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Stock assessment of ling (*Genypterus blacodes*) on the Chatham Rise (LIN 3&4) for the 2018-19 fishing year

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Table of Contents

EXECUTIVE SUMMARY

Holmes, S.J. (2019). Stock assessment of ling (*Genypterus blacodes*) on the Chatham Rise (LIN 3&4) for the 2018-19 fishing year.

***New Zealand Fisheries Assessment Report 2019/70*. 45 p.**

An updated Bayesian assessment is presented here for the LIN 3&4 (Chatham Rise) stock, using the general-purpose stock assessment program CASAL v2.30. The assessment incorporated all relevant biological parameters, the commercial catch histories, abundance indices and age data from a series of trawl surveys, updated CPUE series, and proportions-at-age or proportions-at-length data from the commercial trawl and line fisheries. The model structure allowed the input of catch histories and relative abundance indices associated with fisheries having different fishing methods, seasons, and areas.

The current status of the LIN 3&4 stock was estimated to be 57% B_0, although the level of absolute biomass was uncertain because there was little contrast in the principal abundance index. The assessment incorporated uncertainty in *M* by estimating this parameter in the model. Sensitivity model runs produced fairly similar estimates of current stock status and size, with the 2019 stock size ranging from 32–55% B_0. The base case model and all final sensitivity runs except one excluded longline fishery CPUE data in favour of trawl survey abundance indices, giving primacy to fishery-independent data. Current stock estimates when the longline fishery CPUE data were excluded ranged from 44–55% B_0. The base model suggested that B_0 was about 111 000 t, and was very unlikely to be lower than 100 000 t. Current stock size of LIN 3&4 was estimated to be well above the management target of 40% B_0, and was estimated to be unlikely to change over the next five years at the most recent catch level, but may decline if catches increase to the TACC of 6260 t.

1. INTRODUCTION

Ling are managed as eight administrative QMAs, although five of these (LIN 3, 4, 5, 6, and 7) (Figure 1) currently produce about 95% of landings. Research has indicated that there are at least five major biological stocks of ling in New Zealand waters (Horn 2005): the Chatham Rise, the Sub-Antarctic (including the Stewart-Snares shelf and Puysegur Bank), the Bounty Platform, the west coast of the South Island, and Cook Strait.

In the stock assessment process, the same five biological stocks of ling are recognised, and are defined as follows: Chatham Rise (LIN 3 and LIN 4), Sub-Antarctic incorporating Campbell Plateau and Stewart-Snares shelf (LIN 5, and LIN 6 west of 176º E), Bounty Plateau (LIN 6 east of 176º E), west coast South Island (LIN 7 west of Cape Farewell), and Cook Strait (those parts of LIN 2 and LIN 7 between latitudes 41° and 42° S and longitudes 174° and 175.4° E, equating approximately to statistical areas 016 and 017). These stocks are referred to as LIN 3&4, LIN 5&6, LIN 6B, LIN 7WC, and LIN 7CK, respectively.

This document reports results of Specific Objective 2 of Ministry for Primary Industries Project LIN2018-01. The objective was to conduct a stock assessment, including estimating biomass and sustainable yields, for LIN 3&4. The previously reported assessment of LIN 3&4 was McGregor (2015).

The current assessment used CASAL v2.30, a generalised age- or length-structured fish stock assessment model (Bull et al. 2012). The assessment incorporates a trawl survey biomass series, catch-at-age data from the research survey series and from line and trawl fisheries, catch-at-length data from the line fishery, and a line fishery CPUE series.

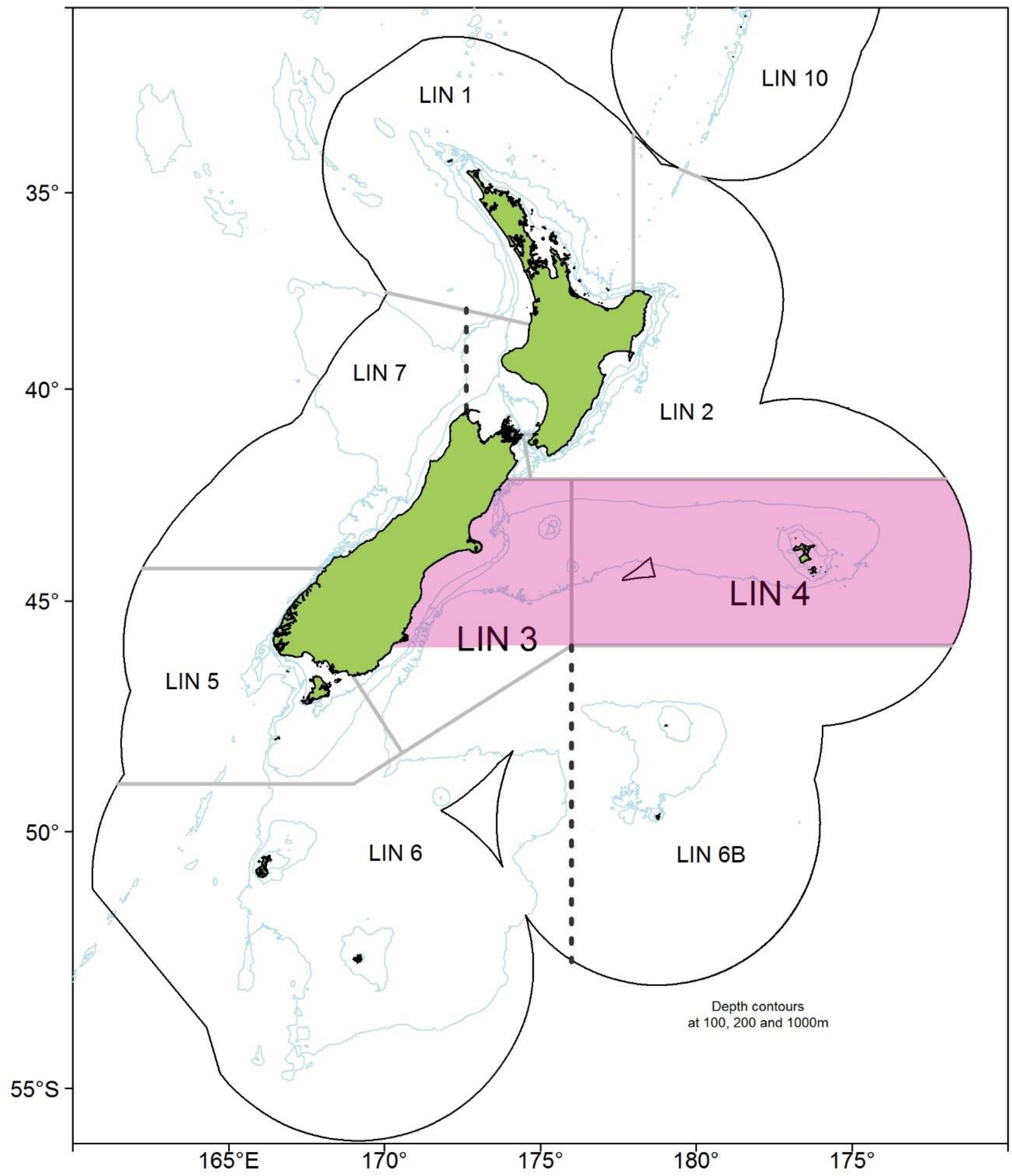


Figure 1: Area of all LIN Fishstocks with LIN3&4 shaded in pink. The boundaries used to separate biological stock LIN 6B from the rest of LIN 6, and the west coast South Island section of LIN 7 from the rest of LIN 7 are shown as broken lines.

2. REVIEW OF THE FISHERY

Reported landings of ling are summarised in Tables 1 and 2. From 1975 to 1980 there was a substantial fishery on the Chatham Rise carried out by Japanese and Korean longliners (Fisheries New Zealand 2019). During the 1980s, most ling were taken by trawl. In the early 1990s a longline fishery developed, with a resulting increase in landings from LIN 3 and 4 (Table 2). A small, but important, quantity of ling is also taken by setnet in LIN 3.

Under the Adaptive Management Programme (AMP), TACCs for LIN 3 and 4 were increased by about 30% for the 1994–95 fishing year to a level that was expected to allow any decline in biomass to be detected by trawl surveys of the Chatham Rise (with CV 10% or less) over the five years following the increase. The TACCs were set at 2810 and 5720 t, respectively. These stocks were removed from the AMP from 1 October 1998, with TACCs maintained at the increased level. Following a decline in catch rates (as indicated from the analysis of longline CPUE data) and assessment model results indicating that current biomass was about 25–30% of B_0, the TACCs for LIN 3 and LIN 4 were reduced to 2060 t and 4200 t, respectively, from 1 October 2000. The sum of these values was at the level of the combined CAY estimate of 6260 t for LIN 3&4 from Horn et al. (2000).

Table 1: Reported landings (t) of ling from 1975 to 1987–88. Data from 1975 to 1983 from MAF; data from 1983–84 to 1985–86 from FSU; data from 1986–87 and 1987–88 from QMS.

					Foreign licensed				
	New Zealand			Longline				Trawl	Grand total
Fishing Year	Domestic	Chartered	Total	(Japan + Korea)	Japan	Korea	USSR	Total	
1975*	486	0	486	9 269	2 180	0	0	11 499	11 935
1976*	447	0	447	19 381	5 108	0	1 300	25 789	26 236
1977*	549	0	549	28 633	5 014	200	700	34 547	35 096
1978–79#	657*	24	681	8 904	3 151	133	452	12 640	13 321
1979–80#	915*	2 598	3 513	3 501	3 856	226	245	7 828	11 341
1980–81#	1 028*	-	-	-	-	-	-	-	-
1981–82#	1 581*	2 423	4 004	0	2 087	56	247	2 391	6 395
1982–83#	2 135*	2 501	4 636	0	1 256	27	40	1 322	5 958
1983†	2 695*	1 523	4 218	0	982	33	48	1 063	5 281
1983–84§	2 705	2 500	5 205	0	2 145	173	174	2 491	7 696
1984–85§	2 646	2 166	4 812	0	1 934	77	130	2 141	6 953
1985–86§	2 126	2 948	5 074	0	2 050	48	33	2 131	7 205
1986–87§	2 469	3 177	5 646	0	1 261	13	21	1 294	6 940
1987–88§	2 212	5 030	7 242	0	624	27	8	659	7 901

* Calendar years (1978 to 1983 for domestic vessels only).
\# 1 April to 31 March.
† 1 April–30 Sept 1983.
§ 1 Oct to 30 Sept.

Table 2: Reported landings (t) of ling from Fishstocks LIN 3 and LIN 4 from 1983–84 to 2017–18 and actual TACCs (t) from 1986–87 to 2017–18.

Fishstock	LIN 3		LIN 4	
QMA (s)		3		4
	Landings	TACC	Landings	TACC
1983–84*	1 306	-	352	-
1984–85*	1 067	-	356	-
1985–86*	1 243	-	280	-
1986–87#	1 311	1 850	465	4 300
1987–88#	1 562	1 909	280	4 400
1988–89#	1 665	1 917	232	4 400
1989–90#	1 876	2 137	587	4 401
1990–91#	2 419	2 160	2 372	4 401
1991–92#	2 430	2 160	4 716	4 401
1992–93#	2 246	2 162	4 100	4 401
1993–94#	2 171	2 167	3 920	4 401
1994–95#	2 679	2 810	5 072	5 720
1995–96#	2 956	2 810	4 632	5 720
1996–97#	2 963	2 810	4 087	5 720
1997–98#	2 916	2 810	5 215	5 720
1998–99#	2 706	2 810	4 642	5 720
1999–00#	2 799	2 810	4 402	5 720
2000–01#	2 330	2 060	3 861	4 200
2001–02#	2 164	2 060	3 602	4 200
2002–03#	2 528	2 060	2 997	4 200
2003–04#	1 990	2 060	2 617	4 200
2004–05#	1 597	2 060	2 758	4 200
2005–06#	1 710	2 060	1 769	4 200
2006–07#	2 089	2 060	2 113	4 200
2007–08#	1 778	2 060	2 383	4 200
2008–09#	1 751	2 060	2 000	4 200
2009–10#	1 718	2 060	2 026	4 200
2010–11#	1 665	2 060	1 572	4 200
2011–12#	1 292	2 060	2 305	4 200
2012–13#	1 475	2 060	2 181	4 200
2013–14#	1 442	2 060	2 373	4 200
2014–15#	1 325	2 060	2 246	4 200
2015–16#	1 440	2 060	2 659	4 200
2016–17#	1 808	2 060	2 565	4 200
2017–18#	2 171	2 060	2 636	4 200

* FSU data.
# QMS data.

3. MODEL INPUTS, STRUCTURE, AND ESTIMATION

3.1 Model input data

A summary of all input data series available is given in Table 3. Data used in the base case run are highlighted in bold. Data from trawl surveys could be input either as a) biomass and proportions-at-age, or b) catch numbers-at-age. For ling assessments the preference is for entering trawl survey biomass and trawl survey proportions-at-age data as separate input series. Francis et al. (2003) presented an argument against the use of numbers-at-age data for hoki from trawl surveys and it was decided that this was also appropriate for ling.

For this assessment, the survey index value from 1990 was removed, the rationale being that the data was collected using a different vessel to the rest of the series, raising issues of unresolved vessel effect biasing the data point relative to the rest of the series. In past assessments the value of an additional data point was considered to outweigh the vessel effect concern but the time series of data using the Tangaroa is now considered long enough to be used exclusively.

The data on longline proportions at length were also removed for this assessment. Pearson residual plots (Figure 2) showed that although residuals remained within ±2 SD there was a noticeable pattern to the residuals. This was true of all sensitivity runs considered. The years covered by the proportions at length data, 1995 to 2002, are also represented in the trawl fishery proportions at age data and trawl survey data. Lastly, CASAL is an age based model. Fitting to proportions at length relies on converting between length and age information using von Bertalanffy growth parameters (which are not known with certainty), introducing another element of uncertainty.

Estimated commercial landings histories are listed in Table 4. Landings up to 1972 were assumed to be zero, although it is likely that small quantities of ling were taken before then. Landings in the year of the assessment, 2018–19, were assumed to be the same as 2017–18.

Estimates of biological parameters and assumed values for model parameters used in the assessments are given in Table 5. Growth and length-weight relationships were revised most recently by Horn (2006). The maturity ogive represents the proportion of fish (in the virgin stock) that are estimated to be mature at each age and are from Horn (2005). The proportion spawning was assumed to be 1.0 in the absence of data to estimate this parameter. A stock-recruitment relationship (Beverton-Holt, with steepness 0.84) was assumed, with the value of 0.84 recommended for steepness for marine demersal fishes by Shertzer & Conn (2012), and used in the Cook Strait ling stock assessment (Horn et al. 2013). Variability in the von Bertalanffy age-length relationship was assumed to be lognormal with a constant CV of 0.1. Ageing error for the observed proportions-at-age data was assumed to have a discrete normal distribution with CV of 0.05 (Table 5).

The RV *Tangaroa* trawl survey catch data from LIN 3&4 were available as estimates of catch-at-age. These data were fitted in the model as proportions-at-age, where estimates of the proportions-at-age and associated CVs by age were estimated using the NIWA catch-at-age software (Bull & Dunn 2002). Zero values of proportion-at-age were replaced with 0.0001. The accompanying RV *Tangaroa* trawl survey biomass index is given in Table 6.

Standardised CPUE series for the longline fisheries (Table 7) were derived following Horn et al. (2013). Catch-at-length data were fitted to the model as proportions-at-length, and estimated using the software described above. Zero values of catch-at-length were replaced with 0.0001.

Table 3: Summary of available model data inputs for the Chatham Rise ling assessment. Data used in the base case model are highlighted in bold.

Data series	Years
Trawl survey proportion at age (*Amaltal Explorer*, Dec)	1990
Trawl survey proportion at age (*Tangaroa*, Jan)	**1992–2014, 2016, 2018**
Trawl survey biomass (*Tangaroa*, Jan)	**1992–2014, 2016, 2018**
CPUE (longline, all year)	1990–2018
Commercial longline proportion-at-age (Jun–Oct); sexed	**2002–2009, 2013–2018**
Commercial longline proportion-at-age (Jun–Oct); unsexed	2002–2009, 2013–2018
Commercial longline length-frequency (Jun–Oct); sexed & unsexed	1995–2002
Commercial trawl proportion-at-age (Oct–May); sexed	**1992, 1994–2018**

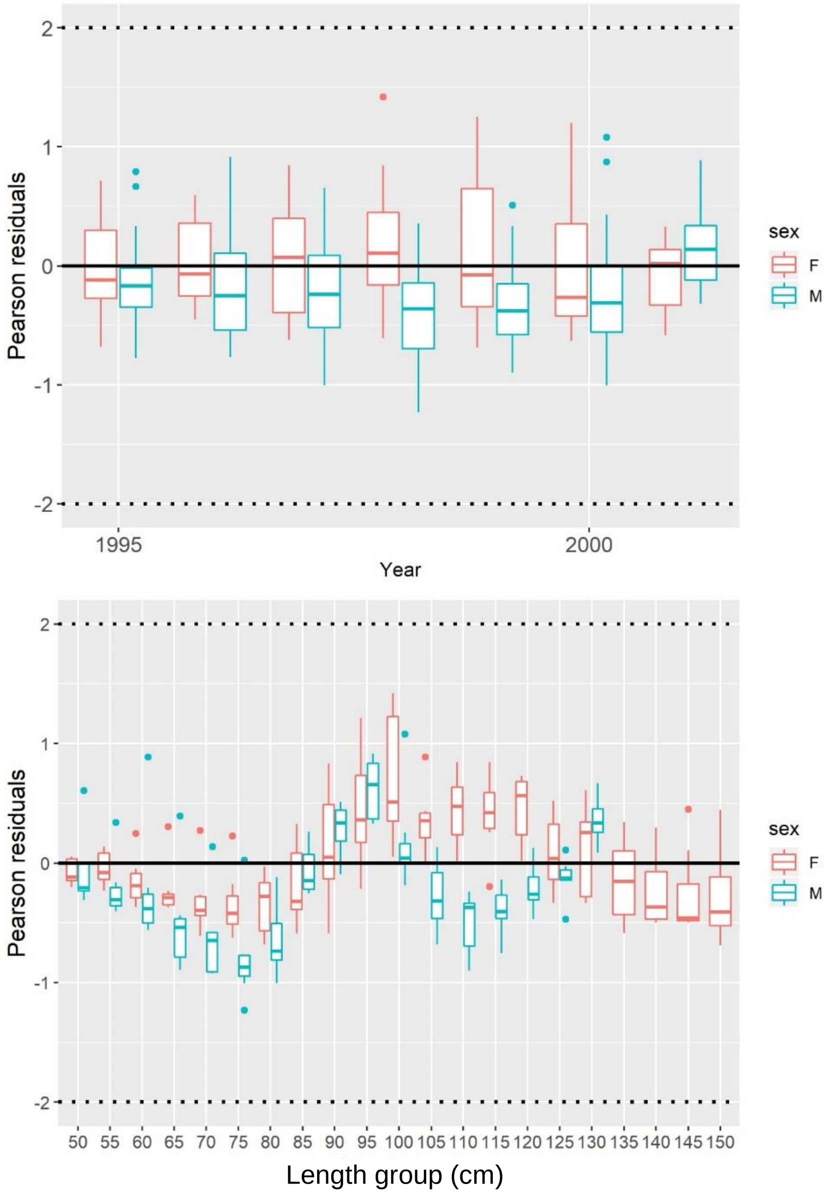


Figure 2: Example of Pearson residuals from fit to longline proportion at length data from an MPD run: Example shown is for a sensitivity run set up as for the base run except that longline proportions at length were retained. This is labled 'run 4' in later sections (see also Table 10).

Table 4: Estimated catch histories (t) for LIN 3&4, separated by fishing method (trawl or line).

Year	Longline catch	Trawl catch	Year	Longline catch	Trawl catch
1973	0	250	1996	4 863	2 725
1974	0	382	1997	4 047	3 003
1975	8 439	953	1998	3 227	4 707
1976	17 436	2 100	1999	3 818	3 282
1977	23 994	2 055	2000	2 779	3 739
1978	7 577	1 400	2001	2 724	3 467
1979	821	2 380	2002	2 787	2 979
1980	360	1 340	2003	2 150	3 375
1981	160	673	2004	2 082	2 525
1982	339	1 183	2005	2 440	1 913
1983	326	1 210	2006	1 840	1 639
1984	406	1 366	2007	1 880	2 322
1985	401	1 351	2008	1 810	2 350
1986	375	1 494	2009	2 217	1 534
1987	306	1 313	2010	2 257	1 484
1988	290	1 636	2011	2 046	1 191
1989	488	1 397	2012	2 190	1 407
1990	529	1 934	2013	2 543	1 113
1991	2 228	2 563	2014	2 778	1 037
1992	3 695	3 451	2015	2 077	1 495
1993	3 971	2 375	2016	2 700	1 399
1994	4 159	1 933	2017	2 716	1 653
1995	5 530	2 222	2018	2 328	1 229

Table 5: Biological and other input parameters used in the Chatham Rise ling assessment.

Weight = a (length)^b (Weight in g, total length in cm)

	a	b
Female	0.00114	3.318
Male	0.001	3.354

von Bertalanffy growth parameters (n, sample size)

	n	k	t_0	L_∞
Female	4 133	0.08	–0.74	156
Male	3 964	0.13	–0.70	114

Maturity ogives (proportion mature at age)

Age	3	4	5	6	7	8	9	10	11	12	13	14	15
Male	0	0.03	0.063	0.14	0.28	0.48	0.69	0.85	0.93	0.97	0.99	1	1
Female	0	0	0.003	0.01	0.014	0.033	0.08	0.16	0.31	0.54	0.76	0.93	1

Miscellaneous parameters

Stock-recruitment steepness	0.84
Recruitment variability CV	0.6
Ageing error CV	0.05
Proportion spawning	1.0
Maximum exploitation rate (U_{max})	0.6

Table 6: Relative biomass index (t) from *Tangaroa* (TAN) trawl surveys with CV.

Trip code	Date	Biomass (t)	CV (%)
TAN9106	Jan-Feb 1992	8 930	5.8
TAN9212	Jan-Feb 1993	9 360	7.9
TAN9401	Jan-94	10 130	6.5
TAN9501	Jan-95	7 360	7.9
TAN9601	Jan-96	8 420	8.2
TAN9701	Jan-97	8 540	9.8
TAN9801	Jan-98	7 310	8.3
TAN9901	Jan-99	10 310	16.1
TAN0001	Jan-00	8 350	7.8
TAN0101	Jan-01	9 350	7.5
TAN0201	Jan-02	9 440	7.8
TAN0301	Jan-03	7 260	9.9
TAN0401	Jan-04	8 250	6
TAN0501	Jan-05	8 930	9.4
TAN0601	Jan-06	9 300	7.4
TAN0701	Jan-07	7 800	7.2
TAN0801	Jan-08	7 500	6.8
TAN0901	Jan-09	10 620	11.5
TAN1001	Jan-10	8 850	10
TAN1101	Jan-11	7 030	13.8
TAN1201	Jan-12	8 100	7.4
TAN1301	Jan-13	8 710	10.1
TAN1401	Jan-14	7 490	7.2
TAN1601	Jan-16	10 200	7.2
TAN1801	Jan-18	8 758	12

Table 7: Chatham Rise longline fishery CPUE index with CV.

Year	Index	CV	Year	Index	CV
1991	1.84	0.07	2013	0.83	0.04
1992	2.33	0.06	2014	0.87	0.04
1993	1.88	0.06	2015	0.71	0.04
1994	1.70	0.05	2016	0.82	0.04
1995	1.80	0.05	2017	0.81	0.04
1996	1.38	0.05	2018	0.83	0.04
1997	0.95	0.04			
1998	0.86	0.05			
1999	0.87	0.04			
2000	0.96	0.04			
2001	0.99	0.05			
2002	0.86	0.04			
2003	0.91	0.05			
2004	0.86	0.05			
2005	0.94	0.04			
2006	0.77	0.05			
2007	0.83	0.04			
2008	0.92	0.05			
2009	0.86	0.04			
2010	0.83	0.04			
2011	0.68	0.04			
2012	0.83	0.04			

3.2 Model structure

The stock assessment model partitioned the Chatham Rise population into sexes and age groups 3–25, with a plus group. There were two fisheries (trawl and longline) on the stock. The model annual cycle for the stock is described in Table 8.

The selectivity ogives for the commercial trawl and line fisheries were age-based and were estimated in the model, separately by sex in all cases. The trawl survey and trawl fishery ogives were estimated using either a double normal or logistic functional form; the estimated line fishery ogive was assumed to be logistic except for one sensitivity run. This sensitivity run offered a double normal functional form for the line fishery ogive but the estimated ogive closely matched the logistic forms obtained from other runs. The same sensitivity run estimated an ogive for females in the survey trawl with high proportion captured at age 1 (approximately 0.7) and slow increase in proportion captured with age such that the estimates at ages 3 to 7 were considerably lower than for other model runs. The working group considered the female trawl survey selectivity for this sensitivity run unrealistic and, given the near logistic form of the estimated line fishery selectivity, a double normal form for the line fishery selectivity was not considered further. For trawl selectivities, male selectivity curves were ‘capped’, i.e. maximum selectivity for males was allowed to vary from 1.0. The functional forms of the double normal and logistic curves were given by Bull et al. (2012). In all fisheries, selectivities were assumed constant over all years, i.e., there was no allowance for annual changes in selectivity.

The maximum exploitation rate was assumed to be 0.6 for both stocks, as was used in the previous Chatham Rise ling stock assessment (McGregor 2015). The choice of the maximum exploitation rate has the effect of determining the minimum possible virgin biomass allowed by the model. This value was set relatively high as there was little external information from which to determine it.

Table 8: Annual cycle of the LIN 3&4 stock model, showing the processes taking place at each time step, their sequence within each time step, and the available observations. Fishing and natural mortality that occur within a time step occur after all other processes, with half of the natural mortality for that time step occurring before and half after the fishing mortality.

					Observations	
Step	Period	Processes	M[1]	Age[2]	Description	$\%Z$[3]
1	Dec–Aug	Recruitment Non-spawning fisheries (trawl & line)	0.9	0.5	Trawl survey (summer) Line CPUE Line catch-at-age/length Trawl catch-at-age	0.2 0.5
2	Sep–Nov	Increment ages	0.1	0.0	–	

1. M is the proportion of natural mortality that was assumed to have occurred in that time step.
2. Age is the age fraction (used for determining length-at-age) that was assumed to occurred by the start of that time step.
3. $\%Z$ is the percentage of the total mortality in the step that was assumed to have taken place at the time each observation was made.

3.3 Model estimation

Model parameters were estimated using Bayesian methods implemented using the CASAL v2.30 software. However, only the mode of the joint posterior distribution (MPD) was estimated in preliminary runs. For final runs, the full posterior distribution was sampled using Markov Chain Monte Carlo (MCMC) methods, based on the Metropolis-Hastings algorithm. Full details of the CASAL algorithms, software, and methods were given by Bull et al. (2012).

For LIN 3&4, the error distributions assumed were multinomial for the proportions-at-age and proportions-at-length data, and lognormal for all other data. The effective sample sizes for the multinomial errors assumed for the composition data were estimated from a regression of log(proportion) against log(CV), where the CV was estimated by bootstrapping from the sample data (Bull & Dunn 2002). The multinomial observation error effective sample sizes for the at-age and at-length data were then adjusted using the reweighting procedure of Francis (2011). In a change to the previous assessment, additional process errors for the trawl survey biomass index and line fishery CPUE were then estimated within the model, a final adjustment to the at-age data weighting following Francis (2011) conducted, and then the process errors were fixed for all subsequent model runs.

Year class strengths were assumed known (and equal to 1) when inadequate (i.e., fewer than three data points) or no catch-at-age data were available for that year. Otherwise, year class strengths were estimated under the assumption that the estimates from the model must average 1. The Haist parameterisation for year class multipliers was used here (see Bull et al. (2012) for details).

4. MODEL ESTIMATES

4.1 Developing a base model

As in the previous assessment (McGregor 2015), the base run for this assessment assumed double-normal selectivity ogives for the trawl survey and trawl fishery. In the previous assessment, where the separate male and female selectivity assumption was applied, males were slightly more vulnerable than females (ogive asymptote for males was greater than 1) to the trawl survey, and less vulnerable than females (ogive asymptote less than 1) to the trawl fishery. This allowed the model to modify the relative vulnerability of males and females, and to match the sex ratios in the proportions-at-age data.

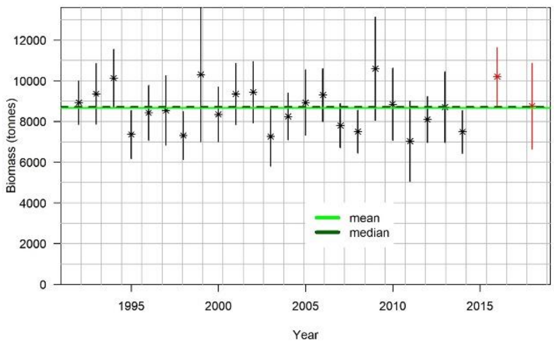
The assumed errors for the composition data were multinomial, and the initial effective sample sizes and re-weighted effective sample sizes are given in Table 9. In initial sensitivity runs the proportion of males, ‘p_male’, was consistently estimated very close to 0.5. It was therefore decided to no longer estimate p_male but rather set it equal to 0.5.

Longline proportions at age data were fitted separated by sex, as opposed to combined over sexes as in the previous assessment (McGregor 2015). To treat the data separated by sex is generally the preferred option on grounds of biological realism, and sensitivity runs indicated (from Pearson residuals and log likelihood results) that the data were sufficient to support fitting separately by sex. In an additional change, natural mortality, M, was estimated by sex rather than assumed the same for males and females. The effect of fitting longline proportions at age and estimating M by sex was tested through a sensitivity run that kept both longline proportions at age and M combined over sexes.

In this assessment, the fit to the trawl survey biomass indices was given primacy. However, as in the previous assessment, the trend shown by the two biomass indices was different, with the longline CPUE declining during the 1990s, and the trawl survey essentially flat (Figure 3). The ‘Base’ run included the trawl survey biomass index and excluded the longline CPUE, the ‘Longline’ run included the longline CPUE and excluded the trawl survey biomass index. This sensitivity run also removed the survey proportions at age data. Four additional sensitivity runs were considered. The ‘Old base case’ run retained single sex longline proportions at age and estimation of M, two runs retained longline proportions at length, the second of these also made use of an informed prior on survey catchability with a relatively high mean (μ=0.6, C.V.=30% opposed to 0.13 and 70% for the base case). The final sensitivity run was as for the base case but using the high survey catchability prior. See Table 10 for an overview of the model runs, with the MPD estimates for B_0 and $B_{current}$(%B_0).

Table 9: Multinomial effective sample sizes (ESS) assumed for the age and length composition data sets. The initial ESS were estimated from the sample data, and the reweighted ESS have been scaled following the technique of Francis (2011).

	Trawl survey proportion-at-age			Trawl fishery proportion-at-age	
Fishing year	**Initial EFS**	**Reweighted EFS**	**Fishing year**	**Initial EFS**	**Reweighted EFS**
1992	473	144	1992	329	38
1993	555	169	1994	245	29
1994	530	161	1995	108	12
1995	311	94	1996	270	32
1996	370	113	1997	147	17
1997	410	125	1998	668	78
1998	365	111	1999	550	64
1999	388	118	2000	385	45
2000	547	166	2001	481	56
2001	637	193	2002	363	42
2002	553	168	2003	322	37
2003	493	149	2004	228	27
2004	508	154	2005	336	39
2005	448	137	2006	204	24
2006	532	161	2007	369	43
2007	451	137	2008	552	65
2008	397	121	2009	245	29
2009	403	122	2010	263	31
2010	415	125	2011	283	33
2011	312	95	2012	317	37
2012	398	121	2013	394	46
2013	407	124	2014	311	37
2014	349	105	2015	174	21
2016	404	123	2016	174	21
2018	308	93	2017	233	28
			2018	351	41
Longline proportion-at-length			**Longline proportion-at-age**		
1995	1 632	75	2002	633	130
1996	1 677	77	2003	624	129
1997	1 860	85	2004	440	90
1998	1 870	86	2005	394	82
1999	1 804	83	2006	145	30
2000	2 056	94	2007	191	40
2001	1 272	58	2008	285	59
			2009	435	89
			2013	254	53
			2014	411	84
			2015	330	68
			2016	439	90
			2017	309	63
			2018	324	67



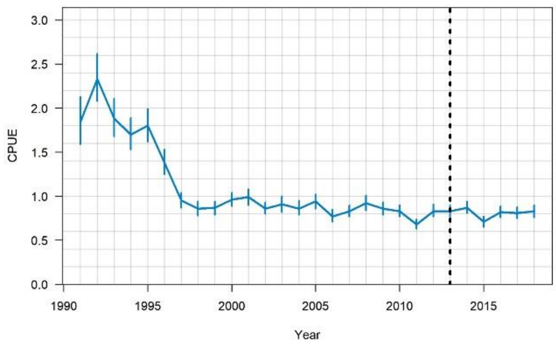


Figure 3: Trawl survey relative biomass (left) and normalised longline CPUE (right). Vertical lines show the 95% confidence intervals. Horizontal lines in survey figure show the mean and median values over the full survey time series; red entries are new data since the previous assessment. Vertical dotted line in CPUE figure shows final year of data available to previous assessment.

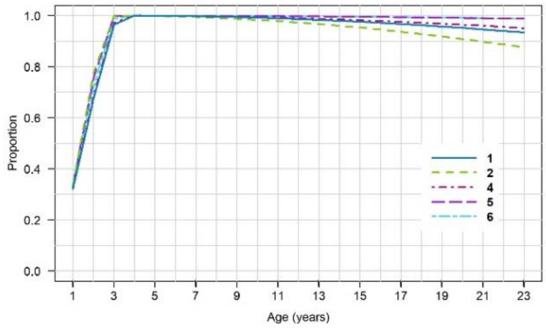
Table 10: Key model run assumptions and MPD estimates for B_0 and $B_{current}(\%B_0)$.

Key run assumptions	B_0 (t)	$B_{current}(\%B_0)$
1. Base run. Longline CPUE excluded; longline proportions at age separated by sex. Longline proportions at length excluded. Trawl survey abundance index included. M estimated for male and female.	113 068	55
2. Old base case run. Same as Base run, but single sex M estimated and combined sex longline proportions at age and longline selectivity. Longline proportions at length retained.	113 398	55
3. Longline run. Same as Base run, but longline CPUE included, trawl survey abundance index excluded and survey proportions at age excluded.	91 470	32
4. Longline proportions at length retained run. Same as Base run, but longline proportions at length retained.	109 670	53
5. Longline proportions at length – high *q* - run. Same as Base run, but longline proportions at length retained and informed prior for survey *q* with with high initial mean (μ=0.6, C.V.=30%).	100 840	44
6. High *q* run. Same as Base run, but informed prior for survey *q* with with high initial mean (μ=0.6, C.V.=30%).	102 953	44

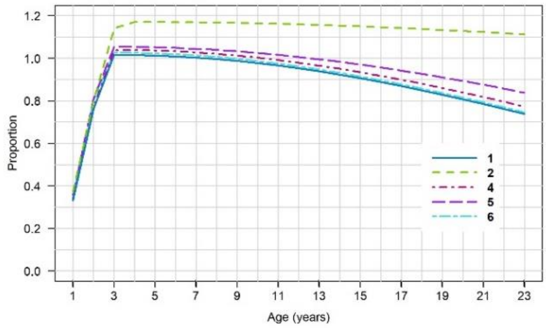
In the current assessment, after adjustments to the base model, males were no longer estimated as more vulnerable than females to the survey (Figure 4). MPD estimates for male trawl fishery and female survey selectivities tended towards being logistic, even when a double normal was offered. Fitting sex specific longline selectivity led to estimates of male vulnerability considerably lower than that of females (Figure 4).

Model fits to the age composition data (longline proportion-at-age, trawl survey proportion-at-age and trawl fishery proportion-at-age) were all fairly good, and almost indistinguishable between model runs (See Appendix A). Fits to the survey biomass index were also similar, with the exception that models using the high survey *q* prior estimated biomass that was high in the early years (Figure 5). The one model to make use of the longline CPUE data was able to fit the data well (Figure 5).

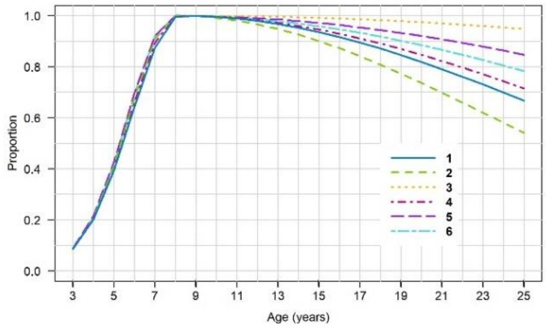
a.) Trawl survey, female selectivity



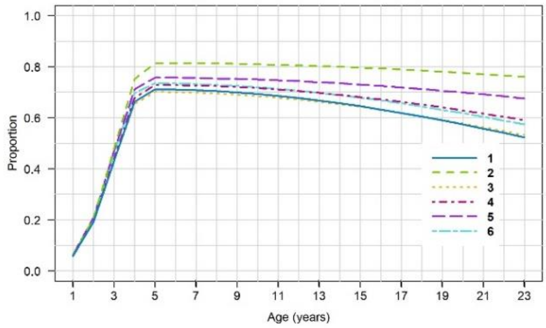
b.) Trawl survey, male selectivity



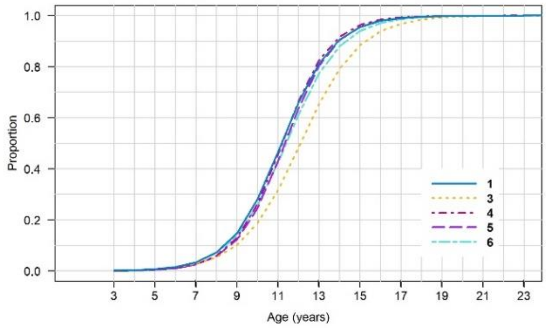
c.) Trawl fishery, female selectivity



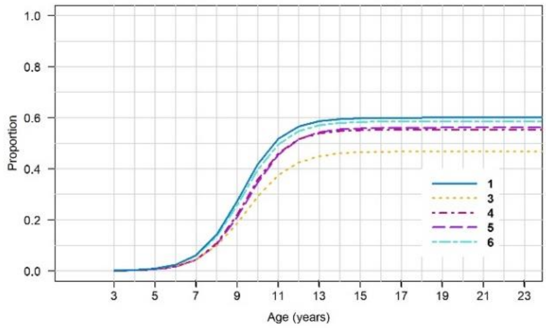
d.) Trawl fishery, male selectivity



e.) Longline fishery, female selectivity



f.) Longline fishery, male selectivity



g.) Longline fishery, combined selectivity

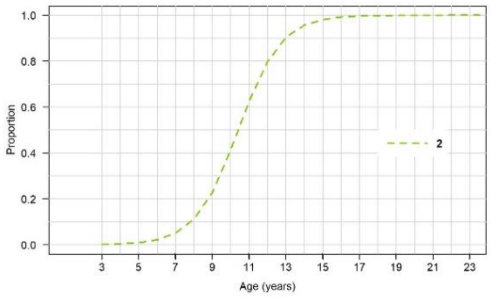


Figure 4: MPD estimates for selectivities for the trawl survey and the trawl and longline fisheries. (1) Base, (2) Old base, (3) Longline, (4) Prop. at length, (5) Prop. at length, high *q* and (6) high *q*.

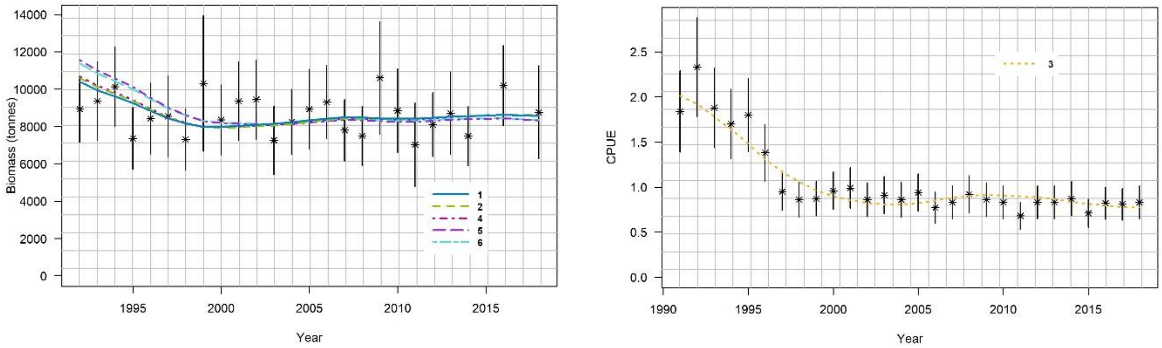


Figure 5: Model fits to biomass indices for the trawl survey (left) and longline CPUE (right). (1) Base run, (2) Old base run, (3) Longline run, (4) Prop. at length run, (5) Prop. at length, high *q*, run and (6) high *q* run. Vertical lines show the 95% confidence intervals.

The year class strengths showed possible weaker year classes since 2000 and in the years 1980–92 compared with the rest of the series, especially in the model run that included the longline CPUE, (Figure 6). The impact of different future mean recruitment levels were investigated when making forward projections (see Section 4.3).

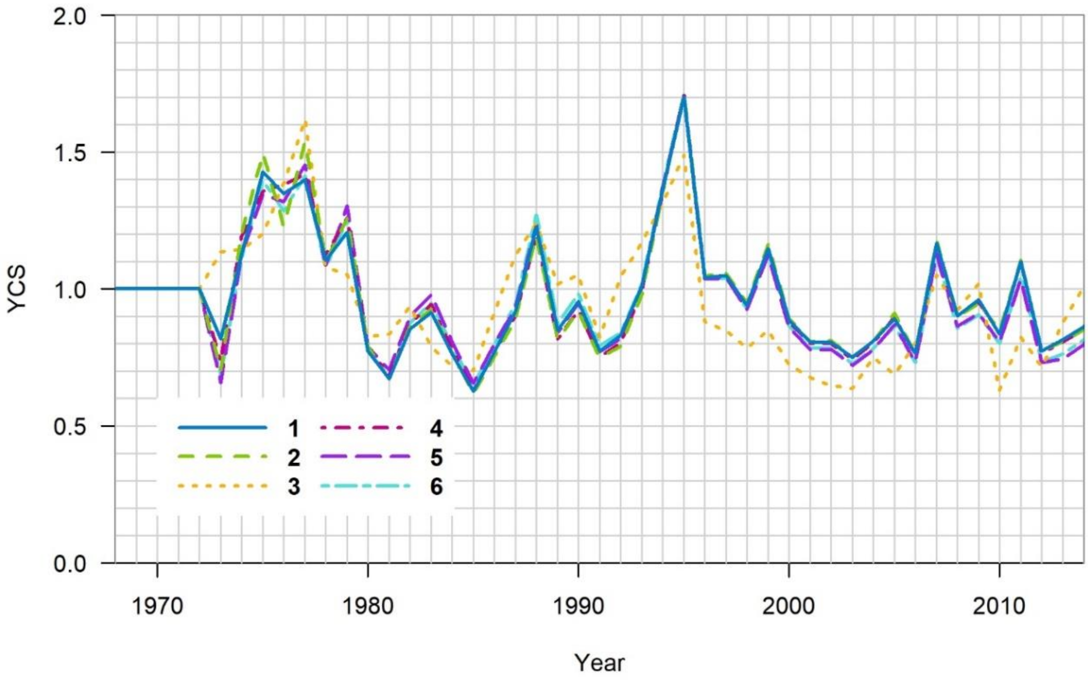


Figure 6: MPD year class strength (YCS) estimates for model runs (1) Base, (2) Old base, (3) Longline, (4) Prop. at length, (5) Prop. at length, high *q* and (6) high *q*.

4.2 MCMC results

Model parameters were estimated using Bayesian estimation implemented using the CASAL software. The full posterior distribution was sampled using Monte Carlo Markov Chain (MCMC) methods, based on the Metropolis-Hastings algorithm. MCMCs were estimated using 6×10^6 iterations, a burn-in length of 1×10^6 iterations, and with every 1000^{th} sample kept, (i.e., a final sample of length 5000 was taken from the Bayesian posterior).

The assumed prior distributions used in the assessment are given in Table 11. Most priors were uninformative, and were specified with wide bounds. One exception was the choice of informative priors for the *Tangaroa* trawl survey *q* which 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. Sensitivity runs showed p_male to be estimated at the prior mean of 0.5. It was deemed unnecessary to estimate p_male and the value was fixed at 0.5.

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 penalty was applied to the estimates of year class strengths to encourage estimates that average to 1.

Table 11: Assumed prior distributions and bounds for estimated parameters in the assessment. Parameter values are mean (in natural space) and CV for lognormal and normal distributions, (except difference in *M* between sexes).

Parameter description	Distribution	Parameters		Bounds	
B_0	Uniform-log	–	–	30 000	500 000
Year class strengths	Lognormal	1.0	0.70	0.01	100
Trawl survey *q*	Lognormal	0.13	0.70	0.02	0.3
CPUE *q*	Uniform-log	–	–	1e-8	1e-3
Selectivities	Uniform	–	–	0	20–200
M	Lognormal	0.2	0.18	0.06	0.5
M sex difference	Normal by stdev	0	0.05	-0.1	0.1

MCMC runs were carried out for the model runs ‘Base’ and ‘Longline’. In the base run, the catchability coefficients (*q*’s) were free. The longline run had difficulty converging using free *q* values (Figure 7) so nuisance *q* values were employed, (Figures B7 to B14). The full set of convergence diagnostic and distribution plots for B_0 and $B_{current}(\%B_0)$ are in Appendix B.

The estimate for $B_{current}$ ($\%B_0$) was lower for the run that included the longline CPUE (Table 12). The 95% lower and upper credible intervals did not overlap between the base model and the CPUE (longline) model. Natural mortality was estimated at around 0.14 for males and 0.16 for females in the base model. For the Longline run, the male and female *M* estimates were approximately 0.13 and 0.15 respectively, but the estimates were considerably less certain (Table 12, Figure 8).

Table 12: MCMC estimates (median, 95% lower and upper credible intervals) for B_0, $B_{current}$(%B_0), and M for each model run.

Model run	Catchability coefficient(s)	B_0 (t)	%B_0	M (male)	M (female)
1. Base	Free	111 067 (102 260 – 126 828)	56.5 (48.2 – 65.5)	0.142 (0.129 – 0.155)	0.159 (0.144 – 0.174)
2. Longline	Nuisance	92 630 (87 605 – 100 986)	34.8 (26.8 – 46.9)	0.131 (0.112 – 0.161)	0.149 (0.128 – 0.187)

1.) Base run 2.) Longline run

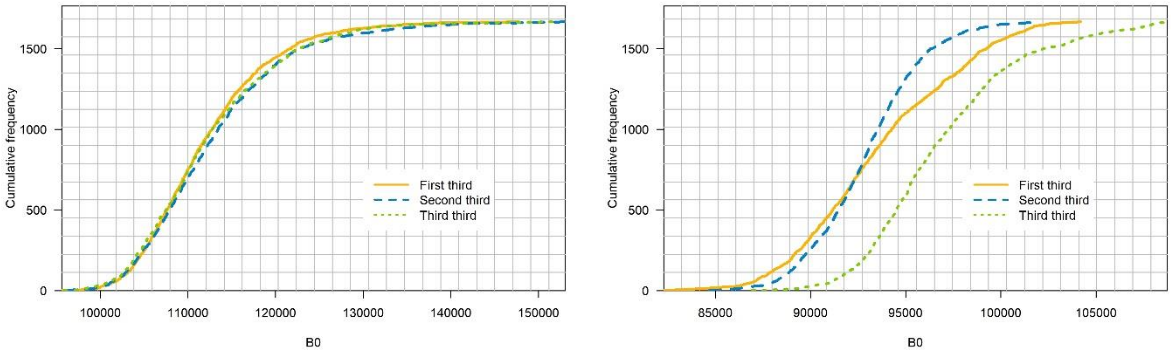


Figure 7: MCMC cumulative frequencies of B_0 for the first (solid gold line), second (dashed blue line) and third (dotted green line) sections of the MCMC chain for model runs (1) Base, (2) Longline when using free catchability coefficients (*q*'s).

3.) Base run 4.) Longline run

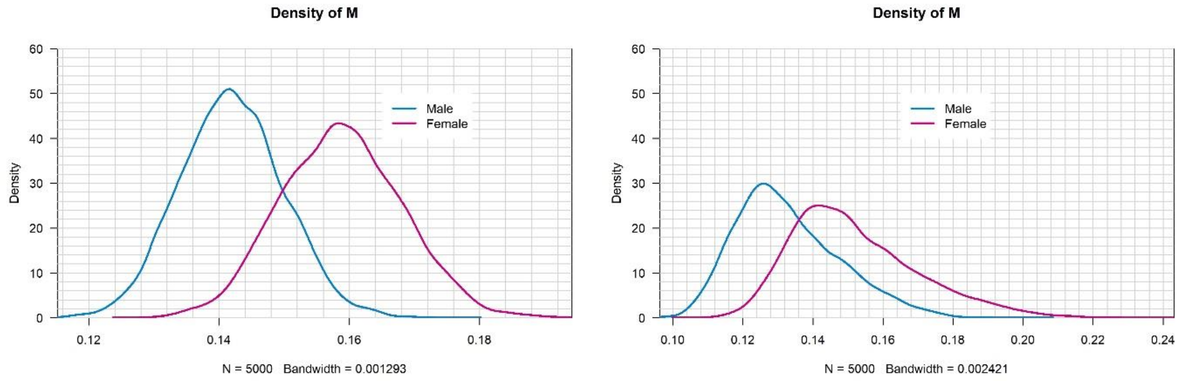


Figure 8: Estimated posterior distribution for M (natural mortality) for model runs (1) Base, (2) Longline.

Selectivities for the trawl fishery and survey tended towards a logistic distribution, although a double normal distribution was offered (Figure 9). Males and females were selected very similarly in the trawl survey (but with wider credible intervals for males) but selection of males was less likely in the trawl fishery (Figure 9). The longline fishery had 50% selectivity by about age 10 for males and age 11 for females, and near 100% selectivity occured by age 14 for males and age 16 for females (Figure 9).

Females Males

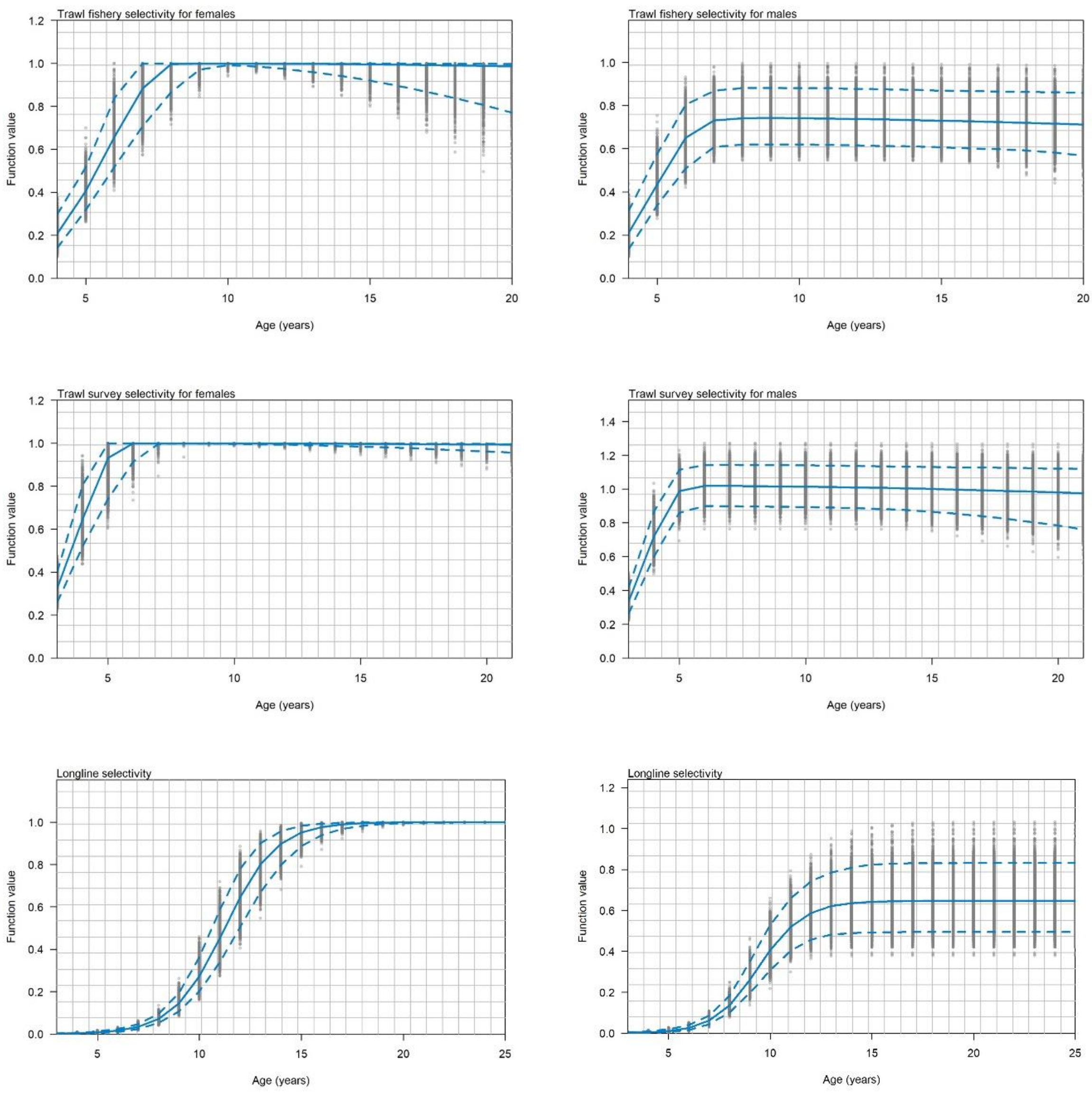


Figure 9: Selectivities for Base run for trawl fishery (top), trawl survey (middle) and longline fishery (bottom) for females (left) and males (right). Grey dots are the selectivity calculated for each age for each link of the MCMC chain, solid blue line is the median, dashed blue lines are the 95% upper and lower credible intervals.

4.3 Biomass projections

Biomass projections from the model were made under two assumed future catch scenarios (Table 13). The first used the average catches from the last five years for the longline and trawl fisheries. The second assumed that the TACC is taken, with the proportional split between longline and trawl matching that found from the last five years of catch data. Two alternative approaches to estimating future year class strengths were also employed. The first made use of all estimated YCS; the second based future year class strengths on the most recent 10 estimated YCS only.

Table 13: Future catch options used in the projections. Relative year class strengths (YCS) from 2020 onwards were selected in two ways (1) The randomised YCS were resampled using all estimated YCS; (2) The randomised YCS were resampled using the most recent 10 estimated YCS.

	Total catch (t)	Longline catch (t)	Trawl catch (t)
Average last 5 years	3 883	2 520	1 363
TACC (split as for av. catches)	6 260	4 063	2 197

Projections were carried out for the Base run and Longline run. The future catch option using the average catch from the last five years is likely to result in a similar biomass in 2024 to that estimated in 2019 (Table 14). If future catches reach the TACC, the biomass is likely to go down to around 86% of the 2019 biomass by 2024 under the Base run, and around 79% for the Longline run, taking $B_{2024}(\%B_0)$ down to approximately 49% and 28% respectively. Very little difference in results occurred between the alternative approaches to estimating future year class strengths. Plots of all projections are in Figures 10–17.

Table 14: Projections from MCMC runs 'Base' and 'Longline'. Median, 95% upper and lower quartiles for B_{2024}, $B_{2024}(\%B_0)$ and $B_{2024}(\%B_{2019})$ under four future catch options.

	Future catch	Future YCS	B_{2024}	$B_{2024}(\%B_0)$	$B_{2024}(\%B_{2019})$
Base Run	Average last 5 years	All estimated YCS	63 300 (46 600, 90 400)	57 (56, 70)	101 (92, 111)
	Average last 5 years	Last 10 yrs YCS	63 100 (46 400, 90 200)	57 (46, 70)	100 (91, 111)
	TACC (split as for av. catches)	All estimated YCS	54 200 (37 500, 81 500)	49 (37, 63)	86 (75, 98)
	TACC (split as for av. catches)	Last 10 yrs YCS	54 000 (37 000, 81 600)	49 (36, 63)	86 (75, 98)
Longline Run	Average last 5 years	All estimated YCS	34 800 (21 400, 59 800)	38 (24, 58)	106 (85, 145)
	Average last 5 years	Last 10 yrs YCS	34 700 (21 100, 60 700)	38 (23, 59)	106 (83, 146)
	TACC (split as for av. catches)	All estimated YCS	25 700 (12 100, 52 200)	28 (13, 50)	79 (49, 121)
	TACC (split as for av. catches)	Last 10 yrs YCS	25 400 (11 400, 52 600)	28 (13, 51)	78 (46, 126)

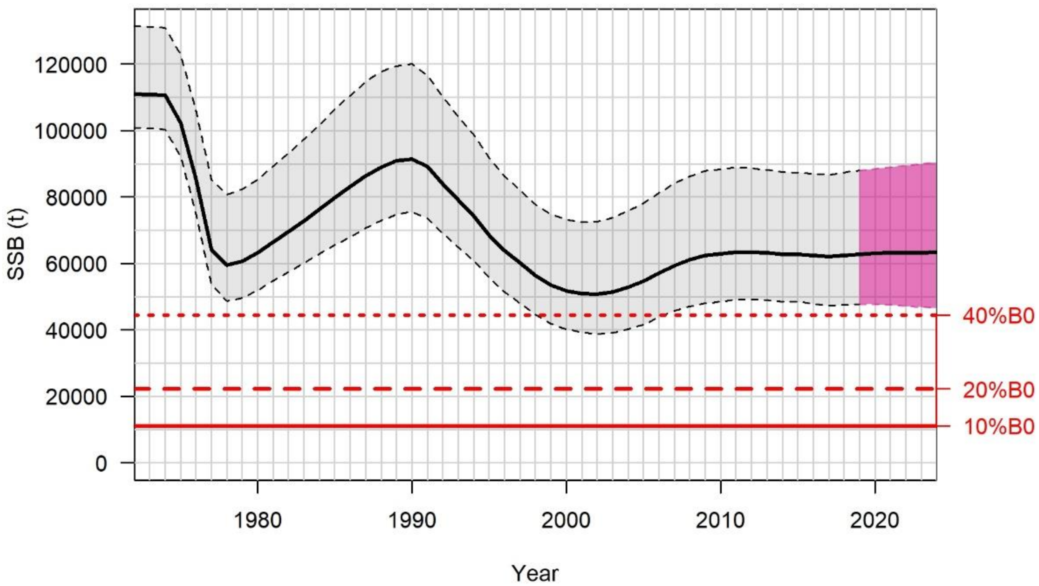


Figure 10: Projection using MCMC. Base run using all estimated year class strengths to estimate future year class strengths. Future catch option: Average last 5 years.

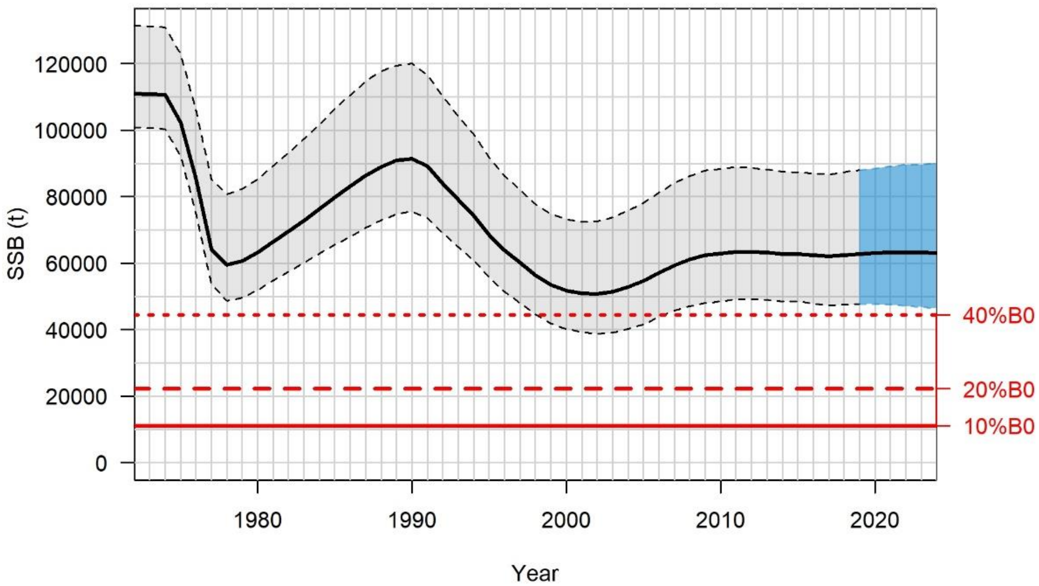


Figure 11: Projection using MCMC. Base run using most recent 10 estimated year class strengths to estimate future year class strengths. Future catch option: Average last 5 years.

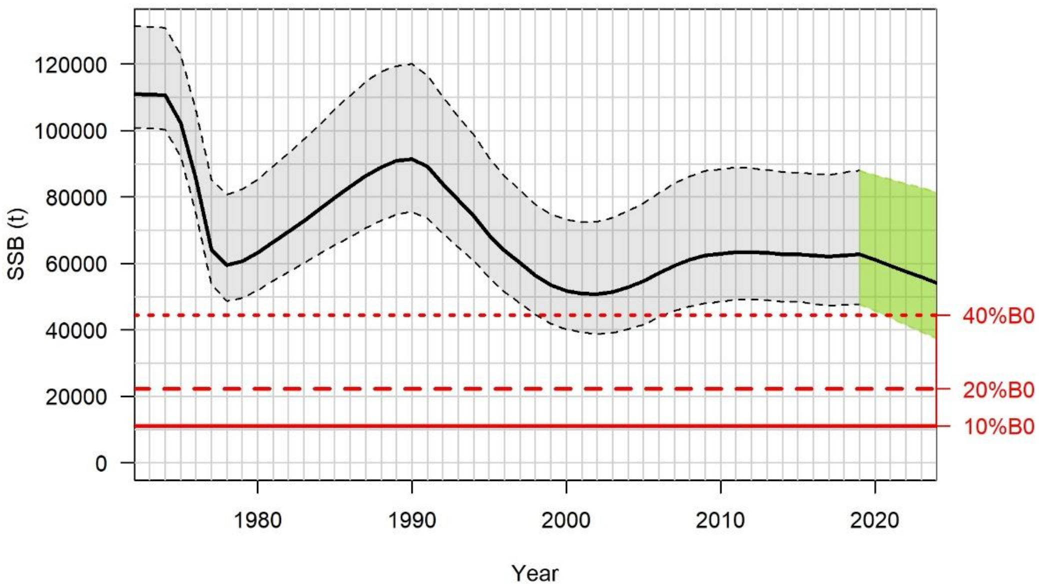


Figure 12: Projection using MCMC. Base run using all estimated year class strengths to estimate future year class strengths. Future catch option: TACC.

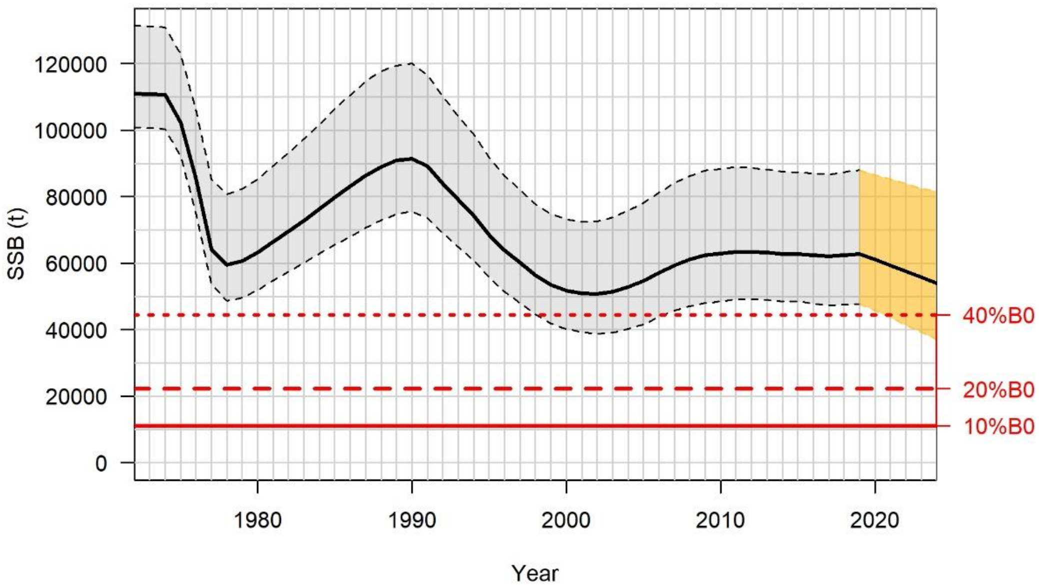


Figure 13: Projection using MCMC. Base run using most recent 10 estimated year class strengths to estimate future year class strengths. Future catch option: TACC.

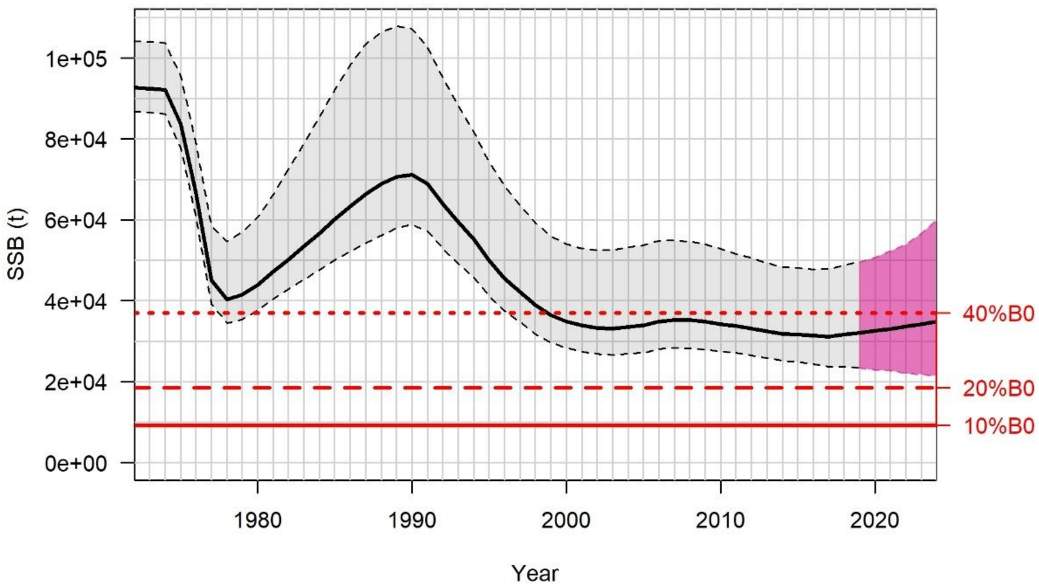


Figure 14: Projection using MCMC. Longline run using all estimated year class strengths to estimate future year class strengths. Future catch option: Average last 5 years.

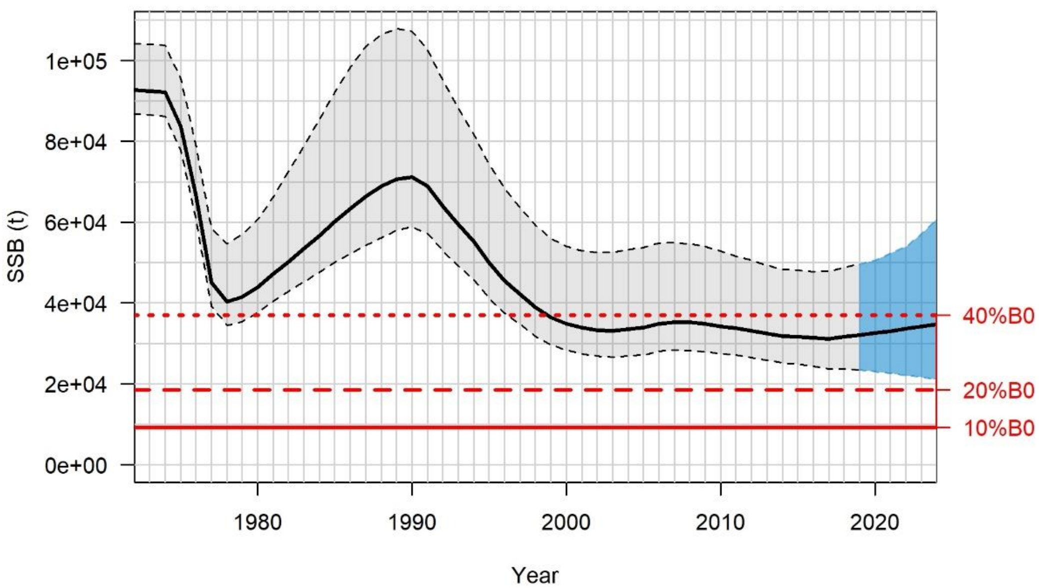


Figure 15: Projection using MCMC. Longline run using most recent 10 estimated year class strengths to estimate future year class strengths. Future catch option: Average last 5 years.

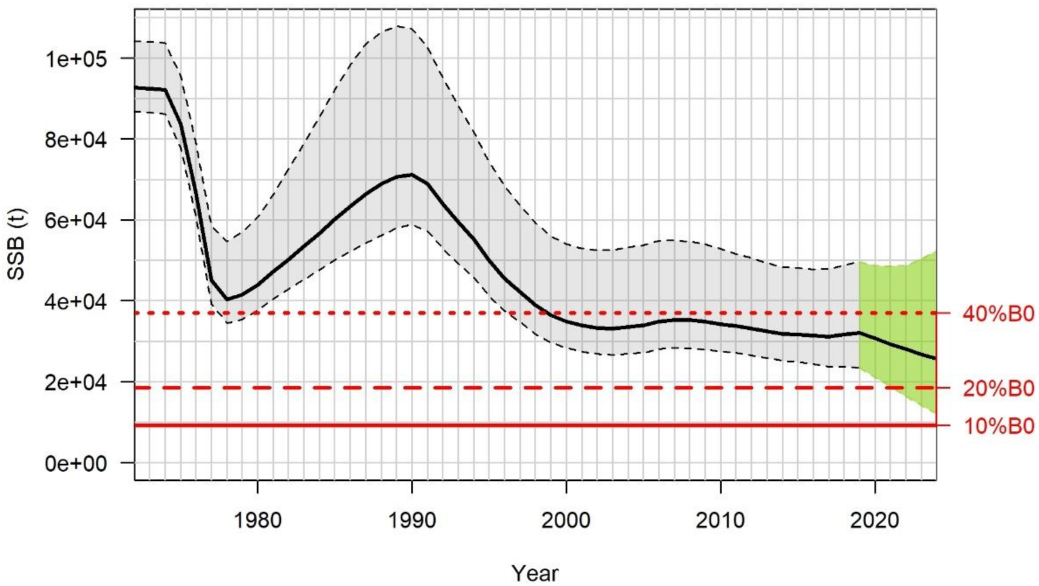


Figure 16: Projection using MCMC. Longline run using all estimated year class strengths to estimate future year class strengths. Future catch option: TACC.

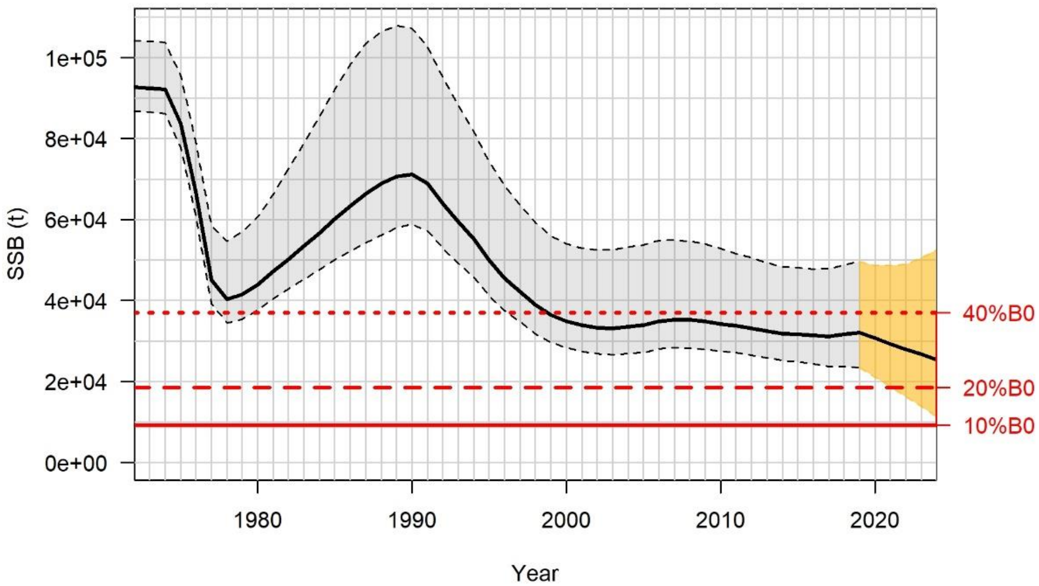


Figure 17: Projection using MCMC. Longline run using most recent 10 estimated year class strengths to estimate future year class strengths. Future catch option: TACC.

4.4 Management biomass targets

Probabilities that current and projected biomass will drop below selected management reference points (i.e., target, 40%B_0; soft limit, 20%B_0; hard limit, 10%B_0) are shown, for the Base model run in Table 15. It appears very unlikely (i.e., less than 1%) that B_{2024} will be lower than the soft target of 20% B_0, but at the higher catch level there is an approximate 8% probability that the stock will fall below the target level (40% B_0). Results are effectively identical between treatments of future year class strength estimation.

Table 15: Probabilities that current (B_{2019}) and projected (B_{2024}) biomass will be less than 40%, 20% or 10% of B_0. Projected biomass probabilities are presented for four scenarios of future annual catch.

‘Current’ year	Future catch	Future YCS	$P(B_{current}<40\%B_0)$	$P(B_{current}<20\%B_0)$	$P(B_{current}<10\%B_0)$
2019	-		0.001	0.0	0.0
2024	TACC (split as for av. catches)	All estimated YCS	0.08	0.0	0.0
2024	TACC (split as for av. catches)	Last 10 yrs YCS	0.08	0.0	0.0
2024	Average last 5 years	All estimated YCS	0.001	0.0	0.0
2024	Average last 5 years	Last 10 yrs YCS	0.001	0.0	0.0

5. DISCUSSION

LIN 3&4 stock status in 2018–19 was estimated to be 57% of B_0, within bounds of 48 to 66%. This means that the median estimate has remained unchanged, but uncertainty has reduced, since the previous assessment (previous bounds 45 to 71%). Catches at the recent level are likely to be sustainable (assuming no exceptional decline in future recruitments), but catches at the TACC are likely to cause a decline. Using the Longline CPUE model, the $\%B_0$ estimate was 35%, below the target 40% B_0 reference point, and in predictions to 2024 the median % B_0 estimate remains between 40% B_0 and the soft limit of 20% B_0.

The two relative abundance series for this stock appear to show different trends: the line fishery CPUE series initially declined and then remained constant, whereas the trawl survey series fluctuated without an apparent trend. The 2008 assessment included both indices in the base model run while the 2011 and 2015 assessments only included the trawl survey index in the base model run, judging the conflict between the indices too great, and unresolvable within the assessment. Horn (2015) showed that much of the marked decline in CPUE apparent in the first seven to nine years of the series was correlated with a reduction in the mean size of ling selected by that fishing method. This could occur even though the overall ling biomass declined only slightly or not at all. Here, the longline CPUE was included only in a sensitivity model run that excluded the trawl survey relative abundance series, thus producing a ‘worst case’ scenario for the Chatham Rise stock.

6. ACKNOWLEDGMENTS

I thank members of the Deepwater Working Group for comments and suggestions on this assessment and Vidette McGregor for reviewing the report. This work was funded by the Ministry for Primary Industries project LIN2018-01.

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APPENDIX A: MPD FITS TO COMPOSITION DATA

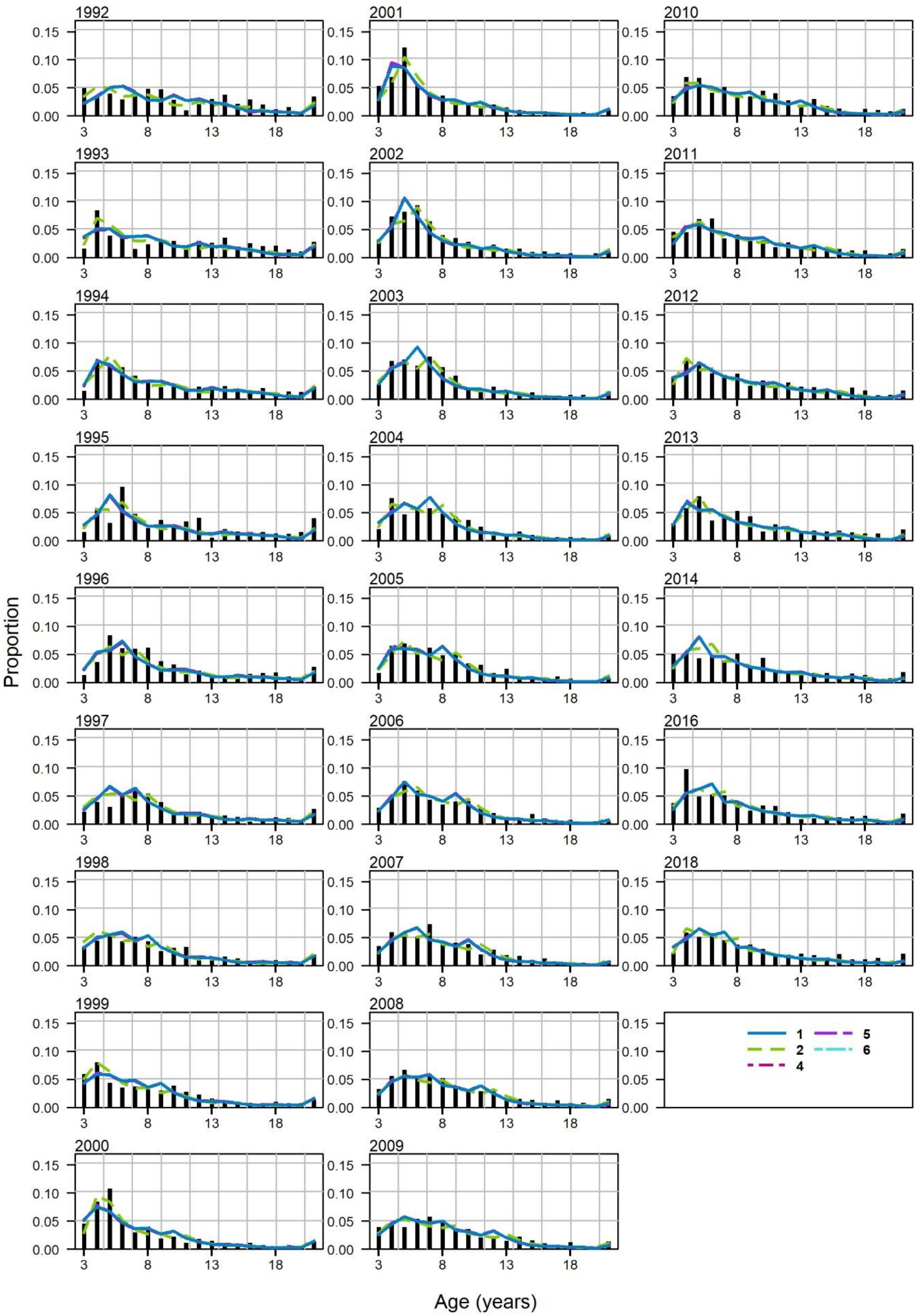

Figure A1: MPD fits to trawl survey female proportion-at-age data for model runs (1) Base, (2) Old base, (4) Longline lengths, (5) Longline lengths, high *q* and (6) High *q*. Note fits to all models are essentially identical, so only the (blue) fit to model 1 is apparent.

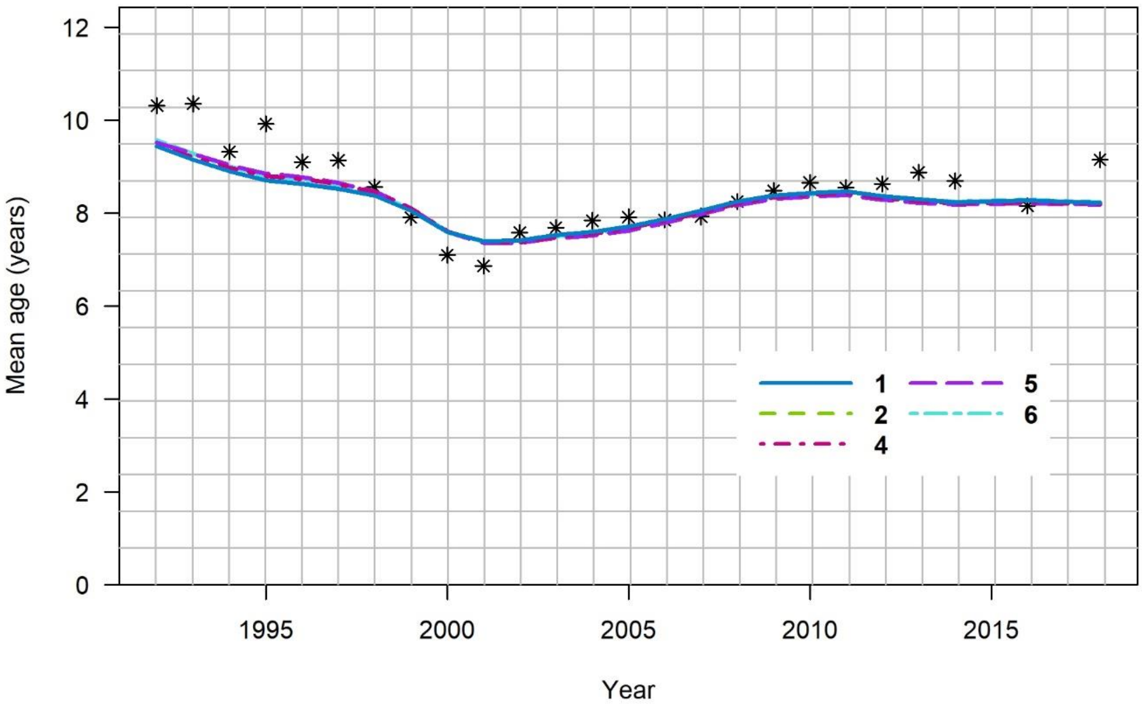

Figure A2: MPD fits to trawl survey female mean age data for model runs (1) Base, (2) Old base, (4) Longline lengths, (5) Longline lengths, high *q* and (6) High *q*.

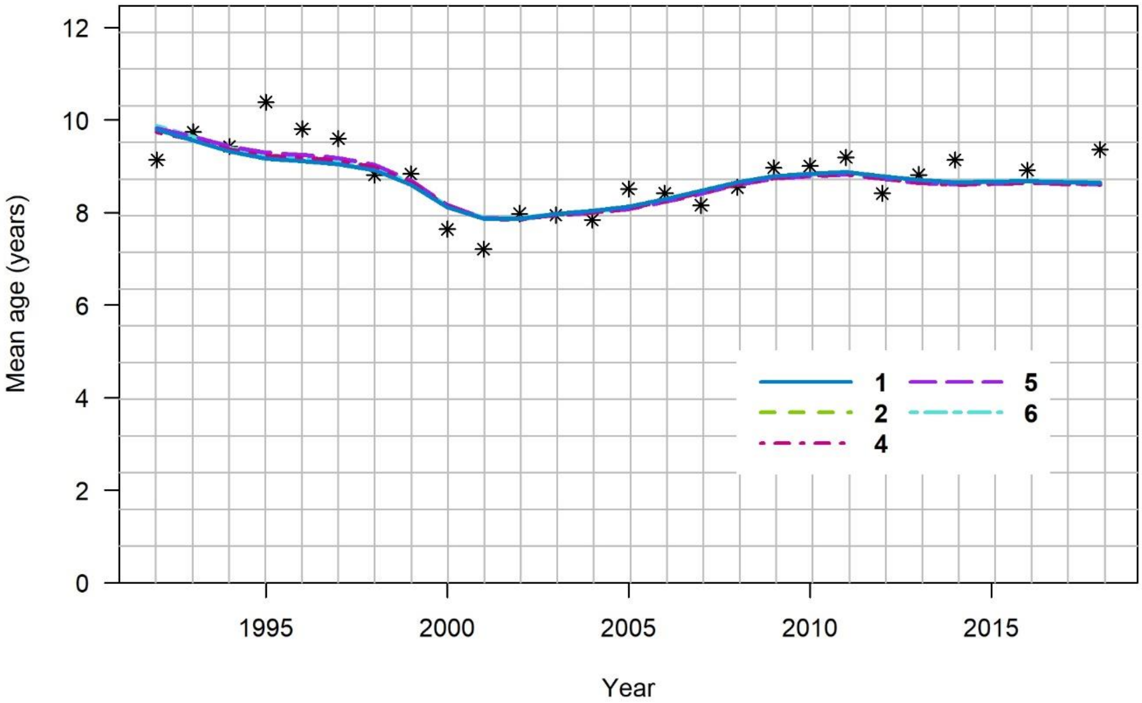

Figure A3: MPD fits to trawl survey male mean age data for model runs (1) Base, (2) Old base, (4) Longline lengths, (5) Longline lengths, high *q* and (6) High *q*.

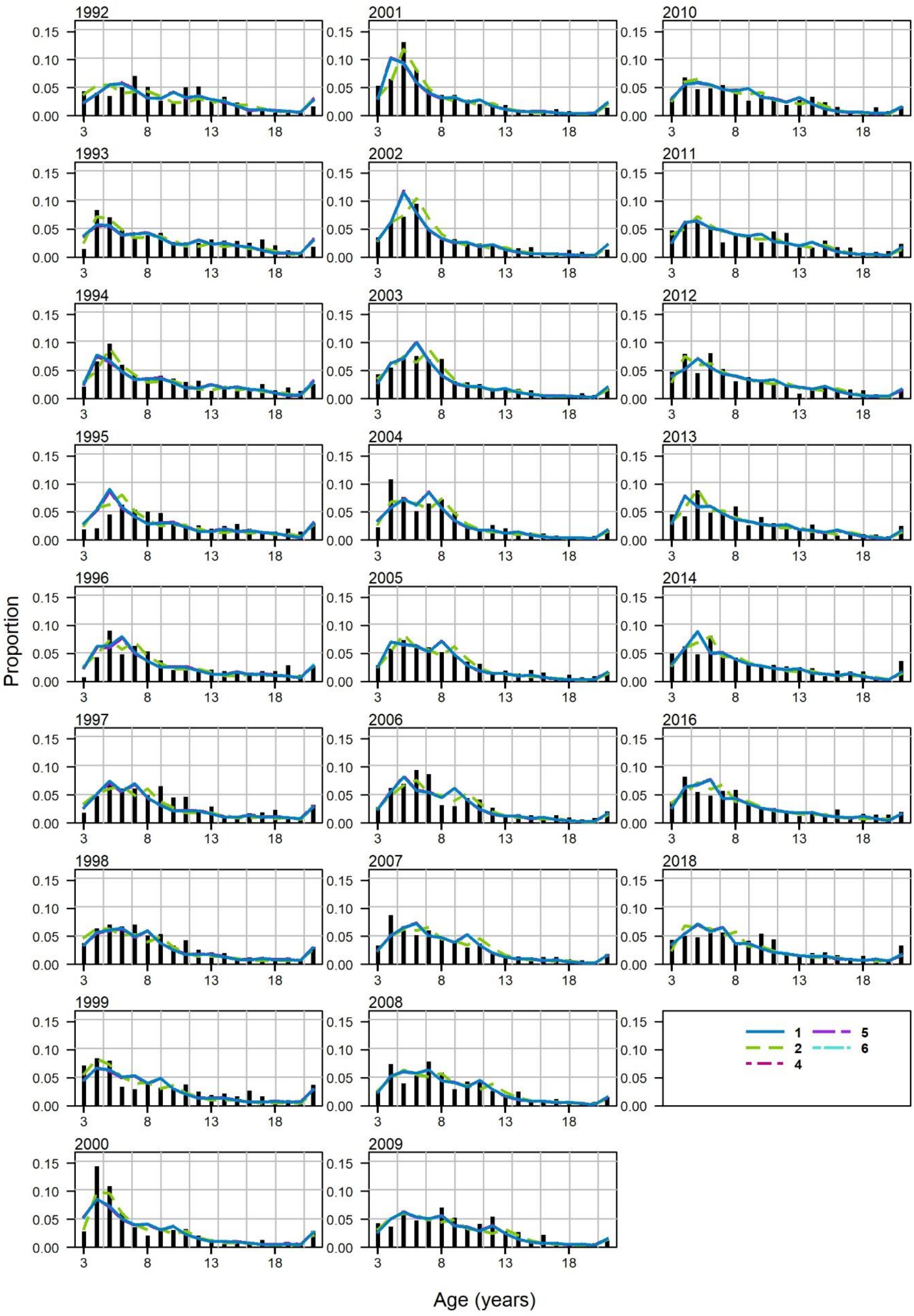

Figure A4: MPD fits to trawl survey male proportion-at-age data for model runs (1) Base, (2) Old base, (4) Longline lengths, (5) Longline lengths, high *q* and (6) High *q*.

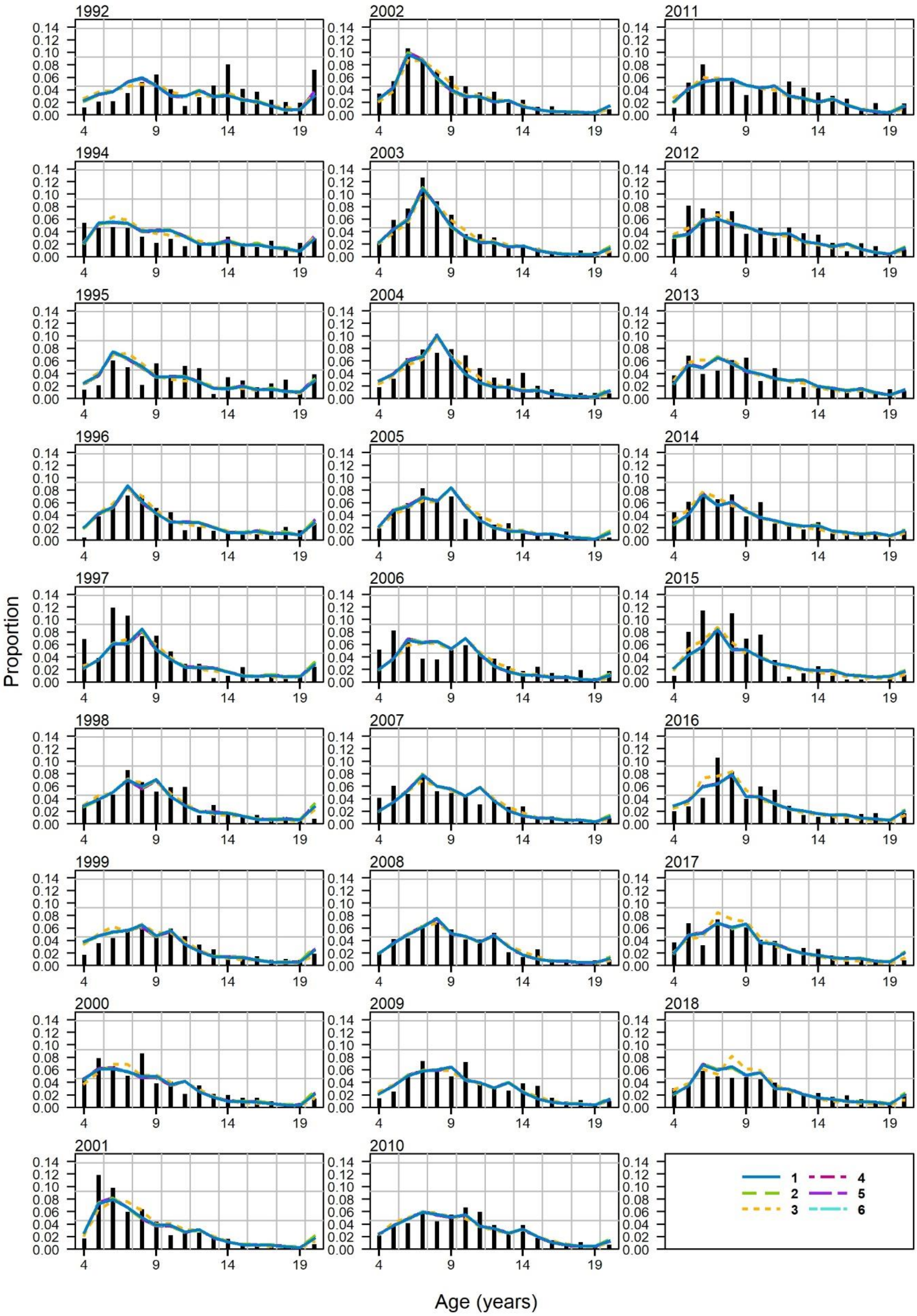

Figure A5: MPD fits to trawl fishery female proportion-at-age data for model runs (1) Base, (2) Old base, (3) Longline, (4) Longline lengths, (5) Longline lengths, high *q* and (6) High *q*.

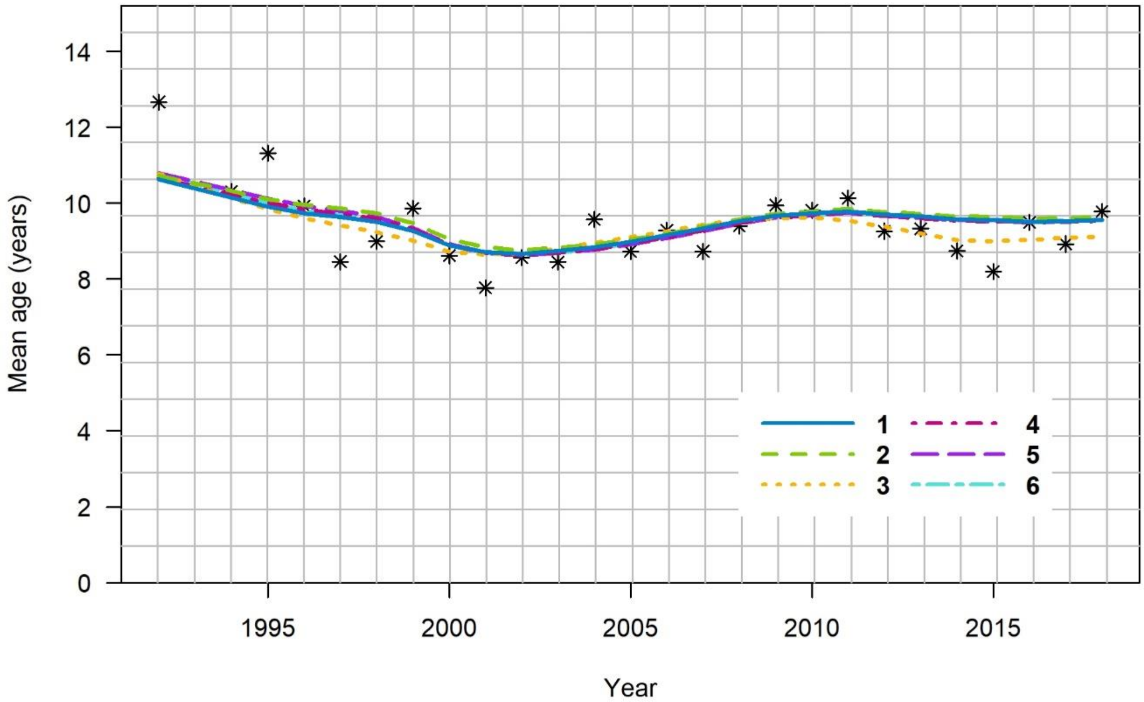

Figure A6: MPD fits to trawl fishery female mean age data for model runs (1) Base, (2) Old base, (3) Longline, (4) Longline lengths, (5) Longline lengths, high *q* and (6) High *q*.

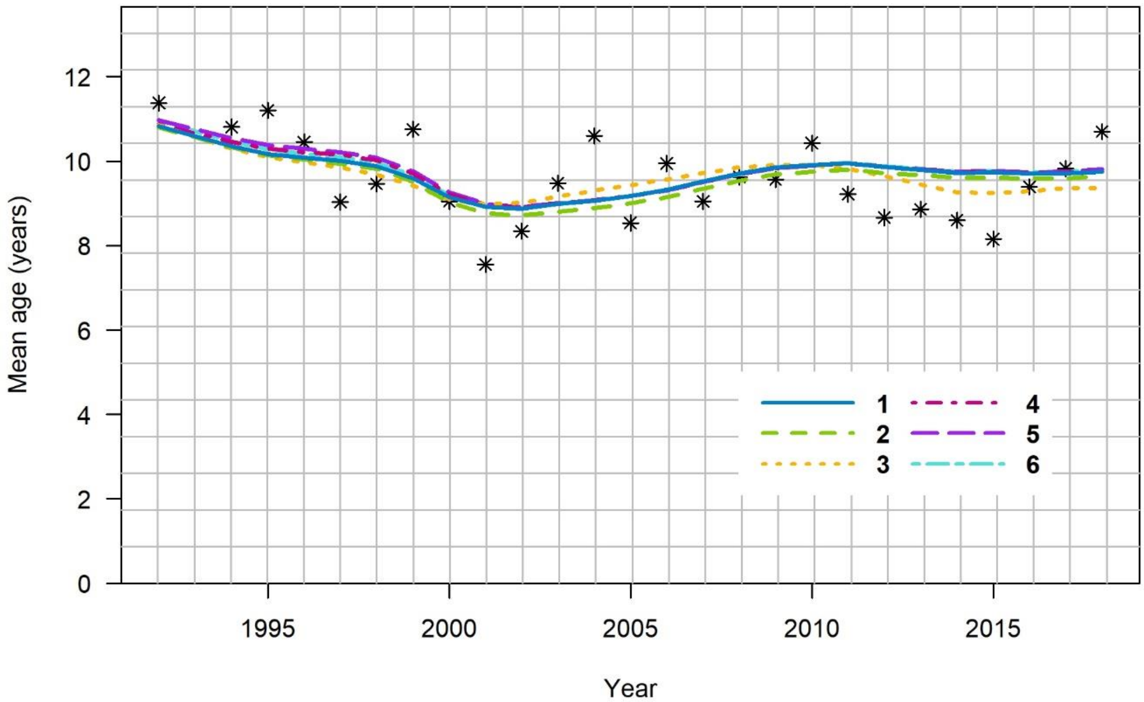

Figure A7: MPD fits to trawl fishery male mean age data for model runs (1) Base, (2) Old base, (3) Longline, (4) Longline lengths, (5) Longline lengths, high *q* and (6) High *q*.

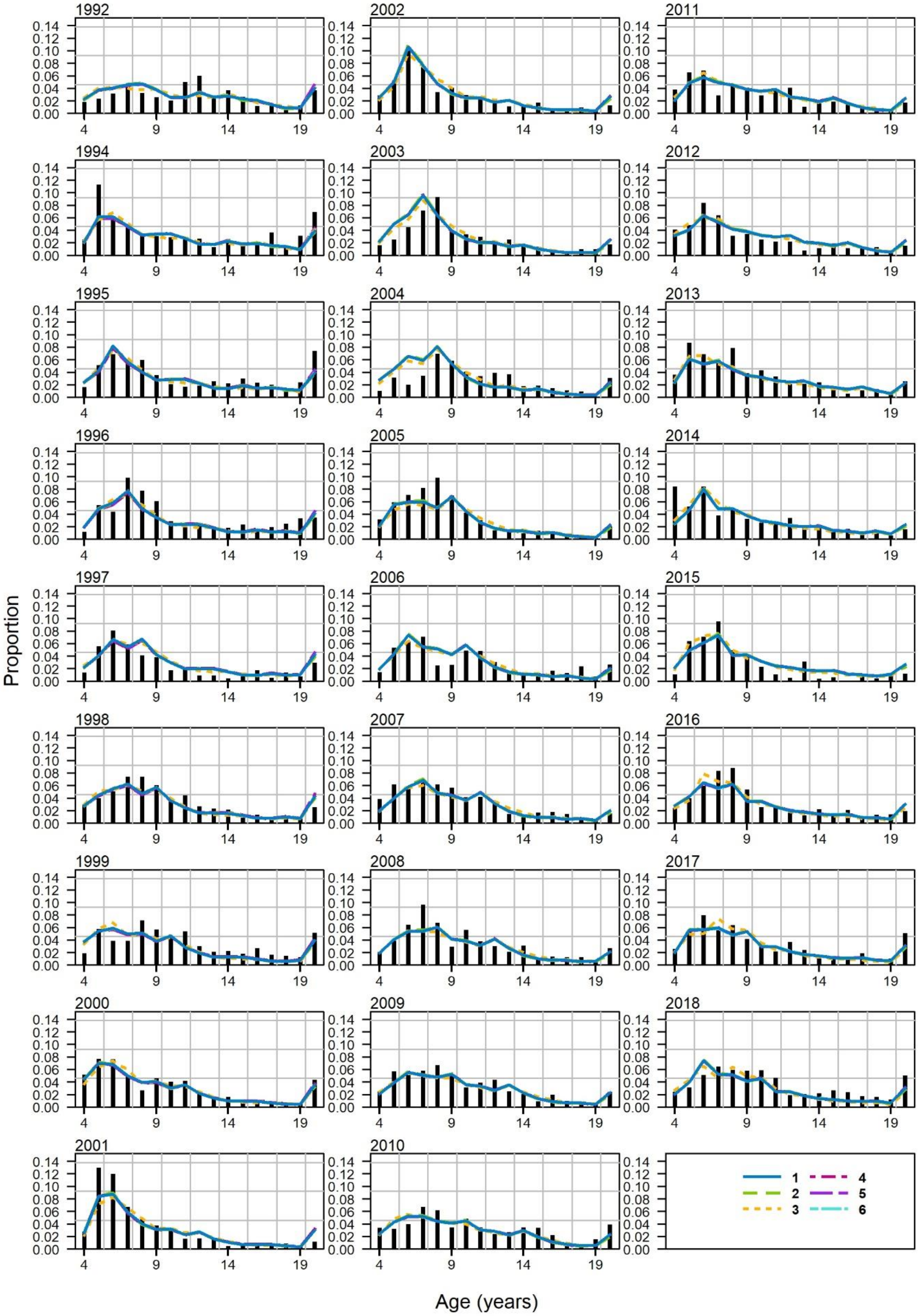

Figure A8: MPD fits to trawl fishery male proportion-at-age data for model runs (1) Base, (2) Old base, (3) Longline, (4) Longline lengths, (5) Longline lengths, high *q* and (6) High *q*.

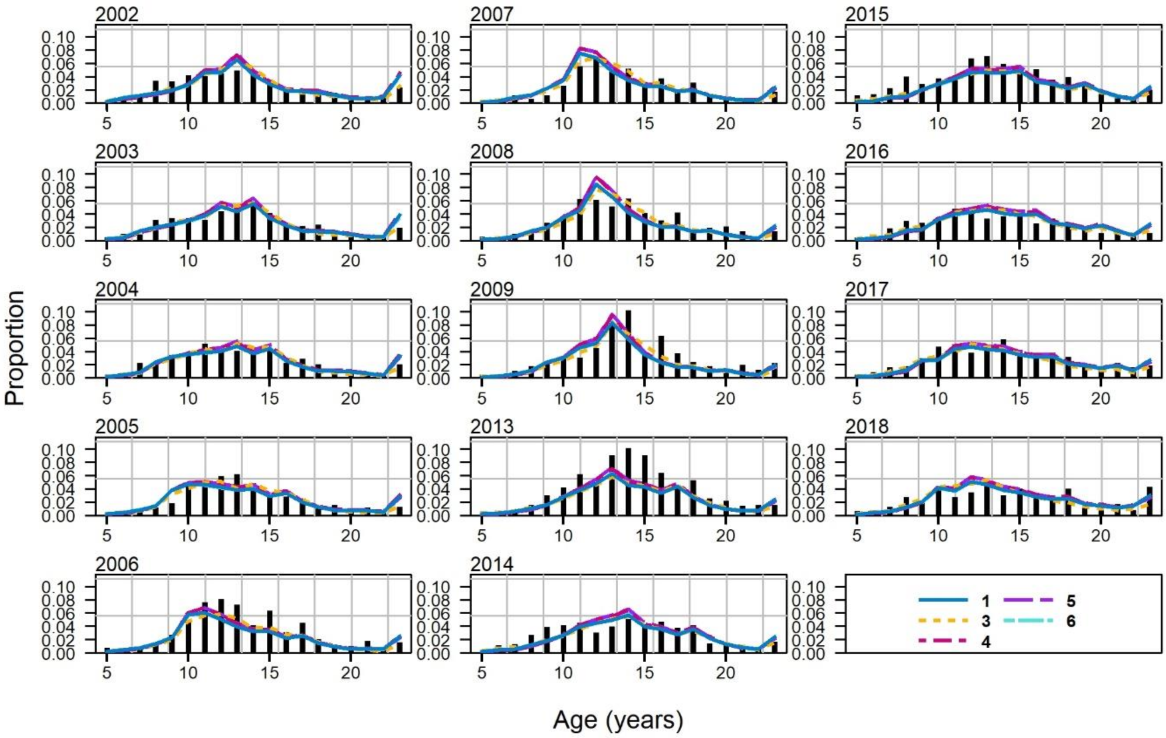

Figure A9: MPD fits to longline fishery female proportion-at-age data for model runs (1) Base, (3) Longline, (4) Longline lengths, (5) Longline lengths, high *q* and (6) High *q*.

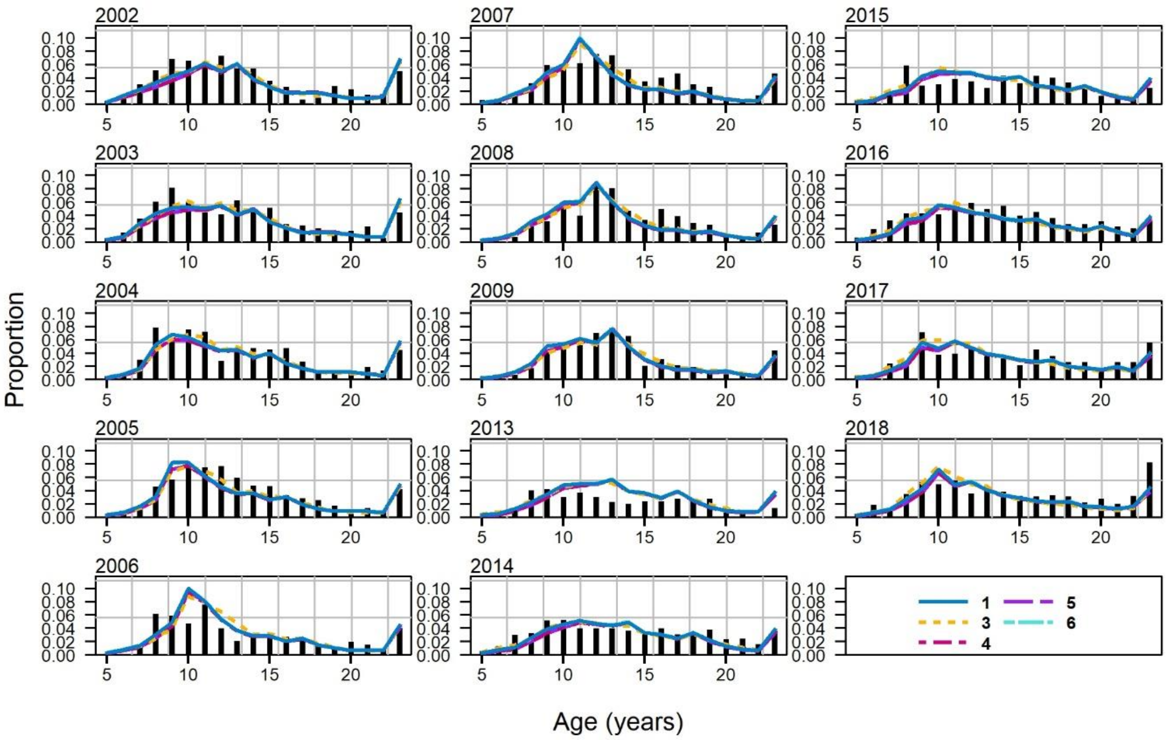

Figure A10: MPD fits to longline fishery male proportion-at-age data for model runs (1) Base, (3) Longline, (4) Longline lengths, (5) Longline lengths, high *q* and (6) High *q*.

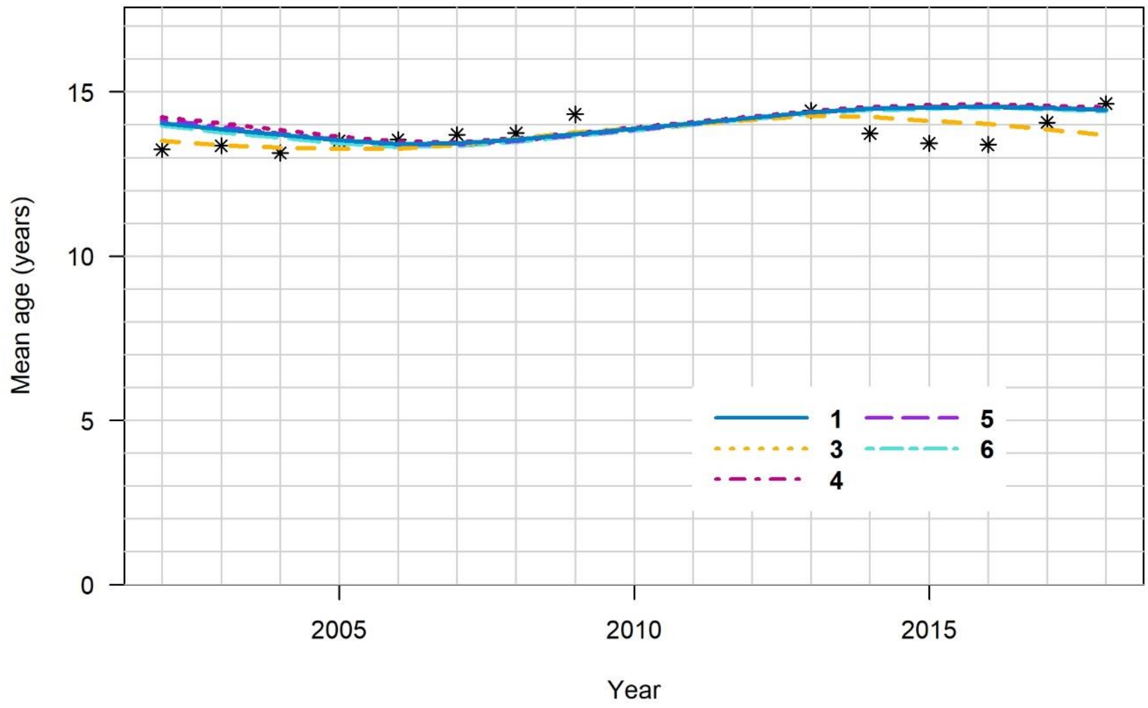

Figure A11: MPD fits to longline fishery female mean age data for model runs (1) Base, (3) Longline, (4) Longline lengths, (5) Longline lengths, high *q* and (6) High *q*.

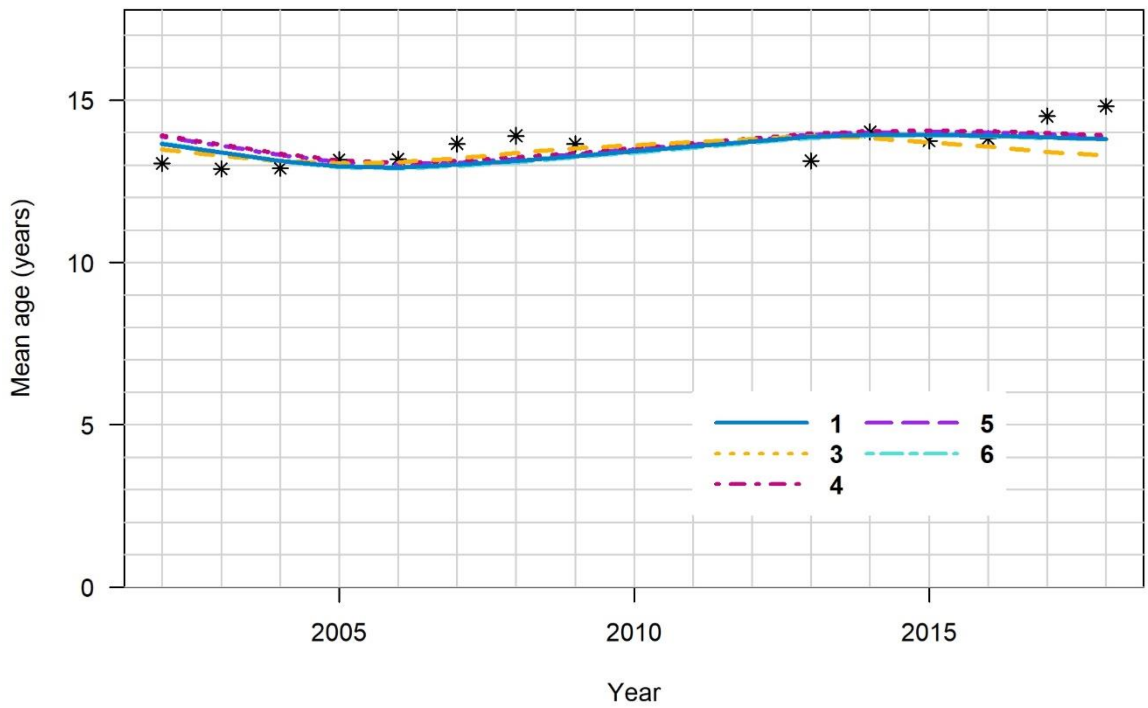

Figure A12: MPD fits to longline fishery male mean age data for model runs (1) Base, (3) Longline, (4) Longline lengths, (5) Longline lengths, high *q* and (6) High *q*.

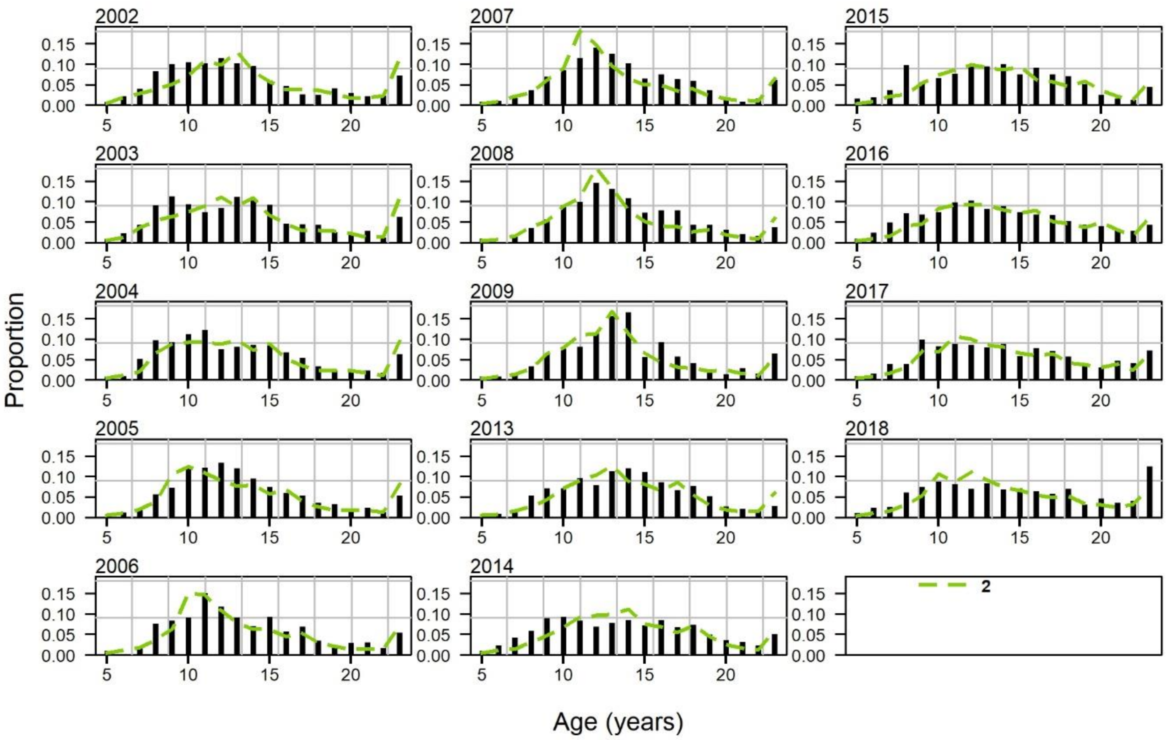

Figure A13: MPD fits to longline fishery combined sex proportion-at-age data for model run (2) Old base.

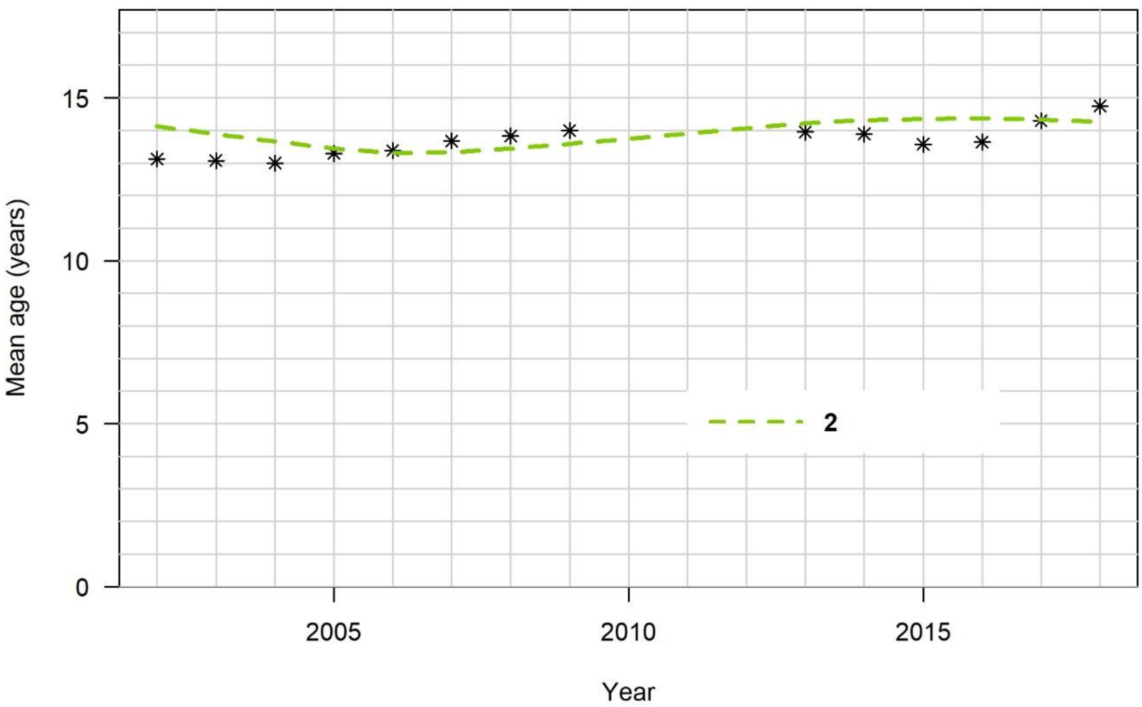

Figure A14: MPD fits to longline fishery combined sex mean age data for model run (2) Old base.

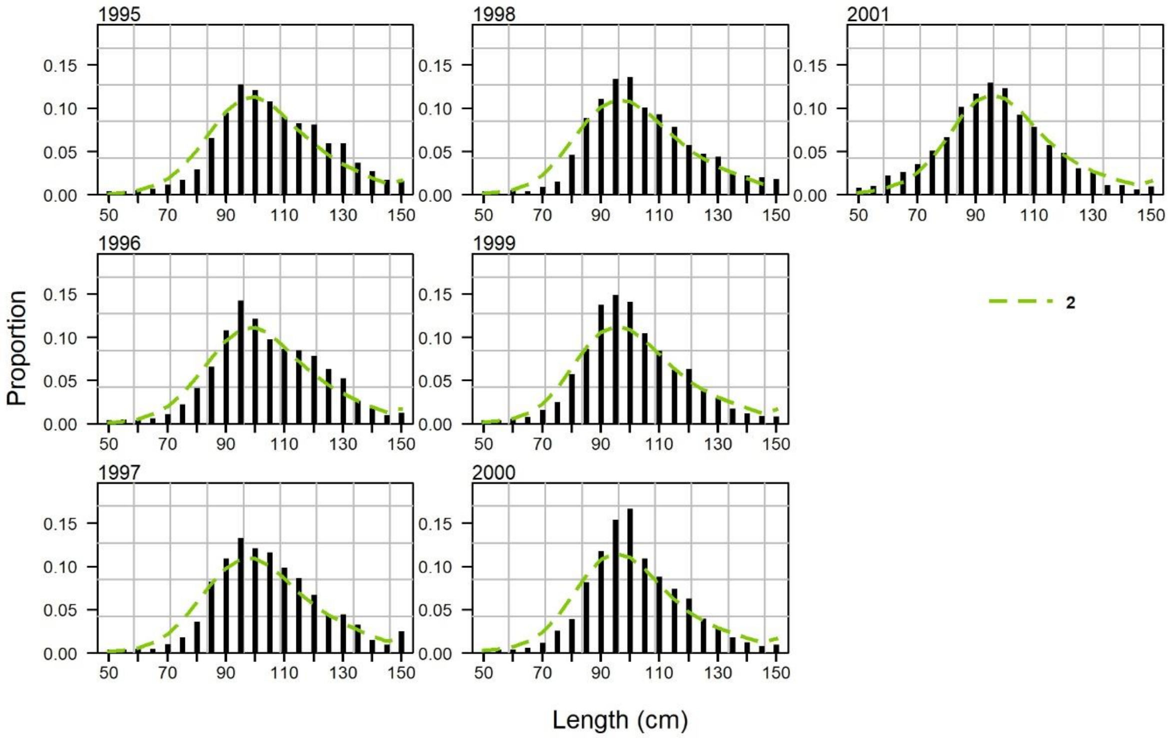

Figure A15: MPD fits to longline fishery combined sex proportion at length data for model run (2) Old base.

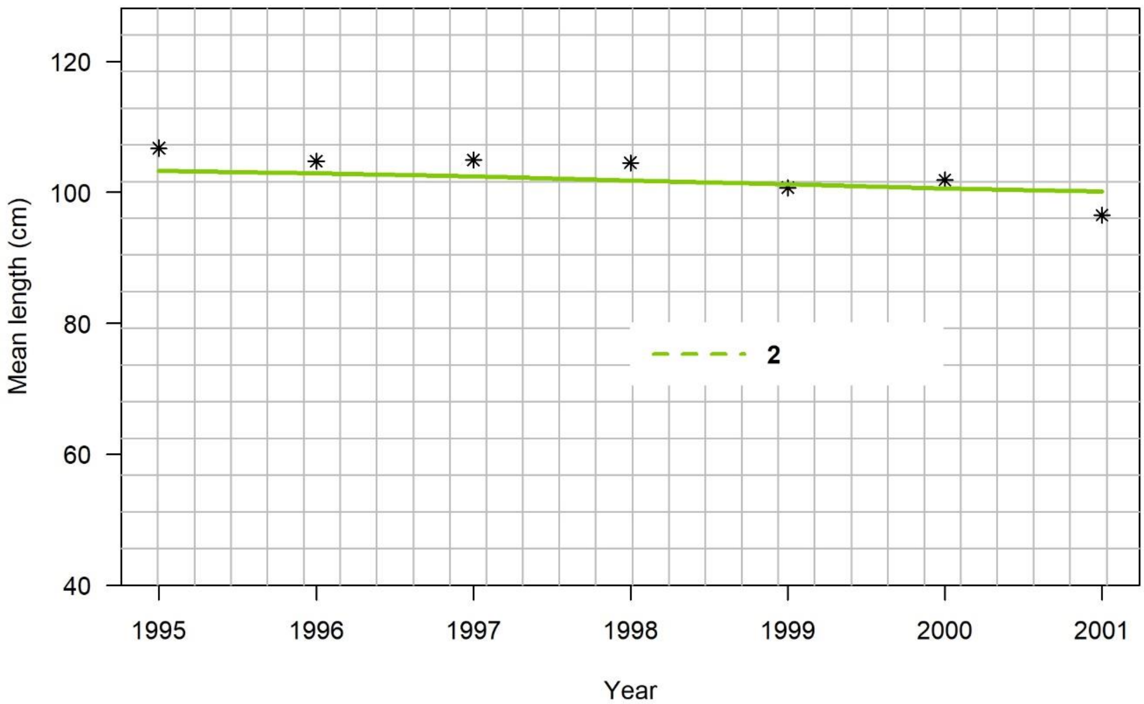

Figure A16: MPD fits to longline fishery combined sex mean age data for model run (2) Old base.

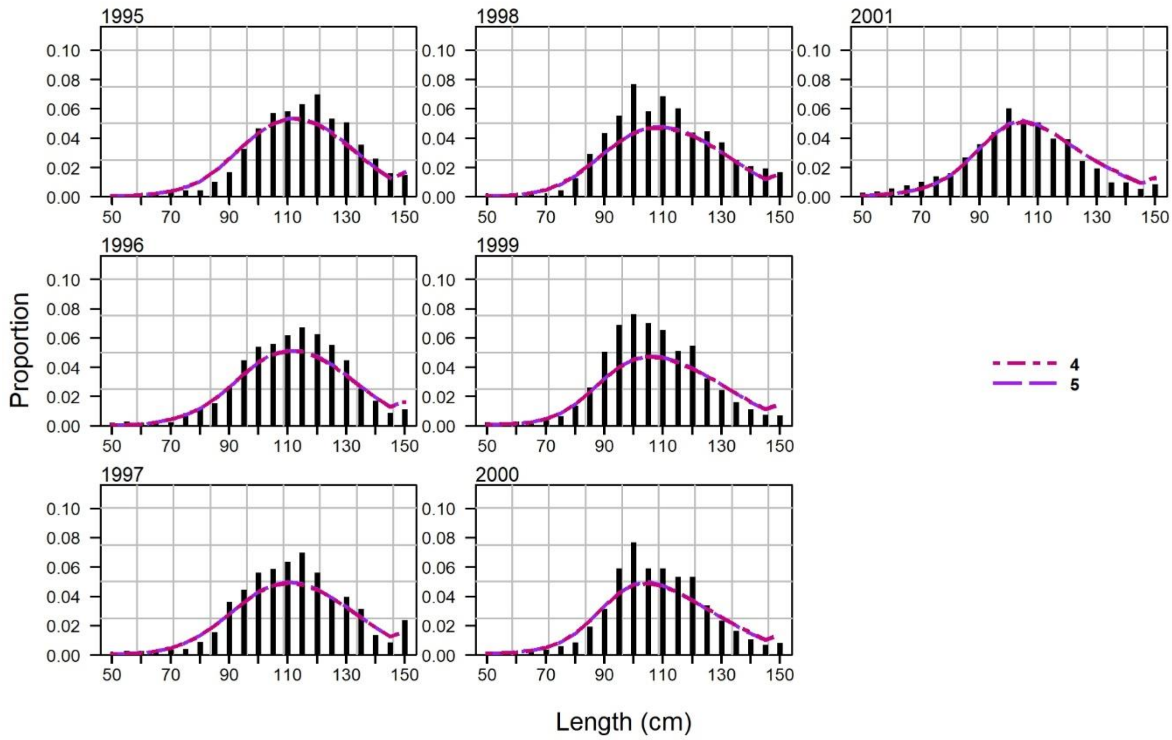

Figure A17: MPD fits to longline fishery female proportion at length data for model runs (4) Longline lengths, (5) Longline lengths, high *q*.

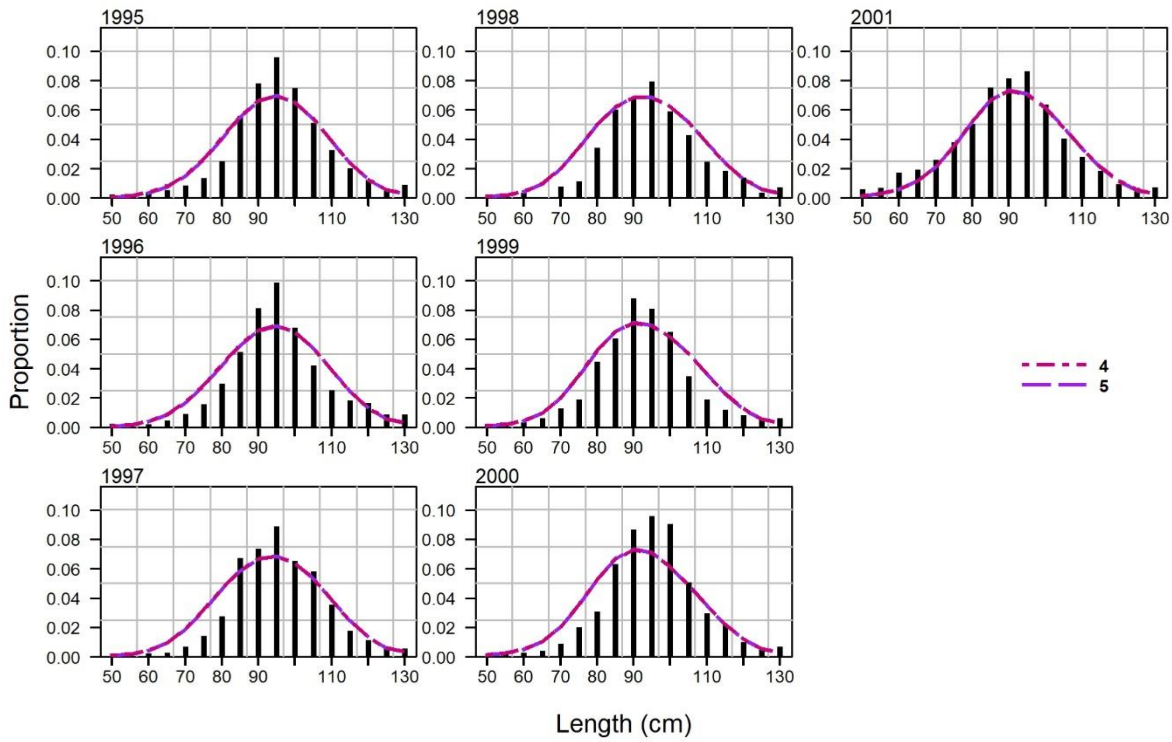

Figure A18: MPD fits to longline fishery male proportion at length data for model runs (4) Longline lengths, (5) Longline lengths, high *q*.

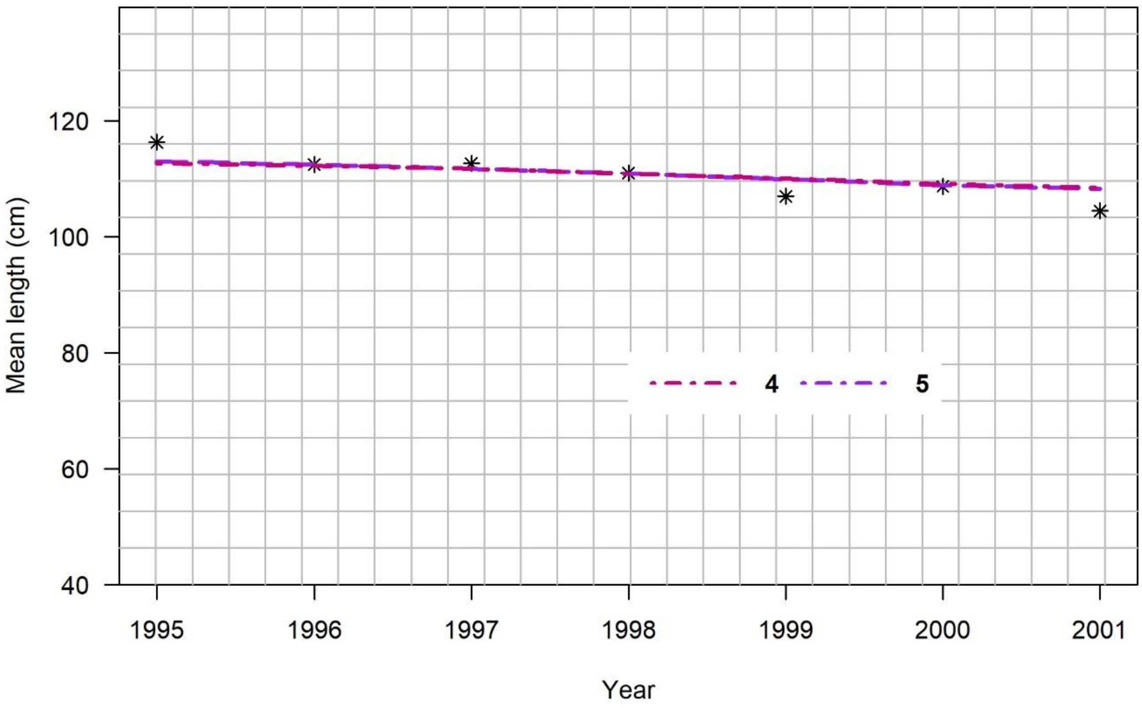

Figure A19: MPD fits to longline fishery female mean length data for model runs (4) Longline lengths, (5) Longline lengths, high *q*.

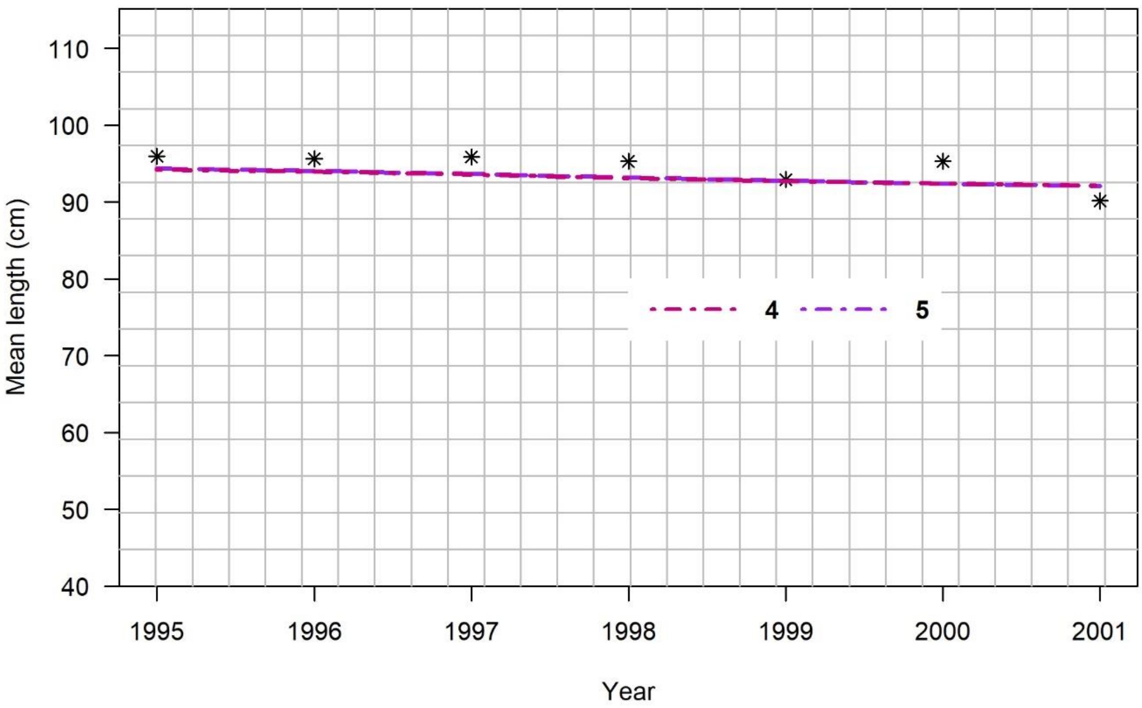

Figure A20: MPD fits to longline fishery male mean length data for model runs (4) Longline lengths, (5) Longline lengths, high *q*.

APPENDIX B: MCMC CONVERGENCE AND DISTRIBUTION PLOTS

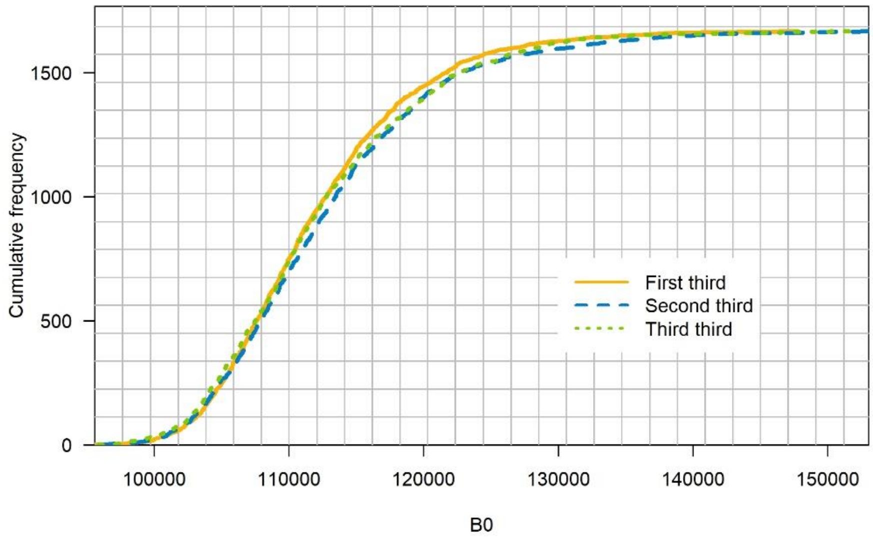

Figure B1: MCMC cumulative frequencies of B_0 for the first (solid gold line), second (dashed blue line) and third (dotted green line) third of the MCMC chain for Base model run with free *q*.

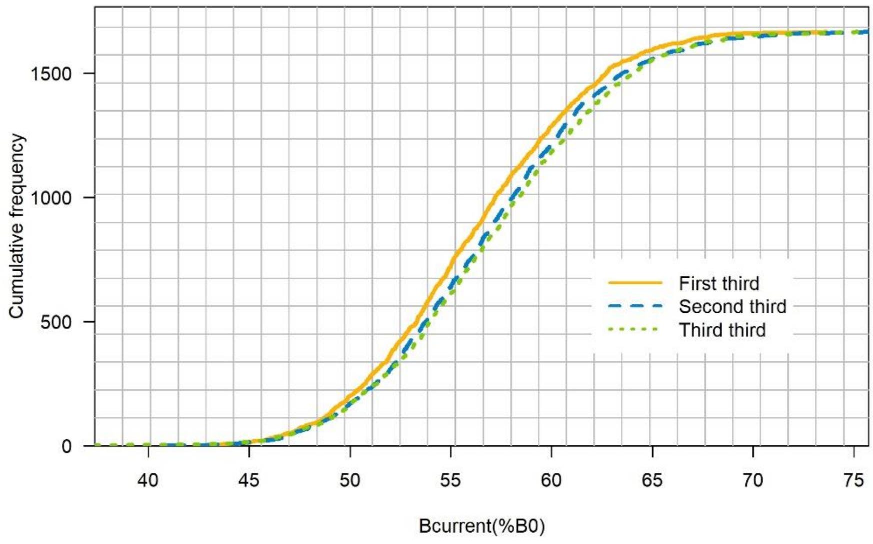

Figure B2: MCMC cumulative frequencies of $B_{current}$(%B_0) for the first (solid gold line), second (dashed blue line) and third (dotted green line) third of the MCMC chain for Base model run with free *q*.

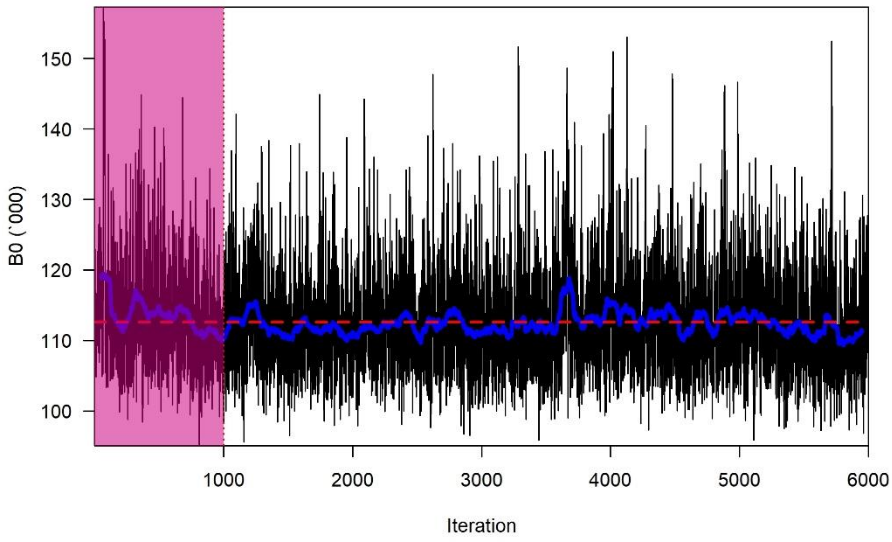

Figure B3: Trace diagnostic plot of the MCMC chain for B_0 in the Base model run with free *q*. The red dashed line is the mean of the entire chain, the blue line is the moving mean of 100 points of the chain. The shaded area shows the outputs removed when forming the posterior probability distribution.

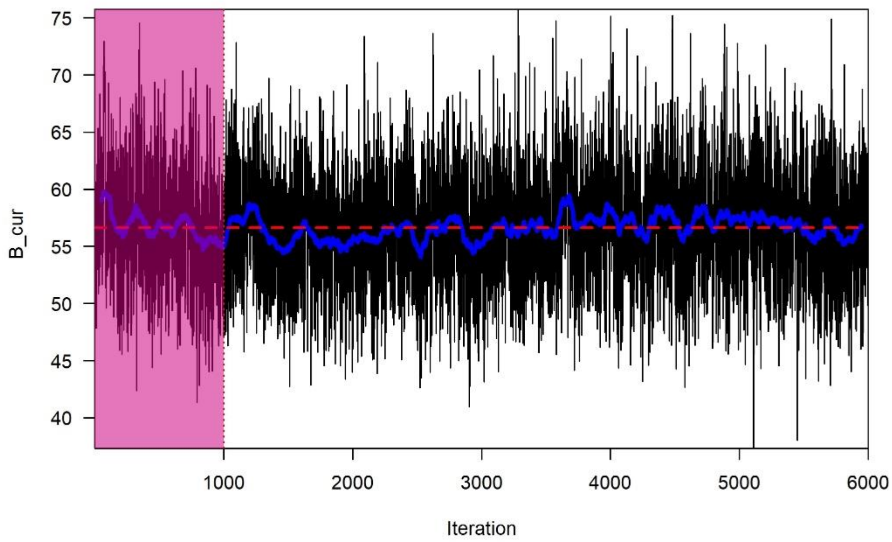

Figure B4: Trace diagnostic plot of the MCMC chain for $B_{current}$(%B_0) in the Base model run with free *q*. The red dashed line is the mean of the entire chain, the blue line is the moving mean of 100 points of the chain. The shaded area shows the outputs removed when forming the posterior probability distribution.

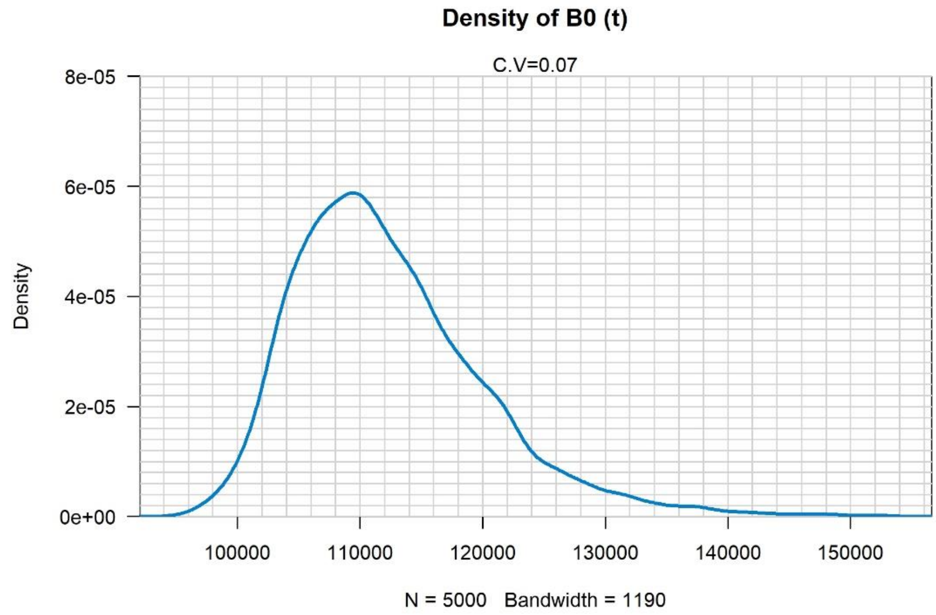

Figure B5: Estimated posterior distribution for B_0 in Base model run.

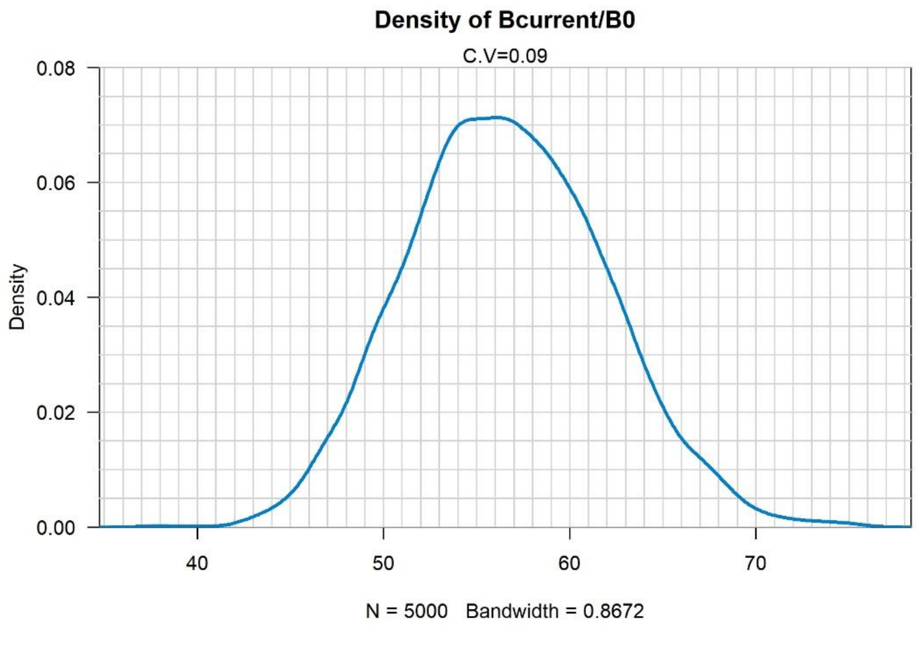

Figure B6: Estimated posterior distribution for $B_{current}$(%B_0) in Base model run.

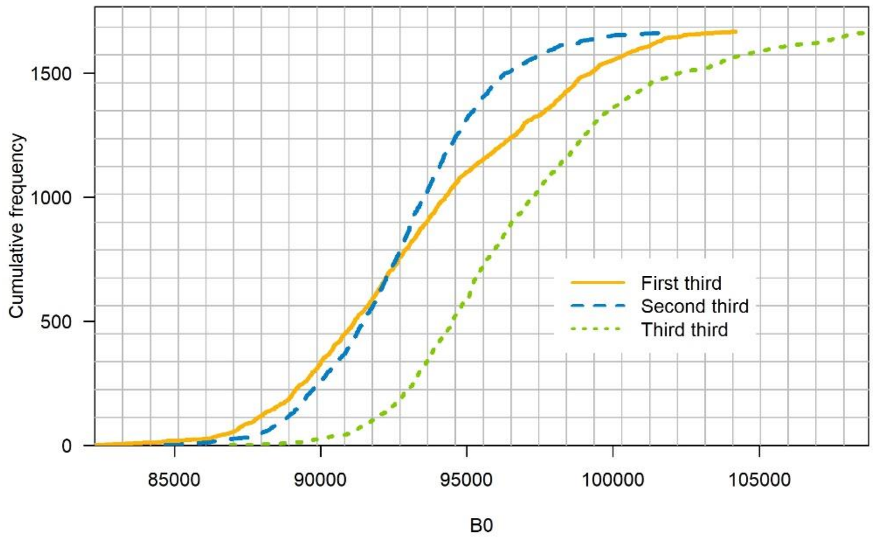

Figure B7: MCMC cumulative frequencies of B_0 for the first (solid gold line), second (dashed blue line) and third (dotted green line) third of the MCMC chain for Longline model run with free *q*.

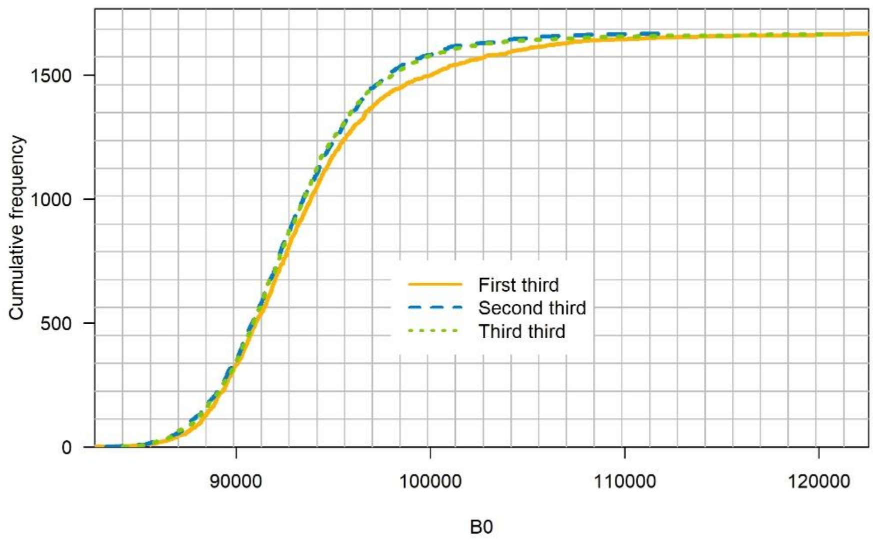

Figure B8: MCMC cumulative frequencies of B_0 for the first (solid gold line), second (dashed blue line) and third (dotted green line) third of the MCMC chain for Longline model run with nuisance *q*.

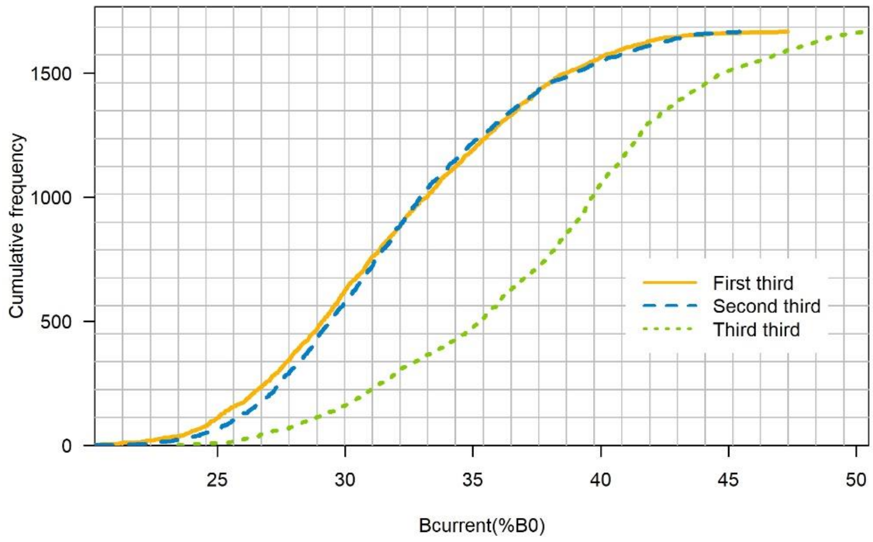

Figure B9: MCMC cumulative frequencies of $B_{current}(\%B_0)$ for the first (solid gold line), second (dashed blue line) and third (dotted green line) third of the MCMC chain for Longline model run with free *q*.

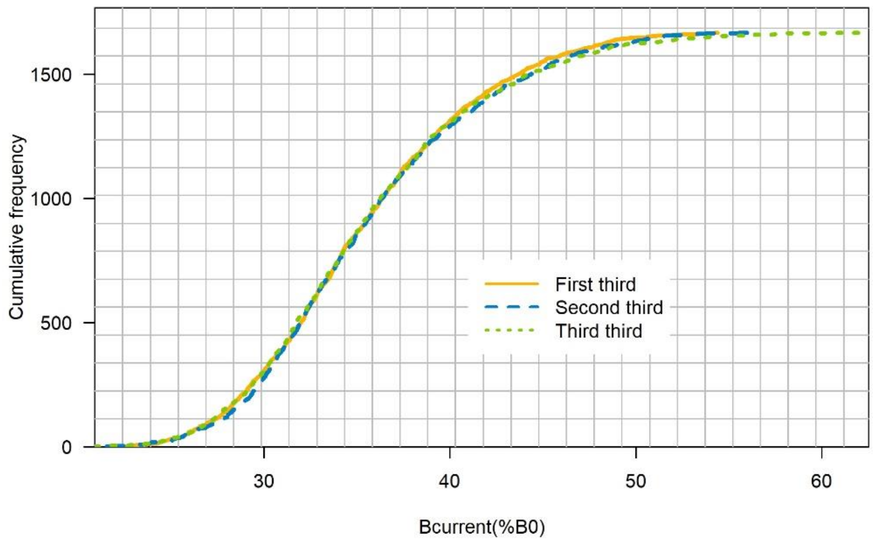

Figure B10: MCMC cumulative frequencies of $B_{current}(\%B_0)$ for the first (solid gold line), second (dashed blue line) and third (dotted green line) third of the MCMC chain for Longline model run with nuisance *q*.

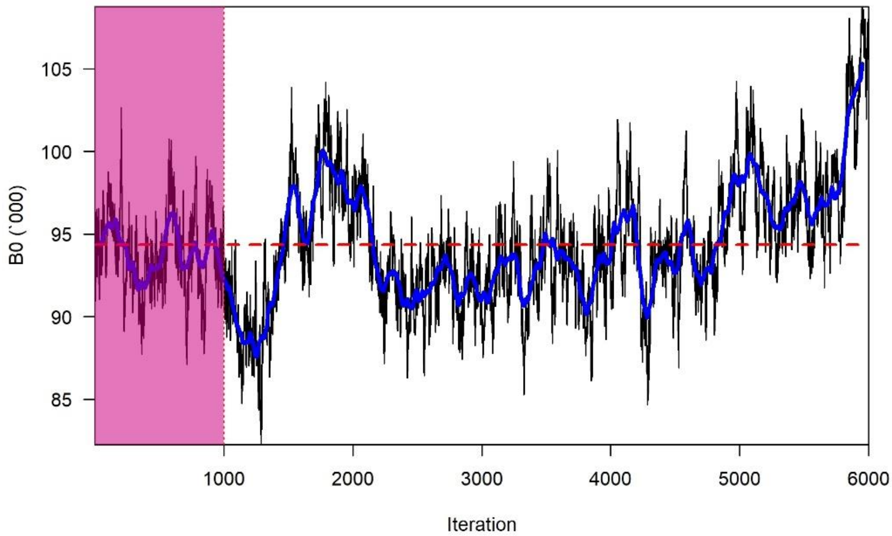

Figure B11: Trace diagnostic plot of the MCMC chain for B_0 in the Longline model run with free *q*. The red dashed line is the mean of the entire chain, the blue line is the moving mean of 100 points of the chain. The shaded area shows the outputs removed when forming the posterior probability distribution.

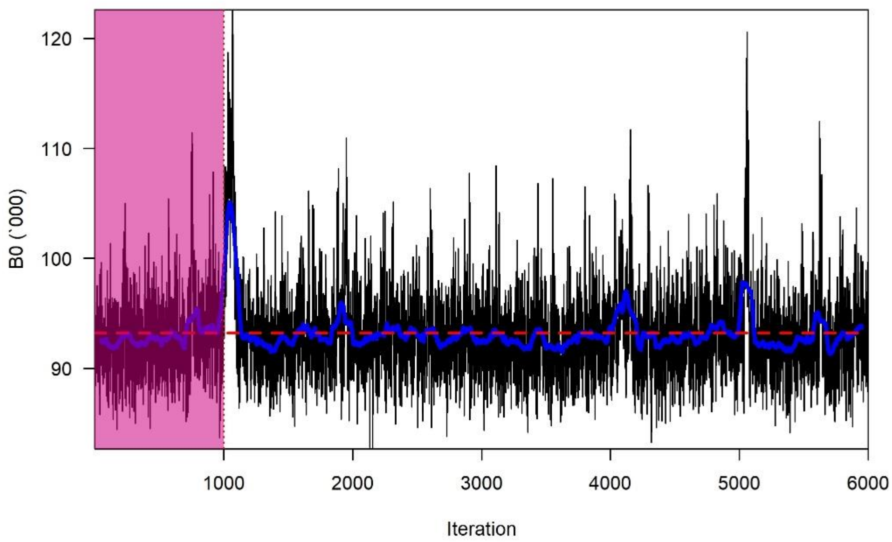

Figure B12: Trace diagnostic plot of the MCMC chain for B_0 in the Longline model run with nuisance *q*. The red dashed line is the mean of the entire chain, the blue line is the moving mean of 100 points of the chain. The shaded area shows the outputs removed when forming the posterior probability distribution.

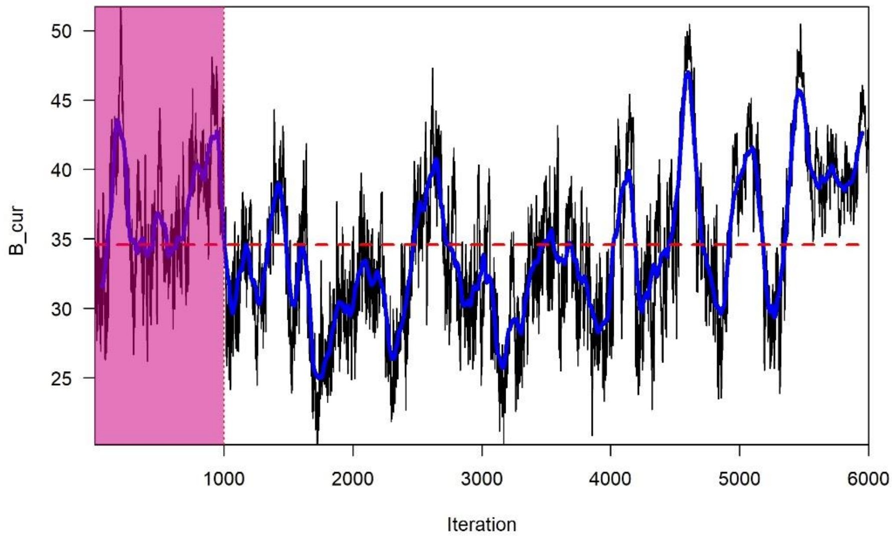

Figure B13: Trace diagnostic plot of the MCMC chain for $B_{current}$(%B_0) in the Longline model run with free *q*. The red dashed line is the mean of the entire chain, the blue line is the moving mean of 100 points of the chain. The shaded area shows the outputs removed when forming the posterior probability distribution.

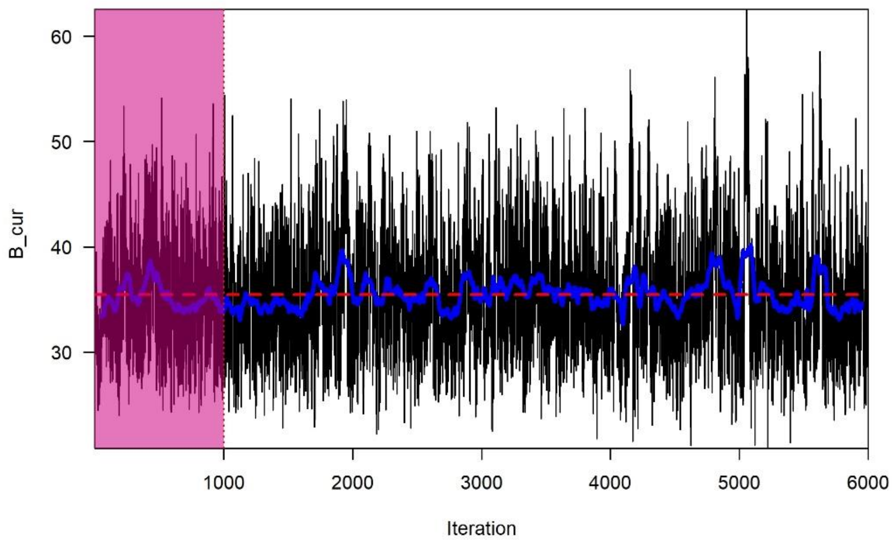

Figure B14: Trace diagnostic plot of the MCMC chain for $B_{current}$(%B_0) in the Longline model run with nuisance *q*. The red dashed line is the mean of the entire chain, the blue line is the moving mean of 100 points of the chain. The shaded area shows the outputs removed when forming the posterior probability distribution.

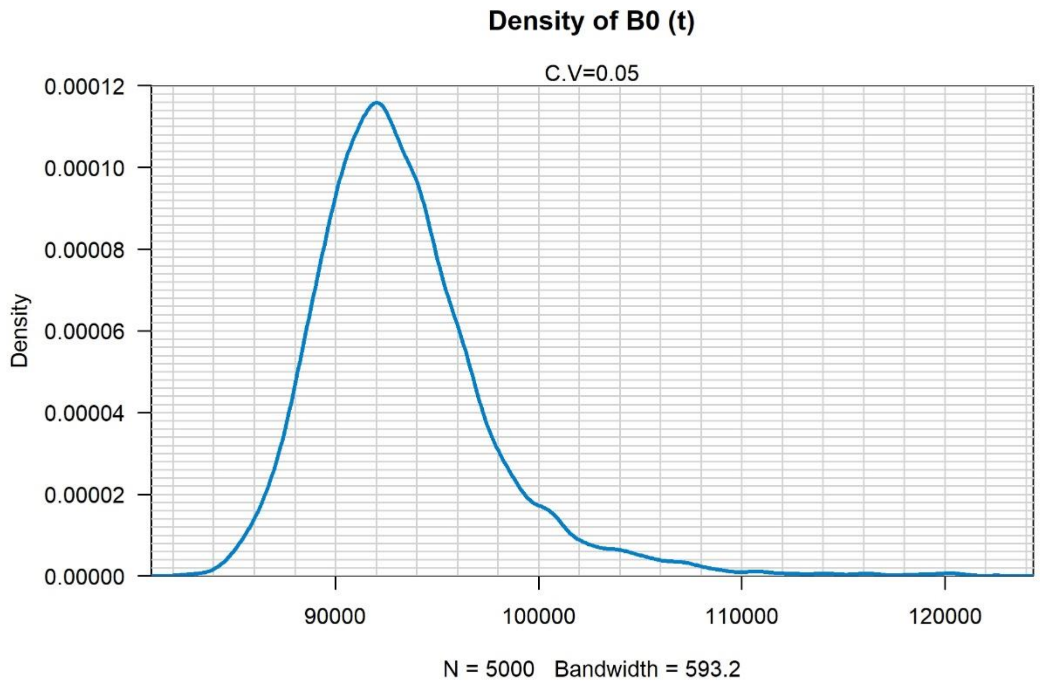

Figure B15: Estimated posterior distribution for B_0 in Longline model run with nuisance *q*.

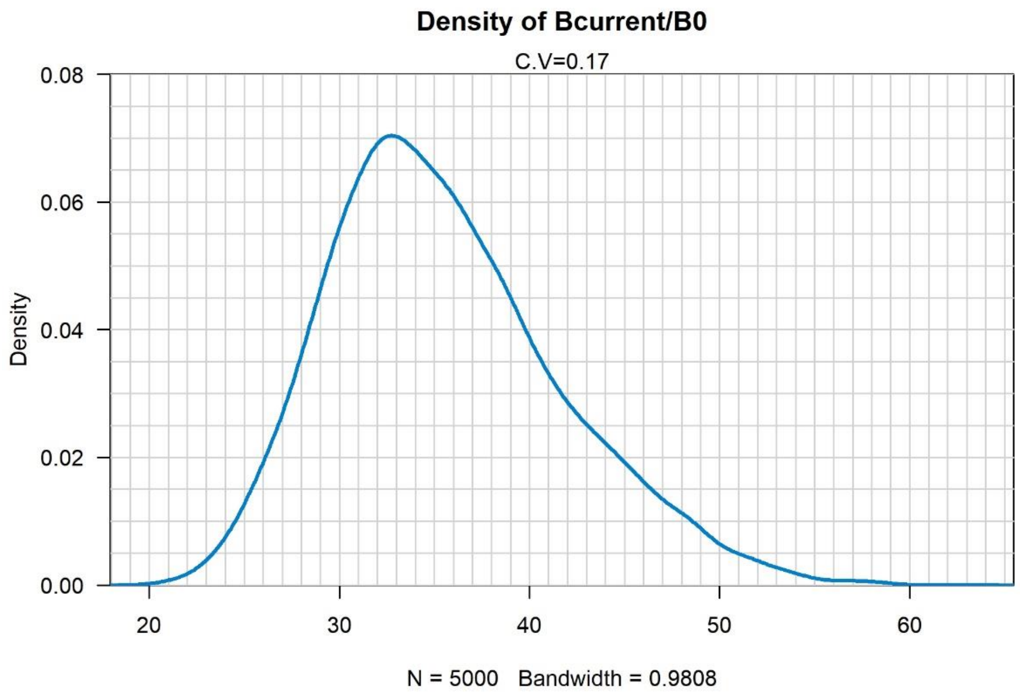

Figure B16: Estimated posterior distribution for $B_{current}(\%B_0)$ in Longline model run with nuisance *q*.