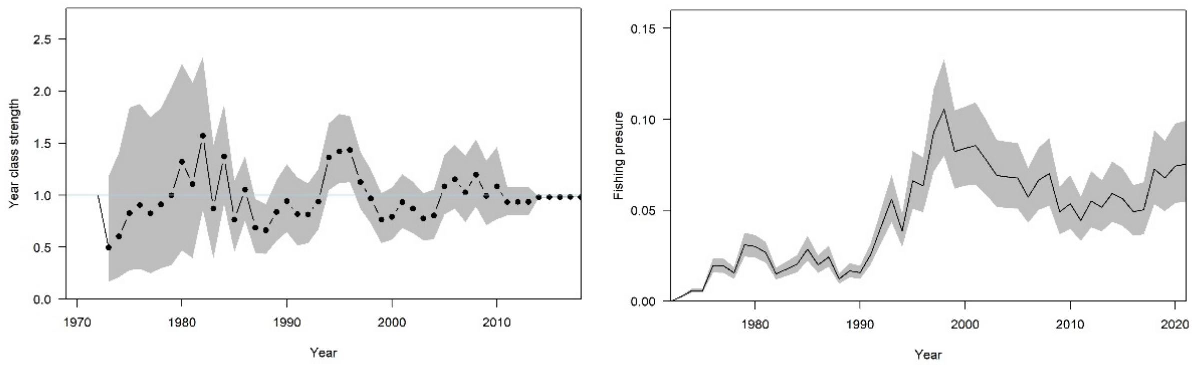


Figure 7: Estimated year class strengths (left) and annual exploitation rate (right) with 95% credible interval for the base case model for Sub-Antarctic ling.

Catchabilities were estimated well to the right of their priors, despite the trawl selectivity priors being biologically derived (Figure A.1). Selectivities were estimated with relatively narrow credible intervals (Figure A.2). Both the longline fleet and the Sub-Antarctic summer trawl survey were estimated to have caught significantly more females than males whereas the trawl fleet and the Sub-Antarctic autumn trawl survey were estimated to have caught near equal proportions of males and females. The longline fleet was estimated to catch larger fish on average than the trawl fleet.

Diagnostics for the base case model run are described in Appendix A. The convergence test of Geweke (1992) and the Heidelberger & Welch (1983) stationarity and half-width tests suggested no evidence of failure to converge of the parameters for the base case (Figure A.3). This was not the case of models R1.0 to R2.0 (not shown). Trace plots showed no evidence of failure to converge for the base case model (Figure A.4 to Figure A.6). Fits to the biomass indices and age frequencies were adequate (Figure A.7 to Figure A.18). Similar results were obtained for the sensitivity runs (not shown) although the stability of the MCMC chains deteriorated slightly in the run with $M = 0.20$ y^{-1}.

3.5 Alternative catch history

An alternative catch history was constructed, which includes the possibility of unreported catches, discards, and small fish going through the nets. Unreported catch prior to the introduction of the Quota Management System (QMS) is not known but assumed to be low due to the high commercial value of ling at that time. Values used in other assessments assumed 5% additional fishery mortality for years before the introduction of the QMS (1986) and 2% thereafter. Discards from the hoki/hake/ling target fishery were likely to be very low (<0.3%, Anderson et al. 2019).

The potential for incidental mortality of small fish associated with escapement was investigated further. Ling smaller than 40 cm in length are only caught in a very small area of the Sub-Antarctic (Figure 8). The annual catch of all ling in that area has ranged from less than 10 t to 120 t at its peak. Even there, small ling have rarely been caught: the 75th percentile proportion of ling less than 40 cm in length was 2.8%. Based on Precision Seafood Harvesting trials (O'Driscoll & Millar 2017), the 50% catchability of 40 cm ling in a 100 mm codend was about 20%. Assuming conservatively 100% mortality of ling less than 40 cm passing through the codend, 3% of the catch in that area was of ling less than 40 cm and only 20% of those fish less than 40 cm being retained by the net, the additional mortality of small ling going through the net might range from 0 to 18 t annually (calculated as catch x proportion small fish / catchability or 120 t x 0.03 / 0.2 = 18 t).

Based on these estimates, a sensitivity model was run that assumed 5% additional fishery mortality for years before the introduction of the QMS (1986) and 2% thereafter. The inclusion of estimates of incidental mortality and pre-QMS unreported catch resulted in very similar estimates of initial and current biomass to the base case (not shown), and a very similar biomass trajectory.

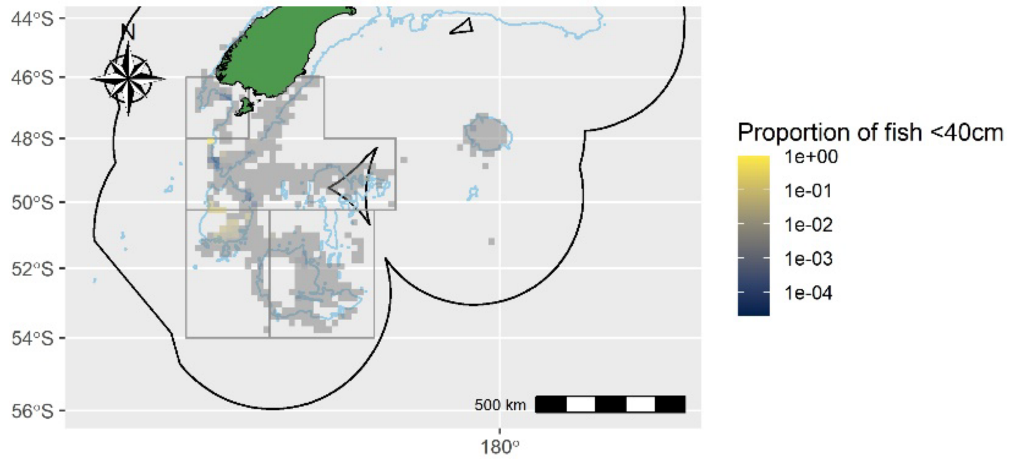


Figure 8: Proportion of ling less than 40 cm length in each fishing event where ling were measured in the Sub-Antarctic. The grey cells represent areas with no fish less than 40 cm in length.

3.6 Projections

Four projection runs were carried out whereby the future annual catch for the next five years was set at the average catch of 6320 t for trawl and 1370 t for longline between 2016 and 2020, the TACC of 13 240 t split 82% trawl and 18% longline reflecting the average proportion of catches between the two fisheries between 2016 and 2020, a 10% increase in the TACC for LIN 5, or a 20% increase in the TACC for LIN 5. The base case model was used for the projections.

Results are shown in Table 10 and Figure 9. Projected stock status in 2026 was expected to be between 58% and 68% of B_0 depending on the projection. In all instances the probability of the stock status in 2026 being above 40% B_0 is greater than 93%, and that of being less than 20% is nil (not shown).

Table 10: LIN 5&6 Bayesian median and 95% credible intervals (in parentheses) of projected B_{2026}, B_{2026} as a percentage of B_0, and B_{2026}/B_{2021}(%) for the base case runs for Sub-Antarctic ling.

Projection	Future catch (t)		B_{2026} (t)	B_{2026} (% B_0)	B_{2026}/B_{2021} (%)
	Trawl	Longline			
Last 5 years	6 320	1 370	129 080	68	95
			(81 670–205 590)	(46– 104)	(72–133)
TACC	10 860	2 380	110 340	58	81
			(63 330–186 650)	(36 – 94)	(57–117)
LIN 5 10% increase	7 428	1 742	123 500	65	91
			(75 550–201 310)	(43–100)	(69–128)
LIN 5 20% increase	7 820	1 834	121 840	65	90
			(73 930–199 650)	(42–100)	(68–127)

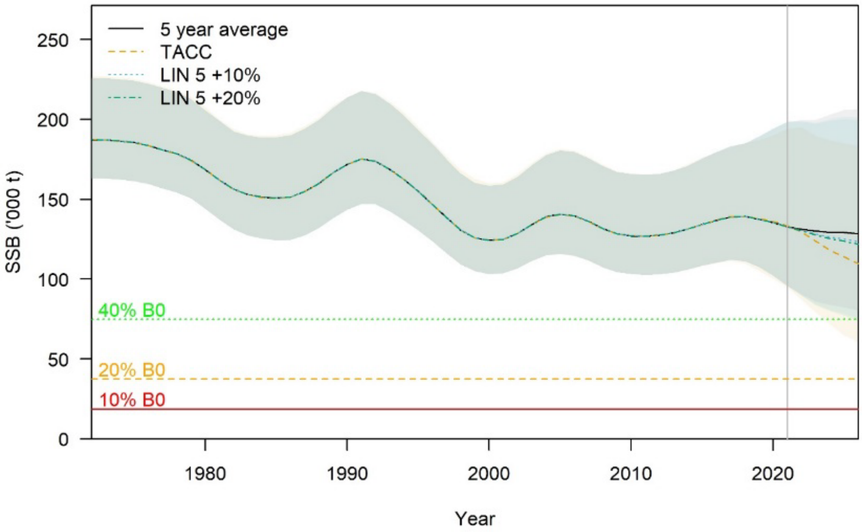


Figure 9: Five-year projections for Sub-Antarctic ling (LIN 5&6) using the base case model and four potential future catch rates, split 82% trawl and 18% longline reflecting the average proportion of catches between the two fisheries between 2016 and 2020. The 95% credible intervals are also shown.

4. DISCUSSION

The stock assessment model for Sub-Antarctic ling (LIN 5&6) updated the 2018 assessment (Masi 2019) with new observations, a revised annual cycle, and combined the spawning and non-spawning longline fisheries into a single longline fishery. The 2018 assessment model had a highly unstable MCMC and large uncertainty around biomass estimates and stock status. Fixing natural mortality, the trawl right-hand limb trawl selectivities and using catchability nuisance *q* parameters resulted in a more stable model; although any one of these changes by itself was not sufficient.

Natural mortality was shown to be poorly informed (Figure 1) and over-estimated by about 0.02 y^{-1} (Figure 3). The mean estimated value was 0.20 y^{-1} (Table 7), and hence natural mortality was fixed at $M = 0.18$ y^{-1}, consistent with previous biological estimates, the values assumed in previous models (Horn 2005, 2008), and with the results from model simulations.

Further investigations into the CASAL software itself seem to indicate that minimisation may be compromised when parameters are very close to zero. This may explain why switching from free to nuisance *q* parameters helped stabilise the model, because model estimates of the longline CPUE catchability *q* were very close to zero (i.e., estimated at about 10^{-5}). In future assessments, fixing the CASAL software or alternatively adding a scaling multiplier to the CPUE index to ensure values of *q* are not close to zero might help resolve this issue.

The 2020 Plenary (Fisheries New Zealand 2020) reported that the major source of uncertainty in the assessment for Sub-Antarctic ling was the lack of contrast in the summer trawl series (the main relative abundance series), and that this made it difficult to accurately estimate the upper bound of the biomass trend. Furthermore, the previous assessment excluded the CPUE indices because they were deemed to not adequately reflect abundance due to lack of fit of the spawning longline CPUE within the model. However, the ling longline fishery is a target fishery which almost exclusively catches ling, and changes in abundance could be reflected in the CPUE indices. Therefore, this CPUE index is included as an index of abundance and used in the base case model.

Further investigations, using MPD profiles, showed that the longline CPUE index did contain some bounding information on stock size which was not available from other data sources (Figure 1). In this updated assessment, the longline fishery was not split between spawning and non-spawning fisheries, and hence the longline CPUE index represented the entire longline fishery. Fits to the longline CPUE index were adequate (Figure A.7). The process error estimated within the model was 0.16, which compared favourably with the process error of the trawl survey (estimated within the model at 0.13), and the longline CPUE index was consistent with the expected biomass trajectory of the model. The addition of the longline CPUE index and fixed natural mortality reduced the uncertainty surrounding the biomass trajectory (e.g., see Figure 4 to Figure 6).

The initial biomass for the base case was substantially lower than in the previous assessment (Masi 2019) at about 187 350 t. However, the sensitivity run with a similar value of $M = 0.20$ y^{-1} had a similar estimate of initial biomass, albeit with much smaller credible intervals (Table 9). In all sensitivity runs the probability of the stock status in 2021 being above 40% B_0 was between 67% and 99%, and that of being below 20% B_0 was less than 1%. This was not surprising because the annual exploitation rate was low (less than 0.1) in all years for the base case model (Figure 7). Alternative catch histories and projections with various future annual catch on the base case model show in all instances the probability of the stock status in 2026 will be above 40% B_0 is greater than 93%, and that of being less than 20% is null.

5. MANAGEMENT IMPLICATIONS

Reference points for ling in the Sub-Antarctic are a management target of 40% B_0, soft limit of 20% B_0, and hard limit of 10% B_0. The overfishing threshold is $F_{40\%B0}$ was calculated as 0.15, using the base case model and the Current Annual Yield (CAY) calculation method in CASAL (Bull et al. 2012). B_{2021} was estimated to be virtually certain to be above the target for all sensitivity runs, exceptionally unlikely to be below the soft or hard limit. Overfishing was exceptionally unlikely to be occurring (Figure 10).

Based on the four projections carried out, the projected stock status was unlikely to change over the next five years at recent catch levels, the level of the TACC or a 10% or 20% increase in the LIN 5 catch. Overfishing is exceptionally unlikely to commence based on these possible future catch rates.

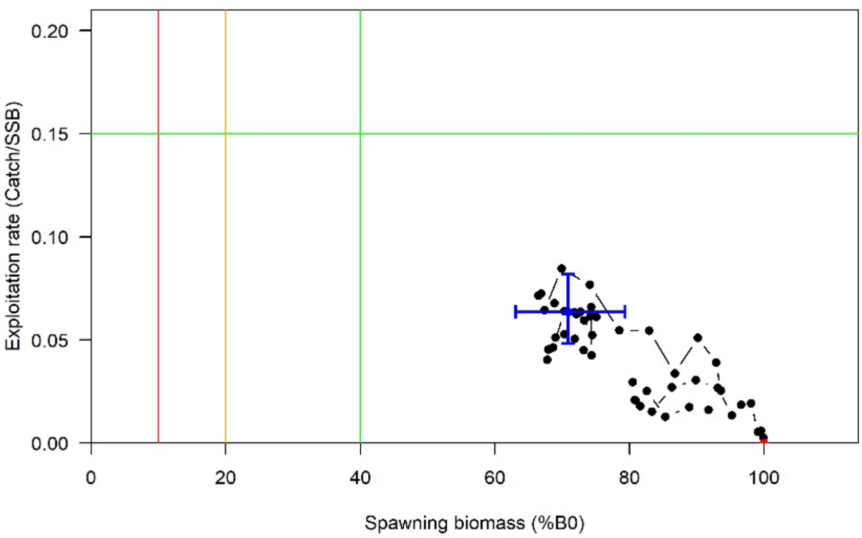


Figure 10: Trajectory over time of exploitation rate (*U*) and spawning biomass (% B_0), for the LIN 5&6 base model from the start of the assessment period in 1972 (represented by a red point), to 2021 (in blue). The red vertical line at 10% B_0 represents the hard limit, the orange line at 20% B_0 is the soft limit, and green lines are the %B_0 target (40% B_0) and the corresponding exploitation rate (U_{40} = 0.15 calculated using CASAL CAY calculation). Biomass and exploitation rate estimates are medians from MCMC results. The blue cross represents the limits of the 95% credible intervals of estimated the ratio of the spawning stock biomass to B_0 and exploitation rate in 2021.

6. ACKNOWLEDGEMENTS

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8. APPENDIX A – DIAGNOSTIC PLOTS FOR THE BASE CASE (R3.0)

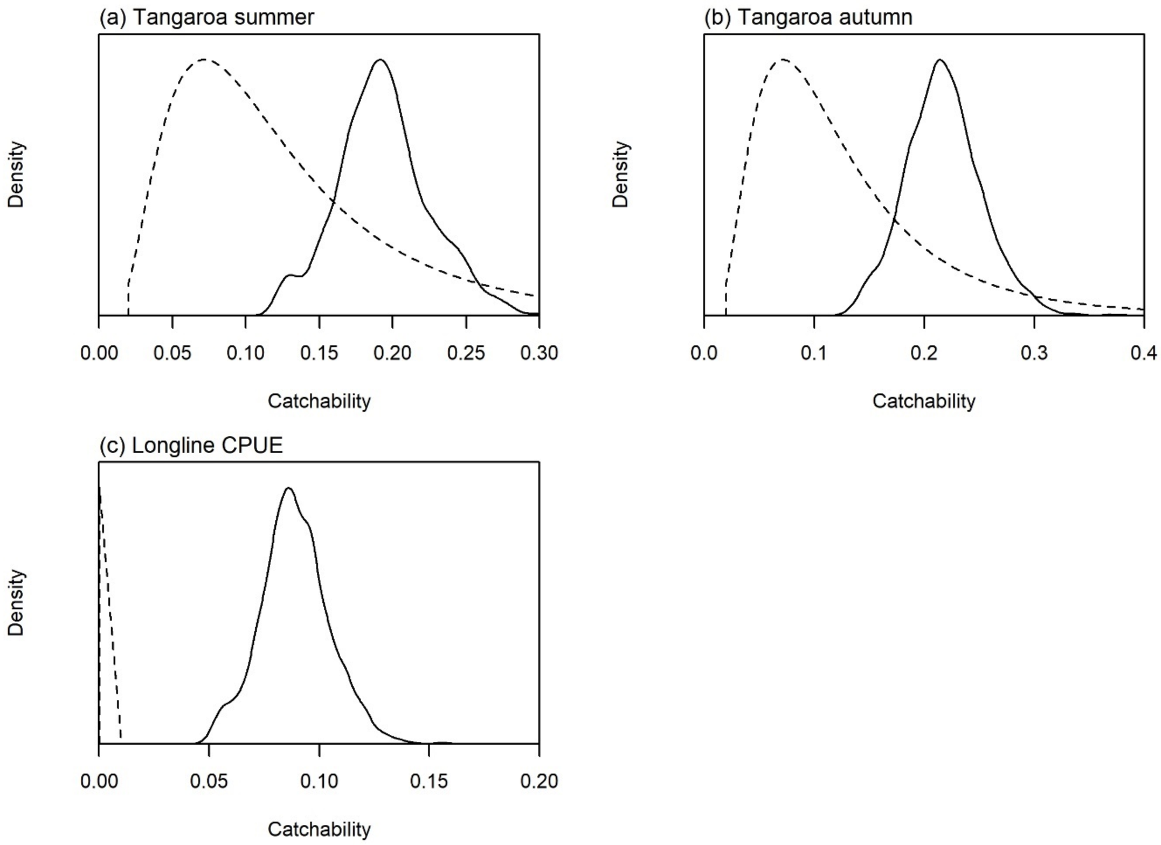

Figure A.1: Catchability parameters, priors in dashed and posteriors in solid lines.

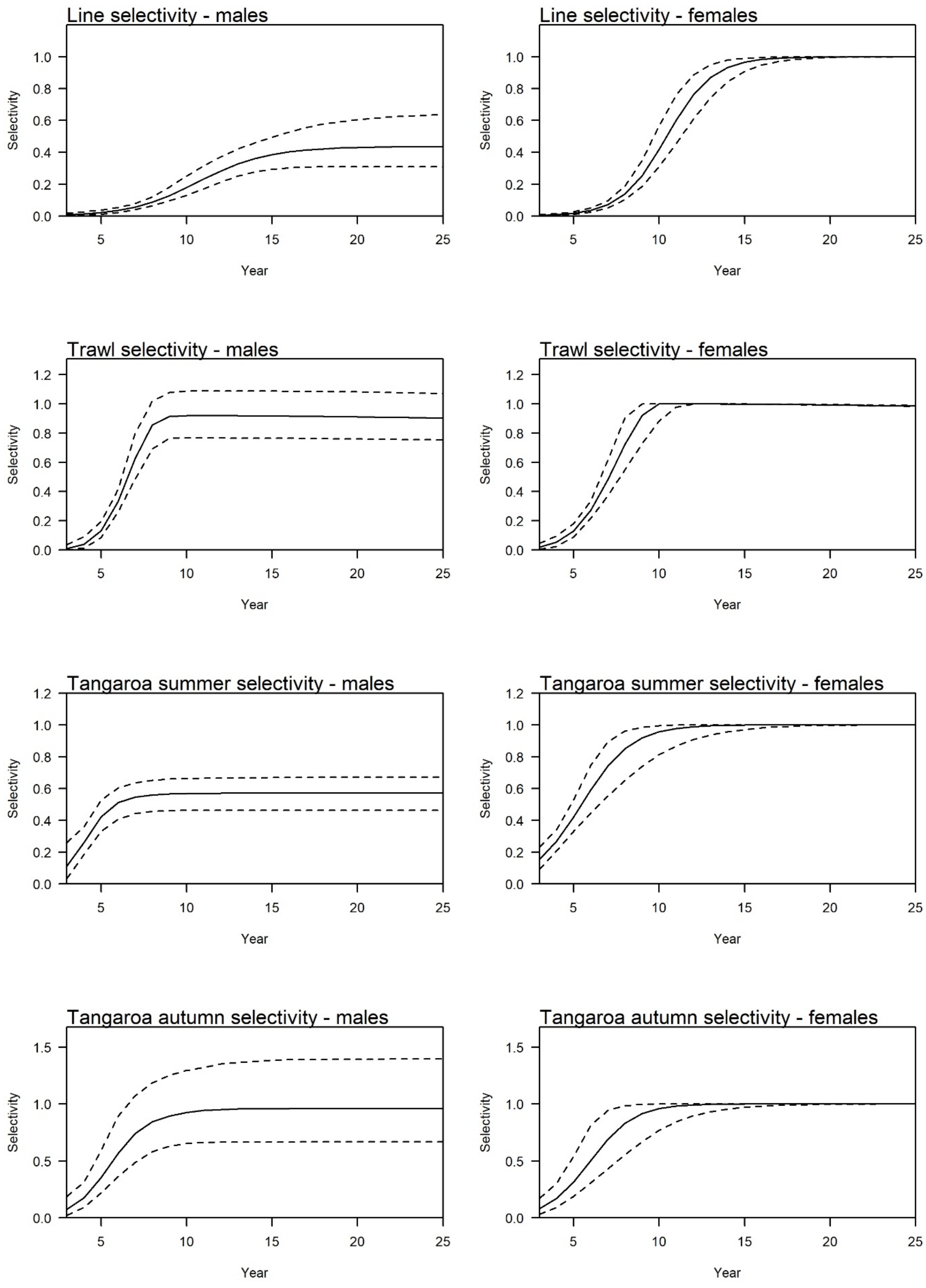

Figure A.2: Estimated selectivity estimates and 95% credible interval.

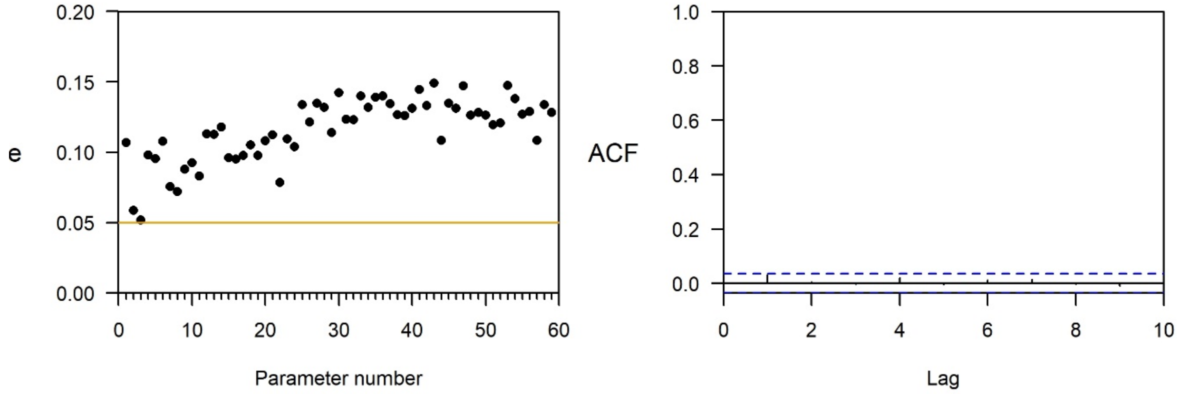

Figure A.3: MCMC posterior diagnostic plots, showing (left) median relative jump size for all parameters, and (right) autocorrelation (ACF) lag plot for *B_0*.

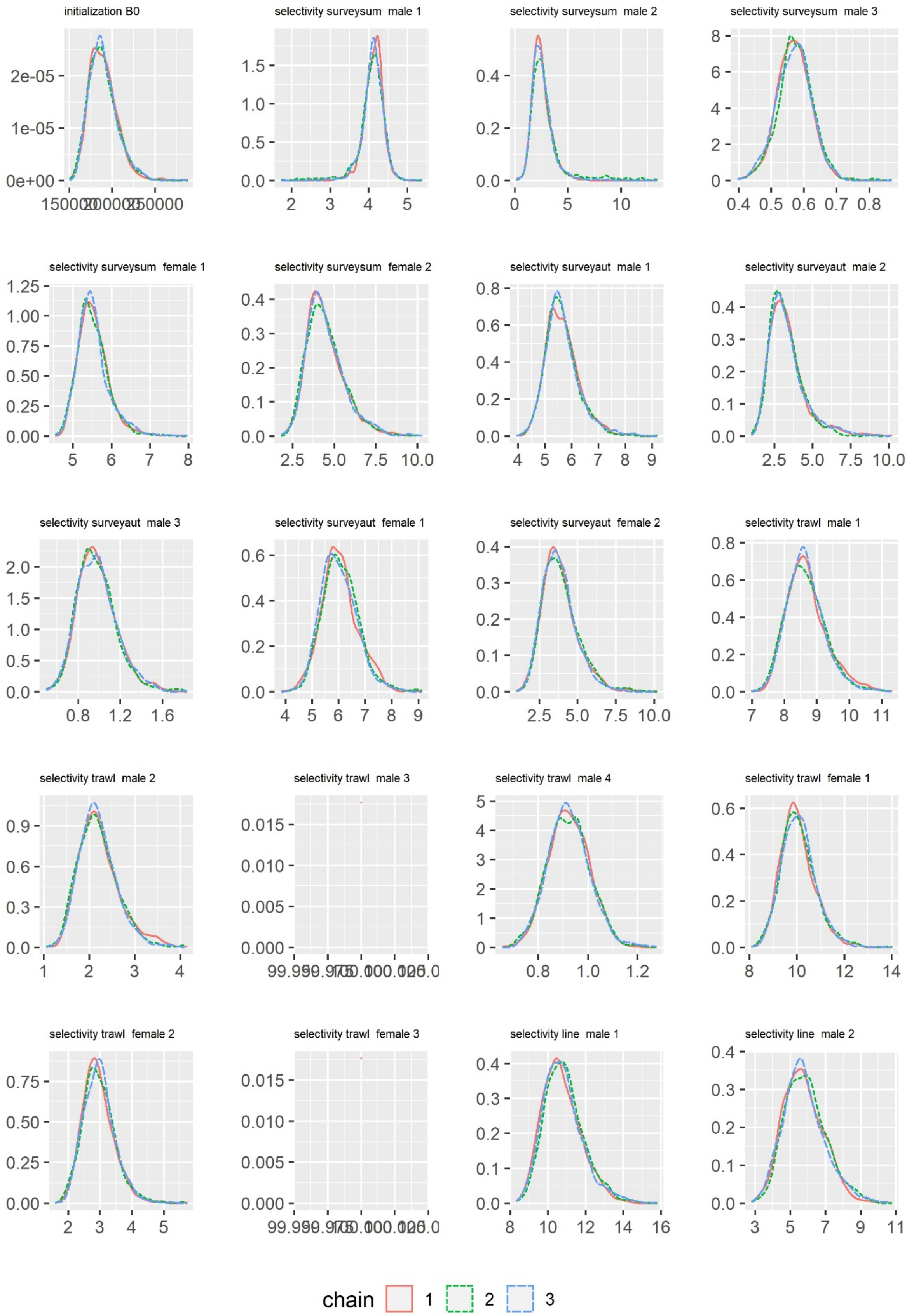

Figure A.4: MCMC chains. A single MCMC was run and the density distribution of its three sections of 1000 values each are plotted on top of each other.

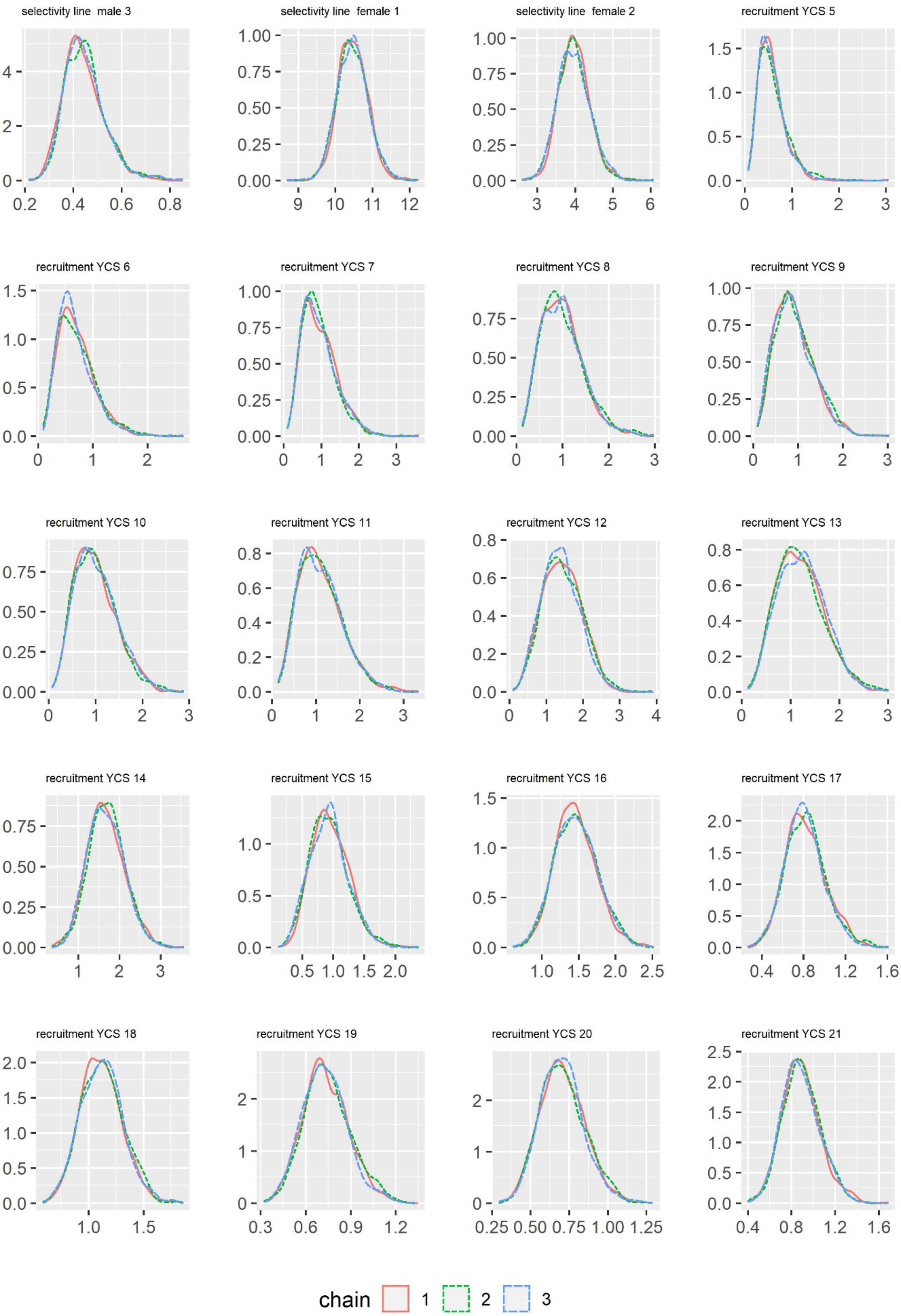

Figure A.5: MCMC chains (continued). A single MCMC was run and the density distribution of its three sections of 1000 values each are plotted on top of each other.

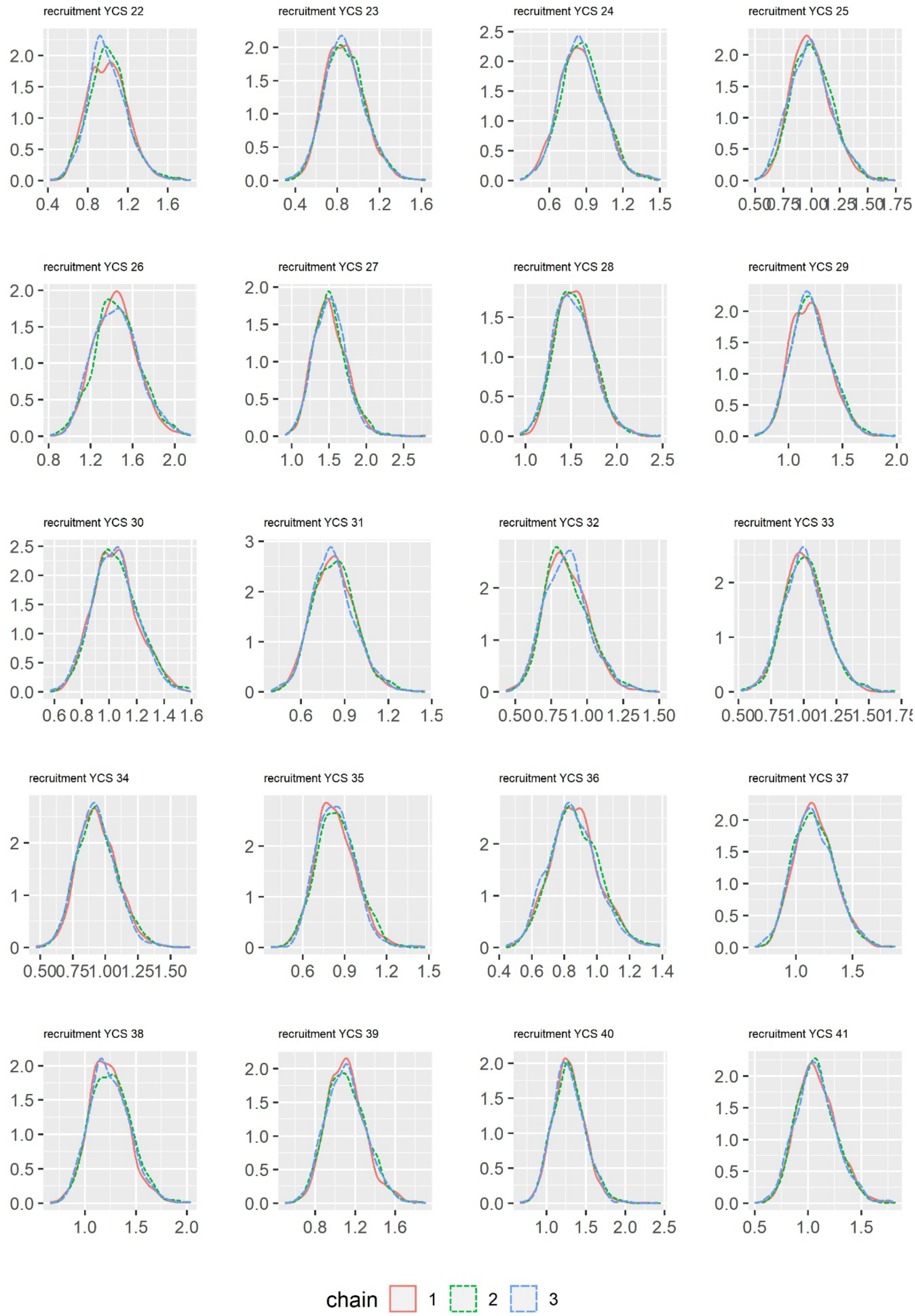

Figure A.6: MCMC chains (end). A single MCMC was run and the density distribution of its three sections of 1000 values each are plotted on top of each other.

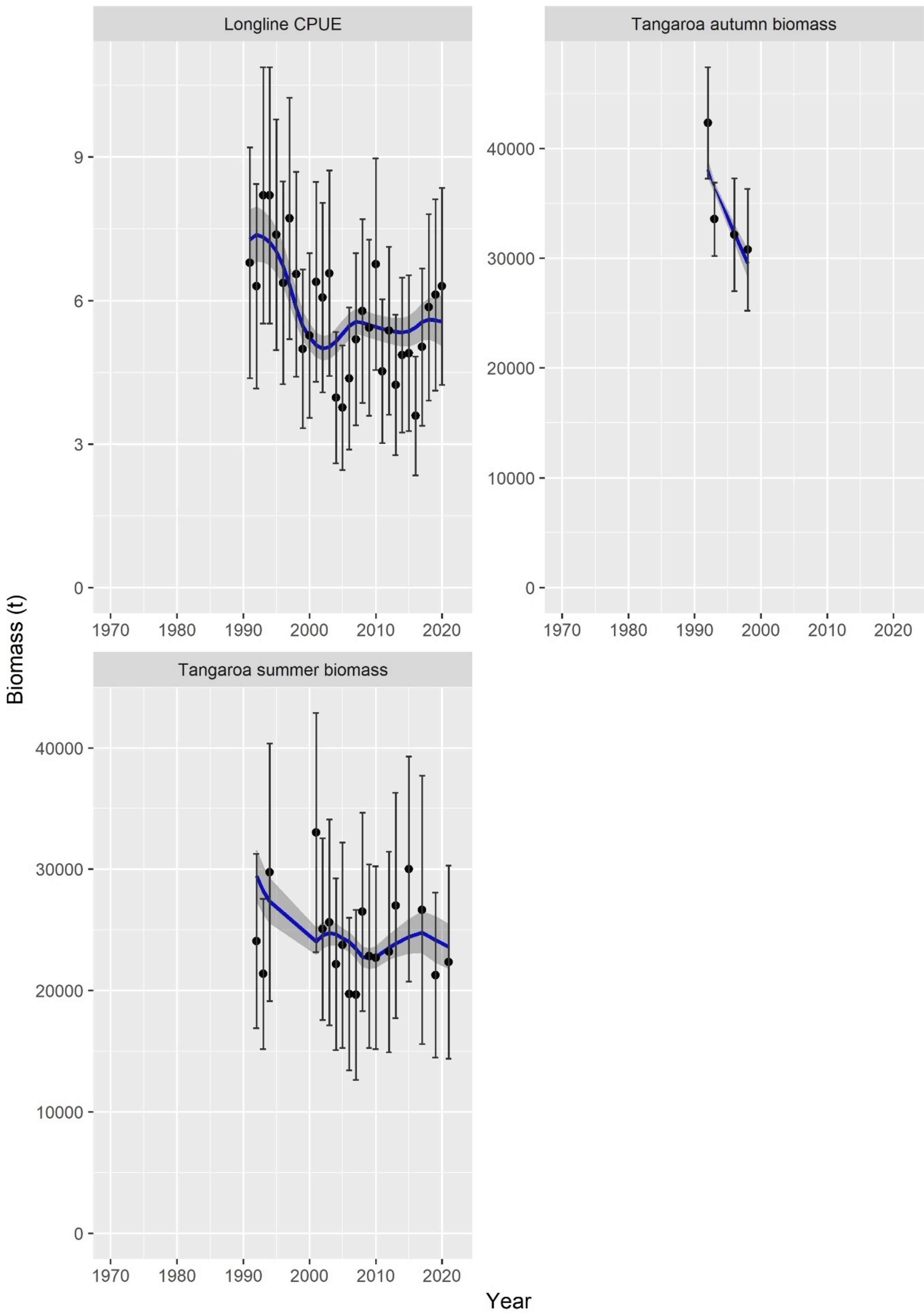

Figure A.7: Survey fits at the MCMC level. Black dots and vertical lines are the observed estimates and 95% credible intervals, blue line is expected and grey band the 95%ile credible interval.

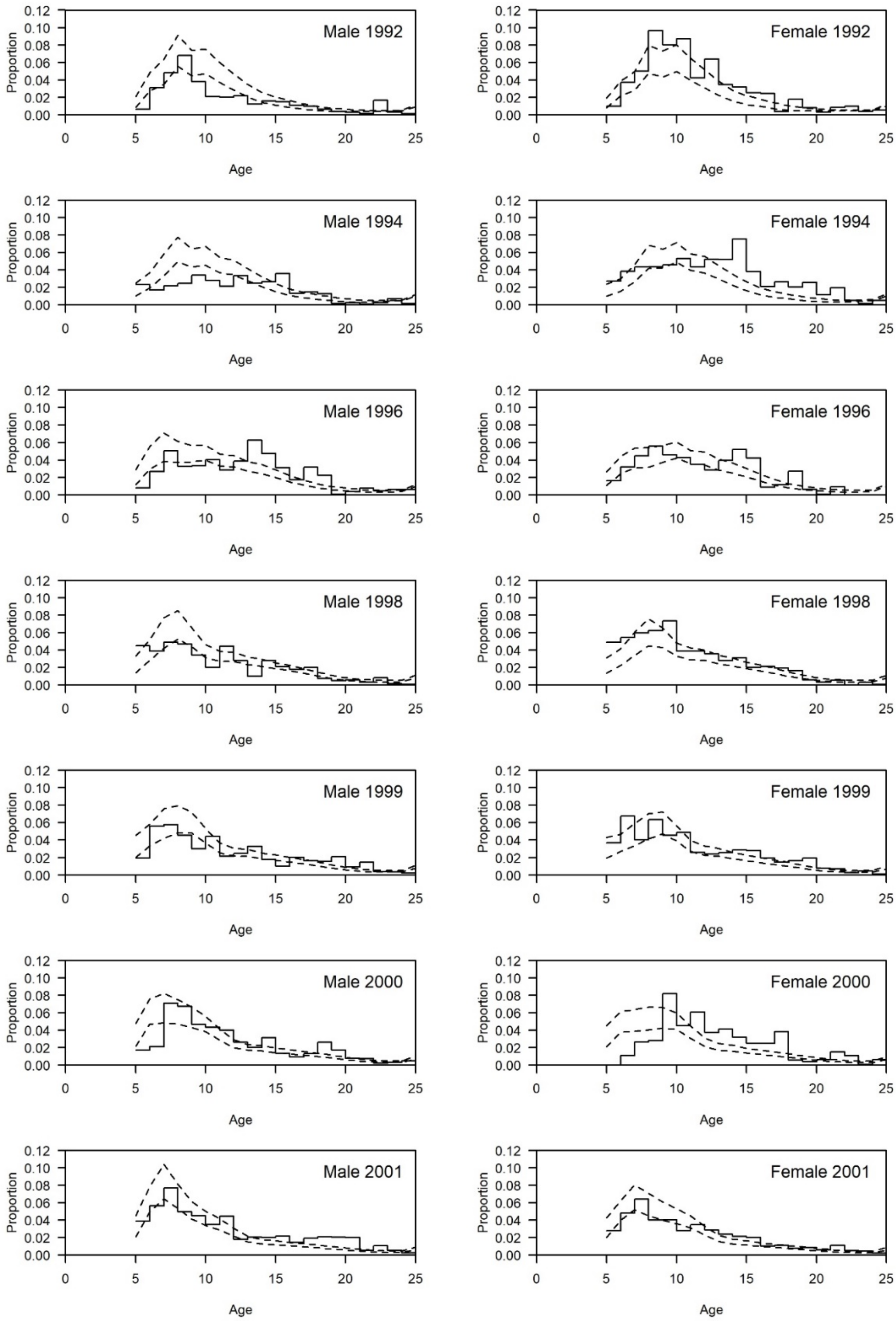

Figure A.8: MCMC fits to the trawl age frequency distributions from 1992 to 2001. Scaled age frequency distributions in solid line and estimated 95% credible interval in dotted lines.

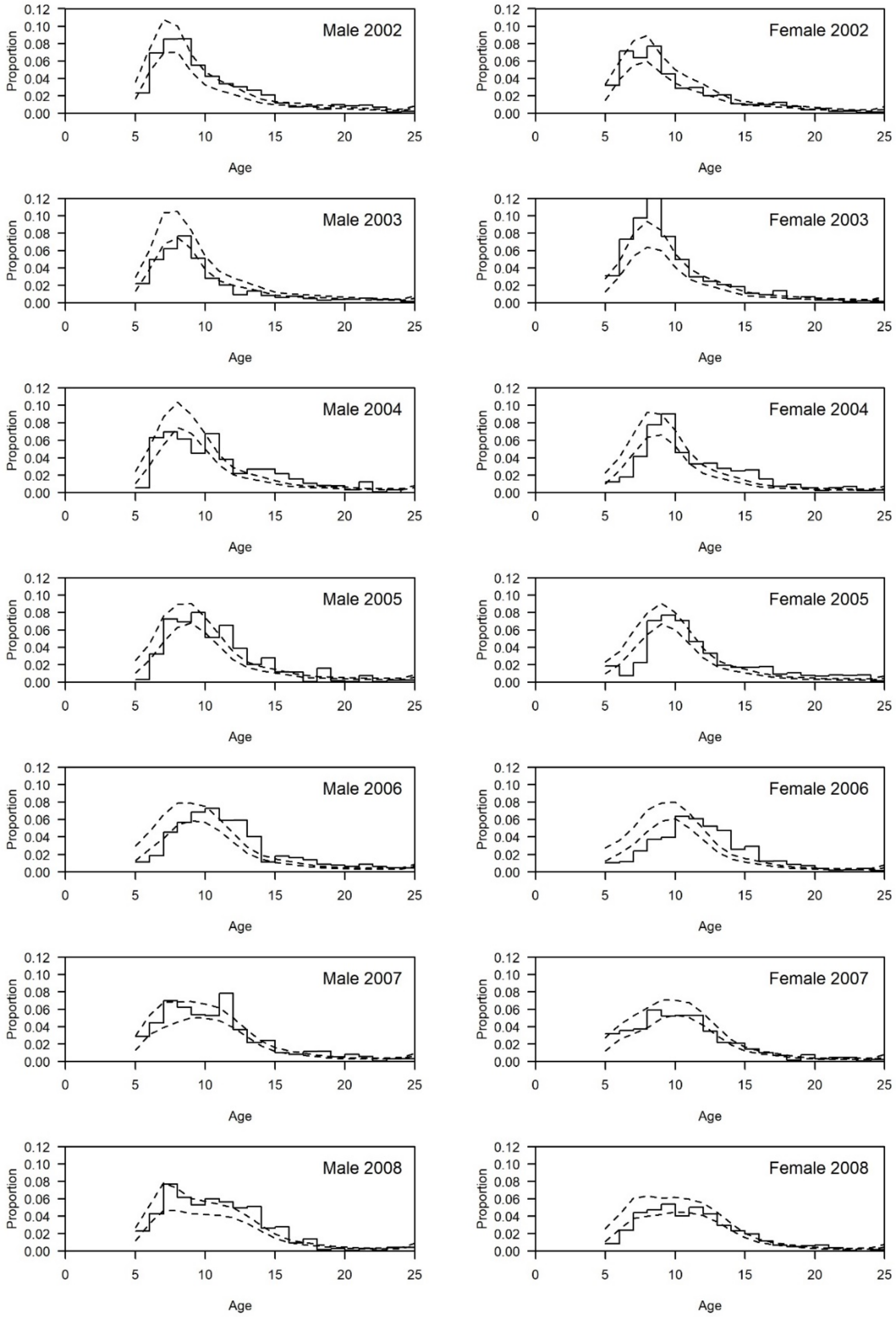

Figure A.9: MCMC fits to the trawl age frequency distributions from 2002 to 2008. Scaled age frequency distributions in solid line and estimated 95% credible interval in dotted lines.

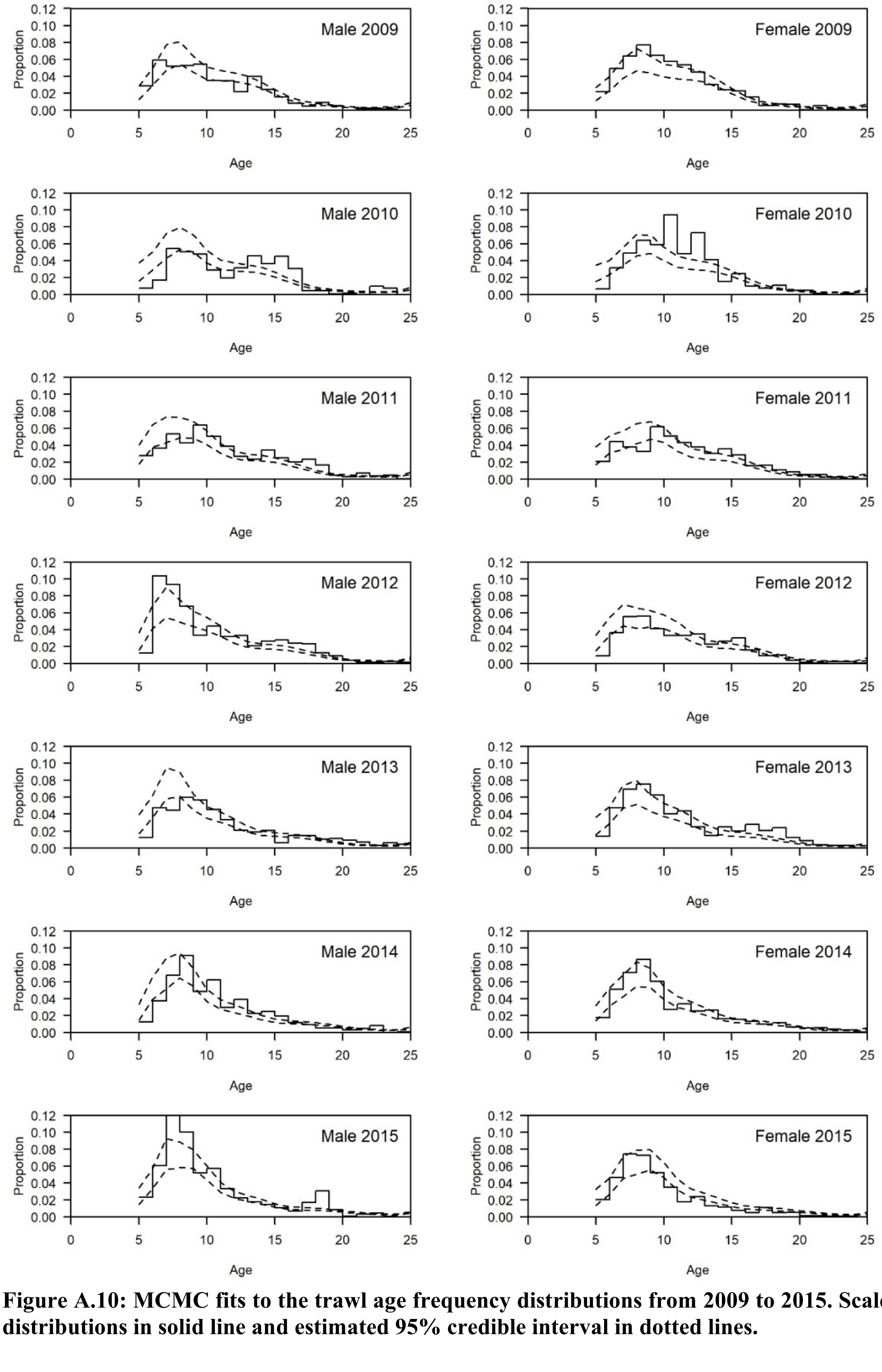

Figure A.10: MCMC fits to the trawl age frequency distributions from 2009 to 2015. Scaled age frequency distributions in solid line and estimated 95% credible interval in dotted lines.

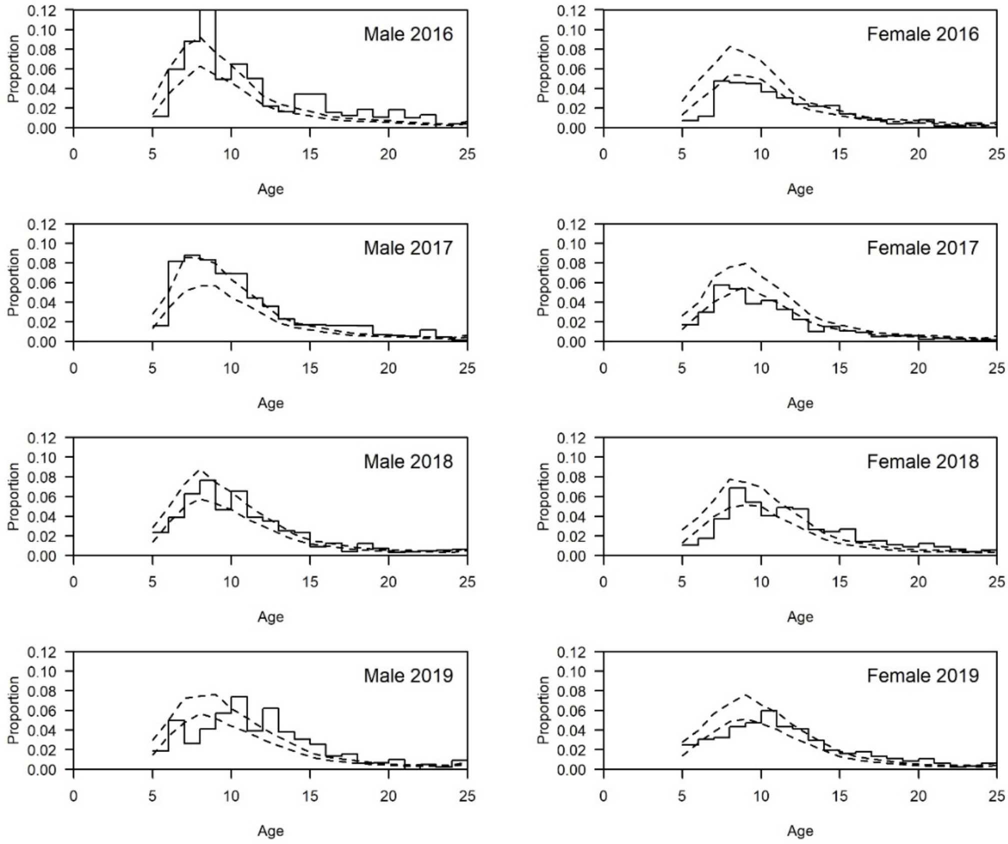

Figure A.11: MCMC fits to the trawl age frequency distributions from 2016 to 2019. Scaled age frequency distributions in solid line and estimated 95% credible interval in dotted lines.

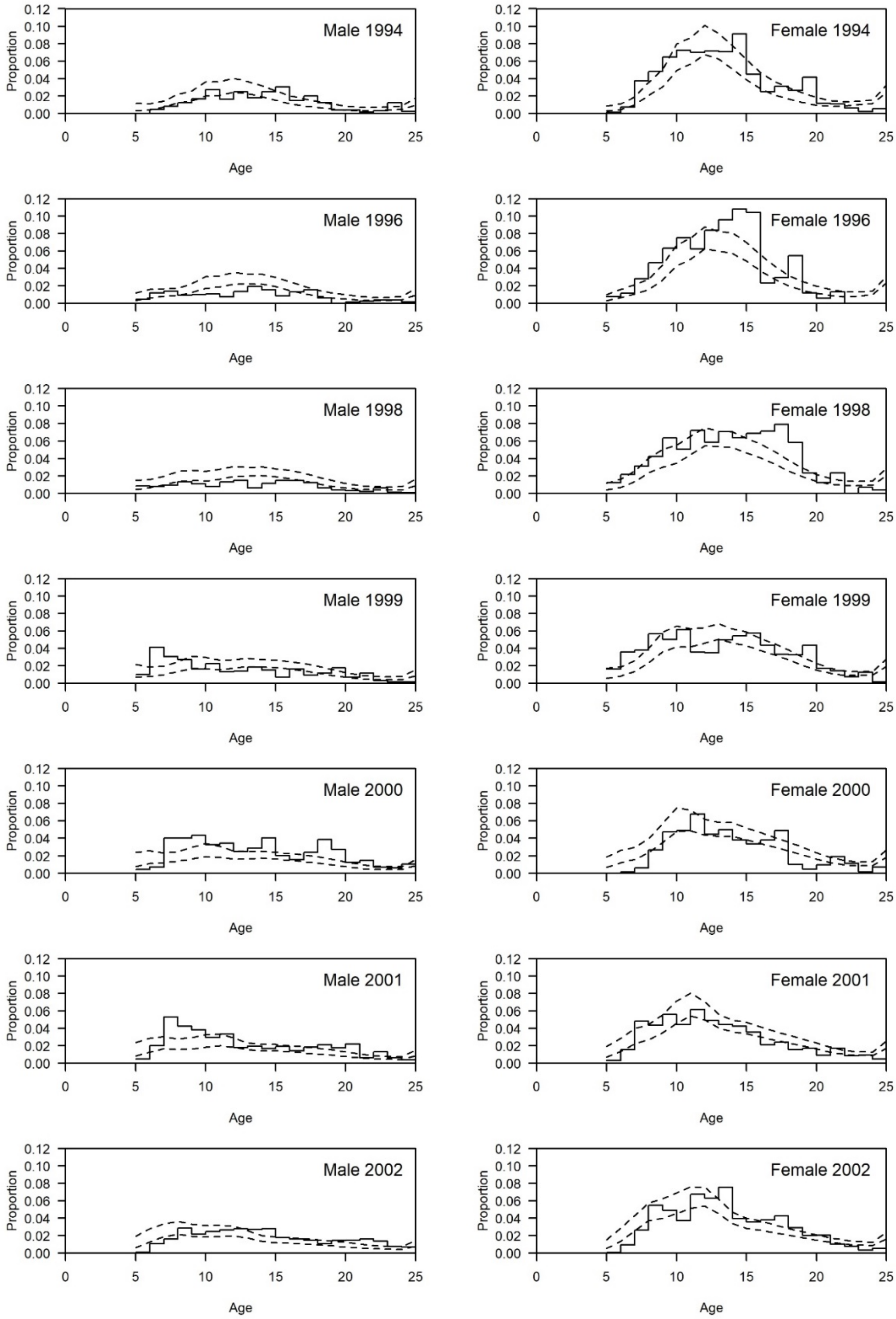

Figure A.12: MCMC fits to the longline age frequency distributions from 1994 to 2002. Scaled age frequency distributions in solid line and estimated 95% credible interval in dotted lines.

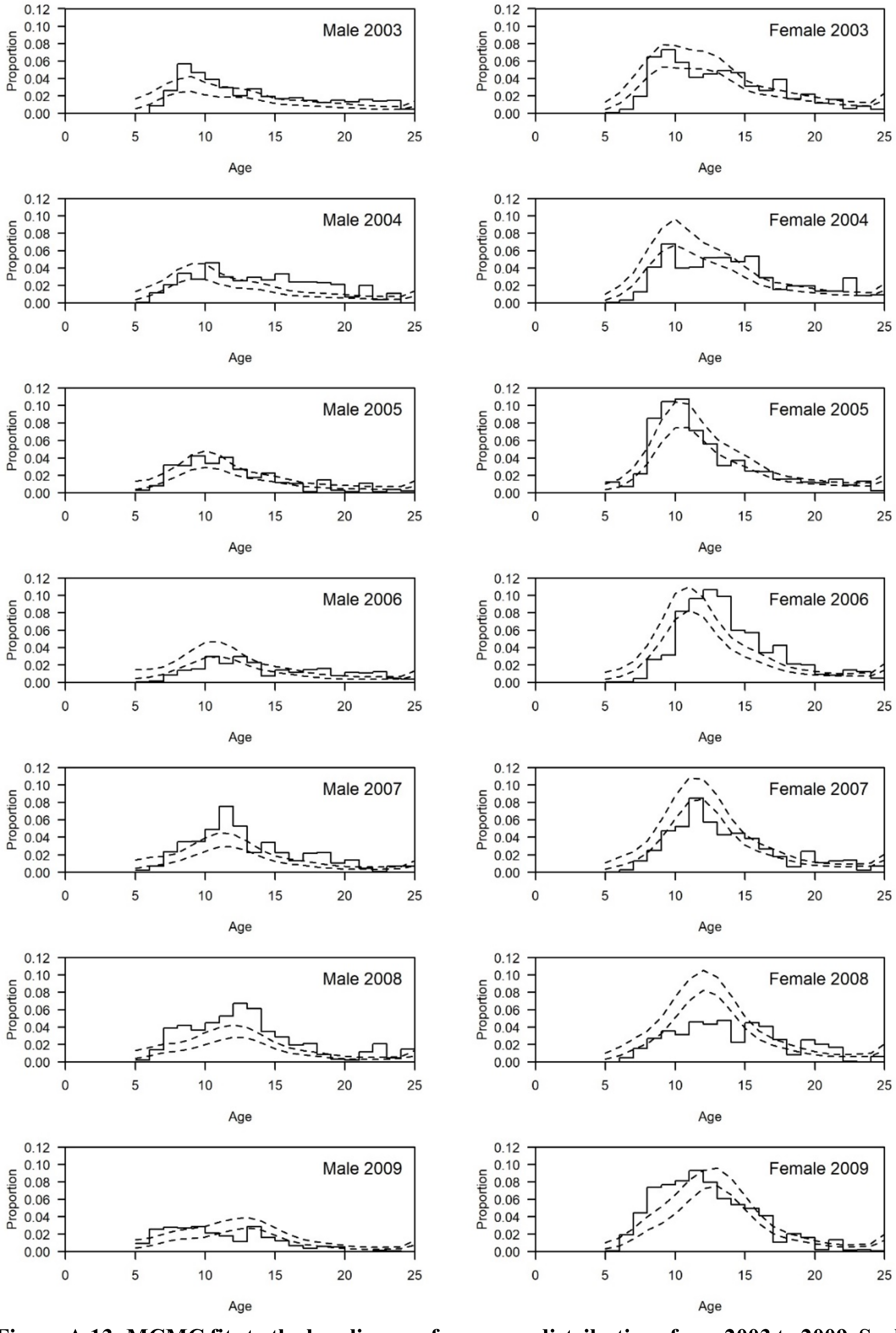

Figure A.13: MCMC fits to the longline age frequency distributions from 2003 to 2009. Scaled age frequency distributions in solid line and estimated 95% credible interval in dotted lines.

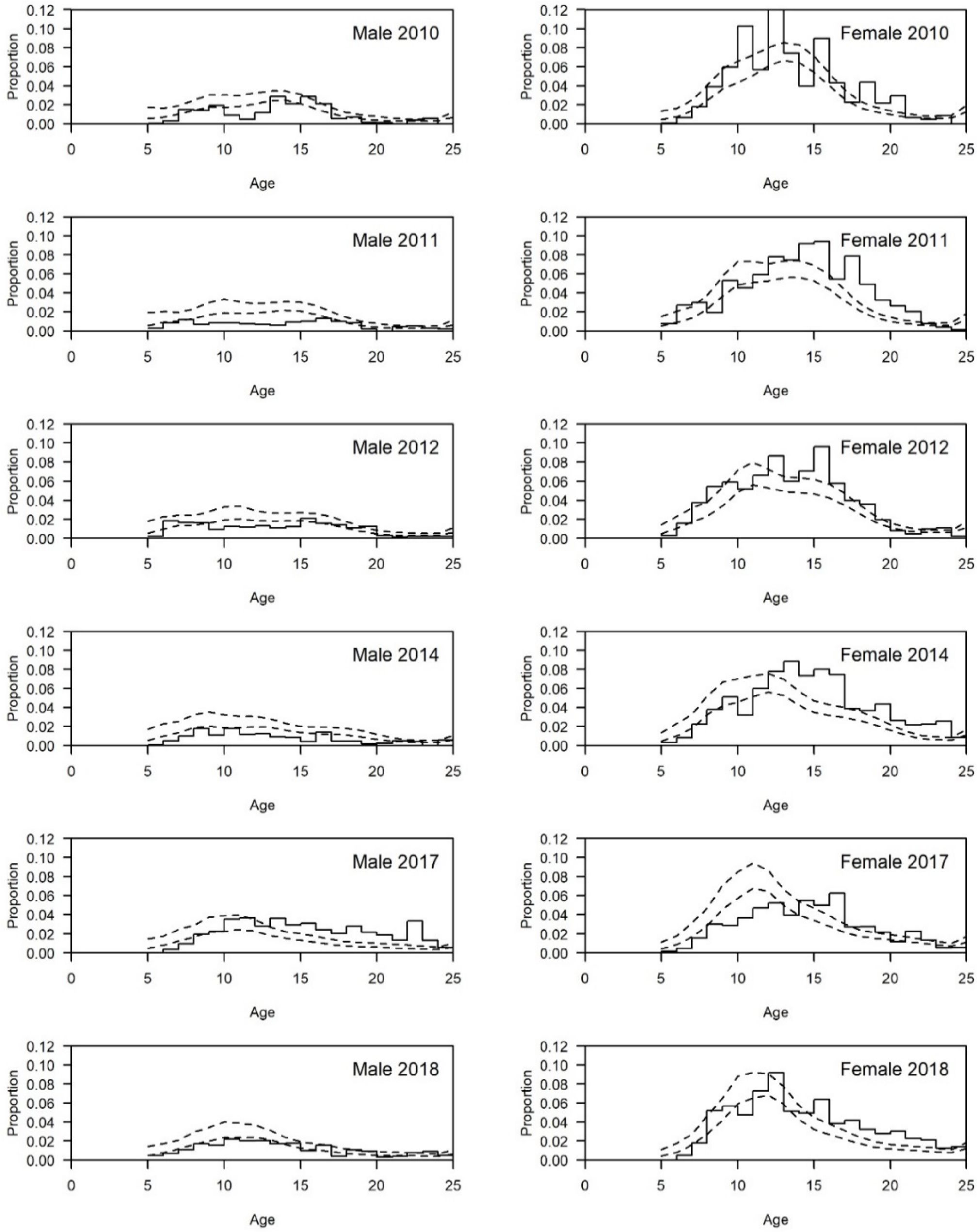

Figure A.14: MCMC fits to the longline age frequency distributions from 2010 to 2018. Scaled age frequency distributions in solid line and estimated 95% credible interval in dotted lines.

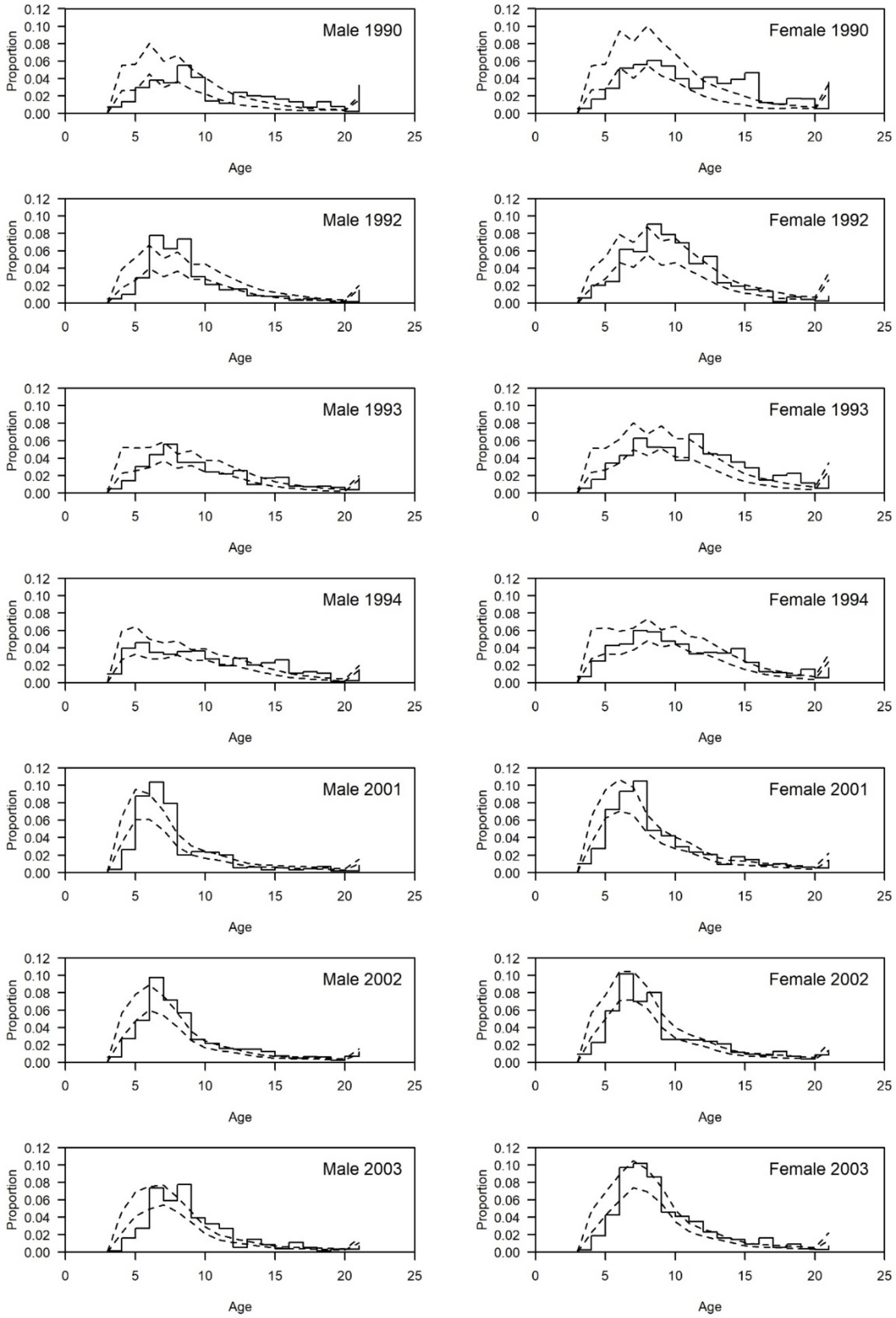

Figure A.15: MCMC fits to the summer Sub-Antarctic trawl survey age frequency distributions from 1990 to 2003. Scaled age frequency distributions in solid line and estimated 95% credible interval in dotted lines.

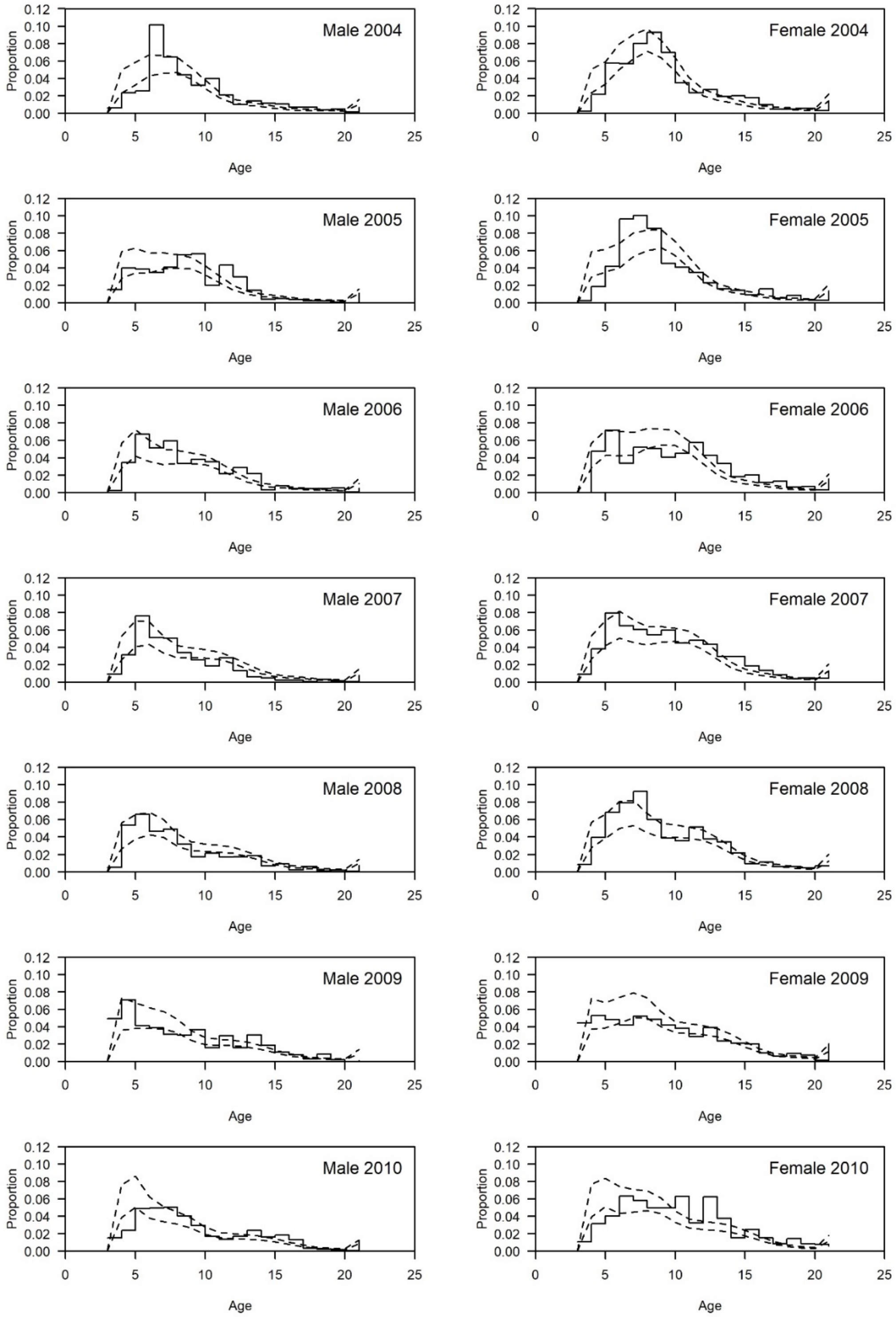

Figure A.16: MCMC fits to the summer Sub-Antarctic trawl survey age frequency distributions from 2004 to 2010. Scaled age frequency distributions in solid line and estimated 95% credible interval in dotted lines.

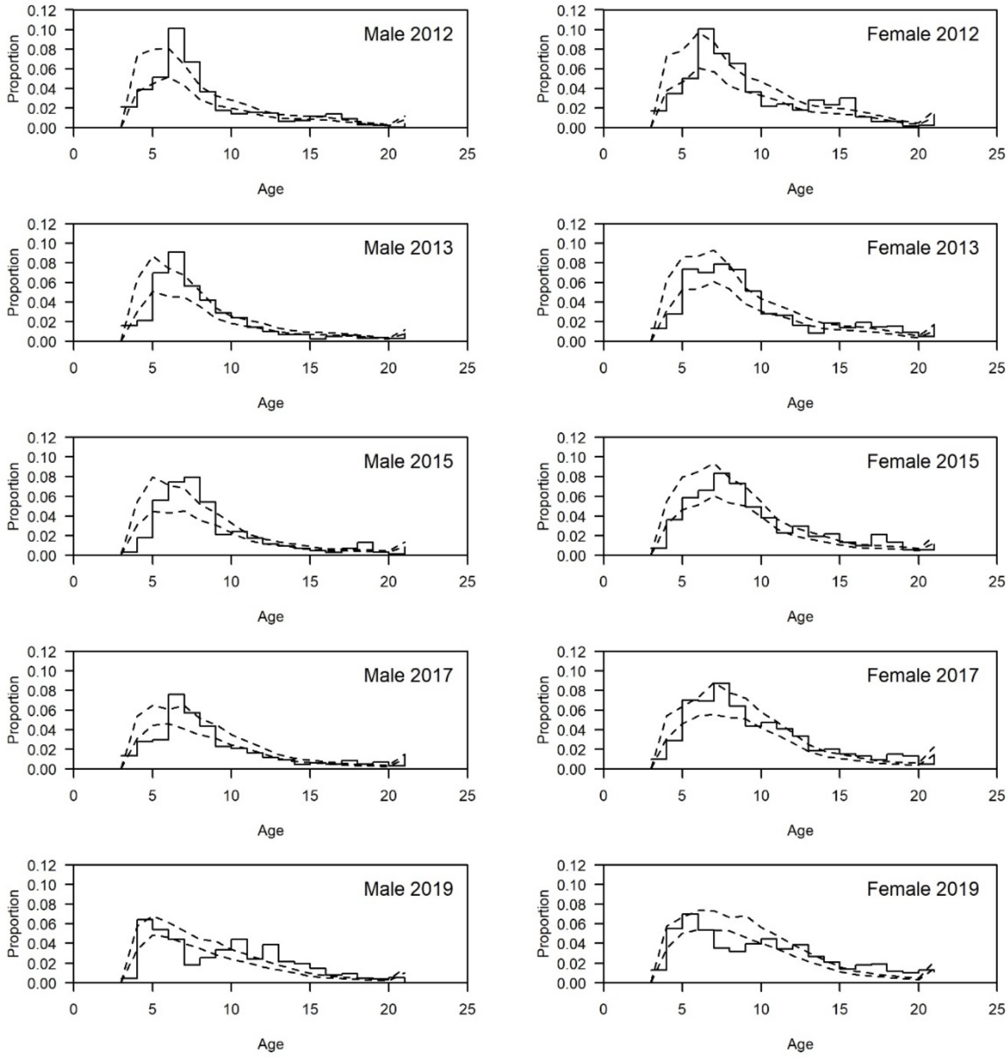

Figure A.17: MCMC fits to the summer Sub-Antarctic trawl survey age frequency distributions from 2012 to 2019. Scaled age frequency distributions in solid line and estimated 95% credible interval in dotted lines.

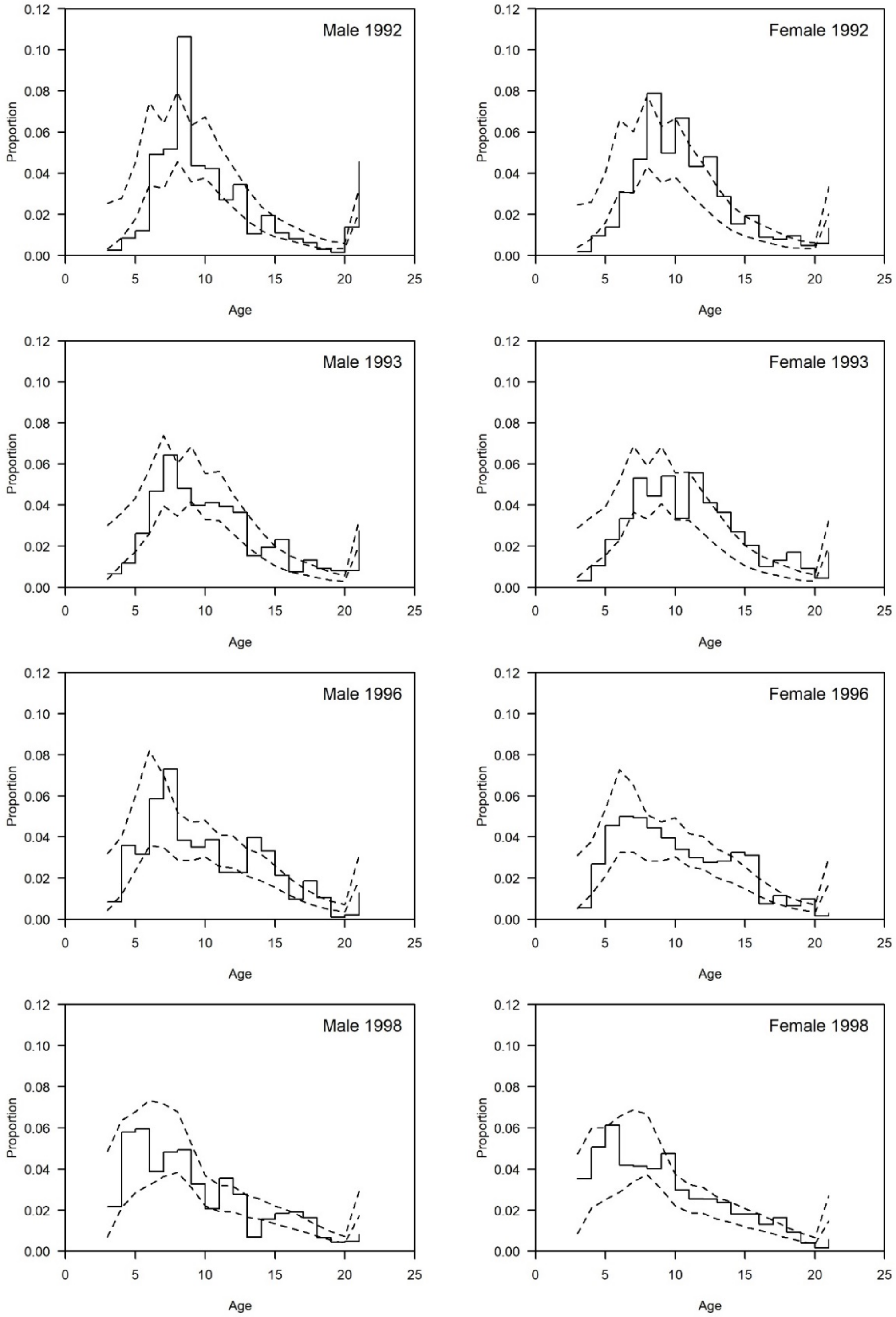

Figure A.18: MCMC fits to the autumn Sub-Antarctic trawl survey age frequency distributions. Scaled age frequency distributions in solid line and estimated 95% credible interval in dotted lines.