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Stock assessment of ling (*Genypterus blacodes*) on the Chatham Rise (LIN 3&4) for the 2021–22 fishing year

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EXECUTIVE SUMMARY

Mormede, S.[1]; Dunn, A.[2]; Webber, D.N.[3] (2023). Stock assessment of ling (*Genypterus blacodes*) on the Chatham Rise (LIN3&4) for the 2021–22 fishing year.

***New Zealand Fisheries Assessment Report 2023/14*. 39 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 waters. Ling are managed as eight administrative Quota Management Areas with five of those reporting about 95% of the landings. There are at least five major biological stocks: the Chatham Rise, the Sub-Antarctic (including the Stewart-Snares shelf and Puysegur Bank), the Bounty Plateau, the west coast of the South Island, and Cook Strait. This report summarises the stock assessment of the Chatham Rise stock (LIN 3&4) for the 2021–22 fishing year.

The main index of abundance provided to the model was the Chatham Rise summer trawl survey biomass series. The commercial longline standardised catch per unit effort (CPUE) series was used in a sensitivity model but had a different trend to the survey biomass series. Estimates of the rate of natural mortality (M) for each sex were relatively well estimated with little bias; however, estimates were higher for the base case model than the CPUE sensitivity model. An additional sensitivity of the base case model with natural mortality values assumed to be fixed at the values from the CPUE sensitivity run was also carried out.

The initial spawning stock biomass (B_0) for both the base case and the CPUE sensitivity models were similar to those reported by the previous assessment in 2019. For the base case model, B_0 was estimated to be about 110 040 t and stock status in 2022 was estimated as 56% B_0. The CPUE sensitivity run resulted in a lower estimate of B_0 at about 92 190 t and hence a lower stock status in 2022 (33.5% B_0). Although the trawl survey biomass index had no trend and the likelihood profiles suggested a conflict with the age composition data (including the survey age composition data), the survey was thought to be a robust and consistent estimate of abundance, while the CPUE index was likely to have been influenced by spatial and vessel operational factors. Therefore, the assessment used the trawl survey biomass series for the base case model in the assessment, over the CPUE index or the age composition data.

In the lower M sensitivity model, stock status in 2022 was estimated at 45% B_0 and the probability of the stock status in 2022 being above 40% B_0 was estimated to be about 95%. In the CPUE sensitivity model, stock status in 2022 was estimated at 34% B_0, the probability of the stock status in 2022 being above 40% B_0 was 5%, and the probability of being below 20% B_0 less than 1%. A sensitivity model with alternative catch histories (assuming a 5% increase in total catch for years before 1986 and 2% increase in catch thereafter) had little impact on estimates of initial spawning stock biomass or stock status from the base case model.

Five-year projections were done using the base case model, two year-class strength resampling periods (1975–2013 or 2003–2013) and two future annual catch scenarios (average of 2019 to 2021 model year catches or the Total Allowable Commercial Catch). Projected stock status in 2027 was expected to be between 46% and 59% of B_0 on average. The probability that the stock status in 2027 will be above 40% B_0 was greater than 85%, and that of being less than 20% was zero. Projections using the CPUE sensitivity model showed similar future biomass patterns but with a lower status in future years.

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1. INTRODUCTION

Ling are an important commercially caught species and are targeted by bottom trawls, demersal longlines, and potting. 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. Small quantities of ling are also caught by inshore trawl, setnets, and increasingly, in LIN 3&4, potting (Mormede et al. 2022).

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

The most recent assessment for LIN 3&4 was carried out by Holmes (2019) and the most recent characterisation of ling in LIN 3&4 was for the 2021–22 fishing year (Mormede et al. 2022). Holmes (2019) reported that the estimated "*…B_0 was about 111 000 t, and was very unlikely to be lower than 100 000 t*". Furthermore, B_{2019} "*was estimated to be 57% B_0, although the level of absolute biomass was uncertain because there was little contrast in the principal abundance* [trawl survey] *index*". Sensitivity model runs estimated a stock status in 2019 ranging from about 32 to 55% B_0. The stock size of LIN 3&4 was predicted to remain constant over the next 5 years at the recent catch levels but decline if catches increased to the Total Allowable Commercial Catch (TACC). Reported catches have decreased slightly since 2019 and now are about 52% of the TACC.

The ling stock assessments have typically been implemented as two-sex single area integrated statistical catch-at-age models. The Bayesian stock assessment software CASAL (Bull et al. 2012) has been used for all assessments since 2002–03 (Horn & Dunn 2003). The fisheries have been defined as trawl and longline using observations from commercial catch-at-age, CPUE indices (as a sensitivity), and resource survey biomass and age frequencies (Holmes 2019). The rate of natural mortality (M) has been estimated as a constant rate for each sex.

The 2020 Fisheries Plenary report (Fisheries New Zealand 2020) reported that the major source of uncertainty in the assessment for ling on the Chatham Rise was the lack of contrast in the summer trawl biomass series (although it was considered the most reliable abundance series). The previous assessment also excluded all CPUE indices from the base case model because they were in contradiction with the survey biomass indices and thought to be less reliable.

This report fulfils Specific Objective 2 of Project LIN2021-01. The overall Objective was "To carry out stock assessments of ling (*Genypterus blacodes*) on the Chatham Rise (LIN 3 and LIN 4) including estimating biomass and stock status" and Specific Objective 2 was "To carry out a stock assessment of the Chatham Rise 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 model was carried out for LIN 3&4 (Chatham Rise) using the stock assessment program CASAL v2.30 (Bull et al. 2012). The stock assessment model assumed a Beverton-Holt stock-recruit relationship and partitioned the population into two sexes for ages 3 to 25, with the oldest age being a plus group. To align more closely with the spawning season (September to December), to the seasons of the target fisheries (particularly in the early years), and allow a single model year for the stock, the model year was set as the calendar year (January to December) rather than the fishing year (October to September). In this document, ‘year’ always refers to the model year unless specifically otherwise stated.

The 2022 investigation of the spatial-temporal structure of ling in LIN 3&4 resulted in the revision of the Chatham Rise ling fisheries into three fisheries defined by gear type: bottom trawl, bottom longline, and potting. The model time steps were also modified to represent the fishery more accurately, with a first time step from January to June, and a second time step for the rest of the year (July to December) (Mormede et al. 2022). The proportional growth in each time step was based on the monotonic growth model (Mormede et al. 2022) which indicated that there is virtually no growth in the second time step (July to December). The model’s annual cycle is described in Table 1. Growth in the model was was assumed to occur 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). Recruitment was assumed to occur during the first time step and spawning in time step two. The fisheries were assigned to time step two as the majority of catch was taken during that timestep.

Table 1: Annual cycle of the stock assessment model of ling on the Chatham Rise (LIN 3&4). The ‘X’ marks when processes or observations occur in the year; for example, recruitment happens in January and is part of timestep 1. Potting is grouped with the longline fishery.

Monthly timing of biological & fisheries processes									Model timing of biological & fisheries processes					
	Recruitment	Maturation and spawning	Trawl catch (%)	Longline catch (%)	*Tangaroa* resource surveys (biomass and AFs)	Trawl fishery AFs	Longline fishery AFs	Fishery CPUE	Model timestep	Ageing	Proportion of growth	Proportion of natural mortality	Trawl catch (%)	Longline catch (%)
									Year start					
Jan	X		15	2	1992–2014, 2016, 2018, 2020									
Feb			9	2					1		0.50	0.9	0	0
Mar			9	3										
Apr			7	3										
May			8	3										
Jun			5	4										
Jul			2	8										
Aug		X	3	22			Jun-Oct	X	2	X	0.00	0.1	100	100
Sep			8	27										
Oct			8	16										
Nov			12	7										
Dec			14	3		Oct-May								
									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. (2022). The rolled-up standardised longline CPUE (further referred to as longline CPUE) was not considered a suitable index of abundance because it conflicted with the trawl survey biomass index prior to 2000 and was assumed to be influenced by fishery operational factors; it was used in a sensitivity model. Analyses of the spatial-temporal distribution of the catch and effort of the longline fishing fleet showed the CPUE index was not unduly influenced by changes in large scale spatial distribution of the fishery (Mormede et al. 2023). 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 and was not used (Holmes 2019).

The Chatham Rise trawl survey biomass and age frequencies were developed by Stevens et al. (2021) and Saunders et al. (2021) and are also summarised in the plenary report (Fisheries New Zealand 2022) in the ling chapter. The trawl survey age composition was provided as ages 3 to 25 (with 25 as a plus group), with fish of ages 1 and 2 ignored. Due to the lack of ageing of small fish in the commercial fisheries, the trawl and longline age composition were provided as ages 5 to 25 (with 25 as a plus group), with fish of smaller lengths and ages 1 to 4 ignored. The longline age composition for 2019 was not included as it had a very low estimated effective sample size with poor coverage of the season and fleet, and consequently large uncertainty (and a very low weighting in the model). 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 allow for sampling error only. Process error, assumed to arise from differences between model simplifications and real-world variation, was added to the sampling variance during modelling. The process error was estimated in the models at maximum posterior density (MPD) level only and then assumed in Markov chain Monte Carlo (MCMC) runs. 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 Chatham Rise ling stock models (LIN 3&4), including source years. Data in bold were used in the base case model.

Data series	Years
Trawl survey biomass (*Tangaroa*, Jan)	**1992–2014, 2016, 2018, 2020, 2022**
Trawl survey proportion at age (*Tangaroa*, Jan), sexed	**1992–2014, 2016, 2018, 2020**
CPUE (longline, all years)	1991–2021
Commercial longline proportion-at-age (Jun–Oct), sexed	**2002–09, 2013–2018, 2020**
Commercial trawl proportion-at-age (Oct–May), sexed	**1992, 1994–2020**

Table 3: Input parameters used in the Chatham Rise ling stock models (LIN 3&4).

Relationship	Reference	Parameter (units)	Value		
			Both	Male	Female
von Bertalanffy growth	(Mormede et al. 2022)	t_0 (y)		-0.65	-0.71
		k (y^{-1})		0.130	0.090
		L_∞ (cm)		112.2	153.3
		CV		0.09	0.09
Length-weight	(Mormede et al. 2022)	a ($g.cm^{-1}$)		$1.28e^{-9}$	$1.38e^{-9}$
		b		3.294	3.271
Stock recruitment relationship					
Stock recruitment steepness	(Holmes 2019)	h	0.84		
Recruitment variability		σ_R	0.6		
Ageing error	(Holmes 2019)	CV	0.05		
Proportion male at birth			0.5		
Proportion of mature that spawn			1.0		
Maximum exploitation rate (U_{max})			0.6		

Table 4: Maturity at age used in the Chatham Rise ling stock models (from Horn 2005).

Age	3	4	5	6	7	8	9	10	11	12	13	14	15
Male	0.0	0.03	0.063	0.14	0.28	0.48	0.69	0.85	0.93	0.97	0.99	1.00	1.0
Female	0.0	0.00	0.003	0.01	0.014	0.033	0.08	0.16	0.31	0.54	0.76	0.93	1.0

2.3 Estimation of parameters

The initial spawning stock biomass (B_0) was estimated in the model, as were year class strengths and the fishing selectivity ogives. The trawl and longline fisheries and research survey selectivity ogives were assumed to be logistic curves. Trawl fishery and research survey selectivity ogives were previously assumed to be double normal curves (Holmes 2019) but the right-hand limb was found to be highly uncertain and was estimated with values that approximated a logistic ogive (Table 5). Due to the low numbers of young fish aged in the fishery, the age composition was truncated at age 5 for the trawl and longline fisheries and age 3 for the trawl survey age composition. The left-hand limb of the selectivity of males in the trawl fishery was fixed at its MPD values due to its high uncertainty (the trawl fishery selects fish younger than 5 years old which is when the age frequency starts). Because only one potting trip had been observed and no age data were available for the fishery, the potting fishery was assumed to have the same selectivity as the longline fishery (Mormede et al. 2022). Selectivities were assumed constant over all years in each of the fisheries and for the survey. Instantaneous natural mortality (M) was estimated as sex-specific and constant at age in the model and parameterised as the average mortality value (M_{avg}) and the male-female difference (M_{diff}).

Most of the priors were assumed to be relatively uninformative (i.e., uniform or uniform-log) and were specified with wide bounds. The exceptions were the choice of informative prior for the trawl survey catchability q. The prior on q for the trawl biomass survey indices were estimated by Horn et al (2013) and assumed 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. In all models, the catchability coefficients (qs) for either the survey or the CPUE index were estimated as free parameters. However, the model that included the longline CPUE as an abundance index that had been standardised to have mean equal to one had difficulty converging at MCMC with q estimated as a free parameter, and this was tracked to the instability of the minimisation routine within CASAL when estimating parameters with very low values (i.e., less than about 10^{-3}, see Webber et al. 2021). The longline CPUE was rescaled to the mean catch (kilogram) per hook (i.e., with a mean of about 3200), allowing q to be estimated at about 0.08 (instead of 10^{-4}) and resulting in a more stable model.

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

For final runs, the full posterior distribution was sampled using Markov chain Monte Carlo, 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 1000th sample taken from the final 3×10^6 iterations (i.e., a final sample of length 3000 was sampled from the posterior).

Table 5: Parameters estimated in the Chatham Rise ling models. YCS = year class strength.

Parameter	Shape	Starting values		Prior distribution	Parameters		Bounds	
B_0		125 000		uniform-log			30 000	500 000
YCS		1		lognormal	1	0.7	0.01	100
survey selectivities	logistic	10	5	uniform			0	20–200
trawl selectivity	logistic	5	2	uniform			0	20–200
line selectivity	logistic	5	2	uniform			0	20–200
survey q		0.13		lognormal	0.13	0.7	0.02	0.3
survey process error		0.1		uniform-log			0.001	2
CPUE q				uniform-log			$10e^{-6}$	$10e^{-2}$
M_{avg}		0.14		lognormal	0.2	0.18	0.06	0.5
M_{diff}		0.02		normal	0	0.05	-0.1	0.1

3. RESULTS

3.1 Model steps from the 2019 base case

The 2019 base case (Holmes 2019) was used as the starting point for model development. The 2022 initial base case model was developed by making incremental changes to the 2019 base case, updating the model structure, catches, biological parameters, and observations. Reweighting of the data was only done once the final data and model structure had been updated, to allow comparison of the models throughout this process. Details of the steps are given in Table 6.

The results showed that fixing the year class strength (YCS) had the most effect. In the 2019 model (Holmes 2019), YCSs were estimated from 1973 to 2014 with age composition observations available from 1990 to 2018. However, as the age classes mostly seen are from age 6 to age 18, the period of YCS estimations was revised to be from 1975 to 2013. Sensitivities were carried out showing the effects of the change in the period of YCS estimation.

Once the data were re-weighted, the 2022 initial case had a slightly higher estimate of initial biomass and natural mortality. The MCMC performance of this initial case was not satisfactory, particularly in terms of selectivities; hence, selectivities were changed to logistic for the base case model. The base case provided similar results as the 2019 initial case, with slightly lower estimates of M_{avg} and M_{diff}. The 2019 base model, 2022 initial model, and the resulting 2022 base case estimates of initial biomass, current status, and natural mortality are summarised in Table 7.

Table 6: Incremental model build from the 2019 base case to the 2022 initial model run, at MPD level. The data were not re-weighted between models R0.1–R0.7 AF = age composition, LL = longline, BT = bottom trawl, YCS = year class strength.

Model	Description	B_0 (%)	B_{2019}/B_0 (%)	M_{avg} (y^{-1})	M_{diff} (y^{-1})	Objective function
R0.1	2019 base case	113 068	55.3	0.143	-0.019	2 771
R0.2	update biological parameters	112 329	56.5	0.145	-0.019	2 770
R0.3	update timing of observations	111 281	59.4	0.146	-0.019	2 775
R0.4	update catches	116 744	55.2	0.149	-0.020	2 776
R0.5	update AFs	118 069	56.8	0.150	-0.021	2 921
R0.6	YCS fixes	124 472	59.2	0.152	-0.022	2 924
R0.7	update to 2022 catches and 2020 AFs	122 700	56.7	0.147	-0.026	3 120
R1.0	2022 initial case (R0.7 reweighted)	122 406	57.9	0.153	-0.020	–

Table 7: 2019 base, 2022 initial model, and the 2022 base case model MPD estimates, once data were re-weighted.

Model	Description	B_0 (%)	B_{2019}/B_0 (%)	M_{avg} (y^{-1})	M_{diff} (y^{-1})
R0.1	2019 base case	113 068	55.3	0.143	-0.019
R1.0	2022 initial case	122 406	57.9	0.153	-0.020
R2.0	2022 base case	108 224	53.1	0.153	-0.015

3.2 Sensitivity runs

A number of sensitivity runs were carried out to investigate the effects of model assumptions and choices of different data or observations, with the three main ones reported here: using the longline CPUE series, fixed natural mortality, and estimating either more or fewer YCS parameters.

The standardised longline CPUE series presented a decline in the initial part of the series in the 1990s, which was not reflected in the trawl survey biomass index. Alternative standardisations of both indices including spatial-temporal standardisations of the longline fishery CPUE and the survey biomass series were carried out to investigate this (Mormede et al. 2022, 2023). The resulting VAST spatial-temporal standardised indices of both the longline fishery and the trawl survey were similar to that obtained through non-spatial standardisation and used in the model. This suggested that the difference in the pattern between the survey and CPUE between 1991 and 1997 was not related to spatial-temporal effects that could be identified using VAST. A sensitivity model was carried out by replacing the survey biomass index with the longline CPUE index (CPUE sensitivity run). This resulted in lower estimates of initial biomass, lower current status, and lower estimates of natural mortality (see Table 8).

A second sensitivity run was carried out using the base case model but fixing the natural mortality parameters at the mean MCMC values of the parameters estimated by the CPUE sensitivity run (Table 8). This model (R4.0) resulted in lower estimates of initial biomass and status than the base case (R2.0) but higher than the CPUE sensitivity run (R3.0).

Table 8: Summary of sensitivity run outputs at MPD level. * indicates fixed parameters.

Model	Description	B_0 (%)	B_{2022}/B_0 (%)	M_{avg} (y^{-1})	M_{diff} (y^{-1})
R2.0	2022 base case	108 224	54.4	0.153	-0.015
R3.0	2022 CPUE sensitivity model	91 960	33.0	0.136	-0.010
R4.0	2022 base case with natural mortality fixed at values estimated in R3.0	101 542	44.6	0.137*	-0.011*

The survey biomass index was mostly flat over its entire series and therefore does not provide any strong information on stock status or the initial biomass. However, survey and commercial ages compositions and the longline CPUE are likely to have some information on the initial biomass and did not suggest a data conflict in models where the survey biomass indices were excluded in favour of the longline CPUE (Figure 1).

The Fisheries New Zealand Deepwater Working Group (DWWG) concluded that the CPUE series was unlikely to be a reliable index of biomass because the longline fishery CPUE showed a sharp drop in the early 1990s when the trawl survey biomass showed no such trend. Although the trawl survey biomass index was in conflict with the age composition data in the model (including the survey age data), the survey was more likely to be unbiased and not affected by vessel or operational changes in the fishing fleet and therefore was more reliable as an index of abundance. Further spatial-temporal analyses of both the survey data and longline fishery did not indicate a change in ling distribution or any other process which may suggest the survey biomass indices or longline CPUE were biased or did not adequately account for potential spatial-temporal changes in ling distribution. Furthermore, the CV for the survey biomass series was low (Fisheries New Zealand 2022), indicating the survey was likely to be adequate for this species. However, we note that the estimates of stock status for LIN 3&4 were sensitive to the choice of biomass index.

Additional sensitivity runs where the YCS was estimated for one additional year (in 2014) or were fixed prior to 1980 showed almost identical results to the base case model.

R2.0: 2022 base case

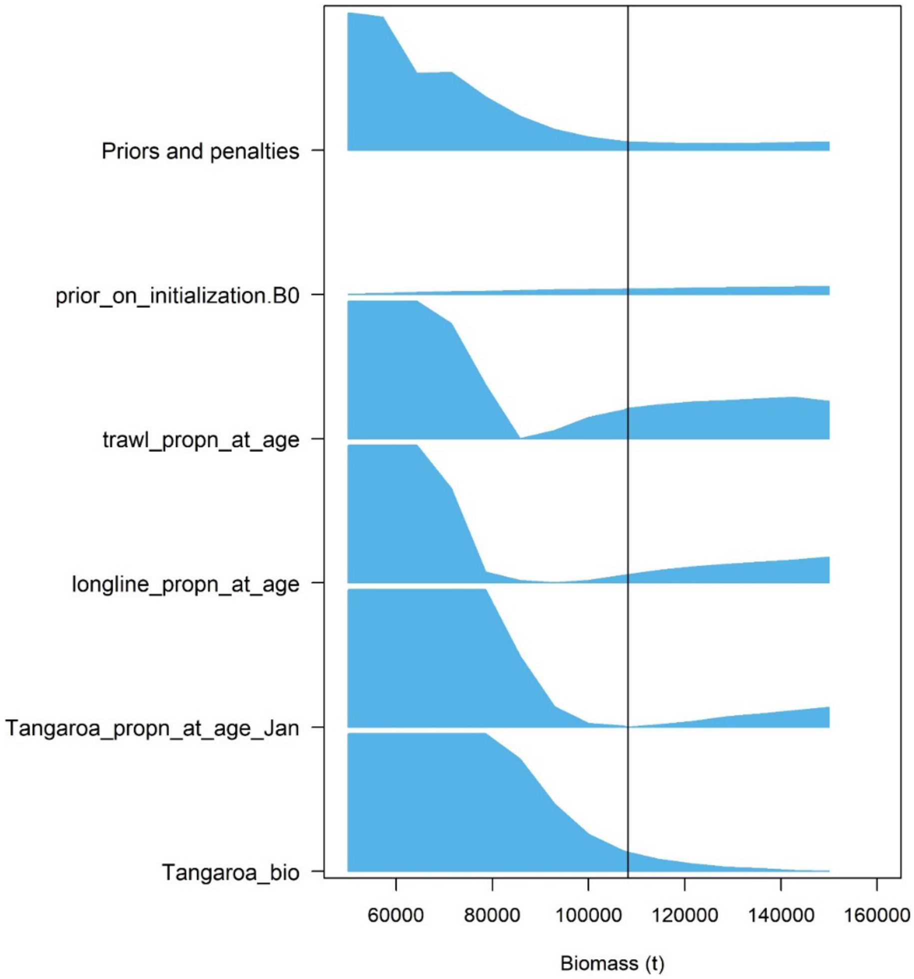


Figure 1: A. MPD profile on the initial biomass parameter B_0 for the base case (model R2.0), expressed for each data series. The maximum possible height of each blue graph represents 10 negative log likelihood (NLL) points. (Continued on next page)

R3.0: CPUE sensitivity run

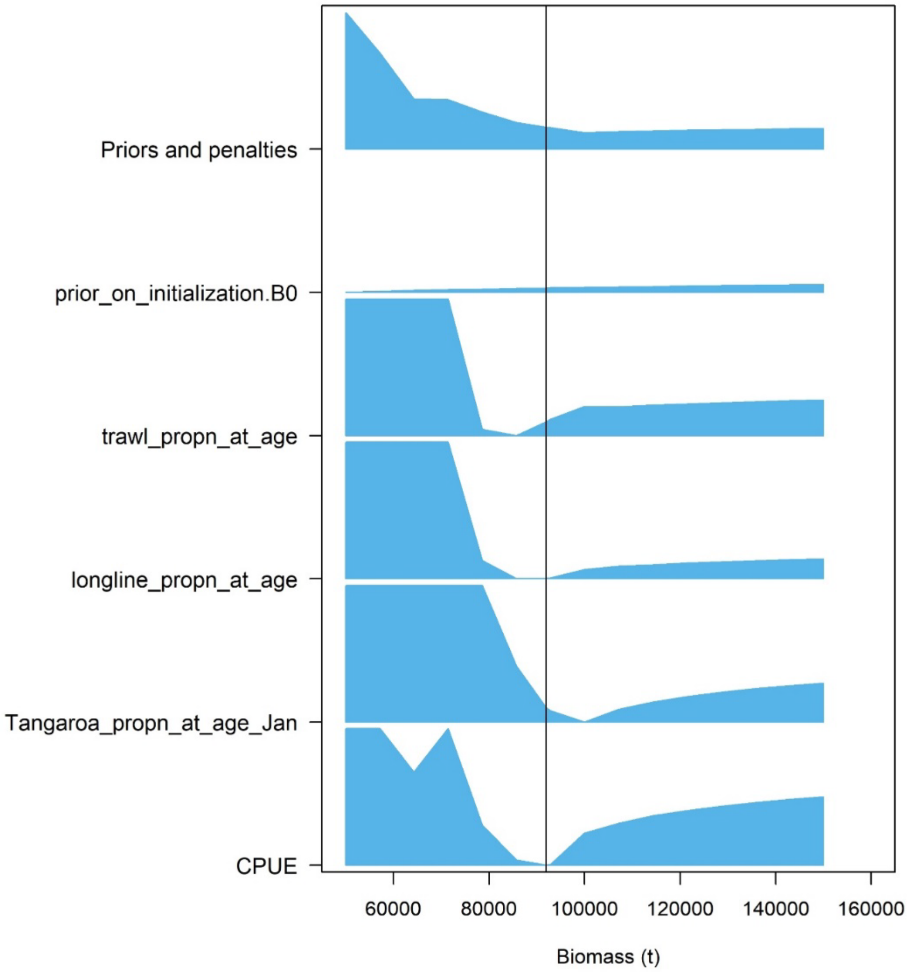


Figure 1 continued: B. MPD profile on the initial biomass parameter B_0 for the CPUE sensitivity run (model R3.0), expressed for each data series. The maximum possible height of each blue graph represents 10 negative log likelihood (NLL) points.

3.3 Investigations of natural mortality

Early estimates of natural mortality (*M*) using methods outside the assessment models suggested that *M* was about 0.18 y^{-1} (Horn 2008). More recently, *M* for ling in LIN 3&4 was estimated at 0.13 y^{-1} for females with a CV of 0.2 by Edwards (2017), based on methods using life history characteristics. In the base case assessment model presented here, *M* for females was estimated at 0.161 y^{-1} but at 0.141 y^{-1} in the CPUE sensitivity model. MPD profiles of *M* showed it was informed strongly by the trawl survey age frequency series (Figure 2).

The estimates of *M* from the assessment models presented here were within the plausible range of the values estimated by Horn (2008) and Edwards (2017), but the different estimated values did result in different estimates of stock status. The ability of the model to estimate *M* within the assessment model was investigated using a simulation experiment for both the base case and CPUE sensitivity models. In each case, a total of 100 observations were simulated from the models, based on model parameters fixed at (i) the MPD and (ii) a random set of 100 values drawn from the posterior distribution. These were then used in MPD estimation, using the same model structure as used to simulate the observations but with the values of natural mortality (M_{avg} and M_{diff}) estimated. Resulting estimates showed that the estimated *M* was similar to the assumed values with little bias and relatively high precision (Figure 3). While the simulation experiment assumed identical model structures and data weightings in estimation as was used in simulation of the observations, the experiment did suggest that estimates of *M* could be obtained from the assessment model if the underlying assumptions of the model data and model structure were correctly specified.

R2.0: 2022 base case

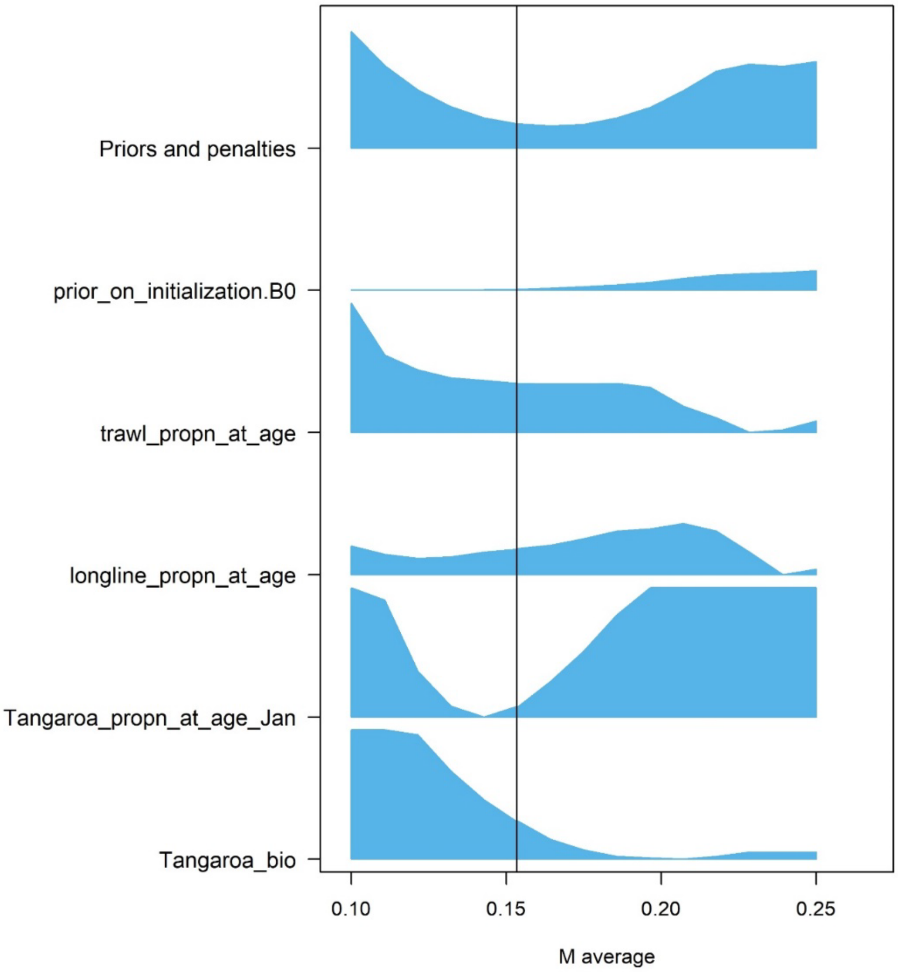


Figure 2: A. MPD profile on the natural mortality parameter *M* for the base case (model R2.0), expressed for each data series. The maximum possible height of each blue graph represents 10 negative log likelihood (NLL) points. (Continued on next page)

R3.0: CPUE sensitivity run

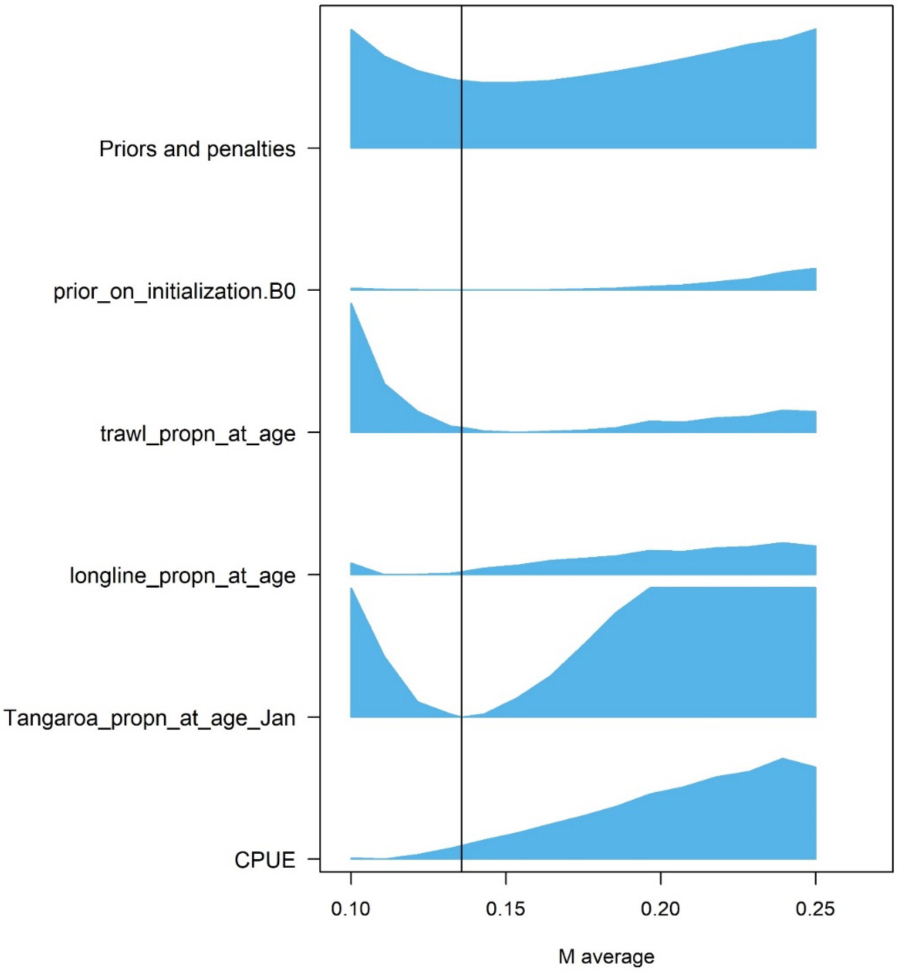
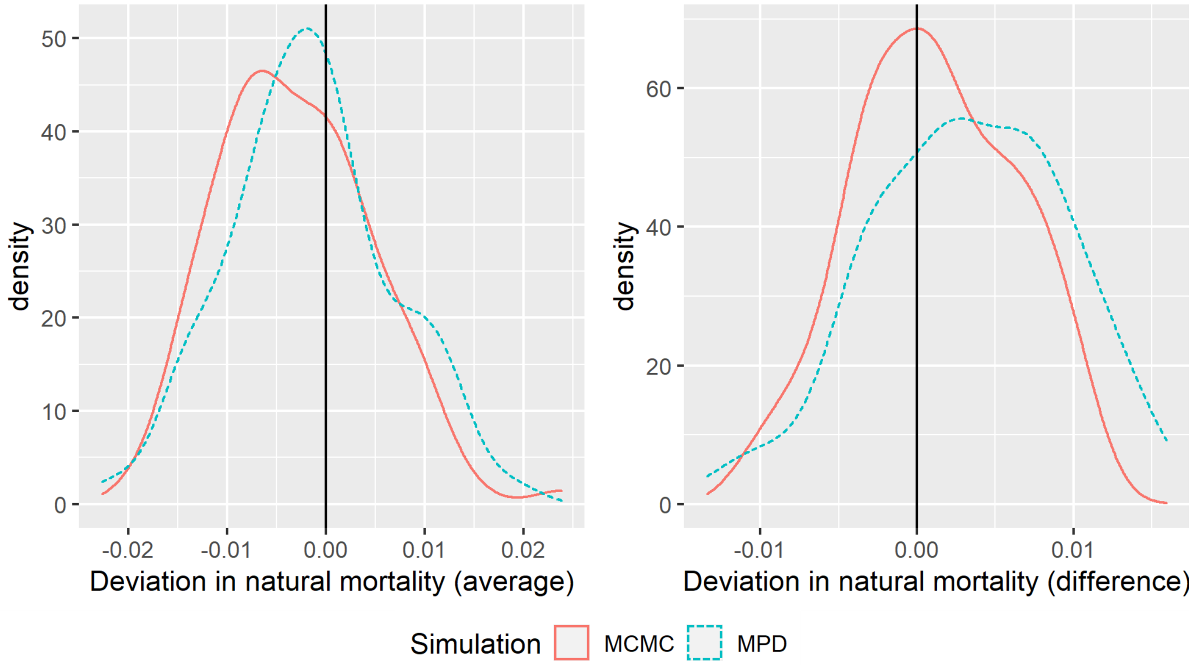


Figure 2 continued: B. MPD profile on the natural mortality parameter *M* for the CPUE sensitivity run (model R3.0), expressed for each data series. The maximum possible height of each blue graph represents 10 negative log likelihood (NLL) points.

R2.0: 2022 base case



R3.0: CPUE sensitivity run

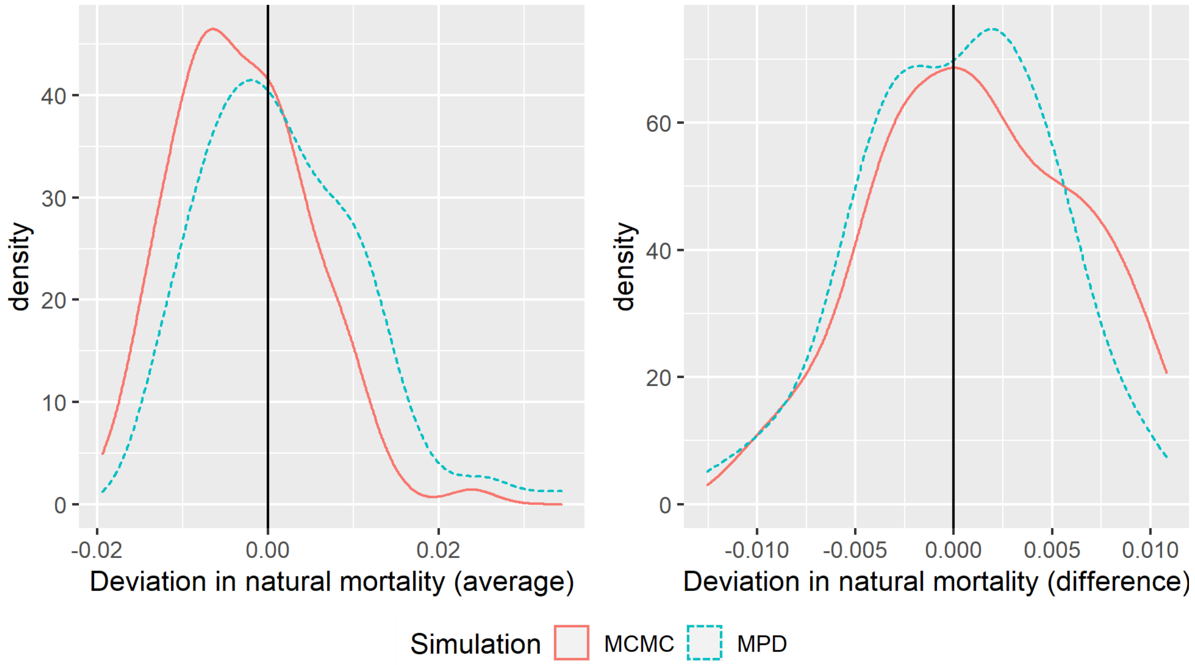


Figure 3: Distribution of the deviation in natural mortality parameters estimated based on either MPD or MCMC pseudo-observations for the base case run (R2.0, top) and the CPUE sensitivity run (R3.0, bottom). The ‘true’ deviation of 0 is showed as a black vertical line.

3.4 Bayesian model runs

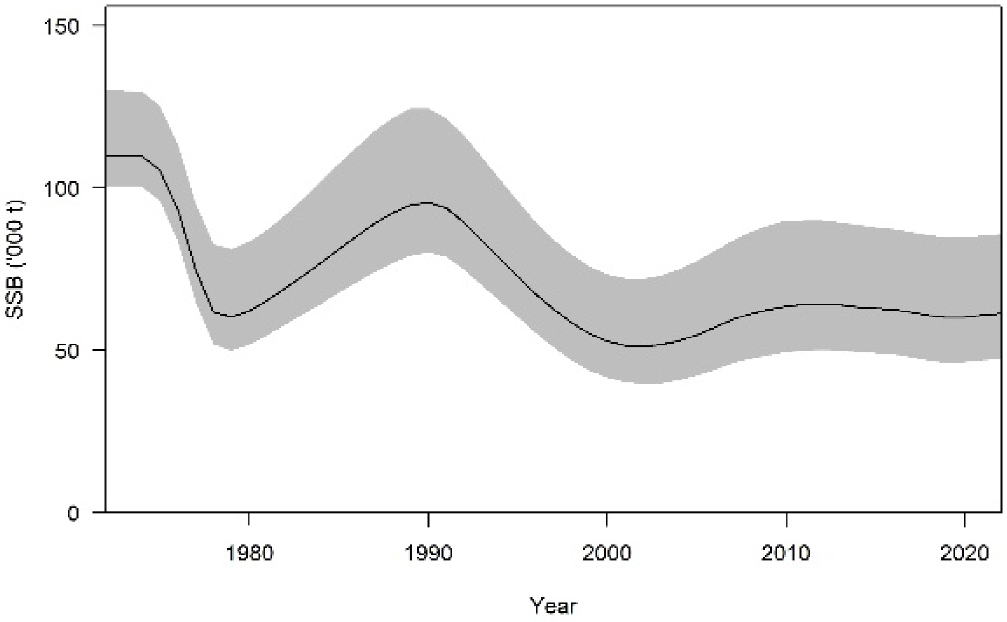
The 95% credible interval of stock status estimates for 2022 from the base case and two sensitivity models were in the range of 27–66% of B_0. The probability of the 2022 status being above 40% B_0 ranged from 5 to 100%, and the probability of it being below 20% B_0 was less than 1% in all instances. Replacing the trawl survey biomass index with the longline CPUE index reduced the initial biomass and the 2022 stock status from an average of 56% B_0 in the base case to 34% B_0 (Table 9). Assuming lower natural mortality estimates than the base case also dropped the stock status, to about 45% B_0.

Table 9: LIN 3&4 median and 95% credible intervals (in parentheses) of the posterior distribution of B_0 and B_{2022} (in tonnes), B_{2022} as a percentage of B_0, and the probability that B_{2022} is above 40% and below 20% of B_0 from the base model and sensitivity runs.

Model run	B_0	B_{2022}	B_{2022} (% B_0)	P(>40% B_0)	P(<20% B_0)
Base case	110 040	61 380	55.8	1.000	0.000
	(100 660 – 129 890)	(47 400 – 85 810)	(46.9 – 66.3)		
CPUE sensitivity	92 190	30 860	33.5	0.052	0.000
	(88 450 – 96 520)	(24 720 – 39 080)	(27.1 – 41.2)		
M_{avg} = 0.137	101 680	45 460	44.7	0.947	0.000
M_{diff} = -0.01	(83 130 – 107 960)	(38 130 – 54 750)	(39.3 – 50.9)		

Biomass estimates for the stock generally declined during the 1990s but have been stable since the early 2000s (Figure 4). The base case model had larger uncertainty (i.e., wider credible intervals) than the CPUE sensitivity. 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 uncertain before 1980 and generally weak for the rest of the series apart from a period of stronger year class strengths in the mid-1990s. There has only been one year of above-average recruitment since 2000. Annual exploitation rates (catch divided by vulnerable biomass) were low from 2005 (less than 0.1, Figure 5).

R2.0: 2022 base case



R3.0: CPUE sensitivity run

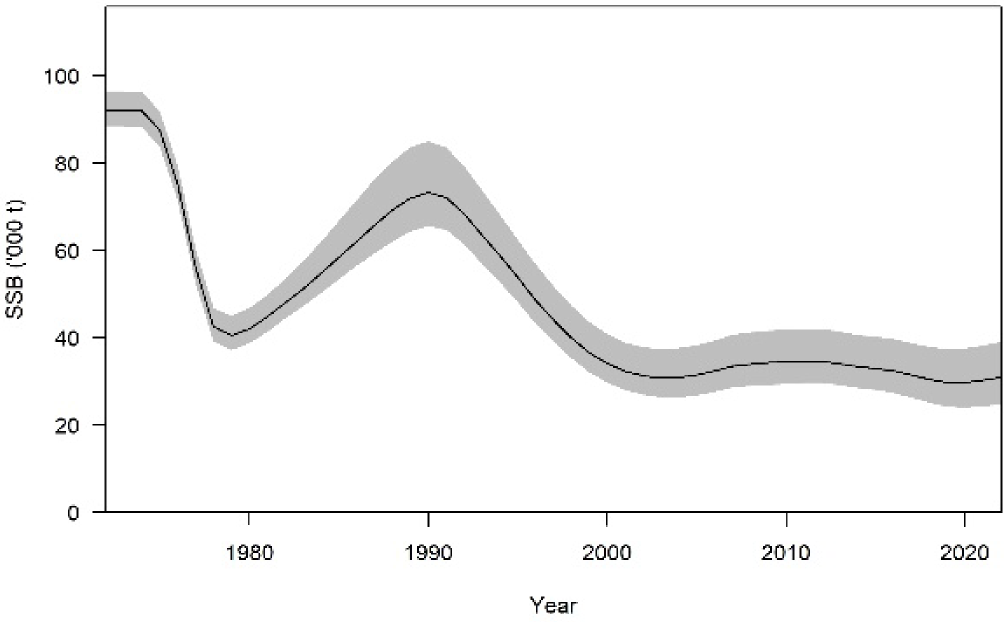


Figure 4: Spawning stock biomass (*SSB*) trajectory for the base case run (R2.0, top) and the CPUE sensitivity run (R3.0, bottom) for Chatham Rise ling, showing the median of the posterior distribution and 95% credible interval.

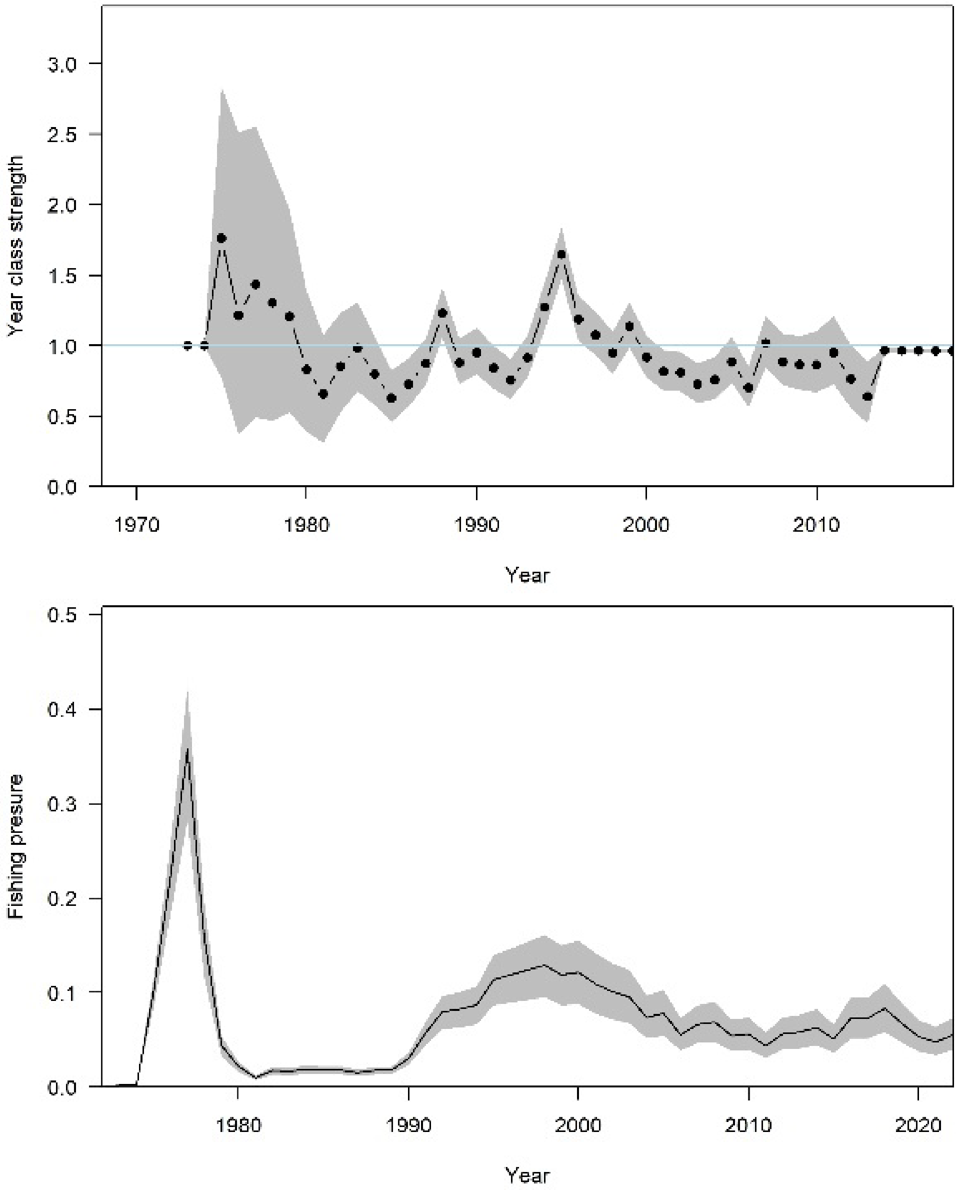


Figure 5: Estimated year class strengths (top) and annual exploitation rate (bottom) showing the median of the posterior distribution and 95% credible interval for the base case model for Chatham Rise ling.

The trawl catchability coefficient (*q*) was estimated within the range of the prior (Figure A.1). Selectivities were estimated with relatively narrow credible intervals, noting that the male trawl selectivity was fixed at the MPD value and therefore presented no variability (Figure A.2). Both the longline and trawl fleet caught significantly more females than males whereas the Chatham Rise trawl survey was 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 are described in Appendix A, and for the CPUE sensitivity in Appendix B. The convergence test of Geweke (1992) and the Heidelberger & Welch (1983) stationarity and half-width tests suggested a high autocorrelation lag for the base case (Figure A.3) but not the CPUE sensitivity model (Figure B.3). Trace plots showed no evidence of failure to converge for either the base case model or the CPUE sensitivity model (Figure A.4, Figure A.5, Figure B.4, Figure B.5). Fits to the biomass indices and age frequencies were adequate for both models (Figure A.6 to Figure A.9 and Figure B.6 to Figure B.9).

3.5 Alternative catch history

An alternative catch history was constructed, which includes the possibility of unreported catches, discards, and mortality of uncaught 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).

Based on these estimates, a sensitivity model was run that assumed 5% additional catch 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 biomass and current status to the base case (not shown), and a very similar biomass trajectory. Projections were not run on this model but would be expected to have very similar outcomes to the base case model.

3.6 Projections

Four scenarios were carried out, all using the base case model. Recent catches have been much lower than the TACC, so the future catches were assumed to be either the average of the 2019 to 2021 model year catches or the TACC, keeping the ratio of catches between the fisheries to that of the average of the 2019 to 2021 model year catches (52% longline, 33% trawl, and 15% pot). Furthermore, year class strengths have been mostly low since 2000 so the year class strengths for the projections were either resampled from the full 1975–2013 range, or from the 2003–2013 range.

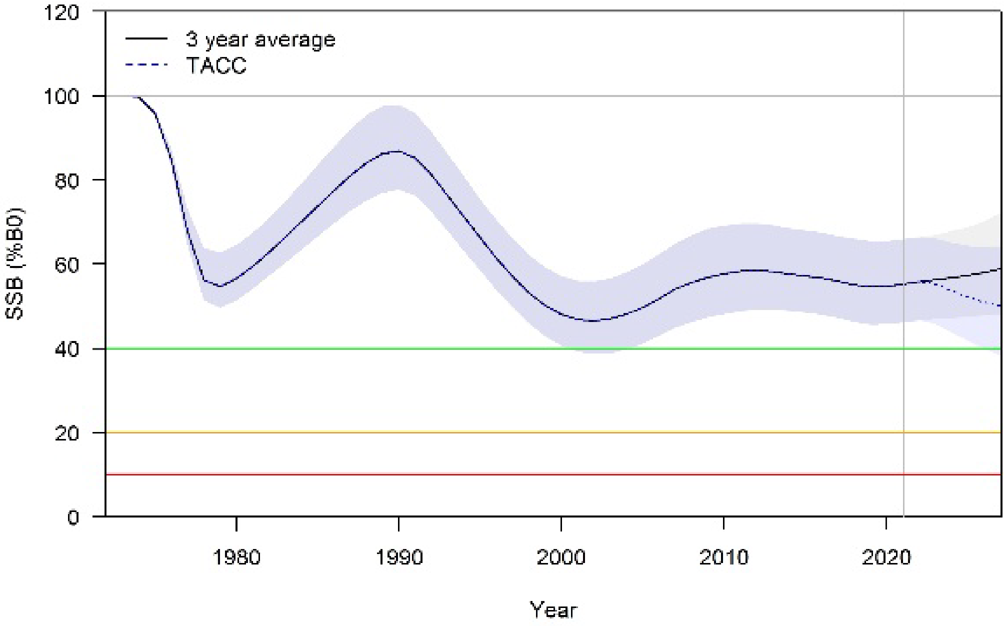
Using the base case model, the stock size in LIN 3&4 is likely to remain about the same or increase by about 5% assuming future catches equal recent catch levels and year class strengths are consistent with recent (2003–2013) or all year class strengths, respectively. However, the stock size in LIN 3&4 is projected to decrease to around 83–89% of the 2022 biomass by 2027 if catches reach the TACC with the same year class strength assumptions. The probability of the biomass in 2027 being above 40% B_0 is 0.85–1.0 and the probability of being below the soft limit (i.e., 20% B_0) is zero for all projection scenarios (Table 10 and Figure 6).

Projections using the CPUE sensitivity presented similar trajectories to that of the base case although starting from a lower status (not shown). In this instance, the probability of the biomass in 2027 being above 40% B_0 is 0.0–0.3 and the probability of being below 20% B_0 is 0.00–0.35 depending on projection scenarios.

Table 10: LIN 3&4 Bayesian median and 95% credible intervals (in parentheses) of projected B_{2027}, B_{2027} as a percentage of B_0, and as a percentage of B_{2022} for the base case run and various assumptions of future catches and year class strengths (YCS). The probability of B_{2027} being above 40% B_0 (p_{40}) and of B_{2027} being below 20%B_0 (p_{20}) are also reported.

		Future catch (t)										
YCS range	Catch range	Trawl	Line	Pot		B_{2027} (t)	B_{2027} (%B_0)		B_{2027} (%B_{2022})		p_{40}	p_{20}
all	2019–2021	1 057	1 701	479	65 150	(49 150–91 170)	59	(48–72)	105	(95–119)	1.00	0
2003–2013	2019–2021	1 057	1 701	479	60 620	(46 160–84 560)	55	(45–66)	99	(93–106)	0.90	0
all	TACC	2 044	3 290	926	55 150	(39 050–81 380)	50	(38–64)	89	(78–103)	0.95	0
2003–2013	TACC	2 044	3 290	926	50 560	(35 980–74 560)	46	(35–58)	83	(74–91)	0.85	0

YCS resampled from 1975–2013 range



YCS resampled from 2003–2013 range

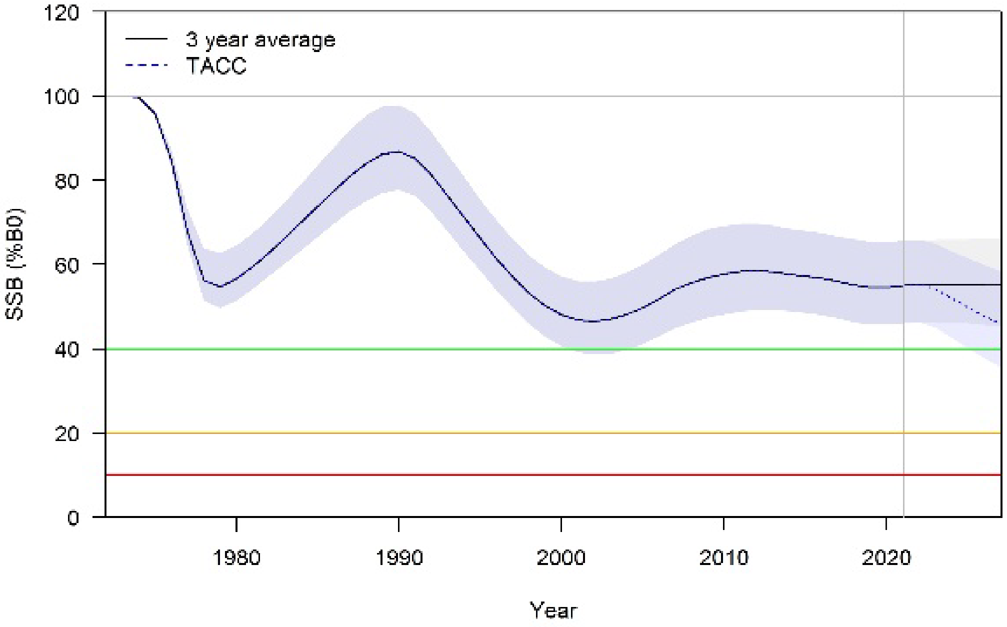


Figure 6: Five-year projections for Chatham Rise ling (LIN 3&4) using the base case model with YCS resampled from the 1965–2013 range (top) or 2003–2013 range (bottom) and two potential future catch scenarios: TACC or the average catch reported from the 2019 to 2021 model years. The catch split was 52% longline, 33% trawl, and 15% pot reflecting the average proportion of catches between the fisheries between 2019 and 2021 model years. The median and 95% credible intervals are shown. The vertical line shows the start year of the projections (2022).

4. DISCUSSION

The stock assessment model for Chatham Rise ling (LIN 3&4) updated the 2019 assessment (Holmes 2019) with new observations, assumed logistic rather than double normal fishery selectivities, and truncated the age composition data at age 5 for the fisheries. The 2022 base case and CPUE sensitivity models provided almost identical initial biomass and stock status as the 2019 base case and CPUE sensitivity stock models, respectively.

Natural mortality (*M*) was estimated, and a simulation experiment suggested that these values would be relatively well estimated with little bias for both the base case and CPUE sensitivity models. However, *M* was estimated to be lower in the CPUE sensitivity compared with the base case model (Figure 3). Most of the information on *M* was obtained from the survey age composition data. Fits to the abundance and age composition data were generally adequate for both models and the MCMC was adequate. However, there was evidence of autocorrelation between samples from the posterior distribution for some estimated parameters (Figure A.3).

The base case and the CPUE sensitivity models had different biomass trajectories and consequently different stock status estimates, driven by the difference between the relatively flat survey biomass index and the longline CPUE index with a decline in the 1990s. Although the trawl survey biomass index was in conflict with the age composition data in the model (including the survey age data) and the longline CPUE series, the survey was more likely to be unbiased and not affected by vessel or operational changes in the fishing fleet and therefore was considered to be more reliable as an index of abundance. The longline CPUE index was used in the Sub-Antarctic ling stock assessment (LIN 5&6) base case model (Mormede et al. 2021); it also presented a strong decline in the 1990s whilst the equivalent survey biomass was mostly flat but highly uncertain.

5. MANAGEMENT IMPLICATIONS

Agreed reference points for ling on the Chatham Rise include a management target of 40% B_0, a soft limit of 20% B_0, and a hard limit of 10% B_0. The overfishing threshold is $F_{40\%B0}$ was calculated as 0.14, using the base case model and the Current Annual Yield (CAY) calculation method in CASAL (Bull et al. 2012). B_{2022} 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. Overfishing was very unlikely to be occurring (Figure 7).

Based on the four projections carried out and for both the base case and CPUE sensitivity run, the projected stock biomass was likely to remain stable over the next five years at recent catch levels and drop slightly at the level of the TACC. Overfishing is highly unlikely to commence based on these possible future catch rates for the base case model.

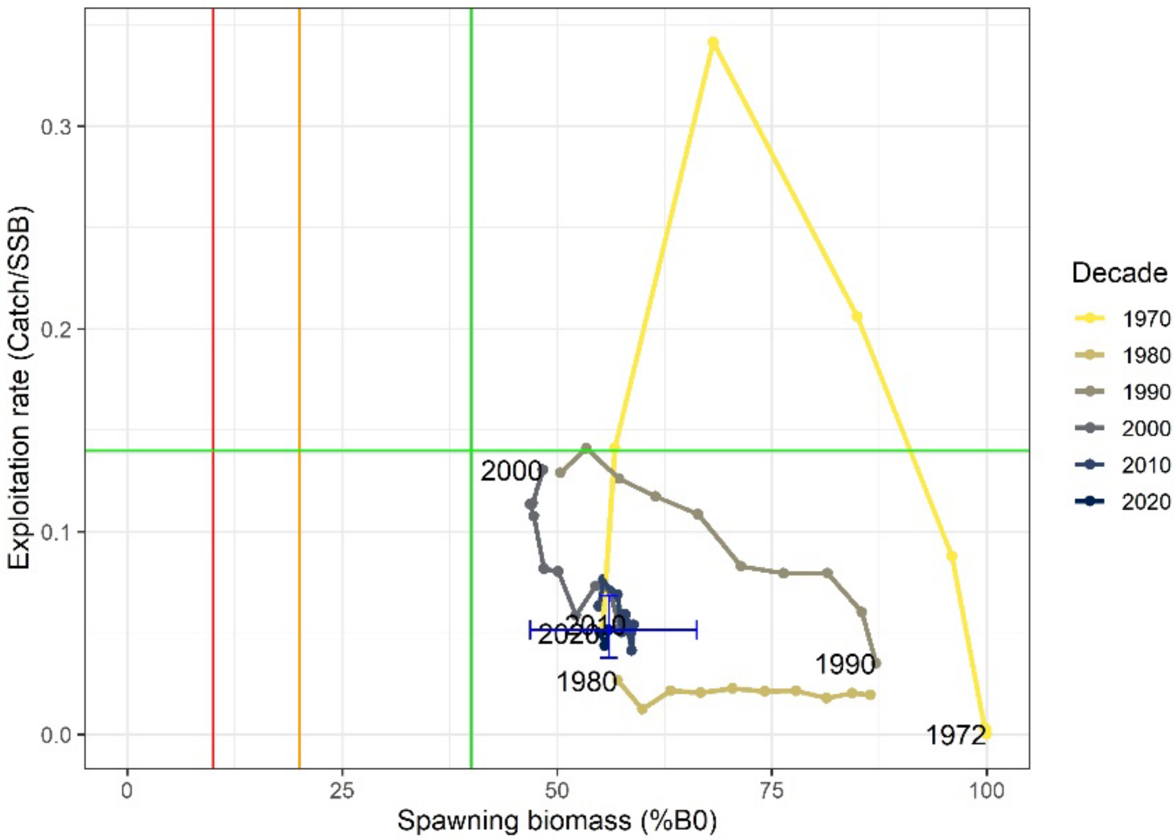


Figure 7: Trajectory over time of exploitation rate (*U*) and spawning biomass (% B_0), for the LIN 3&4 base model from the start of the assessment period in 1972 to 2022. The red vertical line at 10% B_0 represents the hard limit, the orange line at 20% B_0 is the soft limit, and green lines are the % B_0 target (40% B_0) and the corresponding exploitation rate (U_{40} = 0.14 calculated using CASAL CAY function). Biomass and exploitation rate estimates are medians from MCMC posteriors for the base model. The blue cross represents the limits of the 95% confidence intervals of the estimated ratio of the *SSB* to B_0 and exploitation rate in 2022.

6. ACKNOWLEDGEMENTS

We thank the Fisheries New Zealand Research Data Management Team for the data extracts used in these analyses and the additional assistance and information on interpretation and the Fisheries New Zealand Deepwater Team (Gretchen Skea, Tiffany Bock, Dave Foster, Greg Lydon, and Nathan Walker) for supplementary data and helpful discussions. We also thank Sira Ballara, David Middleton, Richard Saunders, and Jack Fenaughty for comments and advice, and members of the Deepwater Working Group for their discussions of this work. This work was funded by the Fisheries New Zealand project LIN2021-01.

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APPENDIX A – DIAGNOSTIC PLOTS FOR THE BASE CASE (R2.0)

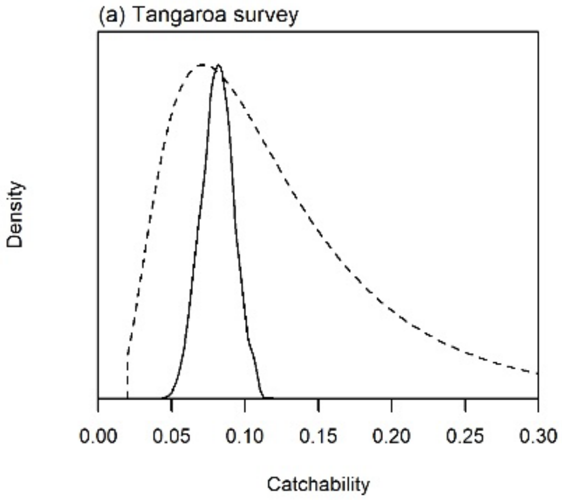

Figure A.1: Research survey catchability parameter, prior distribution in dashed and posterior distribution in solid lines.

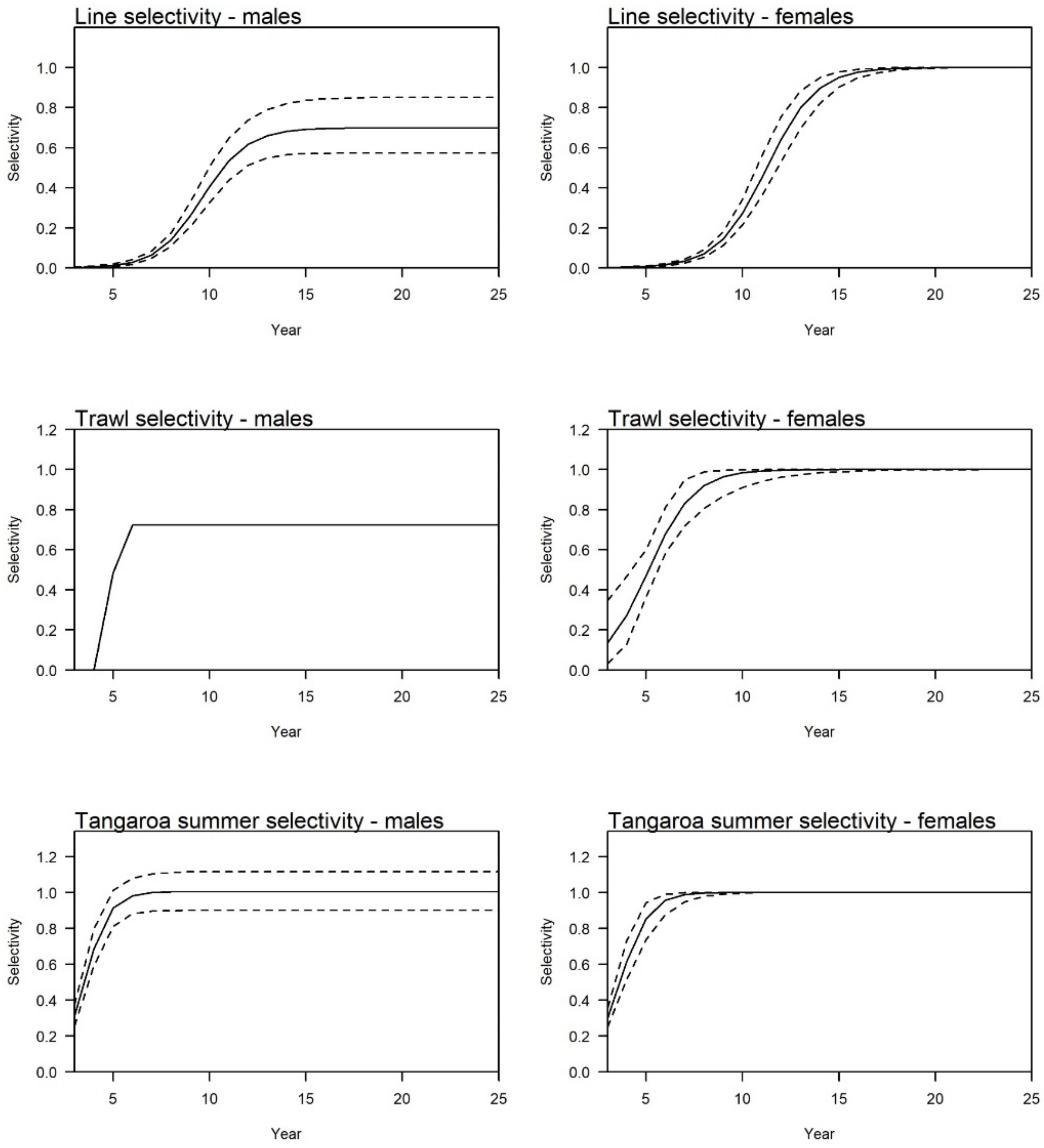

Figure A.2: Estimated selectivity estimates and 95% credible interval.

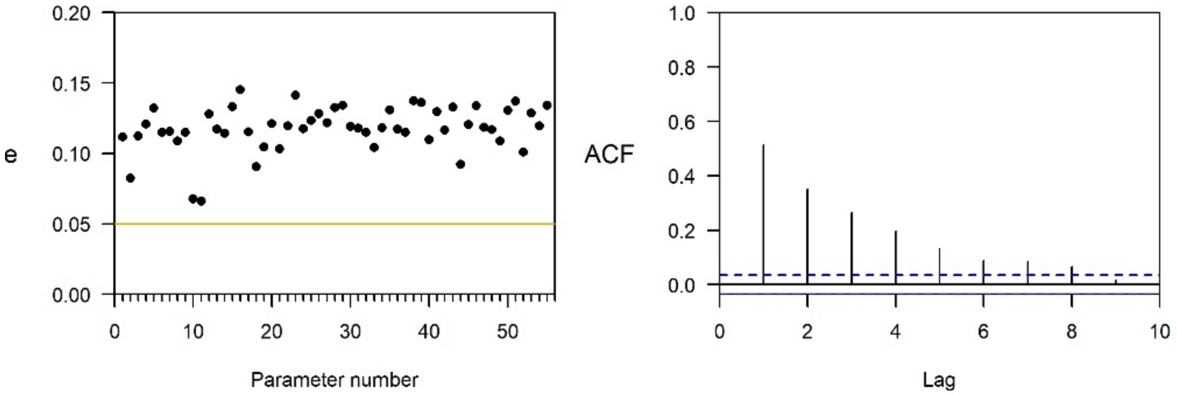

Figure A.3: MCMC diagnostic plots, showing (left) median relative jump size for all parameters, and (right) autocorrelation (ACF) lag plot for B_0.

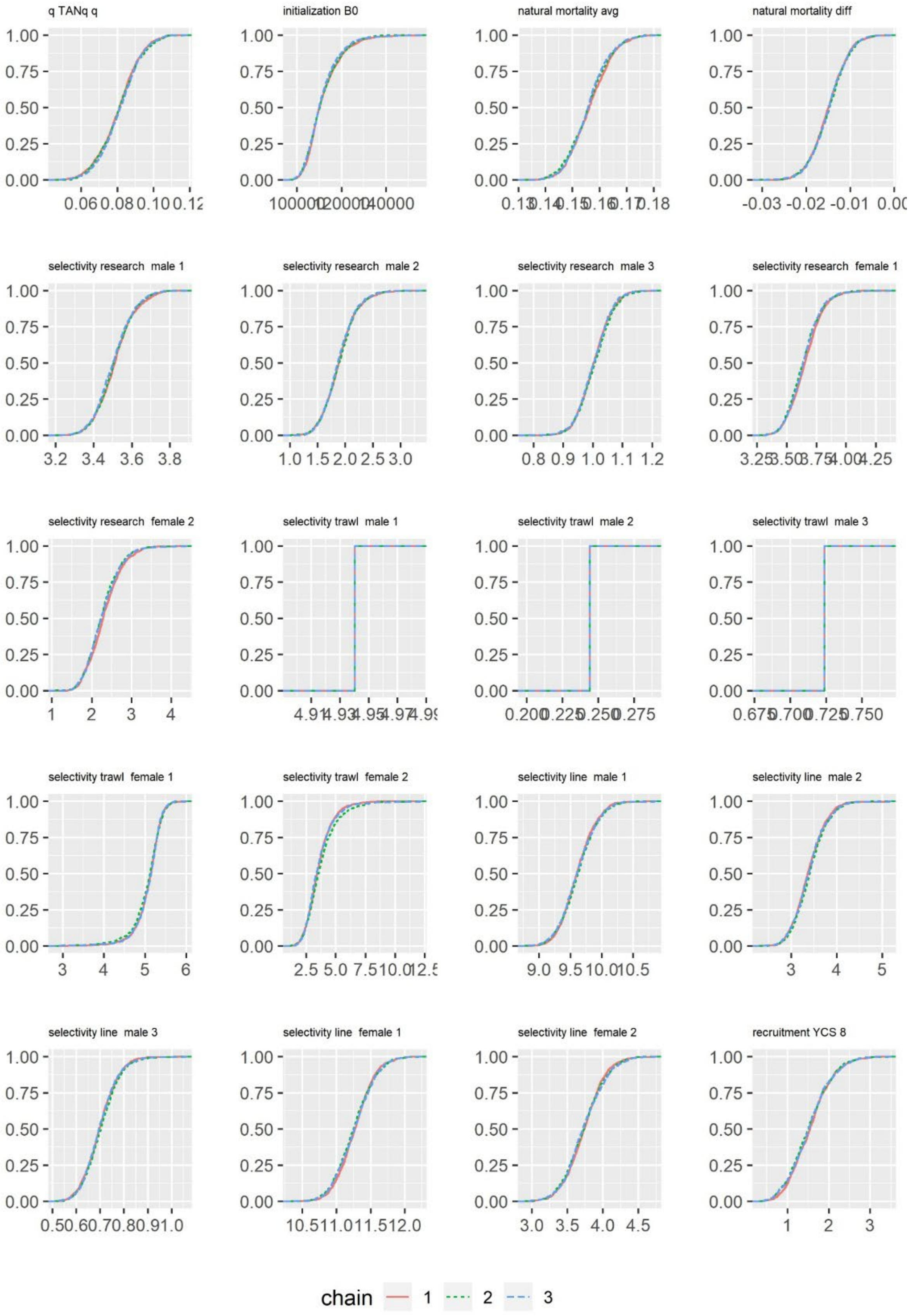

Figure A.4: MCMC chains cumulative plots. A single MCMC was run and the density distribution of its three sections of 1000 values each are plotted on top of each other.

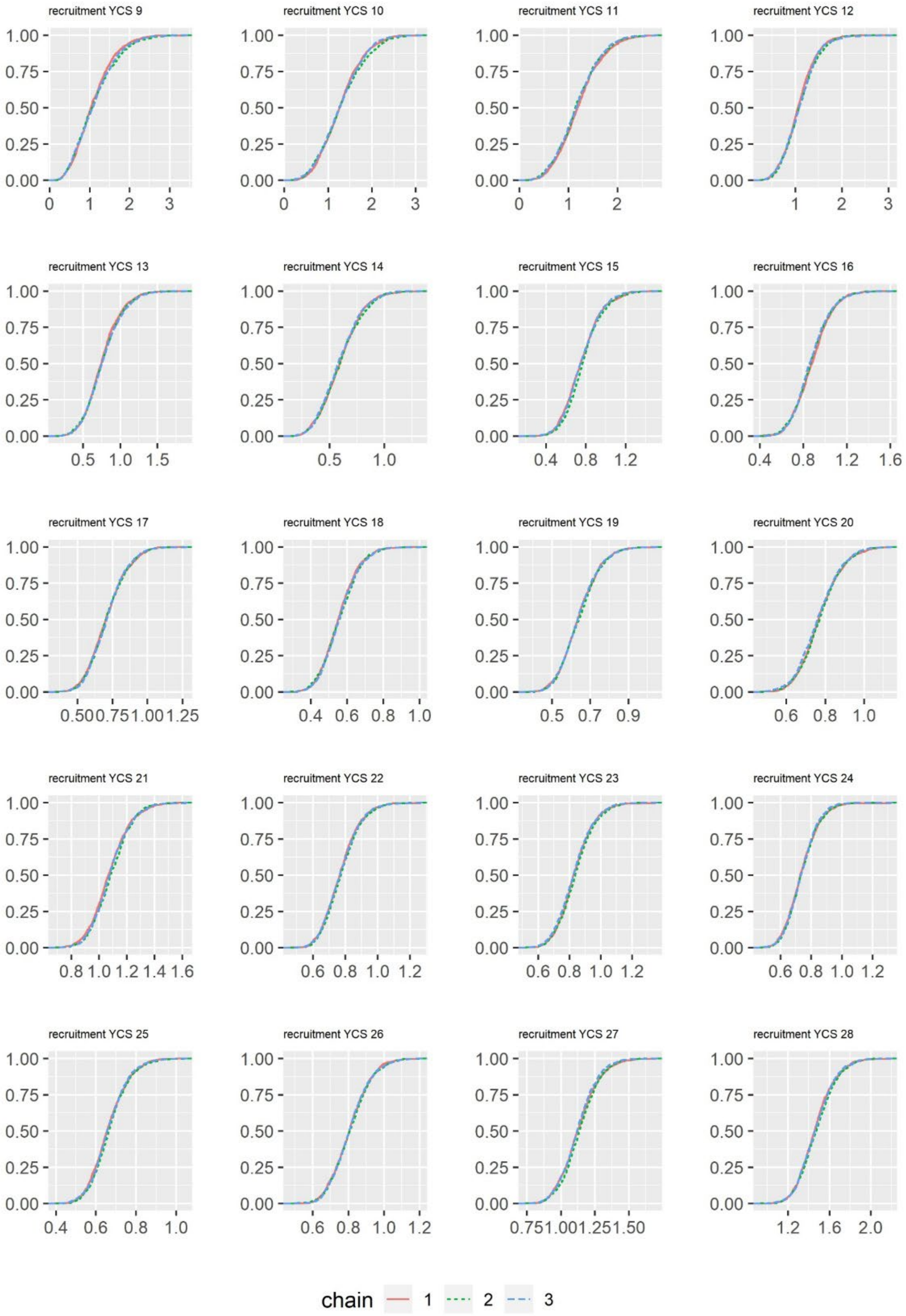

Figure A.5: MCMC chains cumulative plots (continued). A single MCMC was run and the density distribution of its three sections of 1000 values each are plotted on top of each other.

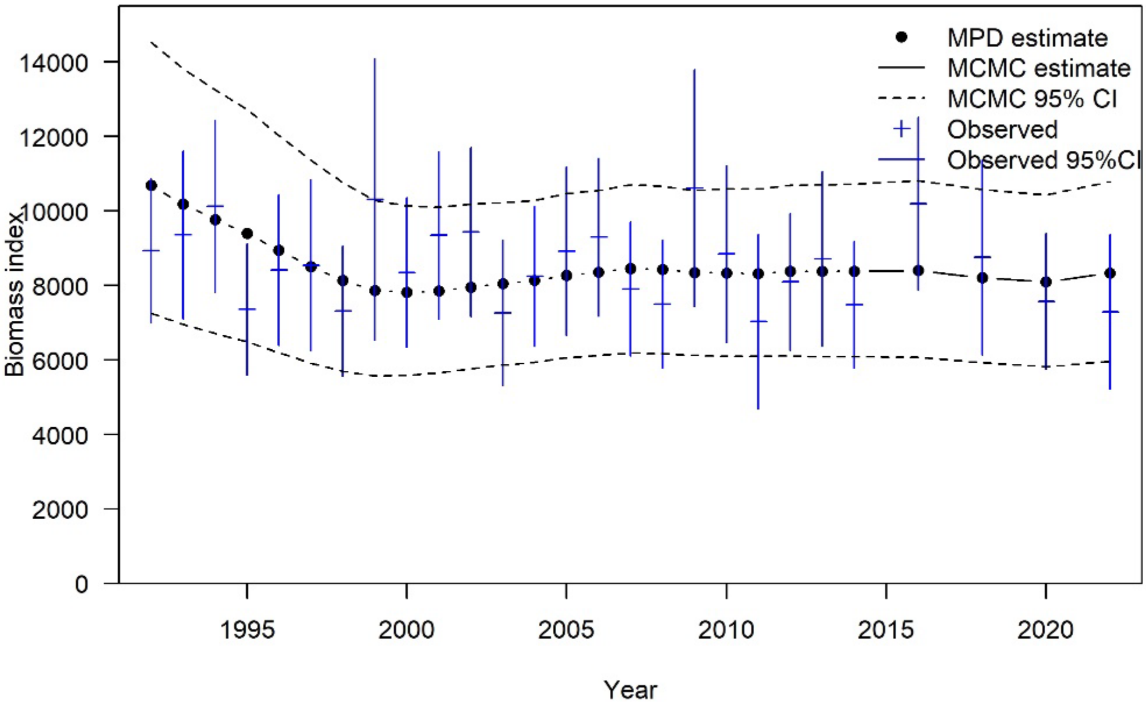

Figure A.6: Fits to the survey biomass index at the MCMC level. Black dots and vertical lines are the observed estimates and 95% credible intervals, blue line is expected and grey band the 95% credible interval.

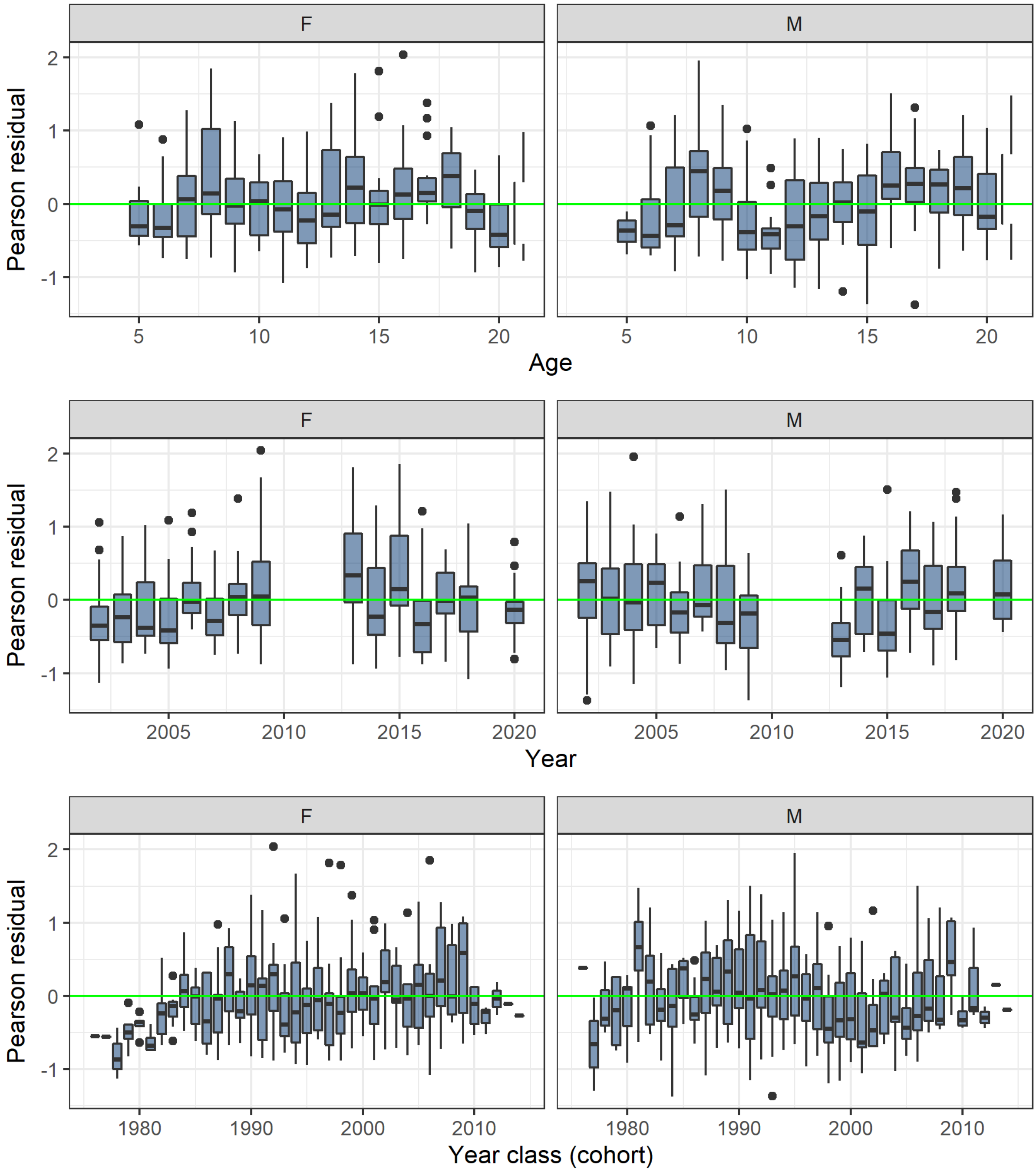

Figure A.7: MPD residual fits to the longline fishery age frequency distributions, by age (top), year of sampling (middle) and year class (bottom).

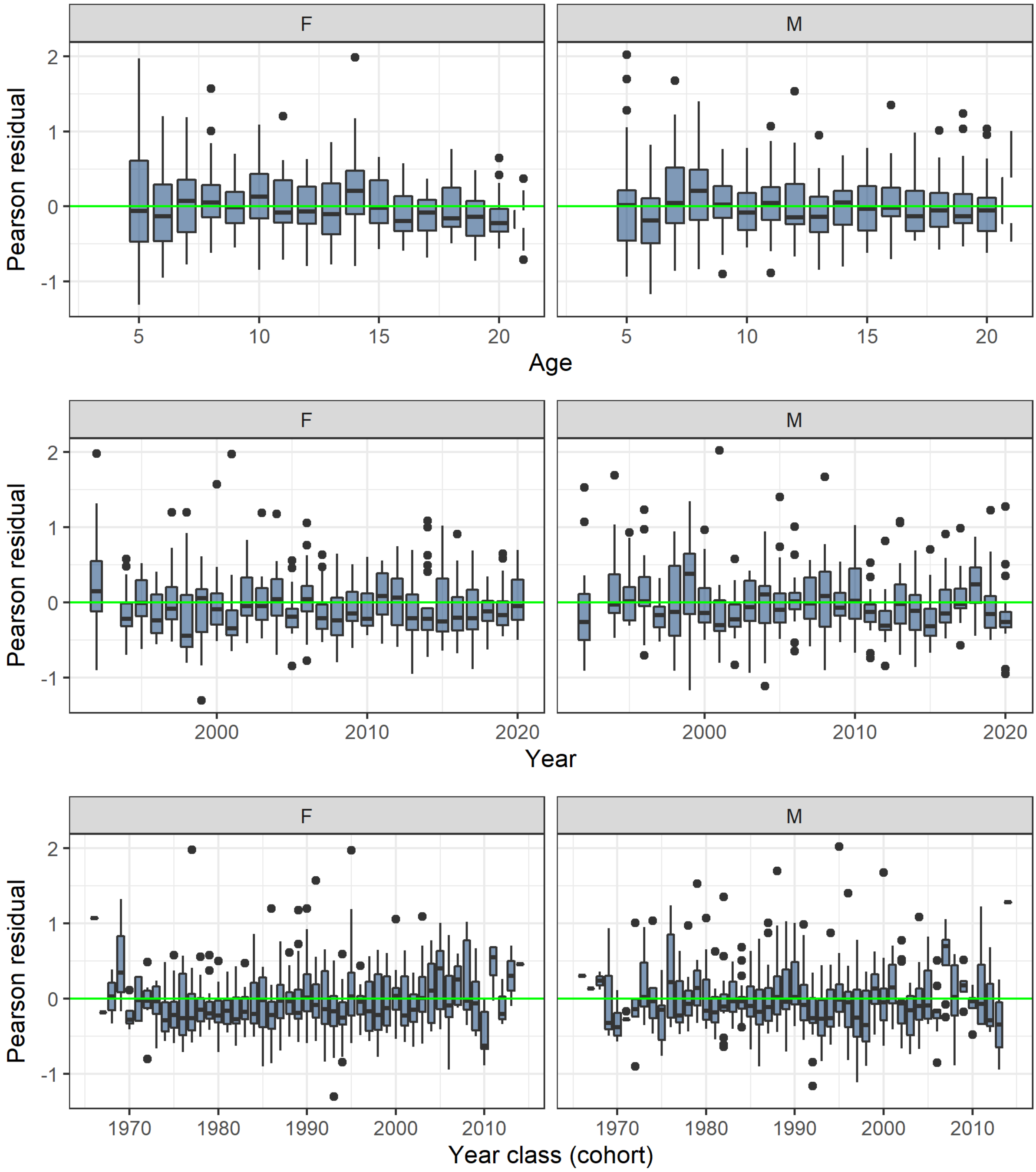

Figure A.8: MPD residual fits to the trawl fishery age frequency distributions, by age (top), year of sampling (middle) and year class (bottom).

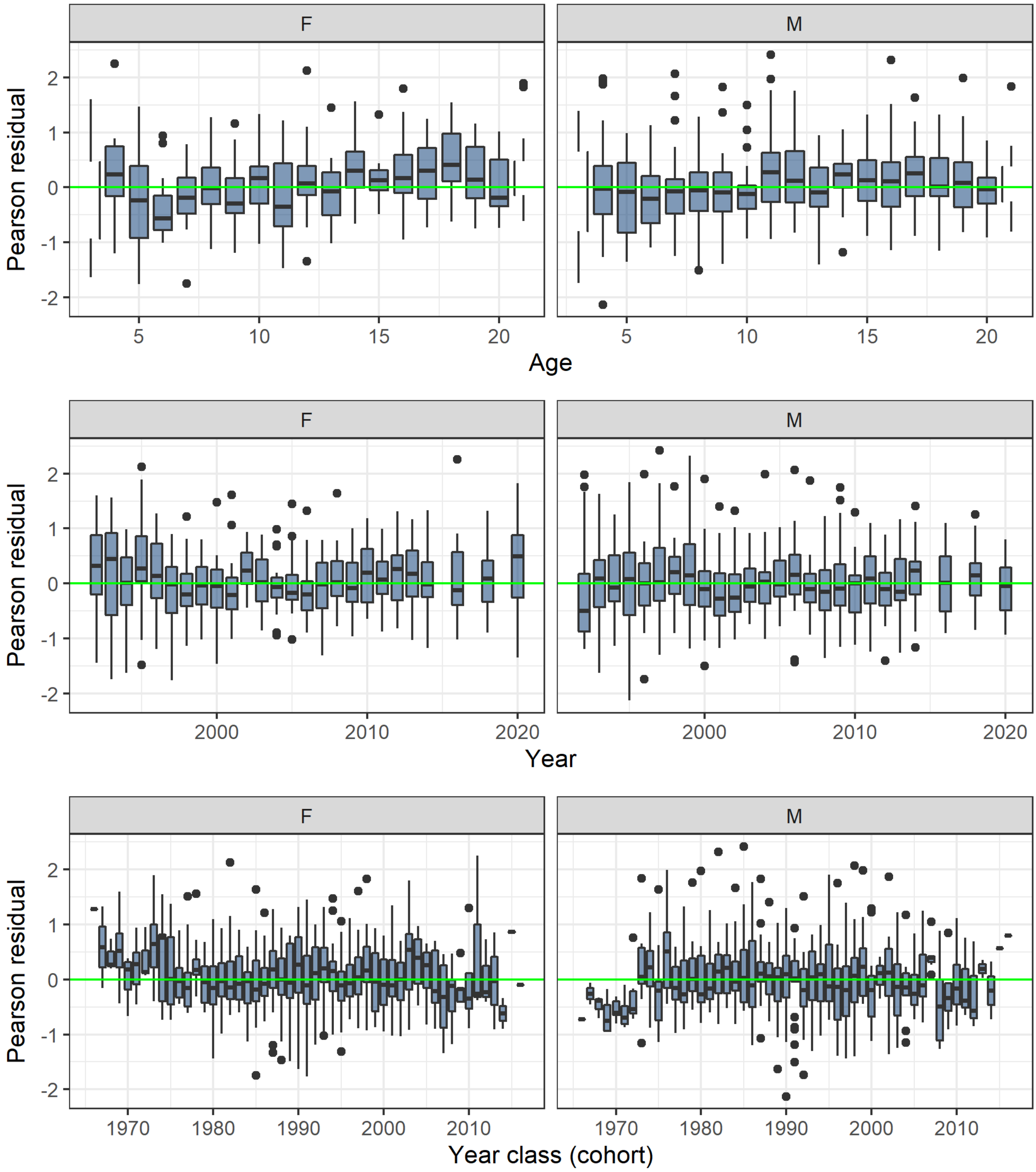

Figure A.9: MPD residual fits to the survey age frequency distributions, by age (top), year of sampling (middle) and year class (bottom).

APPENDIX B – DIAGNOSTIC PLOTS FOR THE CPUE SENSITIVITY RUN (R3.0)

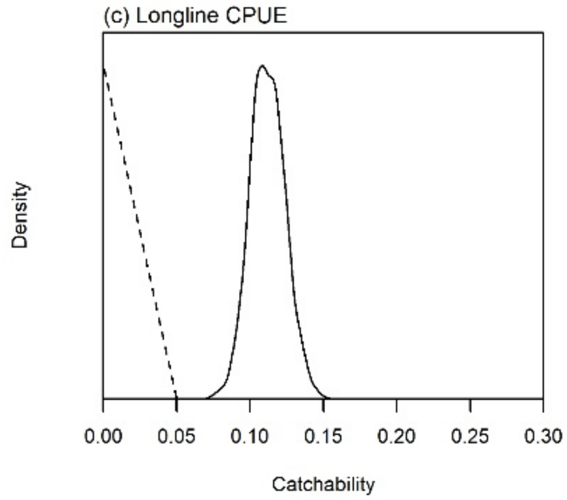

Figure B.1: Longline CPUE index catchability parameter, prior in dashed and posterior in solid lines.

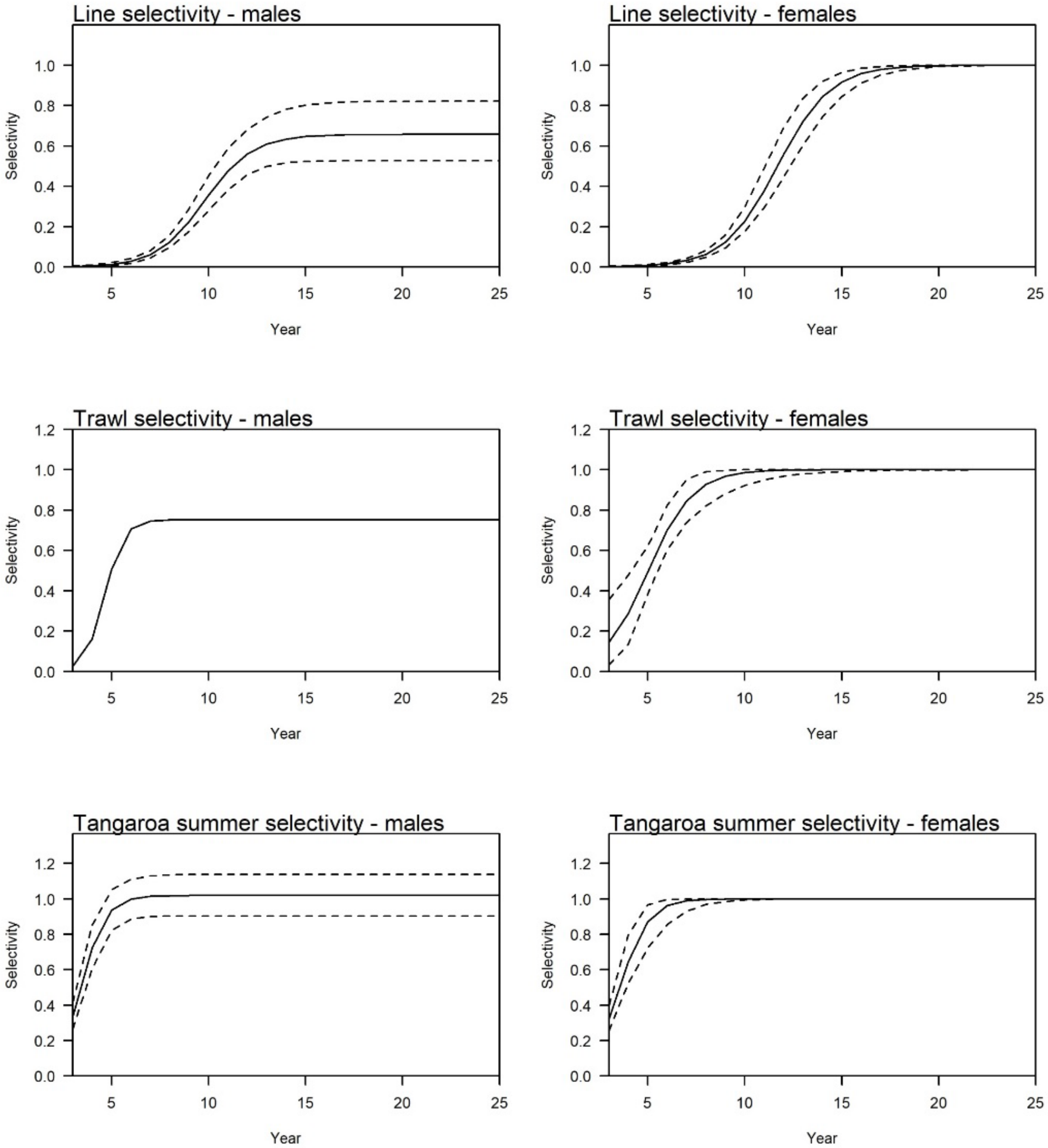

Figure B.2: Estimated selectivity estimates and 95% credible interval.

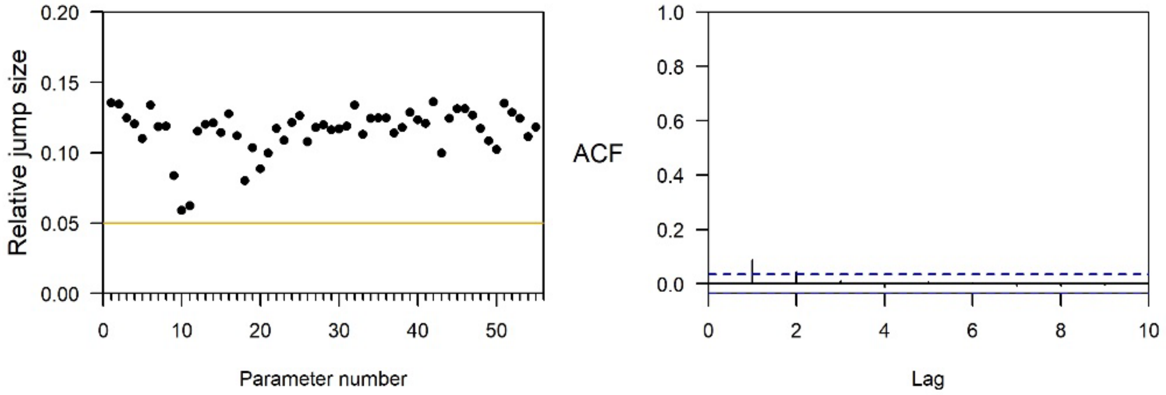

Figure B.3: MCMC posterior diagnostic plots, showing (left) median relative jump size for all parameters, and (right) autocorrelation (ACF) lag plot for B_0.

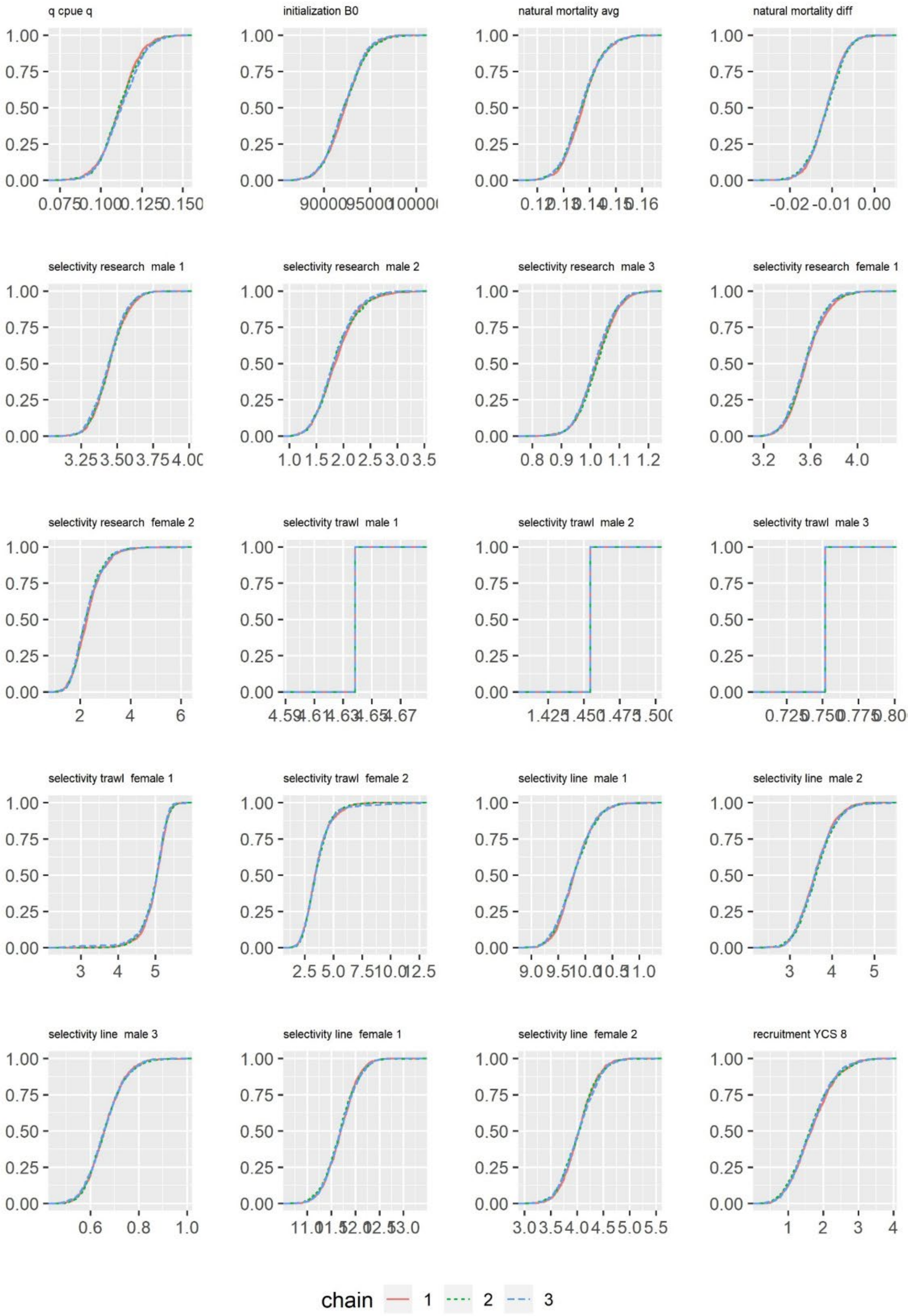

Figure B.4: MCMC chains cumulative plots. A single MCMC was run and the density distribution of its three sections of 1000 values each are plotted on top of each other.

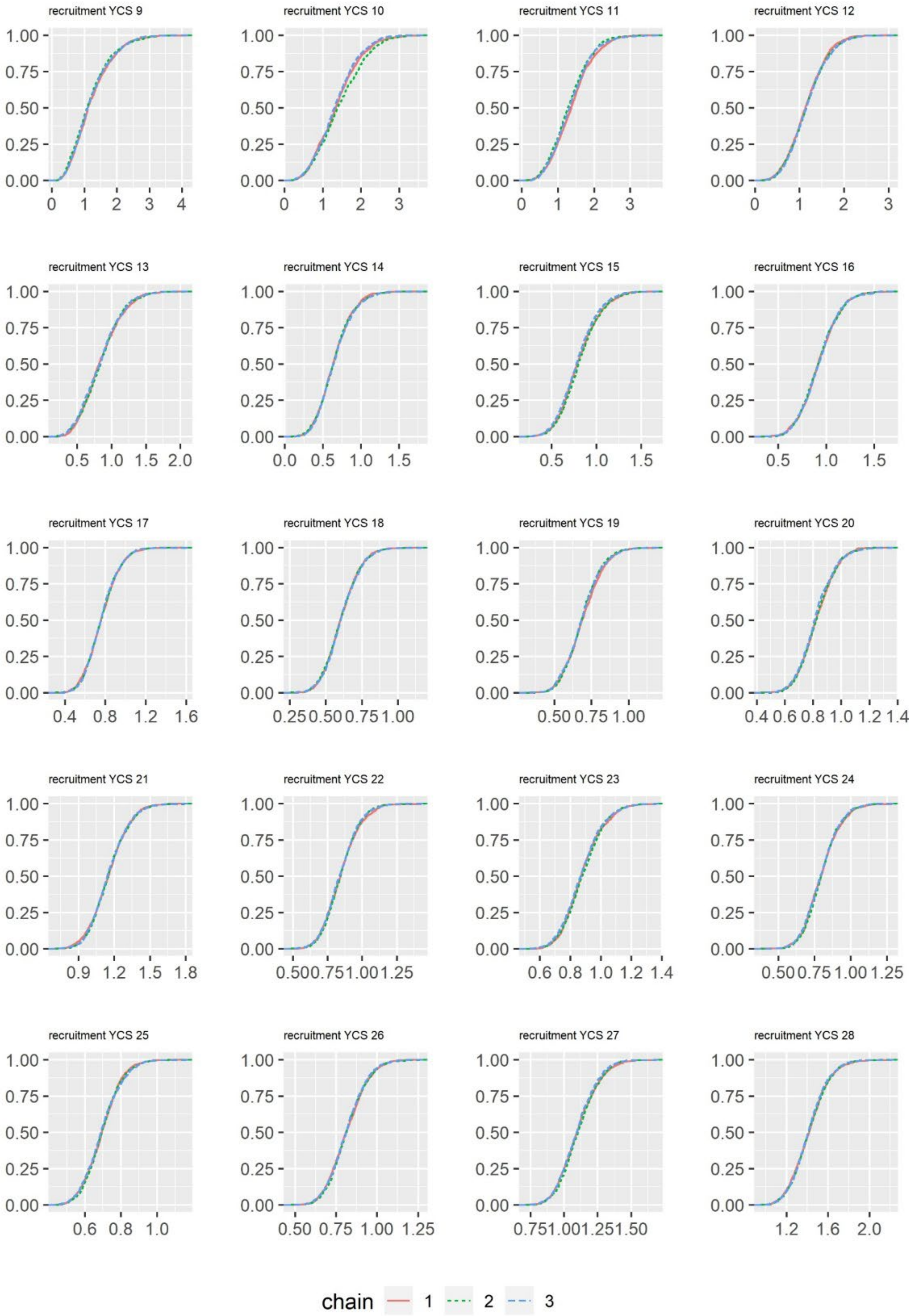

Figure B.5: MCMC chains cumulative plots (continued). A single MCMC was run and the density distribution of its three sections of 1000 values each are plotted on top of each other.

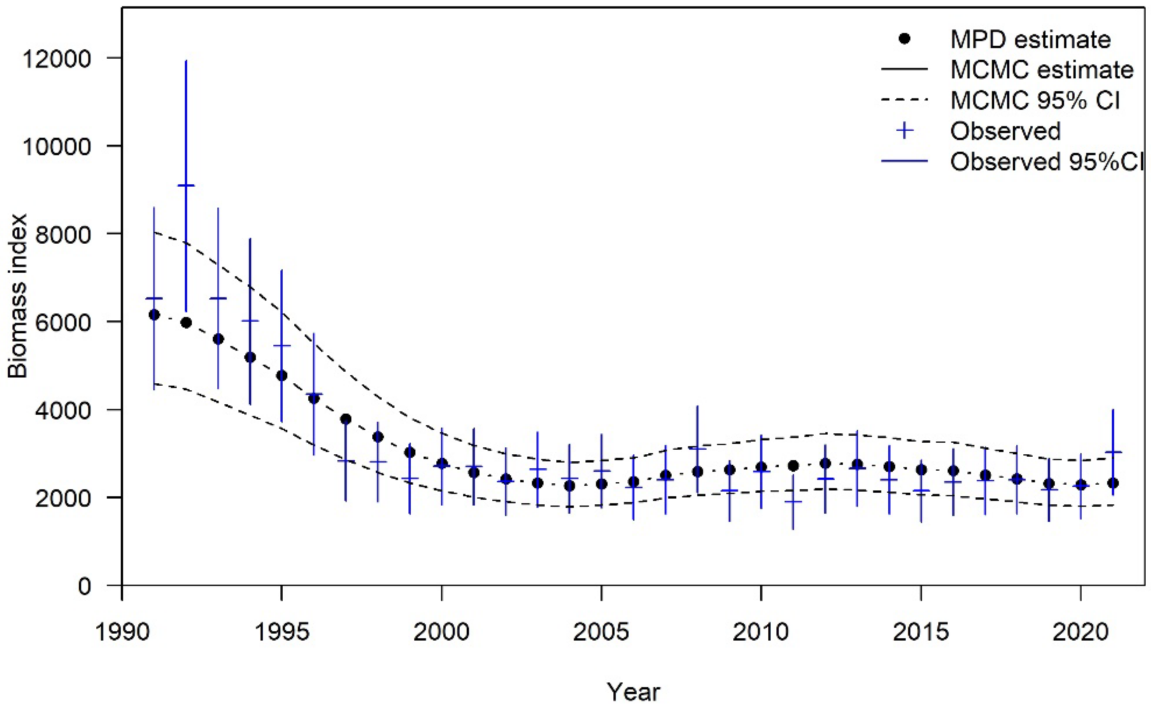

Figure B.6: Fits to the longline CPUE index at the MCMC level. Black dots and vertical lines are the observed estimates and 95% credible intervals, blue line is expected and grey band the 95% credible interval.

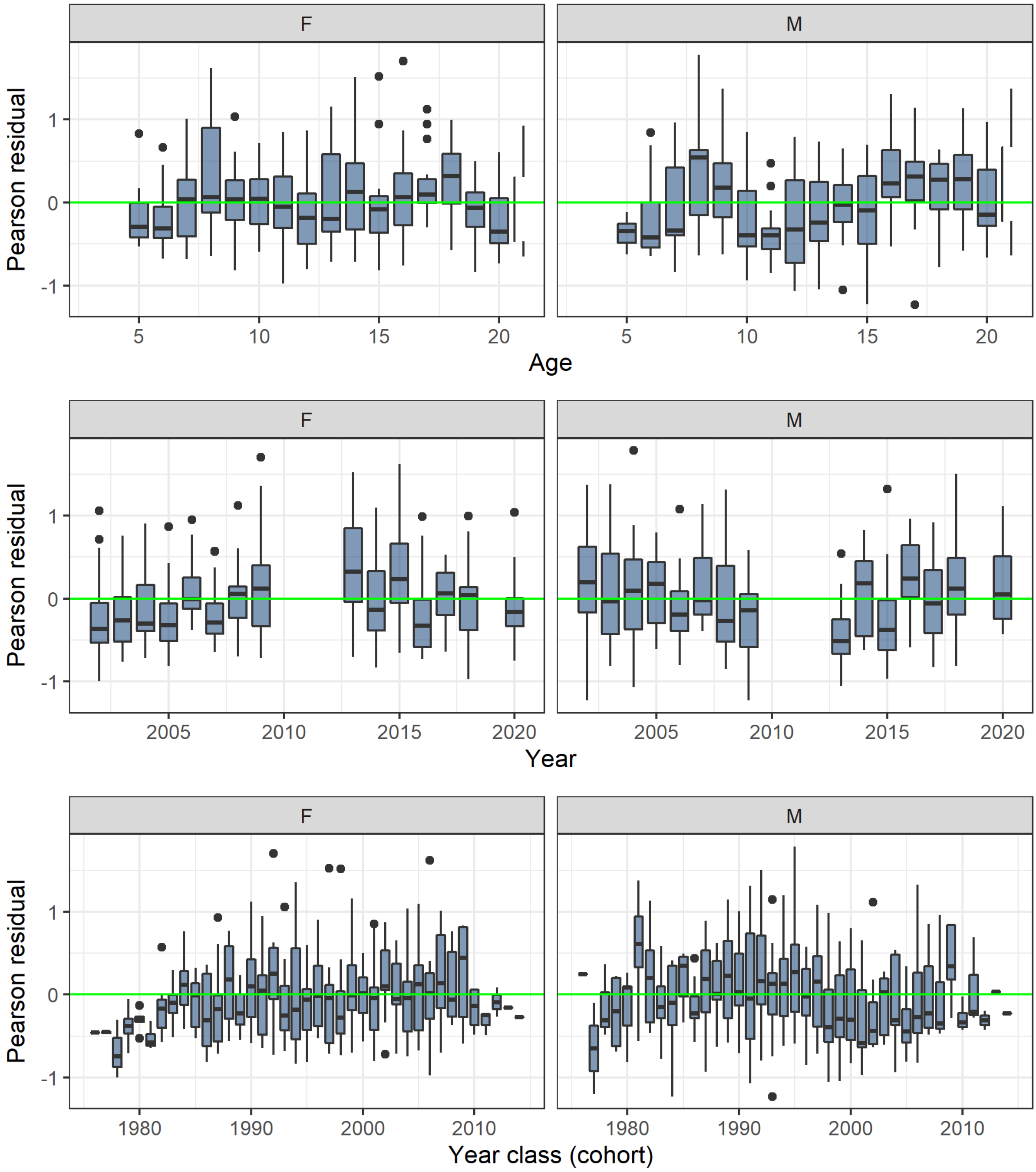

Figure B.7: MPD residual fits to the longline fishery age frequency distributions, by age (top), year of sampling (middle) and year class (bottom).

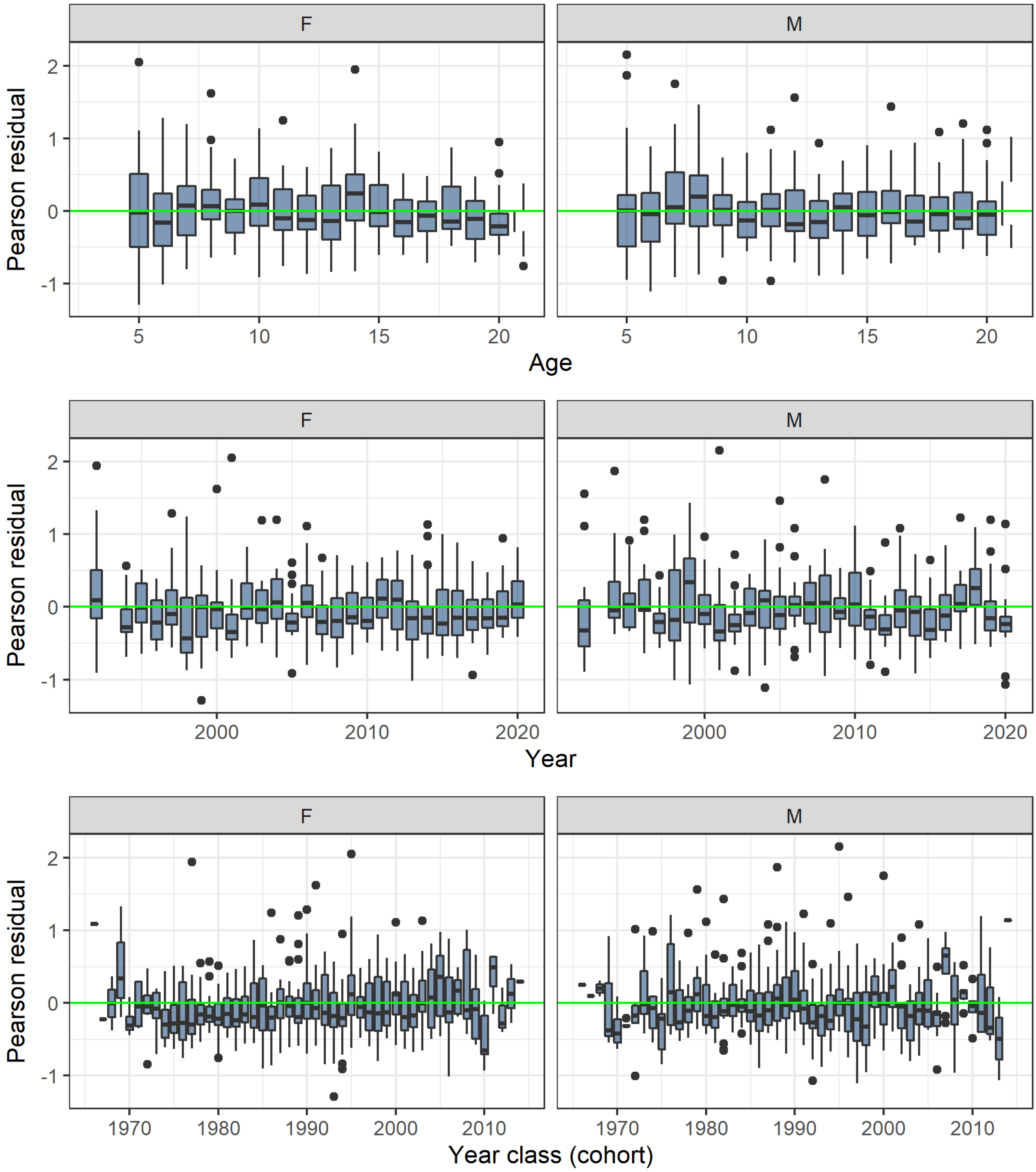

Figure B.8: MPD residual fits to the trawl fishery age frequency distributions, by age (top), year of sampling (middle) and year class (bottom).

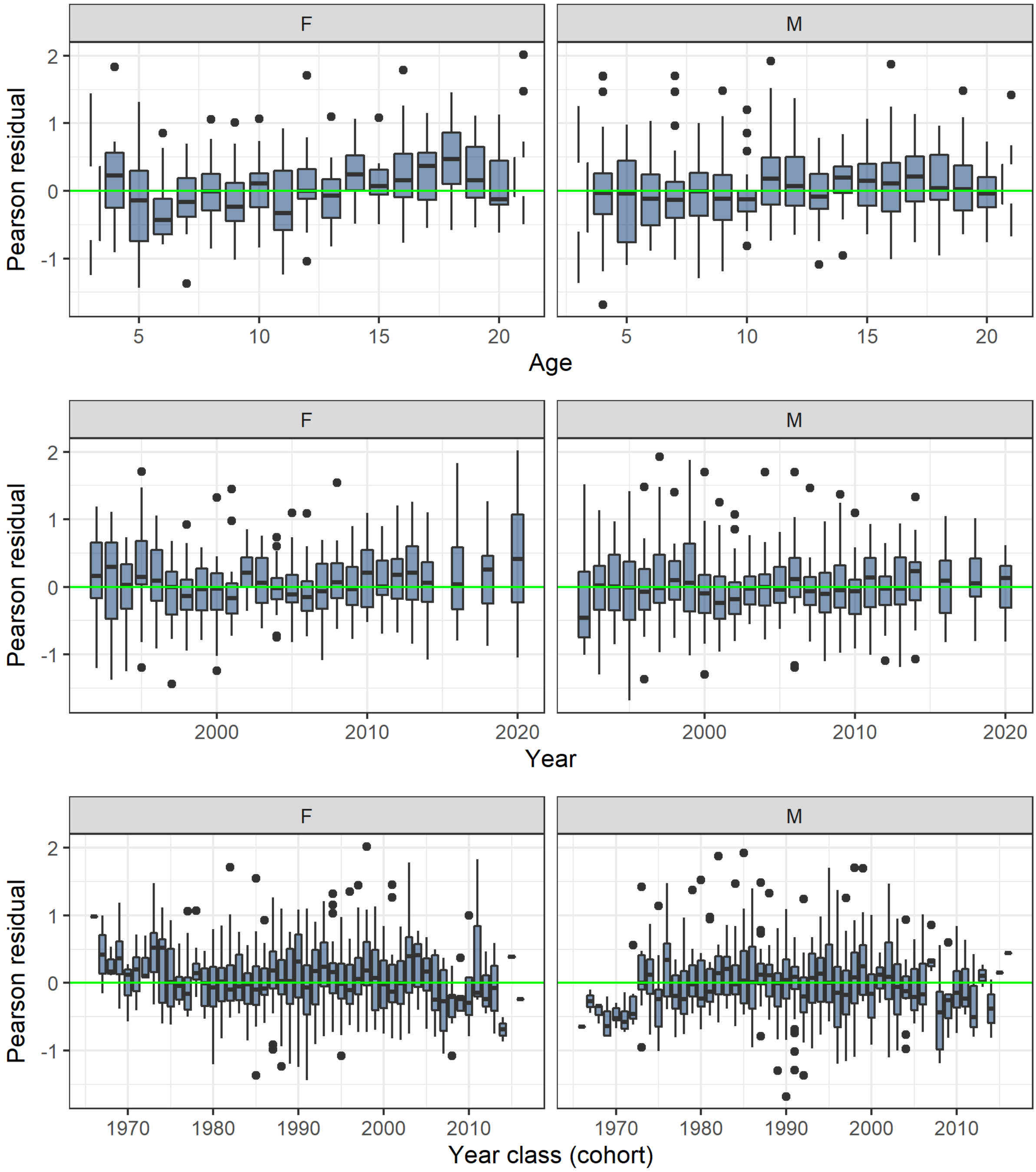

Figure B.9: MPD residual fits to the survey age frequency distributions, by age (top), year of sampling (middle) and year class (bottom).