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Stock assessment of ling (*Genypterus blacodes*) on the Chatham Rise (LIN 3&4) for the 2014–15 fishing year

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V. McGregor

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Table of Contents

EXECUTIVE SUMMARY 1
1. INTRODUCTION 2
2. REVIEW OF THE FISHERY 3
3. MODEL INPUTS, STRUCTURE, AND ESTIMATION 6
3.1 Model input data 6
3.2 Model structure 9
3.3 Model estimation 9
4. MODEL ESTIMATES 10
4.1 Developing a base model 10
4.2 MCMC results 15
4.3 Biomass projections 21
4.4 Management biomass targets 24
5. DISCUSSION 25
6. REFERENCES 26
Appendix A: MPD fits to composition data 27
Appendix B: MCMC convergence and distribution plots 35

EXECUTIVE SUMMARY

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***New Zealand Fisheries Assessment Report 2015/82*. 50 p.**

Ling in QMAs 3–7 and part of QMA 2 are treated as five biological stocks for assessment: Chatham Rise (LIN 3 and LIN 4), 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 making up Statistical Areas 016 and 017 in Cook Strait). These stocks are subsequently referred to as LIN 3&4, LIN 5&6, LIN 6B, LIN 7WC, and LIN 7CK, respectively.

An updated Bayesian assessment is presented 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 series of catch-at-age data from the commercial trawl and line fisheries. The model structure allows the input of catch histories and relative abundance indices attributable to 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 is uncertain because there is little contrast in the principal abundance index. The assessment incorporates 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 current stock ranging from 40–61% B_0. A model excluding longline fishery CPUE data in favour of trawl survey abundance indices was used as the base case, giving primacy to fishery-independent data. The base model suggested that B_0 was about 127 000 t, and was very unlikely to be lower than 110 000 t. Current stock size of LIN 3&4 is estimated to be well above the management target of 40% B_0, and is unlikely to change over the next five years at the most recent catch level, but may decline if catches increase to the TACC.

1. INTRODUCTION

This document reports part of the results of objective 1 of Ministry for Primary Industries Project DEE201002LIND. The specific project objective was to conduct stock assessments, including estimating biomass and sustainable yields, for LIN 3 & 4 (reported here) and LIN 5&6 (reported by Roberts 2015) in 2013–14, and to complete a descriptive analysis of ling fisheries, and update CPUE (reported by Ballara & Horn 2015).

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. The most recently reported assessment of LIN 3&4 was Horn et al. (2013).

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.

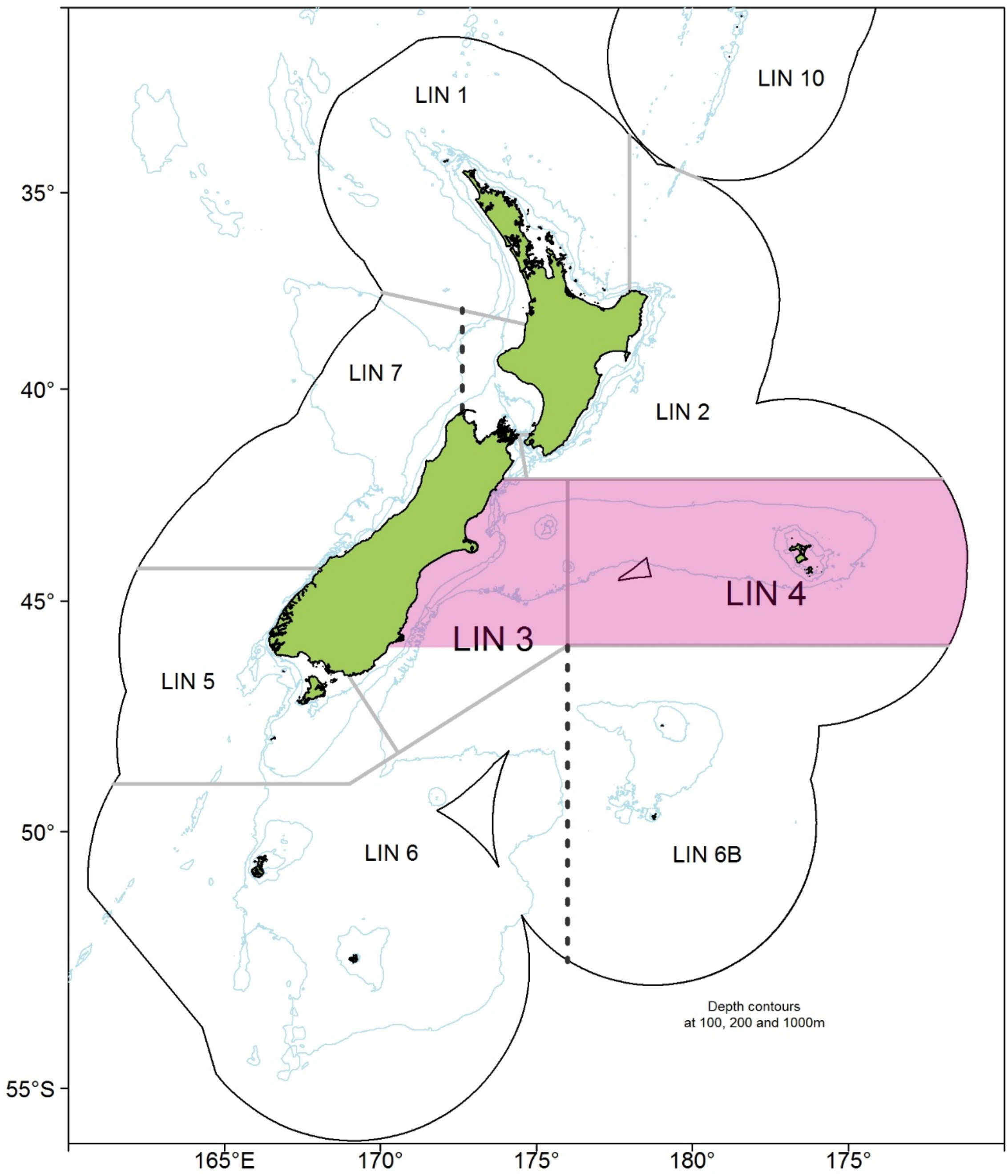


Figure 1: Area of all LIN Fishstocks with LIN3&4 shaded in pink. The boundaries used to separate biological stock LIN 6B from the rest of LIN 6, and the west coast South Island section of LIN 7 from the rest of LIN 7 are shown as broken lines.

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. 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 2013–14 and actual TACCs (t) from 1986–87 to 2013–14.

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#	1 208	2 060	1 397	4 200

* FSU data.
\# QMS data.

3. MODEL INPUTS, STRUCTURE, AND ESTIMATION

3.1 Model input data

A summary of all input data series is given in Table 3. Data from trawl surveys could be input either as a) biomass and proportions-at-age, or b) numbers-at-age. For the ling assessments the preference was for a), i.e., 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 this was appropriate for ling also. The CVs applied to each data set would then give appropriate weight to the signal provided by each series.

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.

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.

The *Tangaroa* trawl survey catch data from LIN 3&4 were available as estimates of catch-at-age. Catch-at-age data were fitted to 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 by bootstrapping (Bull & Dunn 2002). Zero values of proportion-at-age were replaced with 0.0001. 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 *Tangaroa* trawl survey abundance index is in Table 6.

Standardised CPUE series for the longline fisheries (Table 7) were derived in Horn et al. (2013).

Catch-at-length data were fitted to the model as proportions-at-length with associated CVs by length class. These data were also estimated using the software described above. Zero values of catch-at-length were replaced with 0.0001.

Table 3: Summary of model data inputs for the Chatham Rise ling assessment.

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

Table 4: Estimated catch histories (t) for LIN 3&4, separated by fishing method (trawl or line). The 2014 values were required for the current assessment; they were estimated based on recent landing trends (Ballara & Horn 2015).

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

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	0.07
TAN1301	Jan-13	8 710	0.10
TAN1401	Jan-14	7 490	0.07

Table 7: Chatham Rise longline fishery CPUE index with CV (Ballara & Horn 2015).

Year	Index	CV
1991	1.67	0.06
1992	2.43	0.06
1993	1.73	0.05
1994	1.65	0.05
1995	1.68	0.05
1996	1.31	0.05
1997	0.88	0.04
1998	0.90	0.05
1999	0.80	0.04
2000	0.93	0.05
2001	0.93	0.04
2002	0.77	0.04
2003	0.85	0.05
2004	0.81	0.04
2005	0.85	0.04
2006	0.74	0.05
2007	0.81	0.04
2008	1.04	0.04
2009	0.73	0.04
2010	0.84	0.04
2011	0.65	0.04
2012	0.79	0.05
2013	0.80	0.07

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 are two fisheries (trawl and longline) in the stock. The model's 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 for trawl and combined for line. The trawl survey and trawl fishery ogives were estimated using either a double normal or logistic parameterisation; the estimated line fishery ogive was assumed to be logistic. In all cases, male selectivity curves were estimated relative to female selectivity. The parameterisations 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 (Horn et al. 2013). 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 estimation 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 detailed 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. An additional process error CV of 0.15 was added to the trawl survey biomass index following Francis et al. (2001), and a process error CV for the line fishery CPUE was estimated at 0.15 following Francis (2011). The multinomial observation error effective sample sizes for the at-age and at-length data were adjusted using the reweighting procedure of Francis (2011).

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 is used here (see Bull et al. (2012) for details).

4. MODEL ESTIMATES

4.1 Developing a base model

Proportions-at-age data were included in all model runs in this assessment, and *M* estimated. M was estimated as a constant, with a separate value for each sex in a sensitivity run. Initially, two model runs were trialled with double exponential natural mortality. These gave unlikely age patterns (Figure 2), so natural mortality was estimated as a constant in all subsequent model runs.

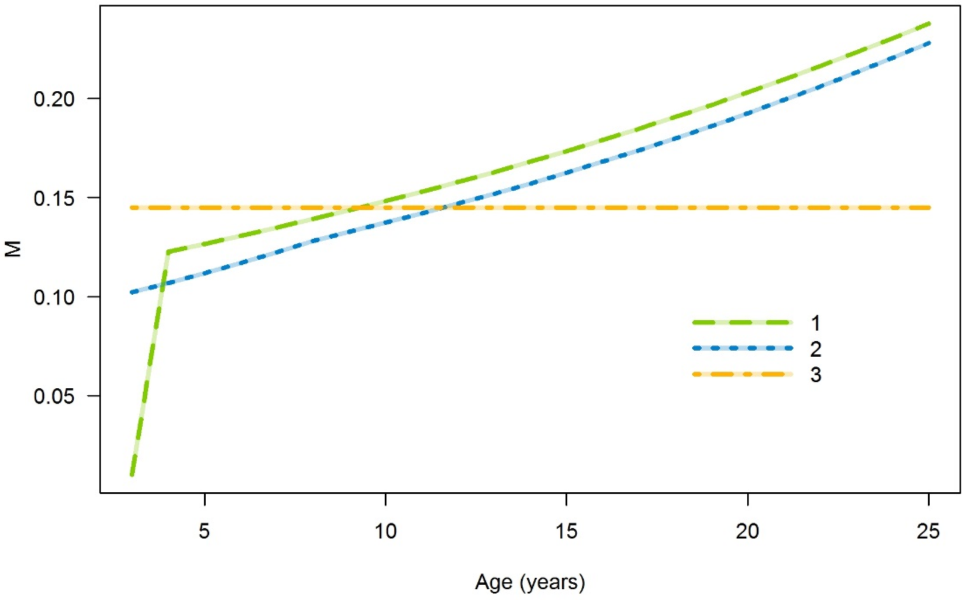


Figure 2: Estimates of natural mortality as a double exponential ogive (blue and green lines) or constant natural mortality (orange line). Run 1 had double normal selectivity for trawl survey and fishery, run 2 had logistic selectivity for trawl survey and fishery, and run 3 had double normal selectivity for trawl survey and fishery.

The process error added to the longline CPUE index was estimated following the recommendations of Francis (2011). The method involves fitting a series of data smoothers having different degrees of smoothing to the CPUE index, and calculating the CV of the residuals of the fit of the smoother to the data. An appropriate CV is chosen from the resulting plots qualitatively, and is the largest CV that still gives a smooth and good fit to the data. For the longline CPUE index, a process error CV of 0.15 was considered appropriate (Figure 3).

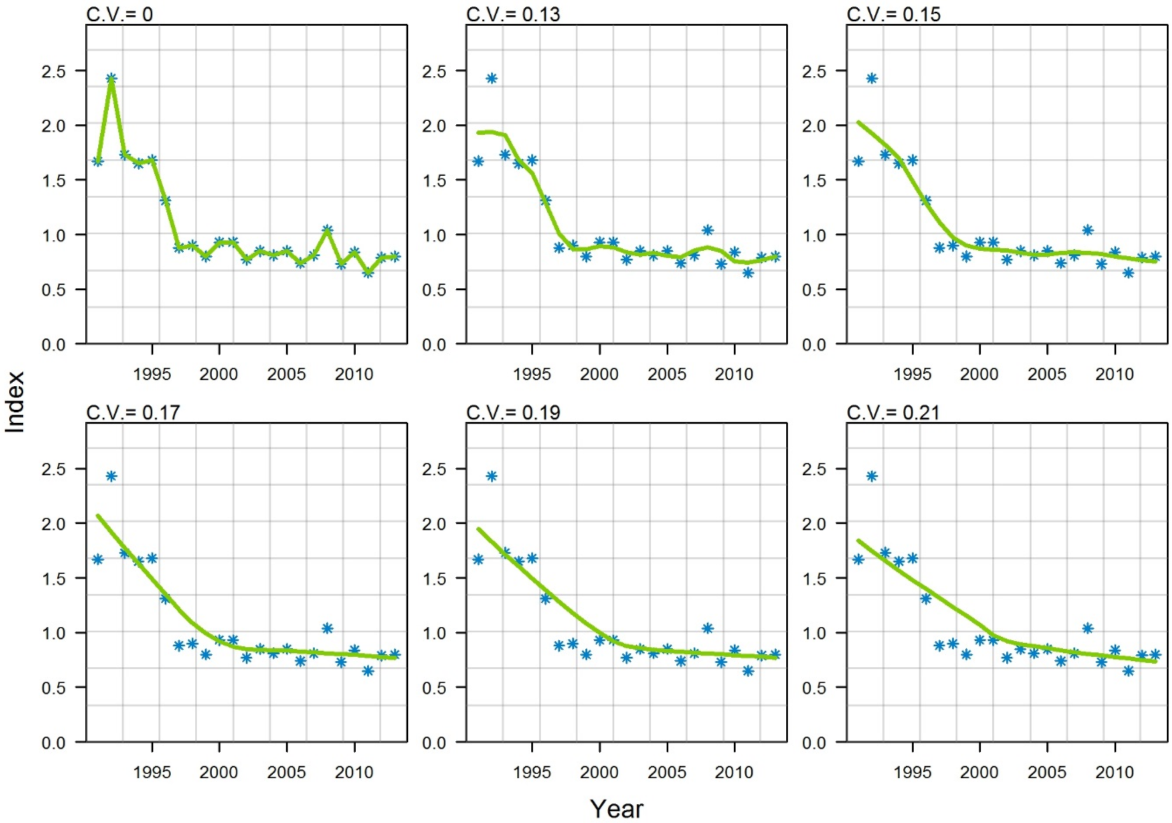


Figure 3: The fit of a data smoother (loess) to the ling longline CPUE index using different degrees of data smoothing. The CV increases as the degree of smoothing (here the "span" of the R function loess) increases.

As in the previous assessment (Horn et al. 2013), the base run for this assessment assumed double-normal selectivity ogives for the trawl survey and fishery, with the ogive for males fitted relative to females. This means that the "capped" ogives in CASAL were used (Bull et al. 2012), allowing the maximum selectivity for males to be other than 1. Where this selectivity assumption was applied, males were slightly more vulnerable than females (ogive asymptote more 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 ratio data in the fishery catches and the stock.

As in the previous assessment, the assumed errors for the composition data were multinomial. The effective sample sizes for the composition samples were estimated from a multinomial model fitted to a regression of log(proportion) against log(CV), where the CV was estimated by bootstrapping from the sample data (Bull & Dunn 2002). Reweighting of the composition data (proportion-at-length and proportion-at-age) followed Francis (2011). The effective sample sizes and re-weighted effective sample sizes are given in Table 9.

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

Trawl survey proportion-at-age		
Fishing year	**Initial EFS**	**Reweighted EFS**
1990	355	50
1992	473	66
1993	555	78
1994	530	74
1995	311	44
1996	370	52
1997	410	57
1998	365	51
1999	388	54
2000	547	77
2001	637	89
2002	553	77
2003	493	69
2004	508	71
2005	448	63
2006	532	75
2007	451	63
2008	397	56
2009	403	56
2010	415	58
2011	312	44
2013	398	56
2014	407	57
Longline proportion-at-length		
1995	1 632	60
1996	1 677	61
1997	1 860	68
1998	1 870	68
1999	1 804	66
2000	2 056	75
2001	1 272	47

Trawl fishery proportion-at-age		
Fishing year	**Initial EFS**	**Reweighted EFS**
1992	329	27
1994	245	20
1995	108	9
1996	270	23
1997	147	12
1998	668	56
1999	550	46
2000	385	32
2001	481	40
2002	363	30
2003	322	27
2004	228	19
2005	336	28
2006	204	17
2007	369	31
2008	552	46
2009	245	20
2010	263	22
2011	283	24
2012	317	26
2013	394	33
Longline proportion-at-age		
2002	633	27
2003	624	26
2004	440	19
2005	394	17
2006	145	6
2007	191	8
2008	285	12
2009	435	18
2013	254	11

In this assessment, the fit to the trawl survey biomass indices was given primacy (Francis 2011). 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 4). Three model runs varied with respect to the biomass indices. 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, and the ‘All’ run included both biomass indices. There was also a ‘Selectivity’ run where the selectivity ogives for trawl survey and fishery were logistic, rather than double normal. There was an ‘M’ run which estimated a separate natural mortality for each sex. See Table 10 for an overview of the model runs, with the MPD estimates for B_0 and $B_{current}(\%B_0)$.

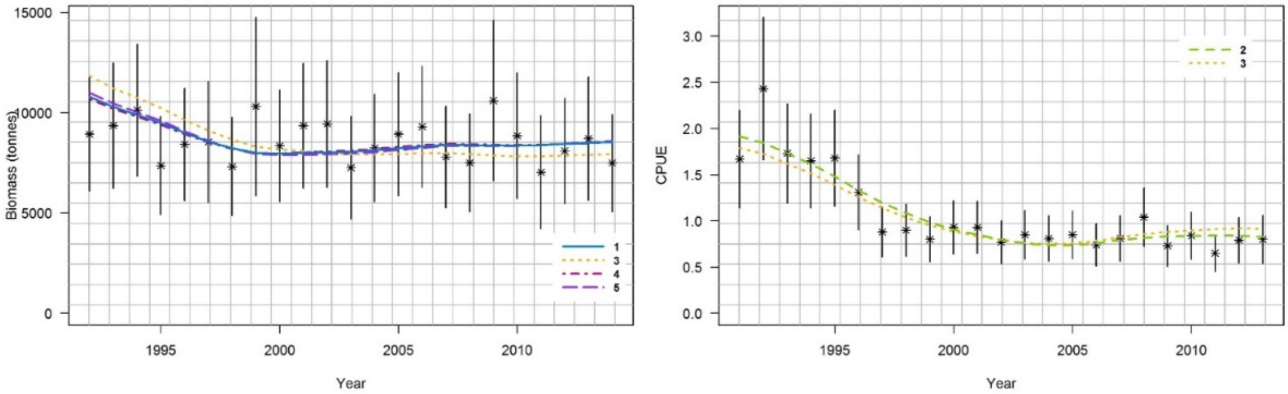


Figure 4: Model fits to the biomass indices for longline CPUE (right) and trawl survey (left). (1) is the Base run, (2) is the Longline run, (3) is the All run, (4) is the M run, and (5) is the Selectivity run. Vertical lines show the 95% confidence intervals.

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.	130 000	58
Longline CPUE excluded		
Trawl survey abundance index included		
Selectivity double normal (capped for males) ogive for trawl survey and fishery		
Selectivity logistic for longline		
Single sex M estimated		
2. Longline run.	105 500	38
Same as Base run, but longline CPUE included and trawl survey abundance index excluded		
3. All run.	115 500	47
Same as Base run, but longline CPUE included		
4. M run.	134 000	60
Same as Base run, but M estimated separately by sex		
5. Selectivity run.	120 600	55
Same as Base run, but selectivity logistic ogive for trawl survey and fishery		

Model fits to the composition data (longline proportions-at-length, 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).

The year class strengths showed possible weaker year classes in the last 10 years and years 1980–92 compared with the rest of the series, especially in the model runs that included the longline CPUE, although not a clear trend (Figure 5).

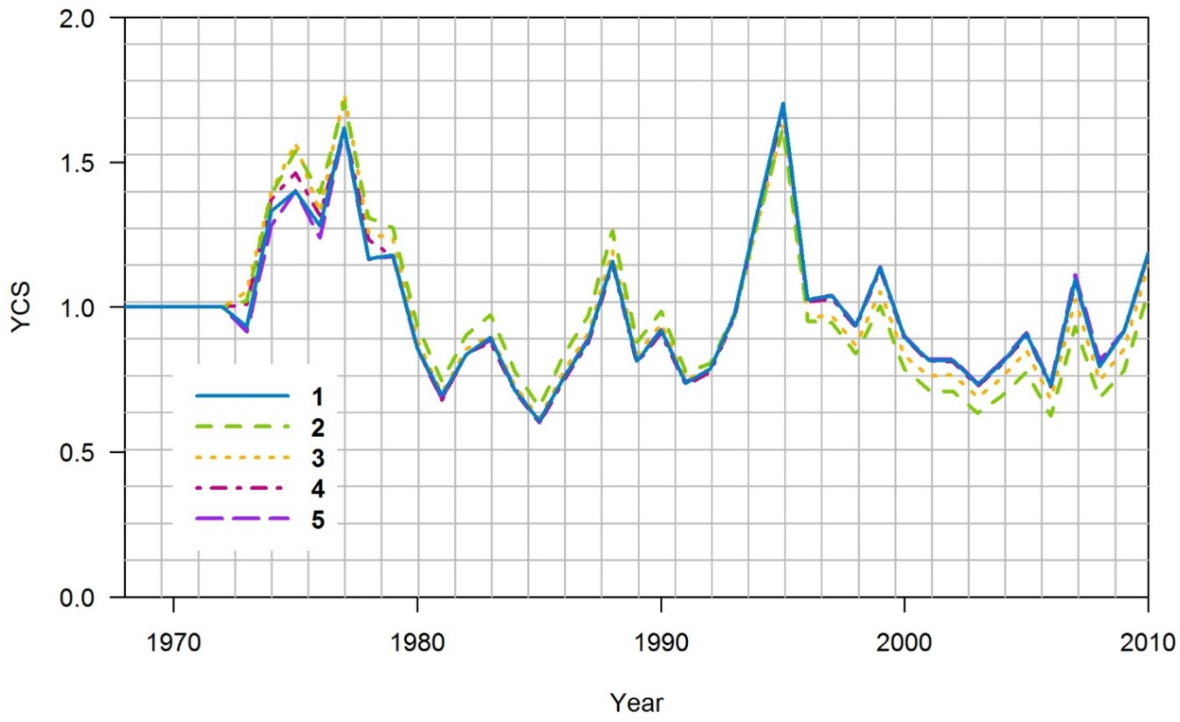


Figure 5: MPD year class strength (YCS) estimates for model runs (1) Base, (2) Longline, (3) All, (4) M, and (5) Selectivity.

MPD estimates for trawl fishery and survey selectivities tended towards being logistic, even when a double normal was offered, in all cases except for females in the trawl fishery (Figure 6).

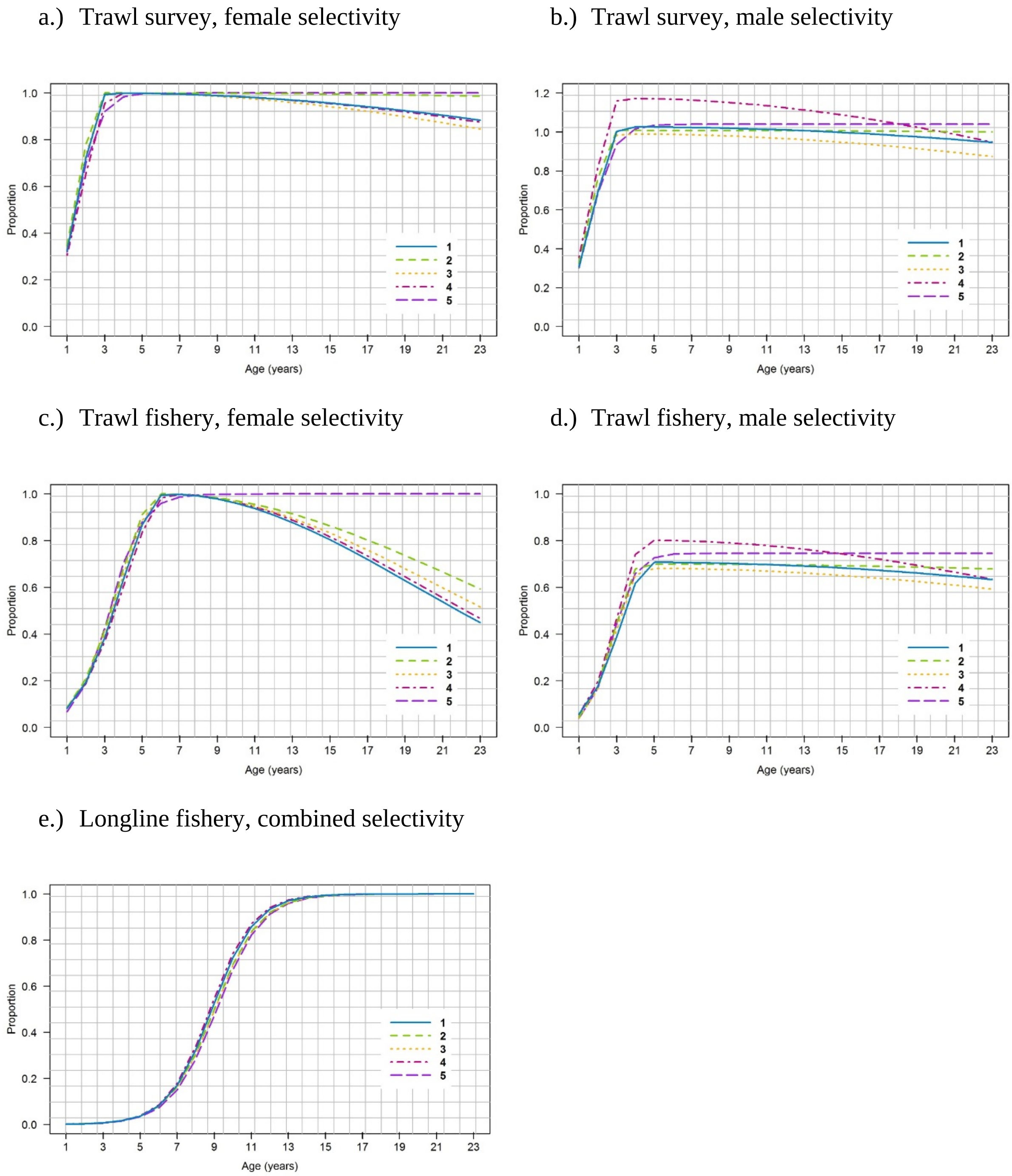


Figure 6: MPD estimates for selectivities for the trawl survey and the trawl and longline fisheries.

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 2×10^5 iterations, and with every 1000^{th} sample kept.

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. The other exception was the normal prior on p_male with μ=0.5, cv=0.15.

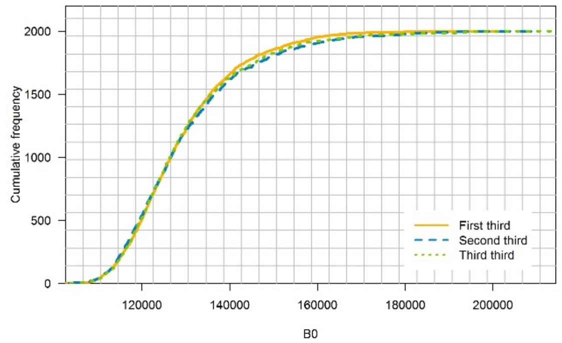
Penalty functions were used to constrain the model so that any combination of parameters that did not allow the historical catch to be taken was penalised. A penalty was applied to the estimates of year class strengths to encourage estimates that average to 1.

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.

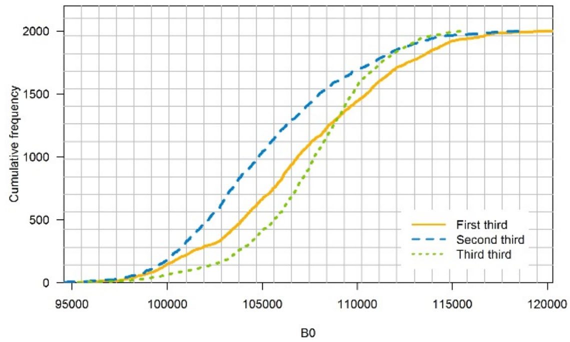
Parameter description	Distribution	Parameters		Bounds	
B_0	Uniform-log	–	–	30 000	500 000
Year class strengths	Lognormal	1.0	0.70	0.01	100
Trawl survey *q*	Lognormal	0.13	0.70	0.02	0.3
CPUE *q*	Uniform-log	–	–	1e-8	1e-3
Selectivities	Uniform	–	–	0	20–200
M	Uniform	–	–	0.01	0.6
p_male	Normal	0.5	0.15	0.1	0.9

MCMC runs were carried out for the model runs ‘Base’, ‘Longline’, ‘All’ and ‘M’. In all runs, the catchability coefficients (*q*’s) were free, unless there were difficulties in convergence, in which case they were set as nuisance variables (they were integrated out). The runs that included the longline CPUE (runs ‘longline’ and ‘all’) had difficulty converging, and the other two runs converged sufficiently with free *q*’s (Figure 7). The full set of convergence diagnostic and distribution plots for B_0 and $B_{current}$(%B_0) are in Appendix B.

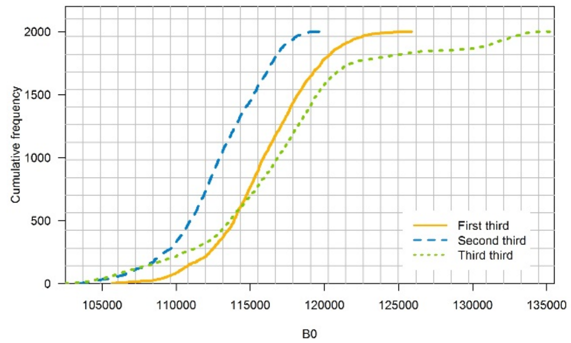
1.) Base run



2.) Longline run



3.) All run



4.) M run

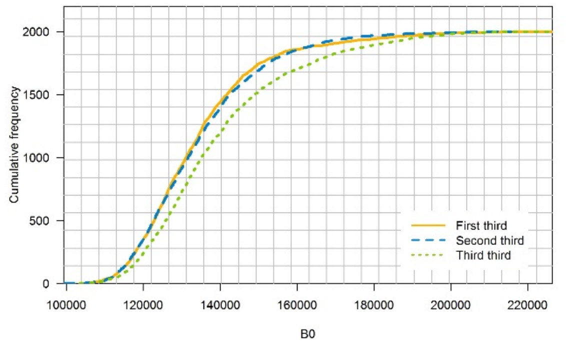


Figure 7: MCMC cumulative frequencies of B_0 for the first (solid gold line), second (dashed blue line) and third (dotted green line) third of the MCMC chain for model runs (1) Base, (2) Longline, (3) All, and (4) M.

The estimates for $B_{current}$(%B_0) were less for the runs that included the longline CPUE (Table 12) and ranged from 40 to 60% across all models.

Natural mortality was estimated at around 0.15 for all models, and higher (0.17) for females in model M (Table 12, Figure 8).

The proportion of recruits that are male (p_male) was estimated at slightly greater than 0.5 for all runs except the M run which estimated this proportion as likely to be less than 0.5. This run also generally estimated a higher natural mortality for females than for males (Table 12, Figure 9).

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

Model run	Catchability coefficient(s)	B_0 (t)	$\%B_0$	M		p_male
1. Base	Free	126 600 (110 700, 165 100)	57 (45, 71)		0.15 (0.13, 0.18)	0.52 (0.44, 0.60)
2. Longline	Nuisance	107 400 (98 700, 122 700)	40 (30, 51)		0.14 (0.12, 0.17)	0.52 (0.45, 0.59)
3. All	Nuisance	117 500 (106 200, 149 300)	50 (40, 62)		0.15 (0.13, 0.18)	0.53 (0.45, 0.60)
4. M	Free	132 700 (112 300, 185 000)	61 (48, 74)	male 0.15 (0.13, 0.17)	female 0.17 (0.14, 0.20)	0.46 (0.36, 0.57)

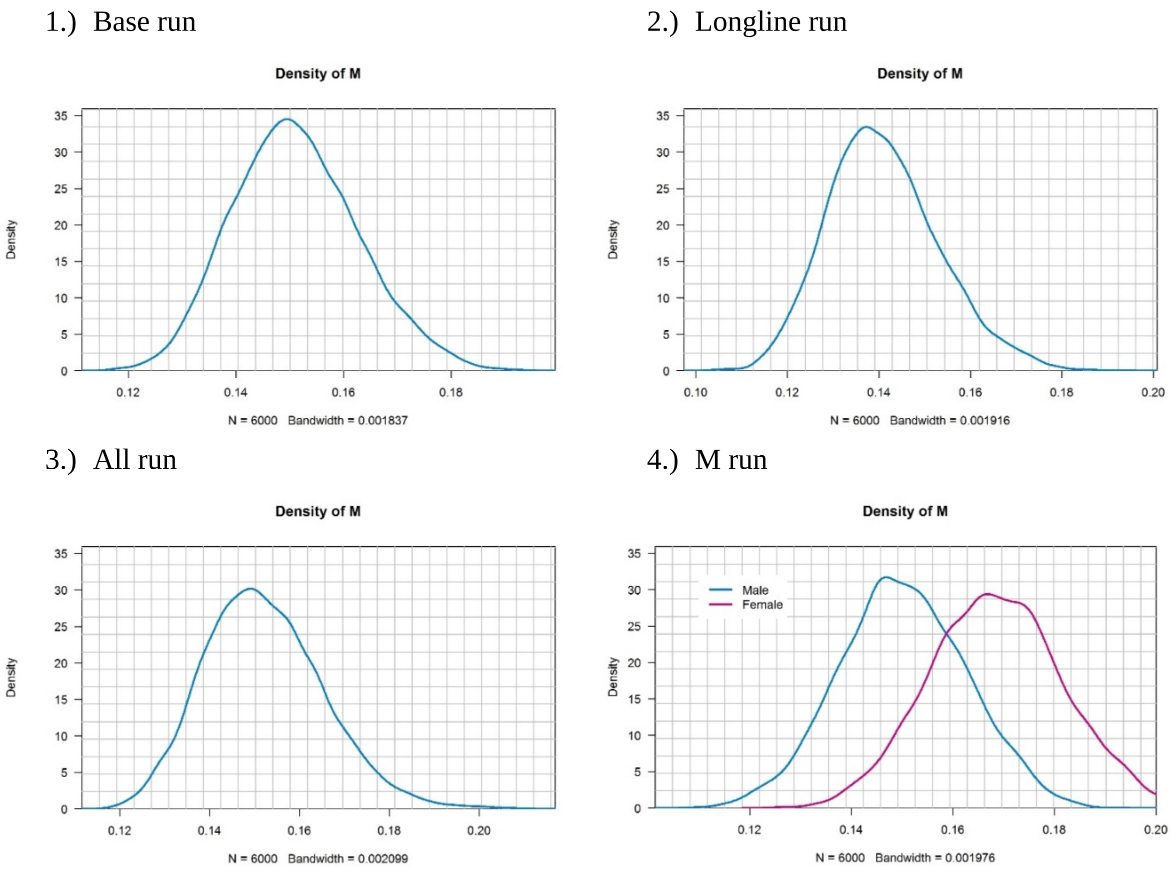
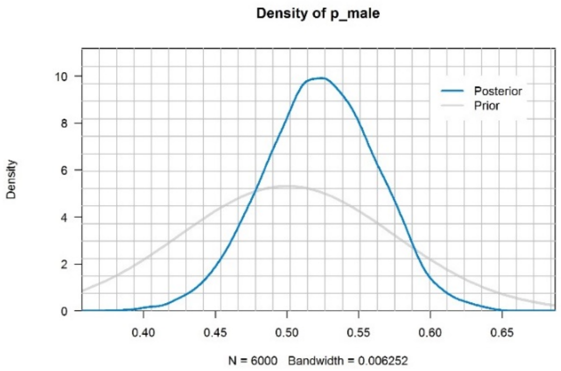
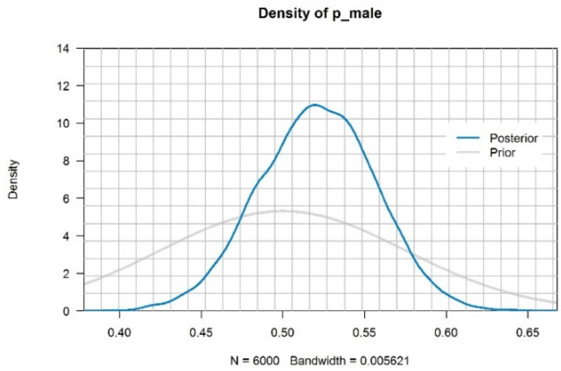


Figure 8: Estimated posterior distribution for M (natural mortality) for model runs (1) Base, (2) Longline, (3) All, and (4) M. All priors were uninformative.

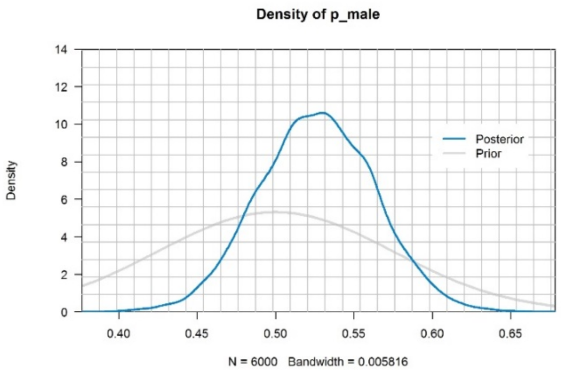
1.) Base run



2.) Longline run



3.) All run



4.) M run

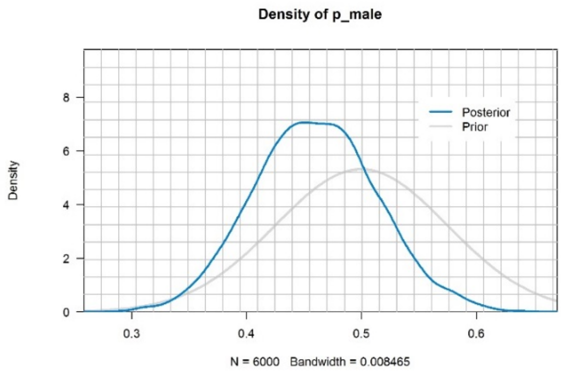


Figure 9: Estimated posterior distribution for p_male (proportion of recruits that are male) for model runs (1) Base, (2) Longline, (3) All, and (4) M. All priors were normally distributed with mean 0.5 and CV 0.15.

Selectivities for the trawl fishery and survey tended towards a logistic distribution, although a double normal distribution was offered (Figure 10). Males were slightly more likely to be selected in the trawl survey and less likely in the trawl fishery (Figure 10). The longline fishery had 50% selectivity by about age 11 years, and close to 100% selectivity by age 15 years (Figure 11).

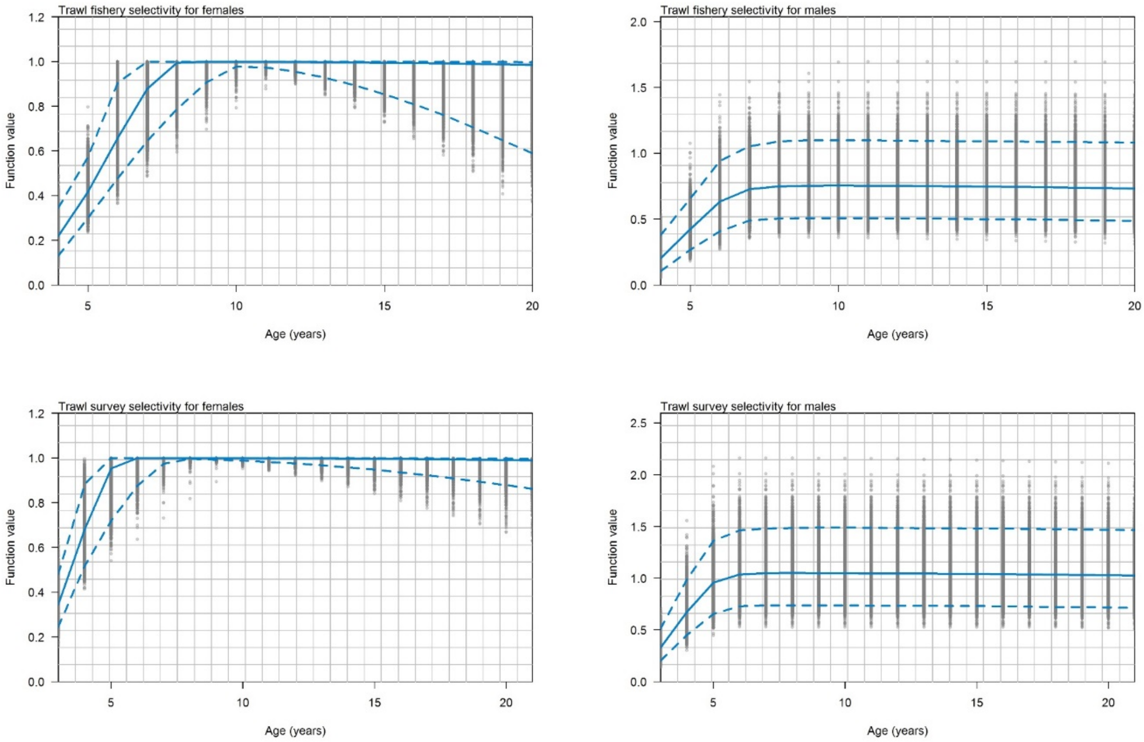


Figure 10: Selectivities for Base run for trawl fishery (top) and trawl survey (bottom) for females (left) and males (right). Grey dots are the selectivity calculated for each age for each link of the MCMC chain, solid blue line is the median, dashed blue lines are the 95% upper and lower quartiles.

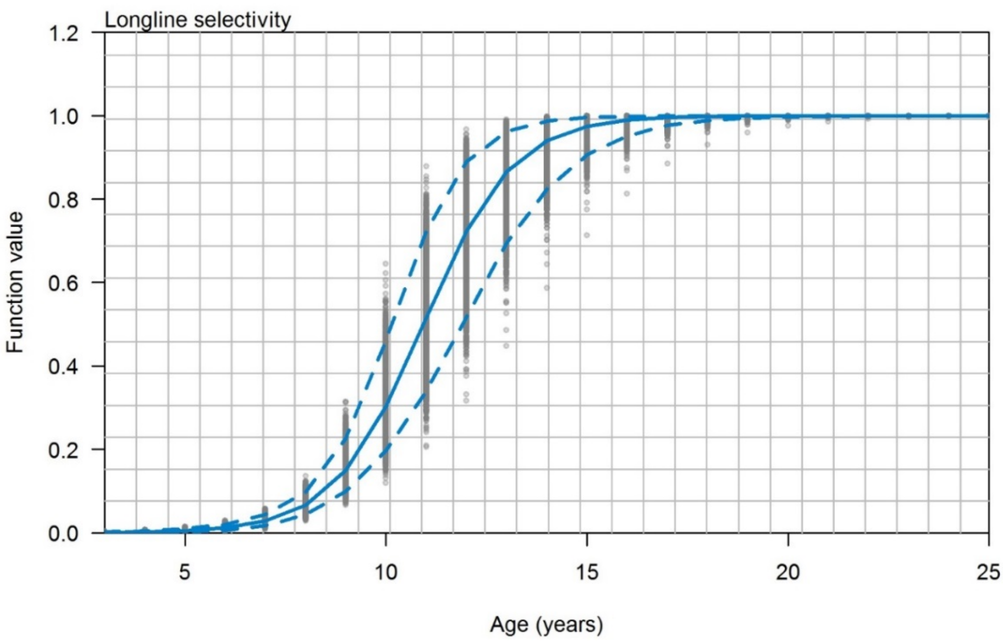


Figure 11: Selectivities for Base run for the longline fishery (males and females combined). Grey dots are the selectivity calculated for each age for each link of the MCMC chain, solid blue line is the median, dashed blue lines are the 95% upper and lower quartiles.

4.3 Biomass projections

Biomass projections from the model were made under three assumed future catch scenarios (Table 13). The first two assume that the TACC is taken, but that it is split differently between the longline and trawl fisheries. TACC (split prev.) is the TACC split that was used in the projections in the previous assessment, TACC (split alt.) is an alternative split requested by MPI for this assessment. The third future catch option used the average catches from the last five years for the longline and trawl fisheries.

Table 13: Future catch options used in the projections.

	Total catch (t)	Longline catch (t)	Trawl catch (t)
TACC (split prev.)	6260	3260	3000
TACC (split alt.)	6260	4630	1630
Average last 5 years	3564	2257	1307

Relative year class strengths from 2015 onwards were selected using the lognormal distribution with standard deviation on the log scale of 0.6.

Projections were carried out for the Base run and Longline run. The future catch option using the average from the last five years is likely to result in a similar biomass in 2019 to that estimated in 2014 (Table 14). If future catches reach the TACC, the biomass is likely to go down to around 90% of the 2014 biomass by 2019 under the Base run, and around 75% for the Longline run, taking $B_{2019}(\%B_0)$ down to approximately 50% and 30% respectively. Plots of all projections are in Figures 12– 17.

Table 14: Projections from MCMC runs 'Base' and 'Longline'. Median, 95% upper and lower quartiles for B_{2019}, $B_{2019}(\%B_0)$ and $B_{2019}(\%B_{2014})$ under three future catch options.

	Future catch	B_{2019}	$B_{2019}(\%B_0)$	$B_{2019}(\%B_{2014})$
Base Run	TACC (split prev.)	63 800 (38 700, 111 900)	50 (34, 69)	88 (73, 106)
	TACC (split alt.)	64 000 (38 900, 112 100)	51 (35, 69)	89 (73, 106)
	Average last 5 years	75 200 (50 400, 122 700)	59 (45, 75)	104 (91, 120)
Longline Run	TACC (split prev.)	31 500 (16 000, 56 700)	29 (16, 47)	74 (50, 97)
	TACC (split alt.)	31 600 (16 000, 56 800)	30 (16, 47)	74 (50, 98)
	Average last 5 years	43 100 (27 700, 67 700)	40 (28, 56)	101 (85, 121)

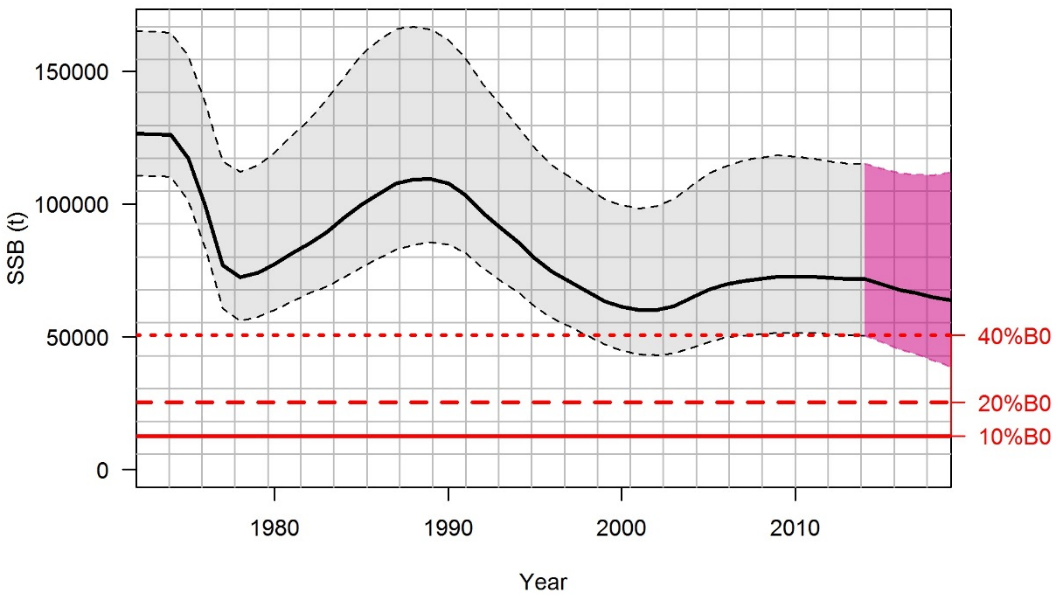


Figure 12: Projection using MCMC Base run with future catch option: TACC prev. split.

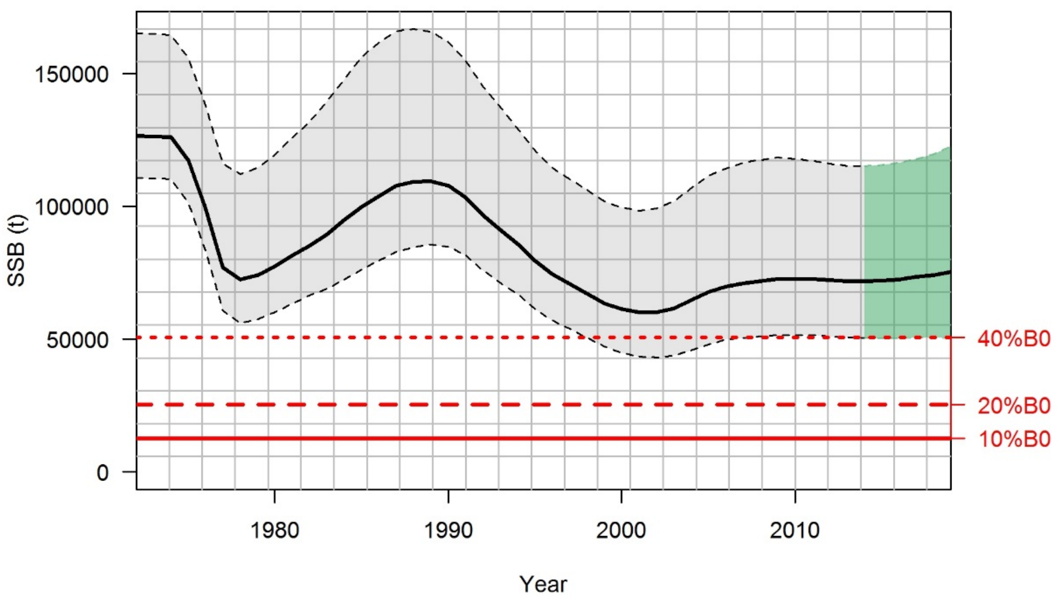


Figure 13: Projection using MCMC Base run with future catch option: Average last 5 years.

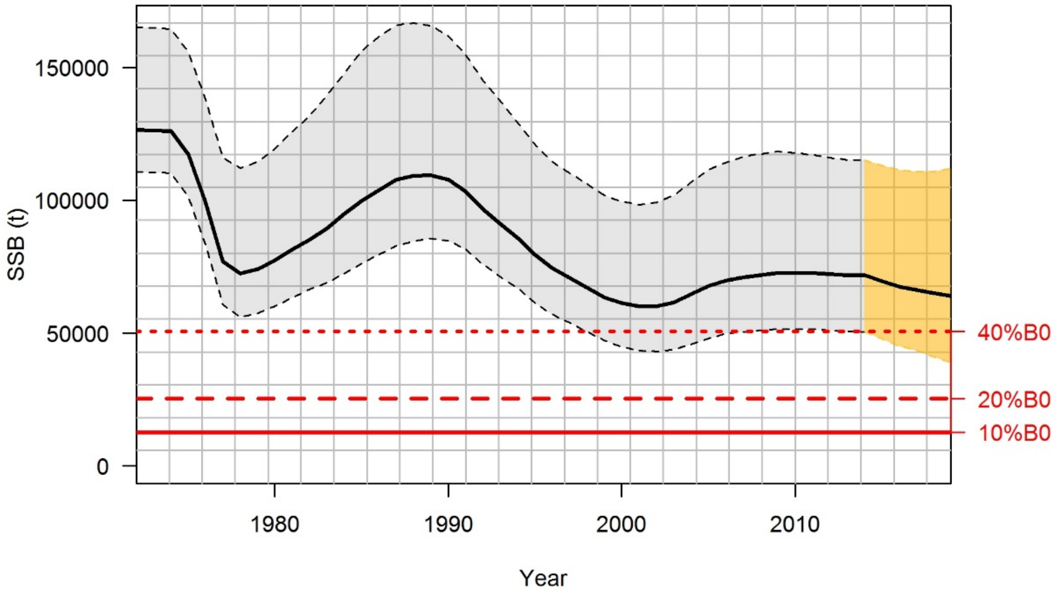


Figure 14: Projection using MCMC Base run with future catch option: TACC (alt.split).

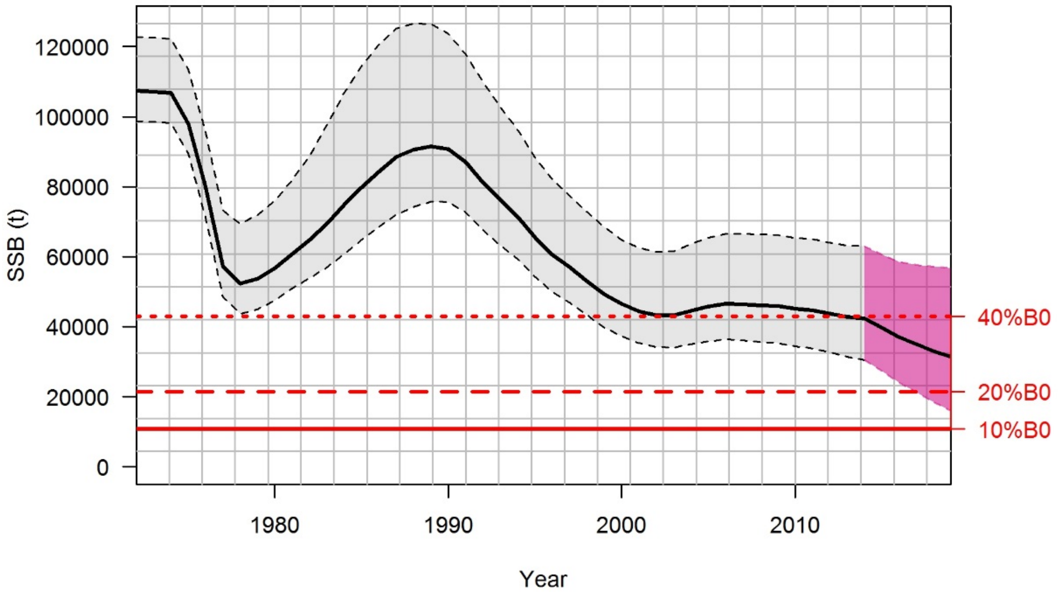


Figure 15: Projection using MCMC Longline run with future catch option: TACC (prev. split).

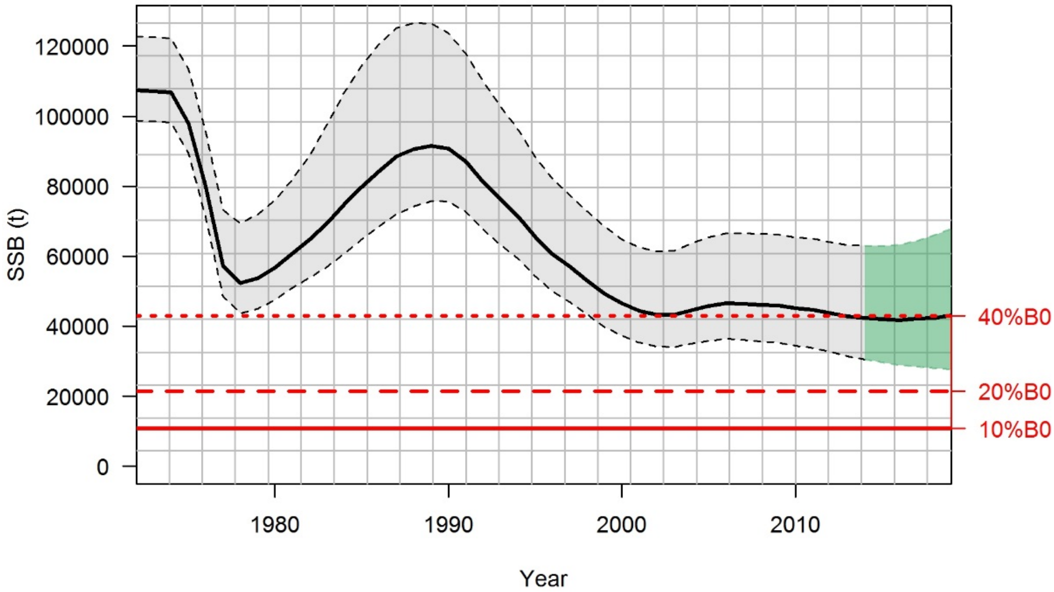


Figure 16: Projection using MCMC Longline run with future catch option: Average last 5 years.

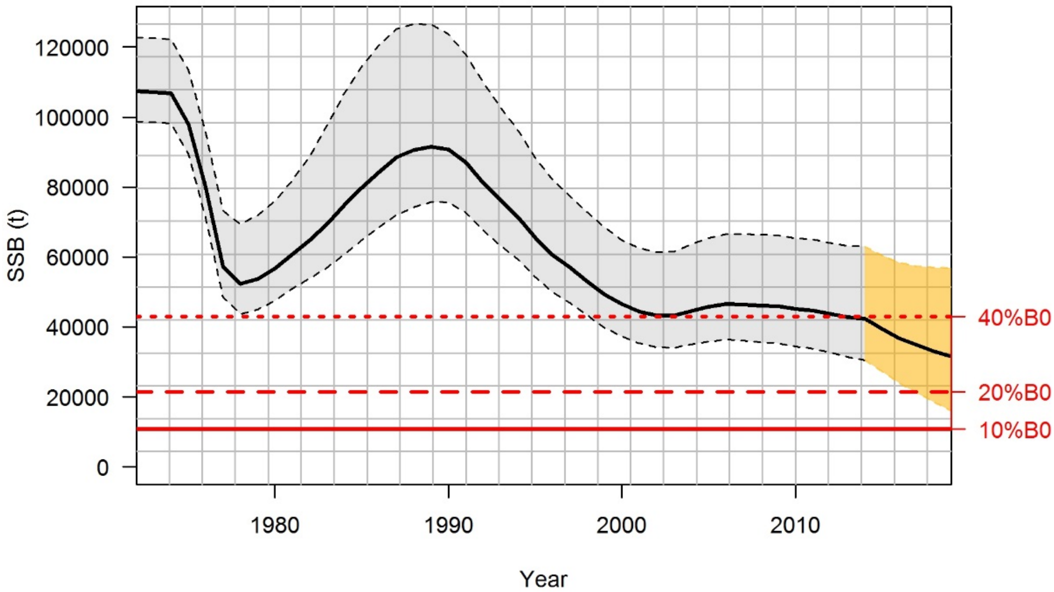


Figure 17: Projection using MCMC Longline run with future catch option: TACC (alt. split).

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_{2019} will be lower than the soft target of 20%B_0, but at the higher catch level there is an approximate 10% probability that the stock will fall below the target level (40% B_0).

Table 15: Probabilities that current (B_{2014}) and projected (B_{2019}) biomass will be less than 40%, 20% or 10% of B_0. Projected biomass probabilities are presented for three scenarios of future annual catch.

‘Current’ year	Future catch	$P(B_{current}<40\%B_0)$	$P(B_{current}<20\%B_0)$	$P(B_{current}<10\%B_0)$
2014	-	0.0	0.0	0.0
2019	TACC (split prev.)	0.1	0.0	0.0
2019	TACC (split alt.)	0.1	0.0	0.0
2019	Average last 5 years	0.0	0.0	0.0

5. DISCUSSION

Model estimates of the state of the LIN 3&4 stock indicate that current biomass is at least 40% of the virgin level, and that it is likely to remain unchanged in the short term. Current stock status is estimated to be 57% of B_0, within relatively wide bounds of 45 to 71%. Catches at the recent level are likely to be sustainable in the long term (assuming no exceptional decline in future recruitments), but catches at the TACC are likely to cause a decline.

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, and the 2011 assessment 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 attributable to 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. It was recommended that the longline CPUE be included only in a sensitivity model run that excludes 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 Peter Horn for reviewing the report. This work was funded by the Ministry for Primary Industries under project DEE201002LIND.

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APPENDIX A: MPD FITS TO COMPOSITION DATA

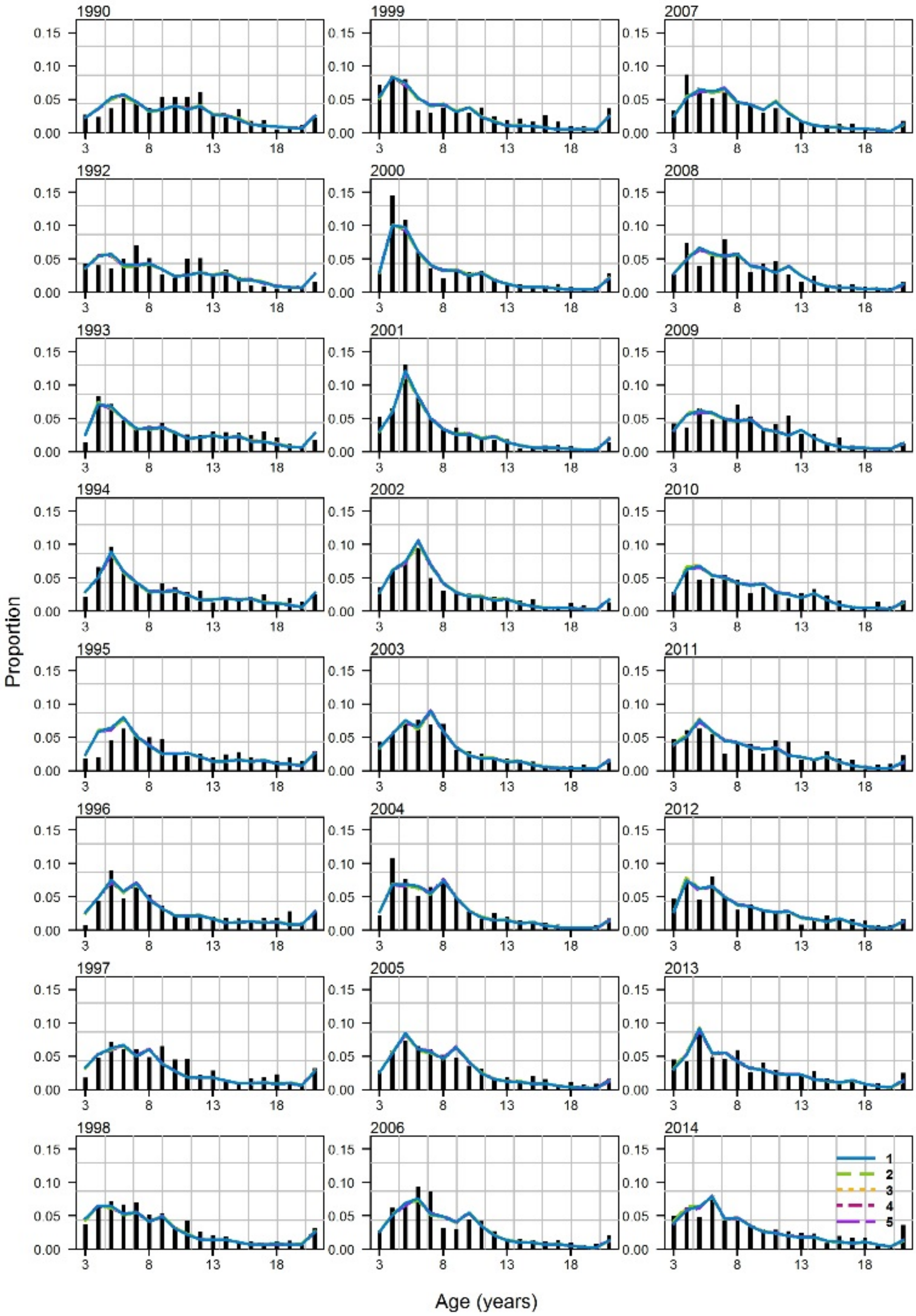

Figure A1: MPD fits to trawl survey female proportion-at-age data for model runs (1) Base, (2) Longline, (3) All, (4) M, and (5) Selectivity. Note fits to all models are essentially identical, so only the (blue) fit to model 1 is apparent.

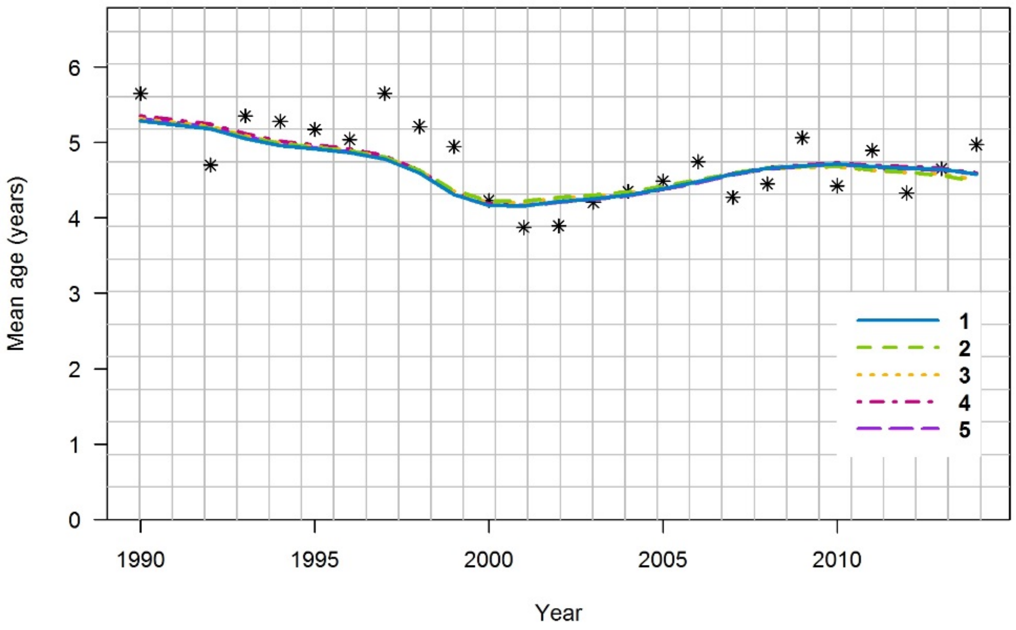

Figure A2: MPD fits to trawl survey female mean age data for model runs (1) Base, (2) Longline, (3) All, (4) M, and (5) Selectivity.

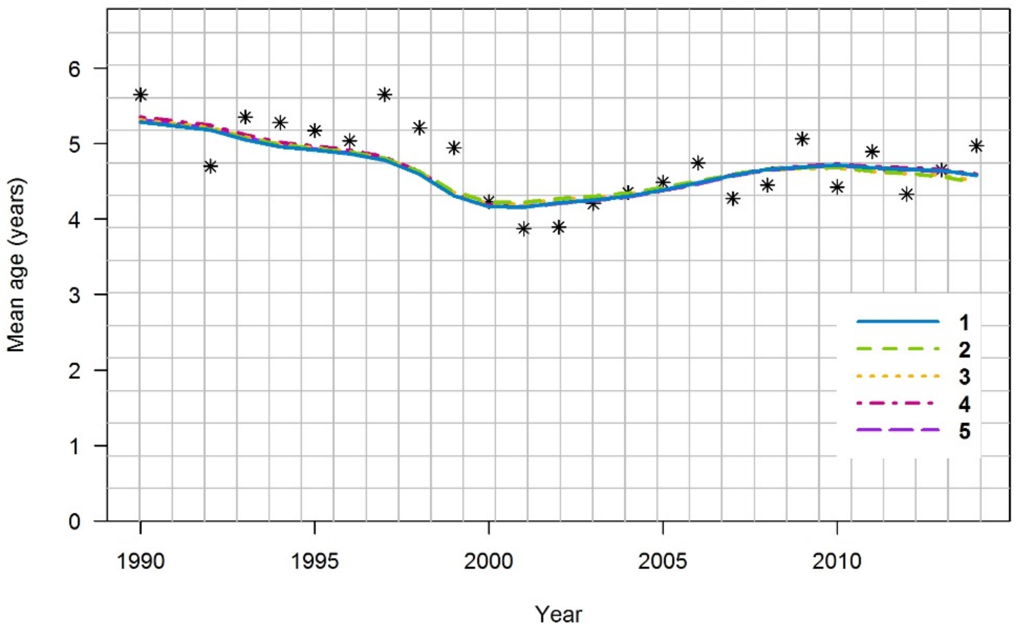

Figure A3: MPD fits to trawl survey male mean age data for model runs (1) Base, (2) Longline, (3) All, (4) M, and (5) Selectivity.

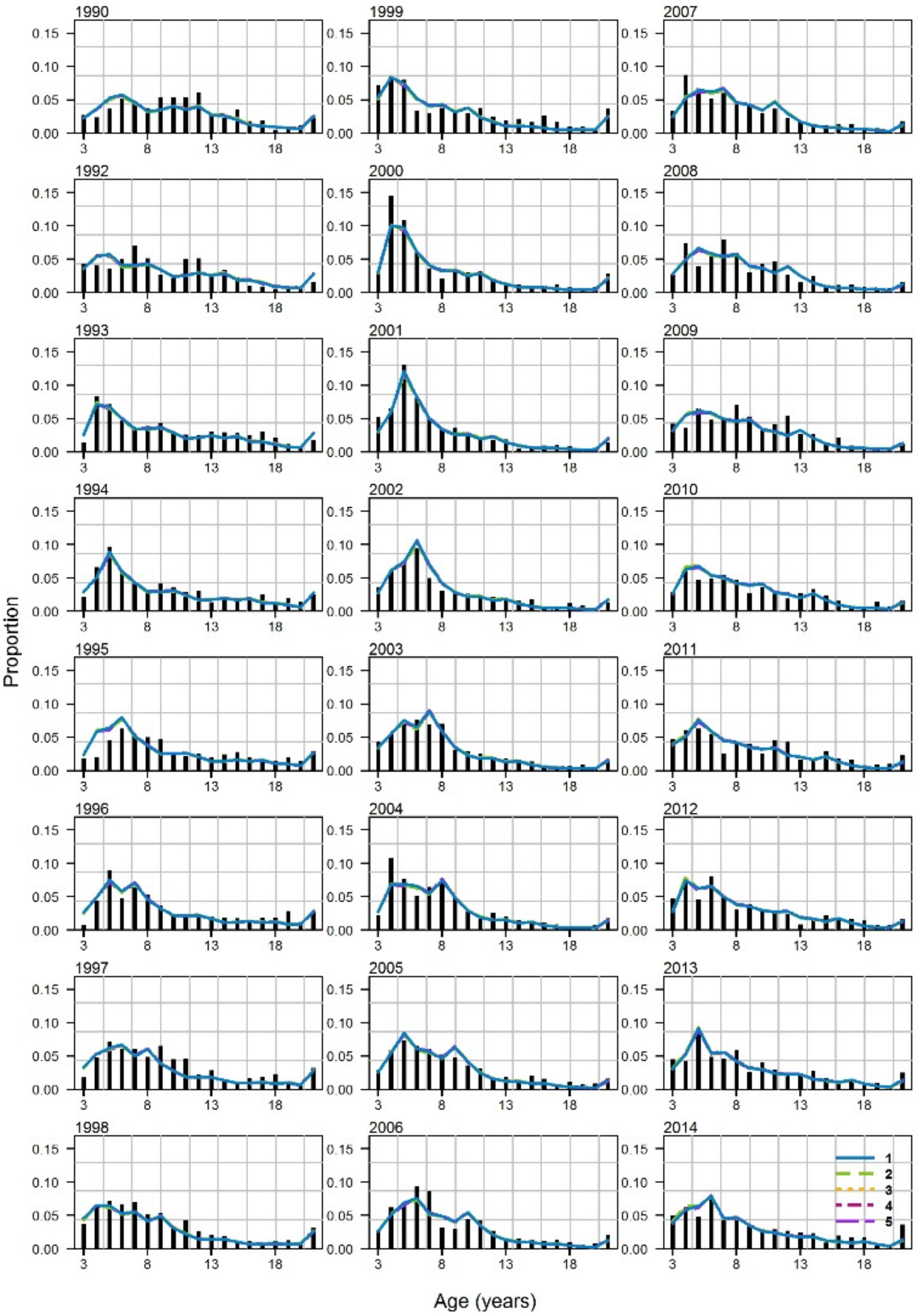

Figure A4: MPD fits to trawl survey male proportion-at-age data for model runs (1) Base, (2) Longline, (3) All, (4) M, and (5) Selectivity.

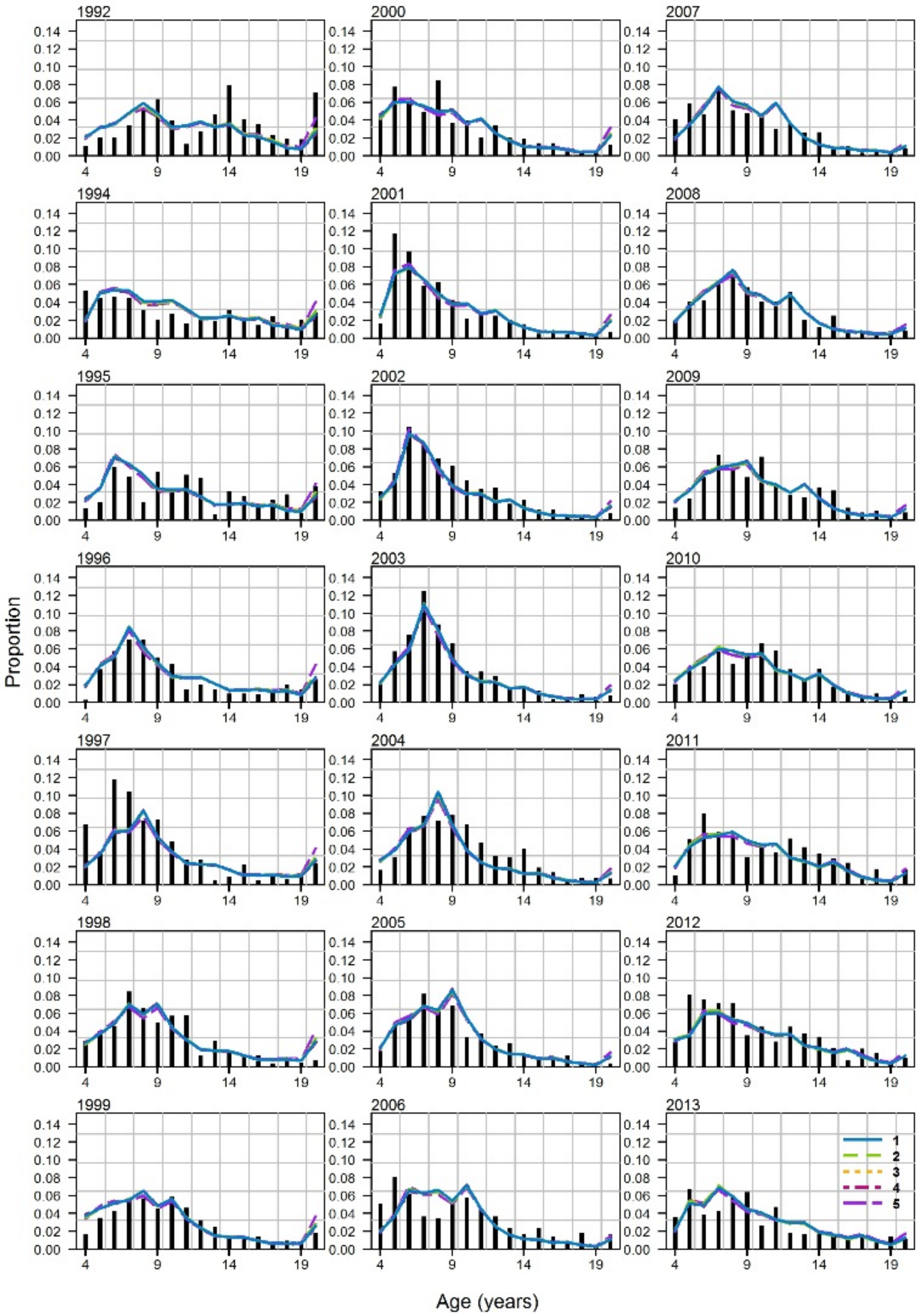

Figure A5: MPD fits to trawl fishery female proportion-at-age data for model runs (1) Base, (2) Longline, (3) All, (4) M, and (5) Selectivity.

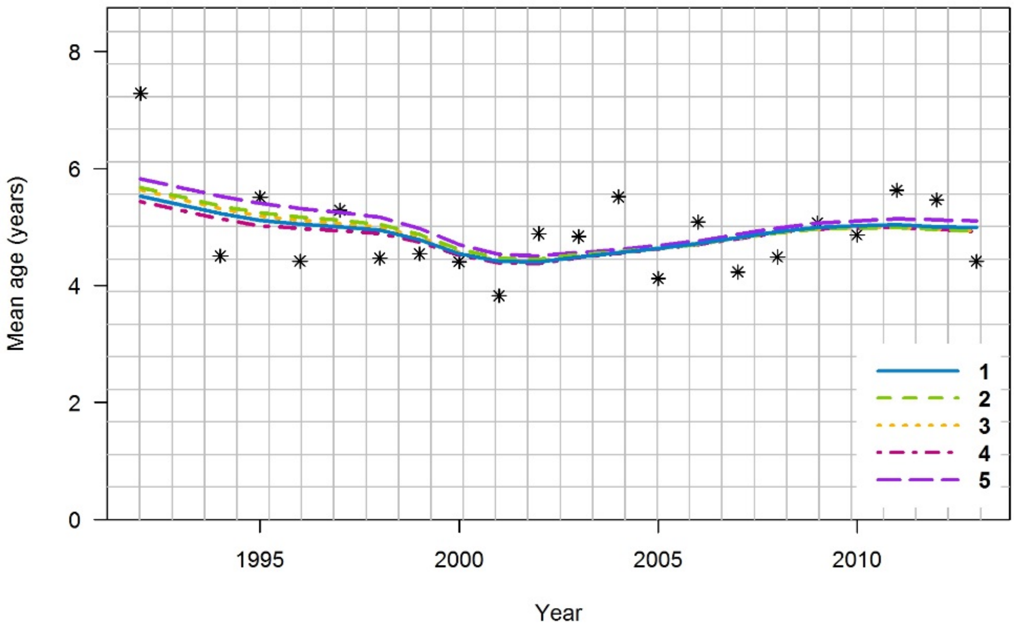

Figure A6: MPD fits to trawl fishery female mean age data for model runs (1) Base, (2) Longline, (3) All, (4) M, and (5) Selectivity.

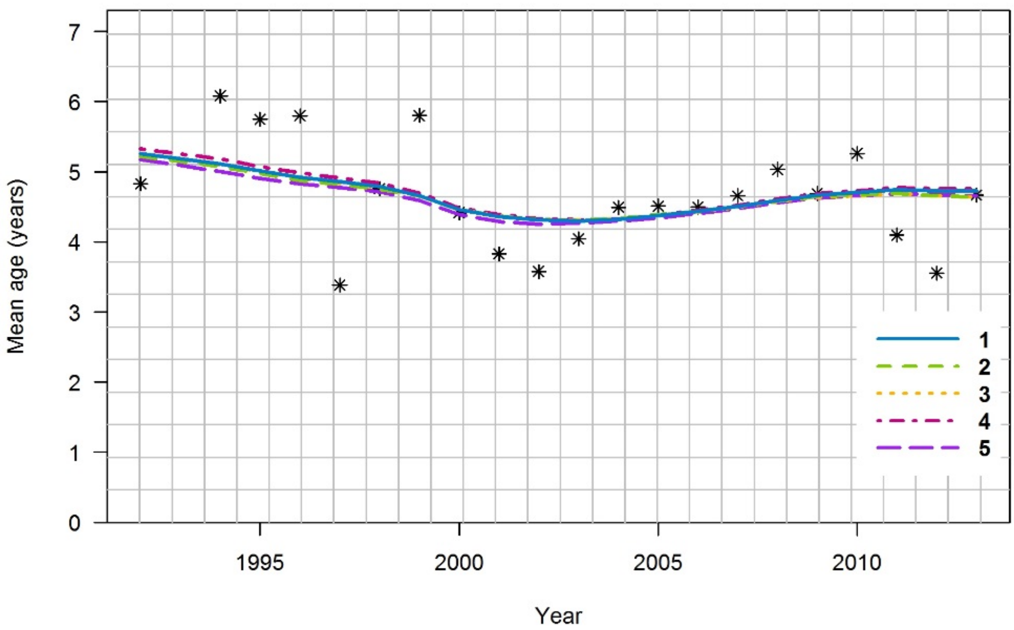

Figure A7: MPD fits to trawl fishery male mean age data for model runs (1) Base, (2) Longline, (3) All, (4) M, and (5) Selectivity.

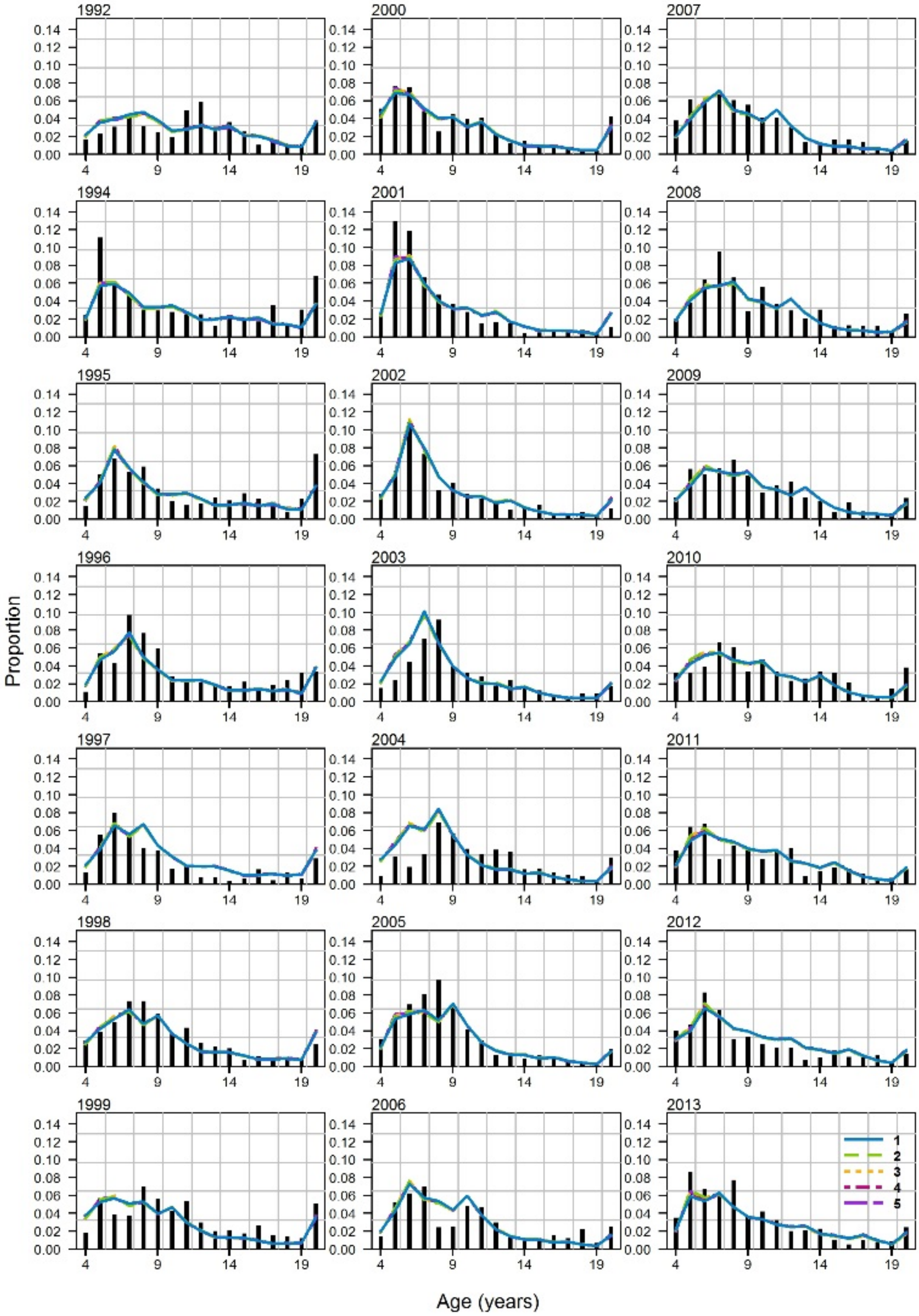

Figure A8: MPD fits to trawl fishery male proportion-at-age data for model runs (1) Base, (2) Longline, (3) All, (4) M, and (5) Selectivity.

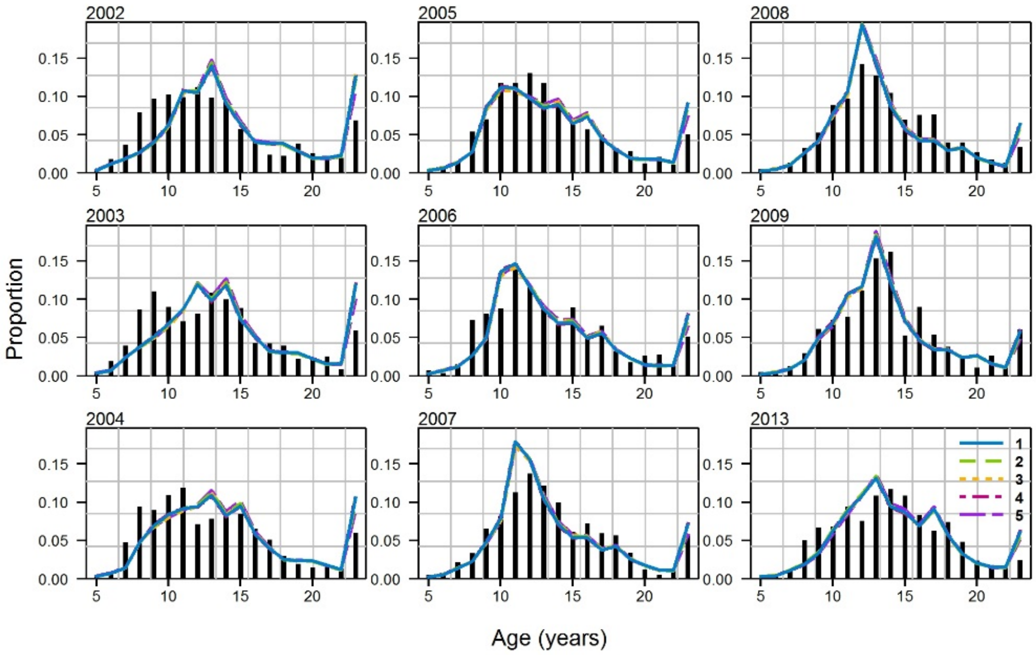

Figure A9: MPD fits to longline fishery proportion-at-age data for model runs (1) Base, (2) Longline, (3) All, (4) M, and (5) Selectivity.

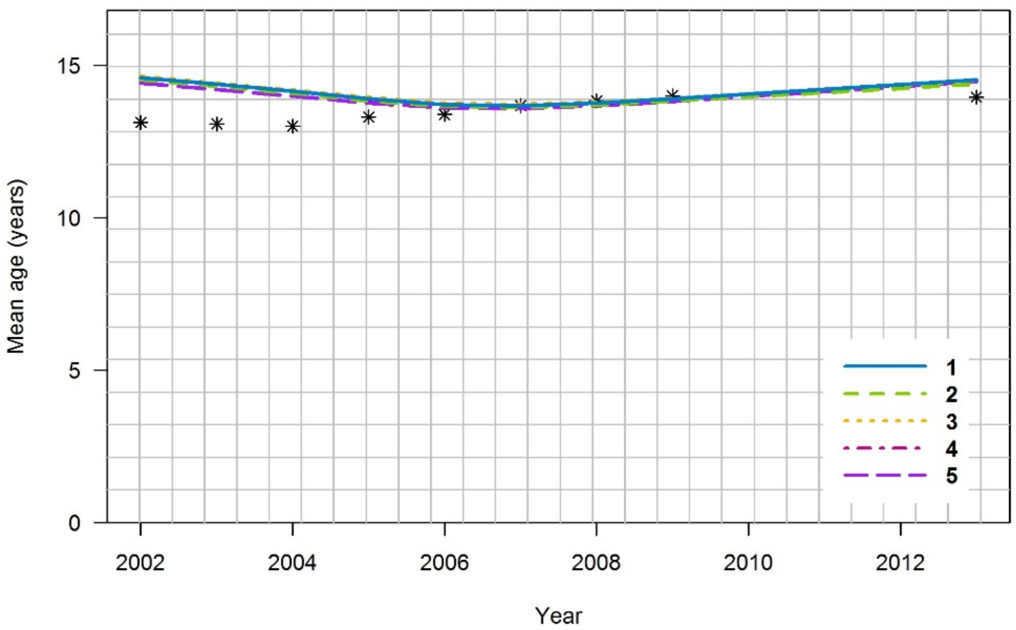

Figure A10: MPD fits to longline fishery mean age data for model runs (1) Base, (2) Longline, (3) All, (4) M, and (5) Selectivity.

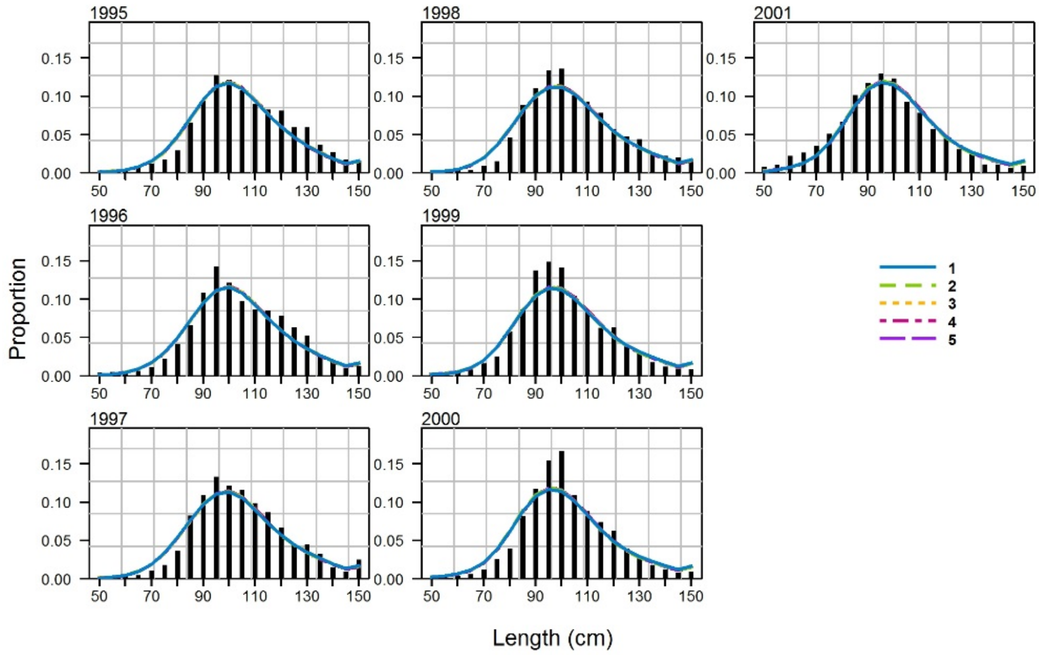

Figure A11: MPD fits to longline fishery proportion at length data for model runs (1) Base, (2) Longline, (3) All, (4) M, and (5) Selectivity.

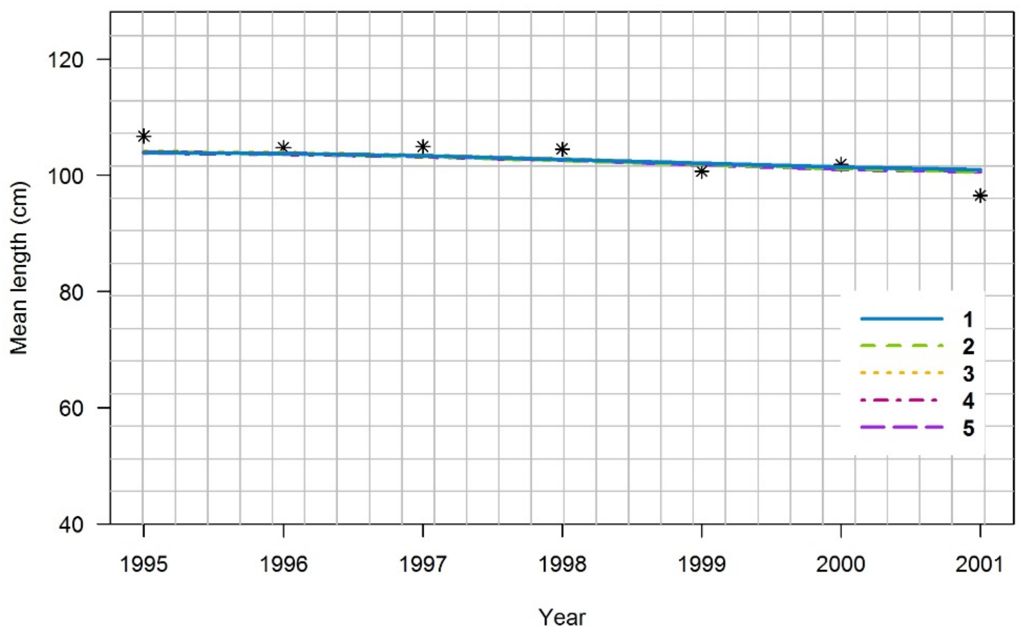

Figure A12: MPD fits to longline fishery mean length data for model runs (1) Base, (2) Longline, (3) All, (4) M, and (5) Selectivity.

APPENDIX B: MCMC CONVERGENCE AND DISTRIBUTION PLOTS

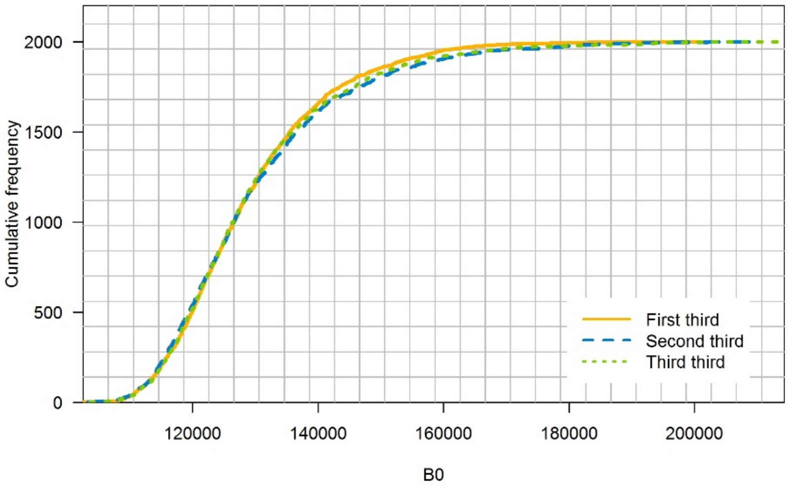

Figure B1: MCMC cumulative frequencies of B0 for the first (solid gold line), second (dashed blue line) and third (dotted green line) third of the MCMC chain for Base model run with free *q*.

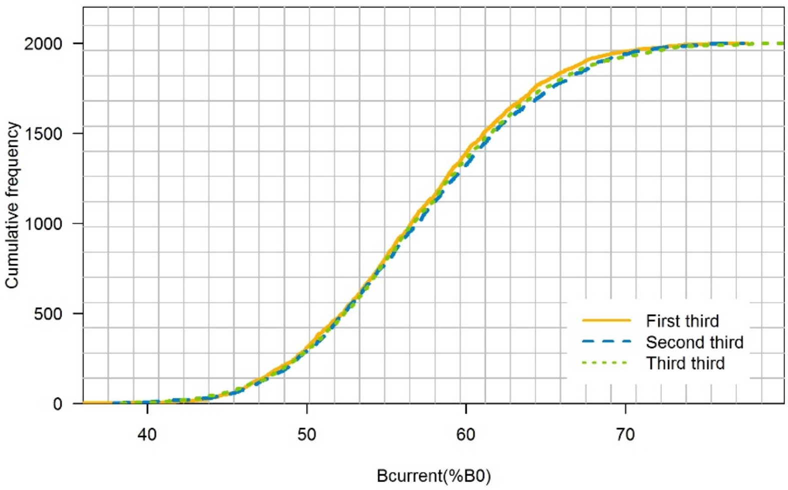

Figure B2: MCMC cumulative frequencies of $B_{current}(\%B_0)$ for the first (solid gold line), second (dashed blue line) and third (dotted green line) third of the MCMC chain for Base model run with free *q*.

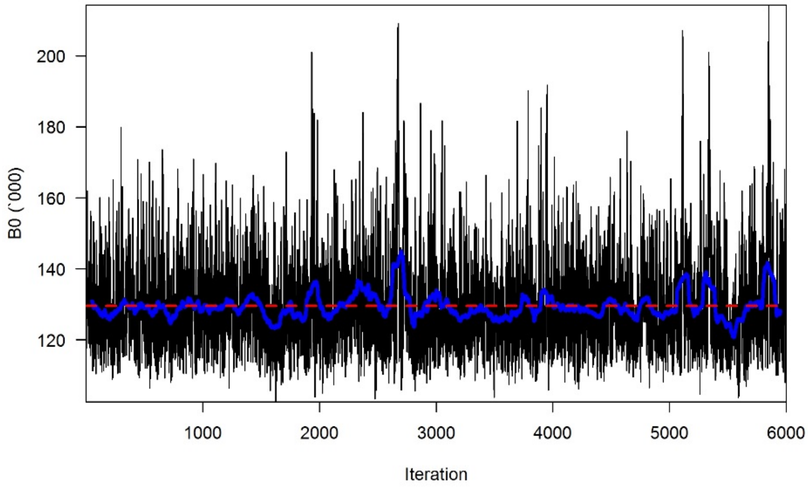

Figure B3: Trace diagnostic plot of the MCMC chain for B_0 in the Base model run with free *q*. The red dashed line is the mean of the entire chain, the blue line is the moving mean of 100 points of the chain.

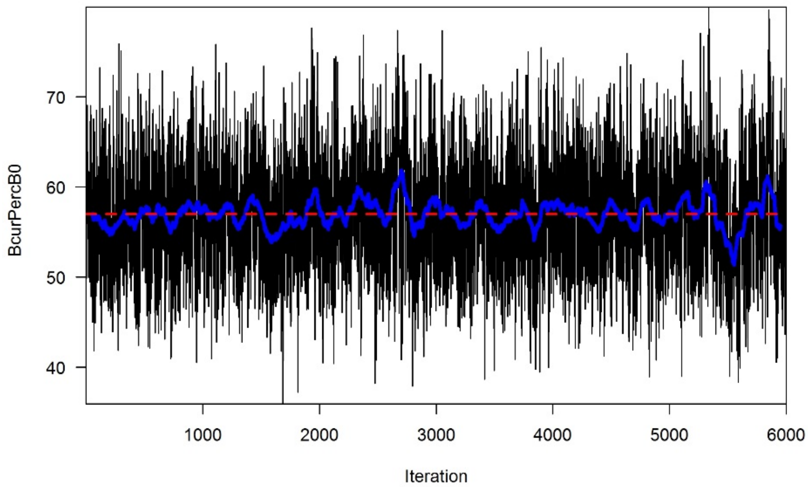

Figure B4: Trace diagnostic plot of the MCMC chain for $B_{current}$(%B_0) in the Base model run with free *q*. The red dashed line is the mean of the entire chain, the blue line is the moving mean of 100 points of the chain.

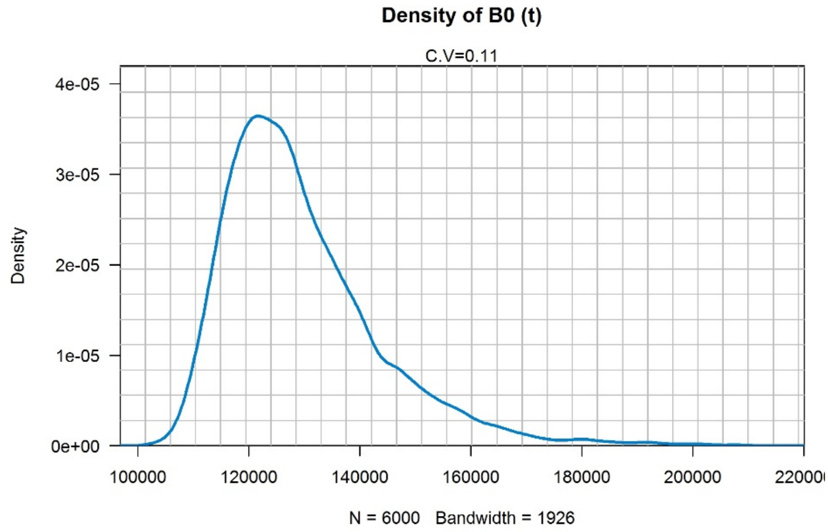

Figure B5: Estimated posterior distribution for B_0 in Base model run.

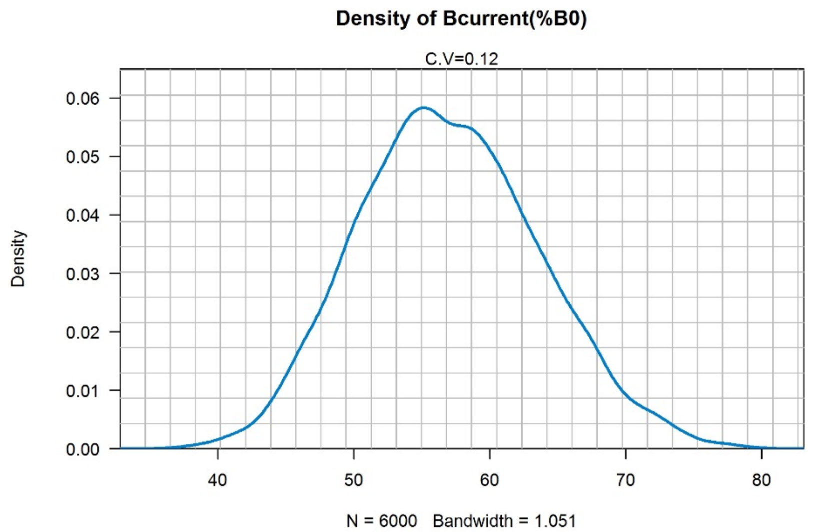

Figure B6: Estimated posterior distribution for $B_{current}$(%B_0) in Base model run.

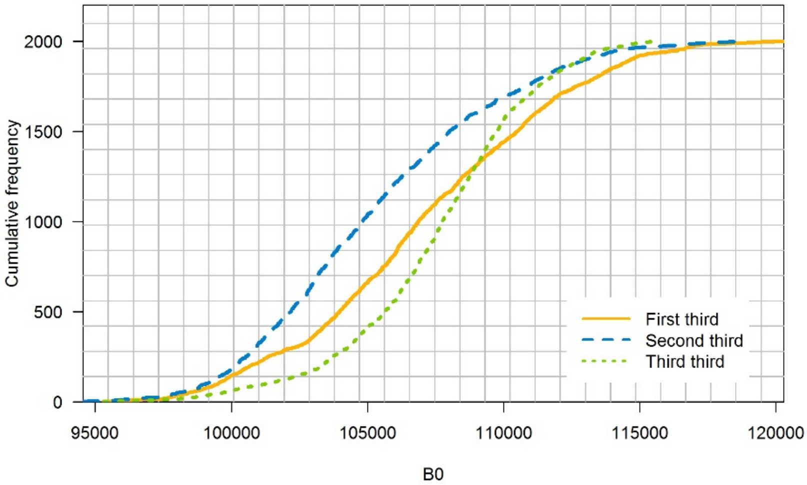

Figure B7: MCMC cumulative frequencies of B_0 for the first (solid gold line), second (dashed blue line) and third (dotted green line) third of the MCMC chain for Longline model run with free *q*.

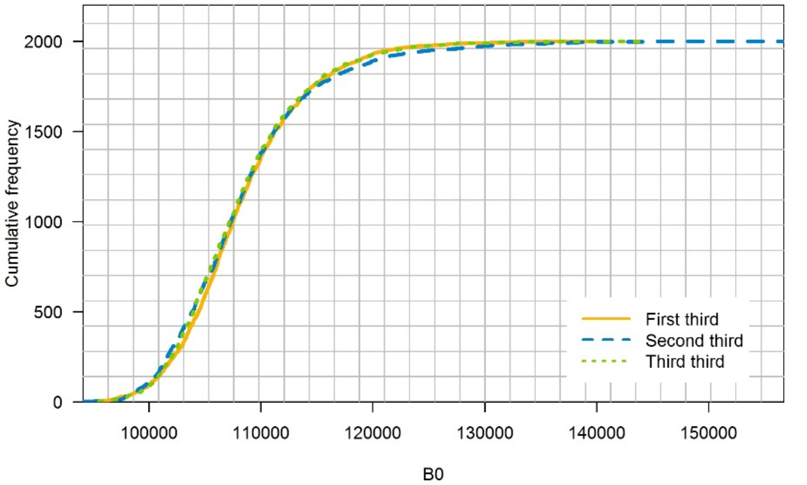

Figure B8: MCMC cumulative frequencies of B_0 for the first (solid gold line), second (dashed blue line) and third (dotted green line) third of the MCMC chain for Longline model run with nuisance *q*.

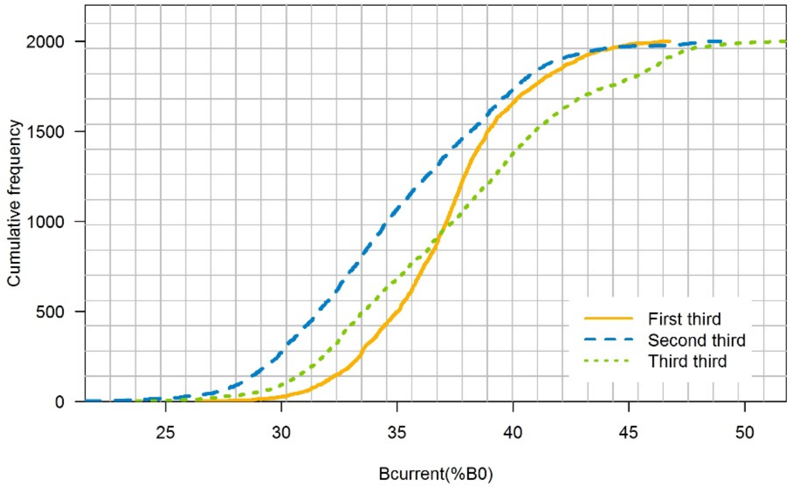

Figure B9: MCMC cumulative frequencies of $B_{current}(\%B_0)$ for the first (solid gold line), second (dashed blue line) and third (dotted green line) third of the MCMC chain for Longline model run with free *q*.

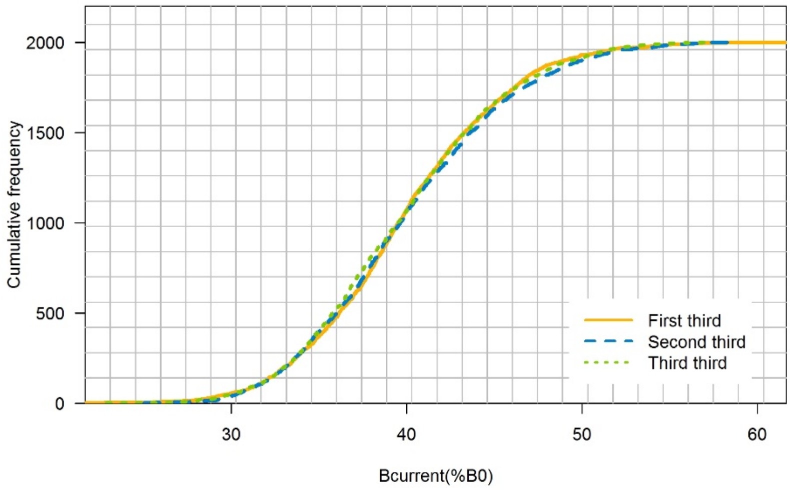

Figure B10: MCMC cumulative frequencies of $B_{current}(\%B_0)$ for the first (solid gold line), second (dashed blue line) and third (dotted green line) third of the MCMC chain for Longline model run with nuisance *q*.

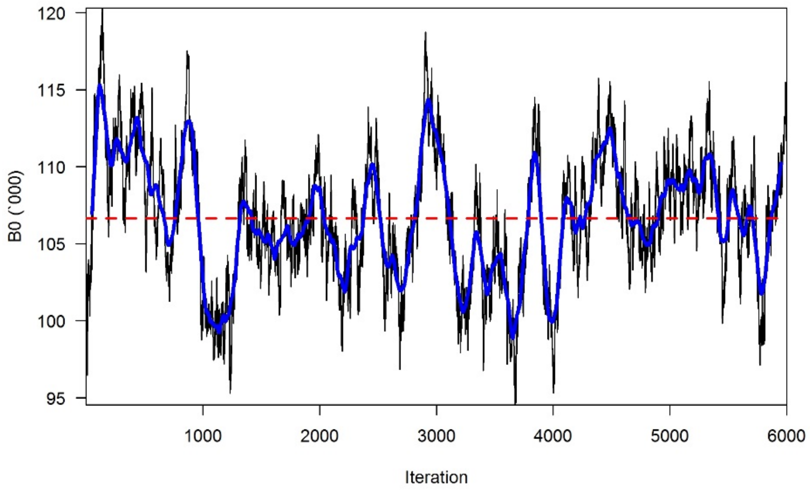

Figure B11: Trace diagnostic plot of the MCMC chain for B_0 in the Longline model run with free *q*. The red dashed line is the mean of the entire chain, the blue line is the moving mean of 100 points of the chain.

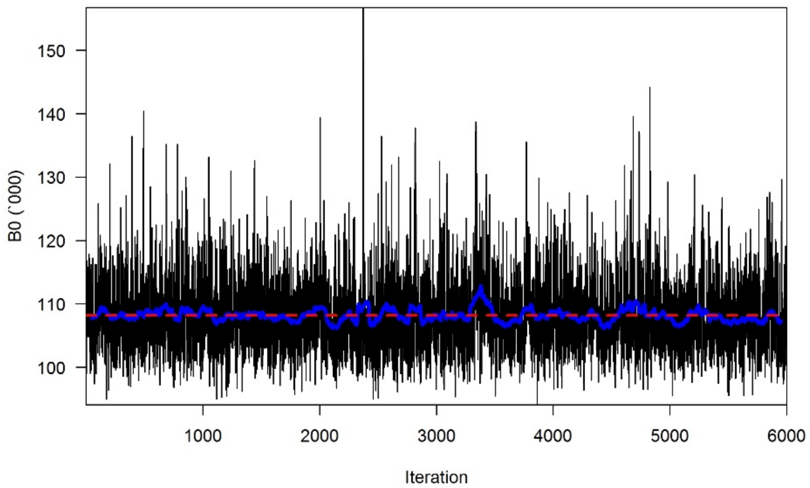

Figure B12: Trace diagnostic plot of the MCMC chain for B_0 in the Longline model run with nuisance *q*. The red dashed line is the mean of the entire chain, the blue line is the moving mean of 100 points of the chain.

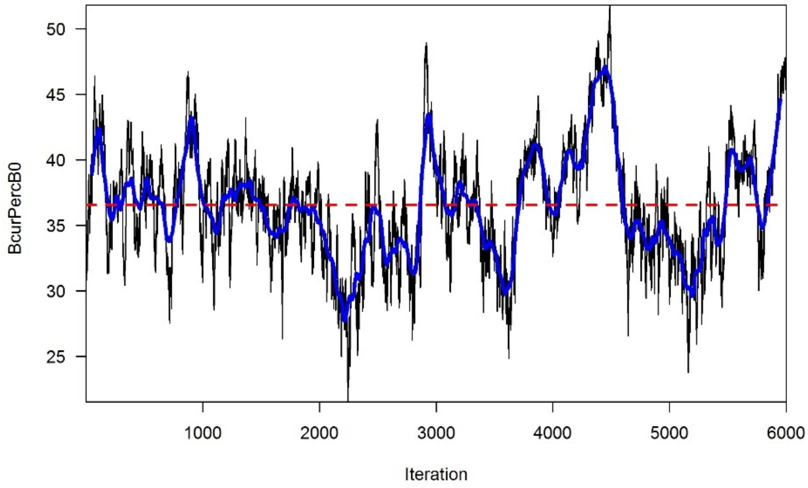

Figure B13: Trace diagnostic plot of the MCMC chain for $B_{current}(\%B_0)$ in the Longline model run with free *q*. The red dashed line is the mean of the entire chain, the blue line is the moving mean of 100 points of the chain.

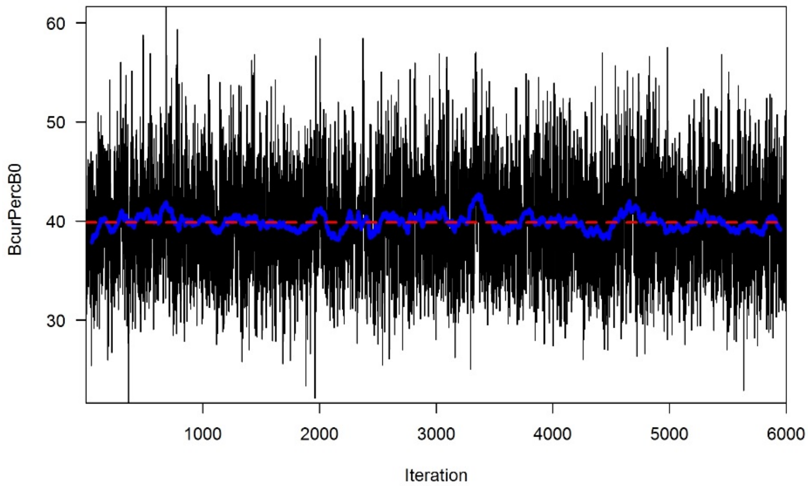

Figure B14: Trace diagnostic plot of the MCMC chain for $B_{current}(\%B_0)$ in the Longline model run with nuisance *q*. The red dashed line is the mean of the entire chain, the blue line is the moving mean of 100 points of the chain.

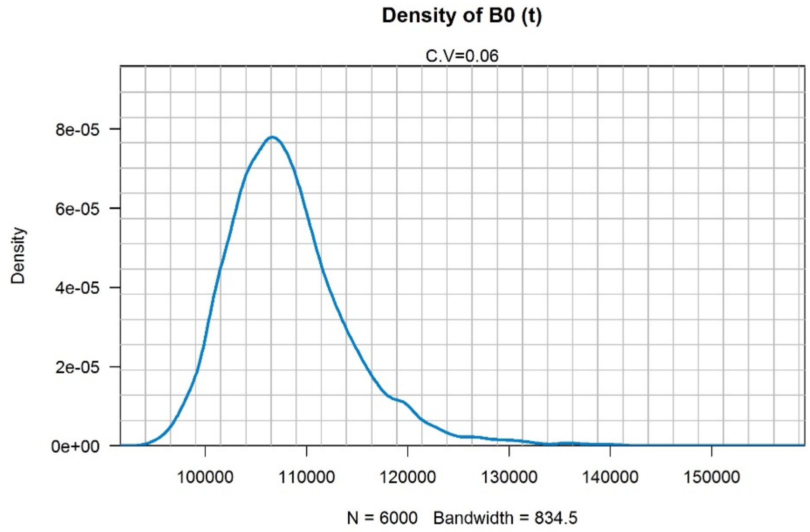

Figure B15: Estimated posterior distribution for B_0 in Longline model run.

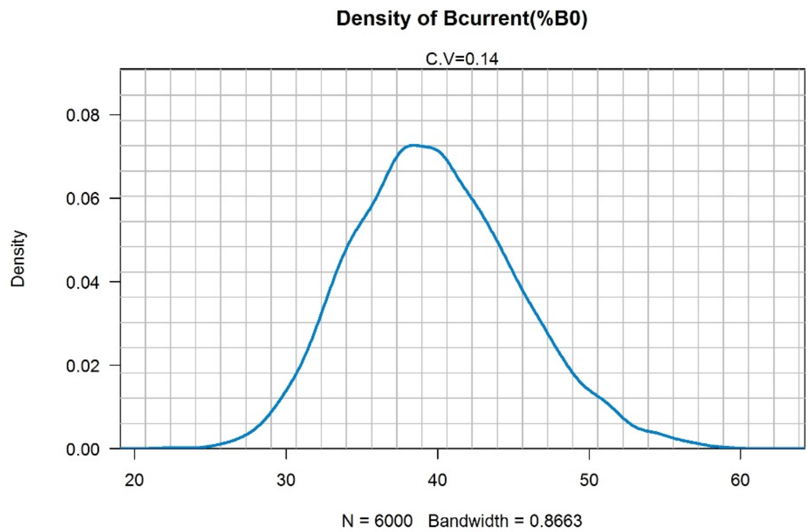

Figure B16: Estimated posterior distribution for $B_{current}$(%B_0) in Longline model run.

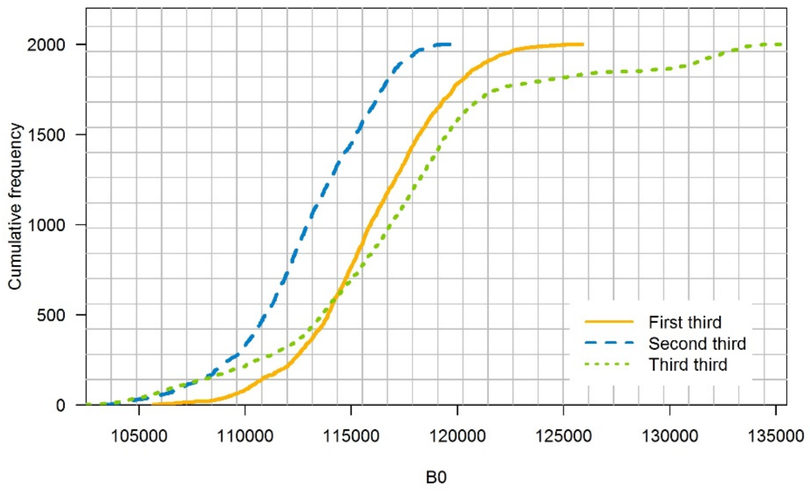

Figure B17: MCMC cumulative frequencies of B_0 for the first (solid gold line), second (dashed blue line) and third (dotted green line) third of the MCMC chain for All model run with free *q*'s.

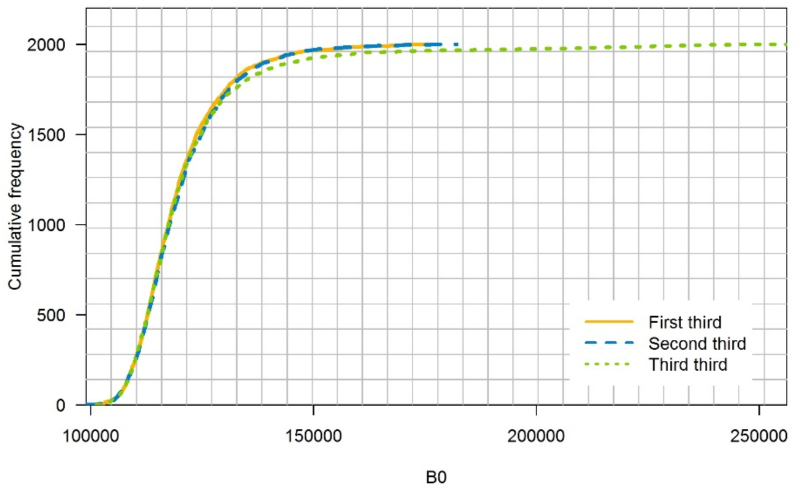

Figure B18: MCMC cumulative frequencies of B_0 for the first (solid gold line), second (dashed blue line) and third (dotted green line) third of the MCMC chain for All model run with nuisance *q*'s.

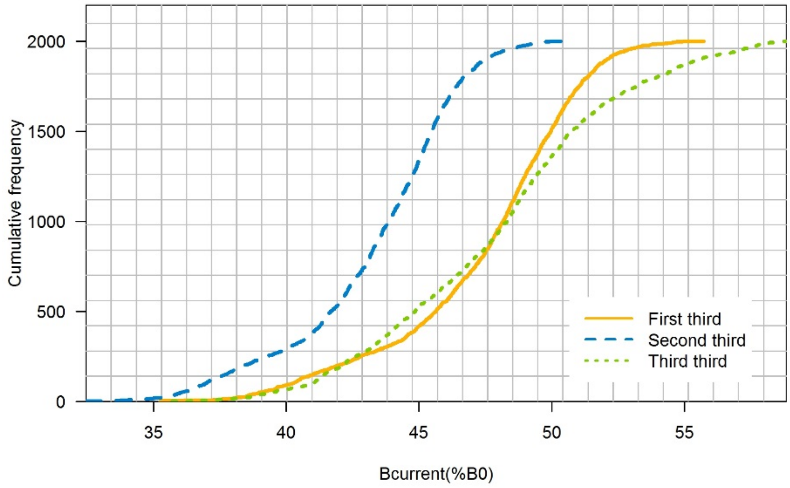

Figure B19: MCMC cumulative frequencies of $B_{current}(\%B_0)$ for the first (solid gold line), second (dashed blue line) and third (dotted green line) third of the MCMC chain for All model run with free *q*'s.

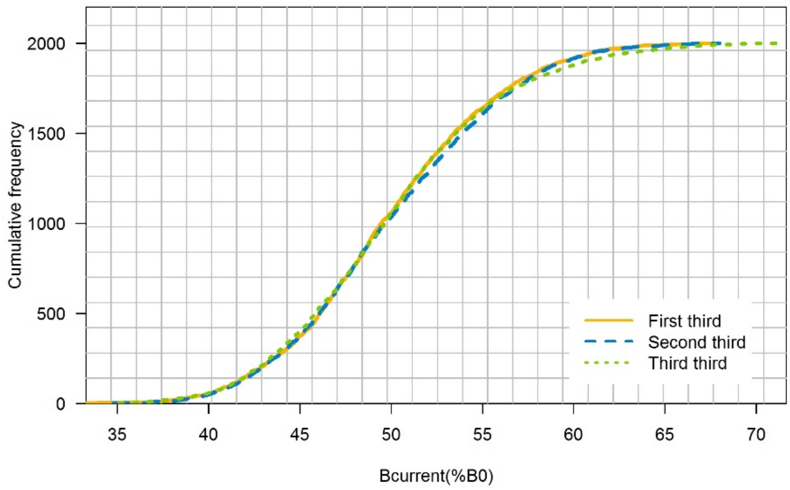

Figure B20: MCMC cumulative frequencies of $B_{current}(\%B_0)$ for the first (solid gold line), second (dashed blue line) and third (dotted green line) third of the MCMC chain for All model run with nuisance *q*'s.

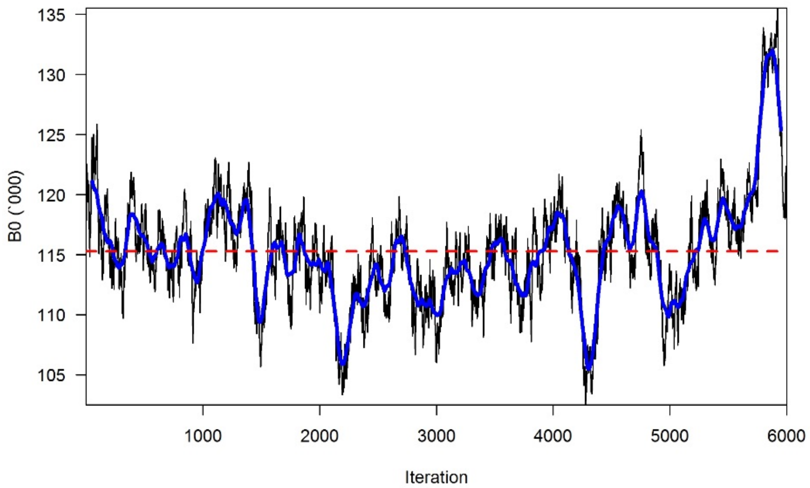

Figure B21: Trace diagnostic plot of the MCMC chain for B_0 in the All model run with free *q*'s. The red dashed line is the mean of the entire chain, the blue line is the moving mean of 100 points of the chain.

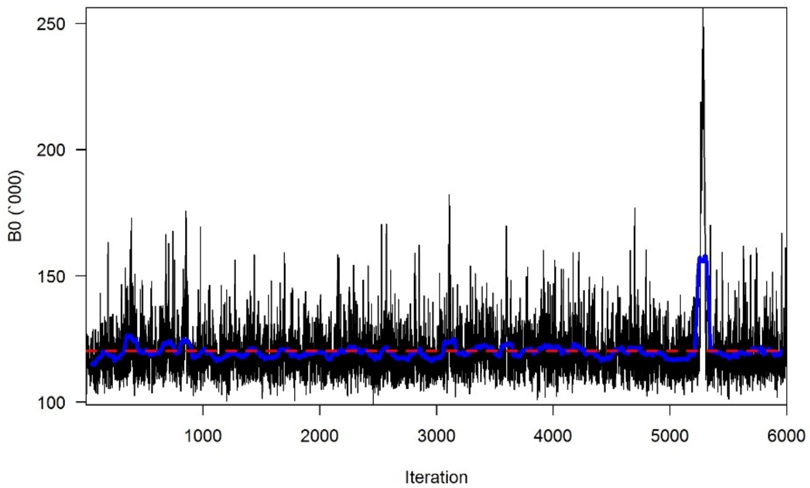

Figure B22: Trace diagnostic plot of the MCMC chain for B_0 in the All model run with nuisance *q*'s. The red dashed line is the mean of the entire chain, the blue line is the moving mean of 100 points of the chain.

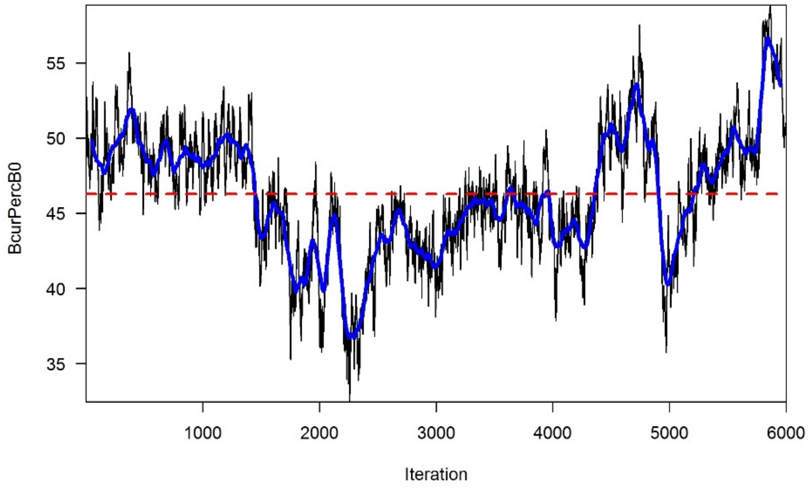

Figure B23: Trace diagnostic plot of the MCMC chain for $B_{current}$(%B_0) in the All model run with free *q*'s. The red dashed line is the mean of the entire chain, the blue line is the moving mean of 100 points of the chain.

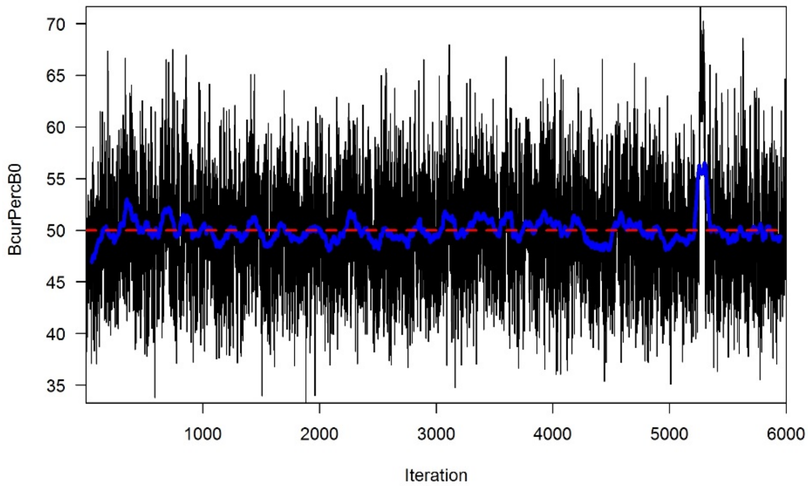

Figure B24: Trace diagnostic plot of the MCMC chain for $B_{current}$(%B_0) in the All model run with nuisance *q*'s. The red dashed line is the mean of the entire chain, the blue line is the moving mean of 100 points of the chain.

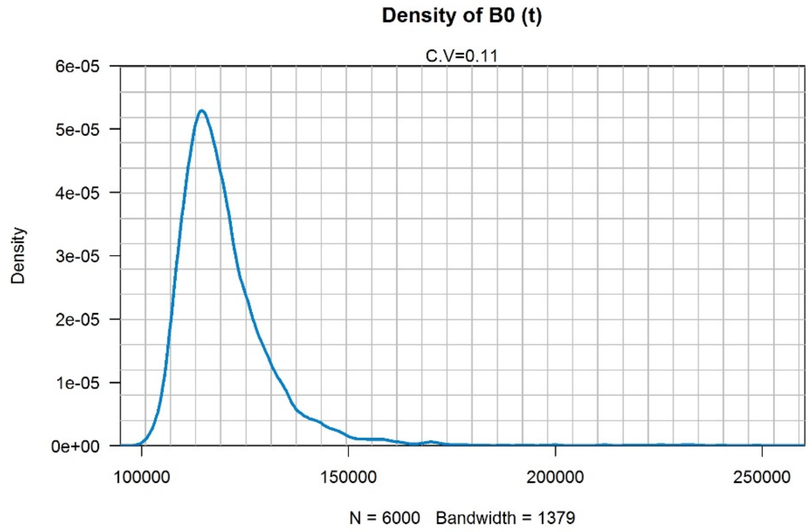

Figure B25: Estimated posterior distribution for B_0 in All model run.

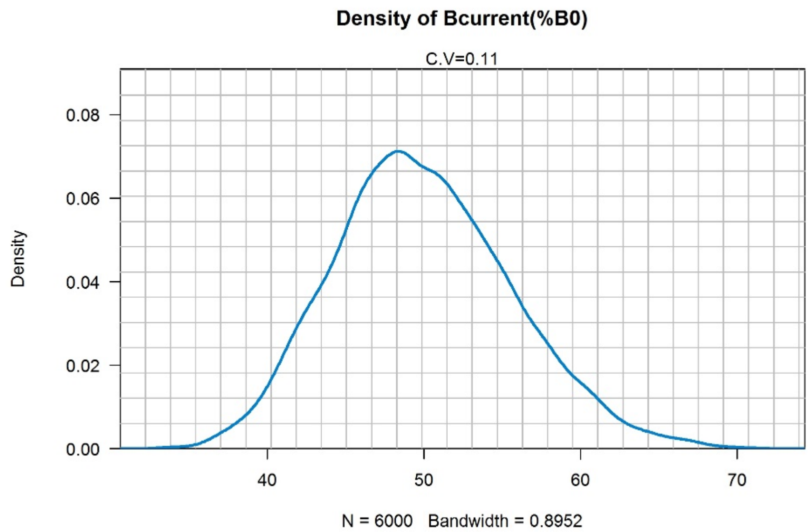

Figure B26: Estimated posterior distribution for $B_{current}$(%B_0) in All model run.

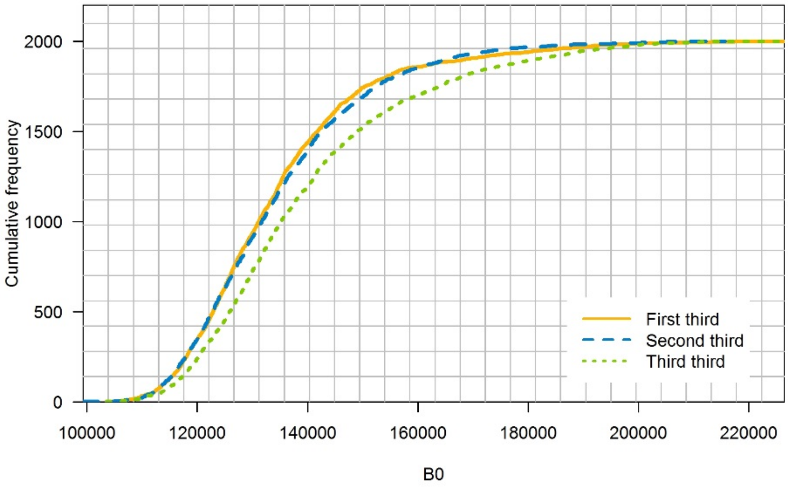

Figure B27: MCMC cumulative frequencies of B_0 for the first (solid gold line), second (dashed blue line) and third (dotted green line) third of the MCMC chain for M model run with free *q*.

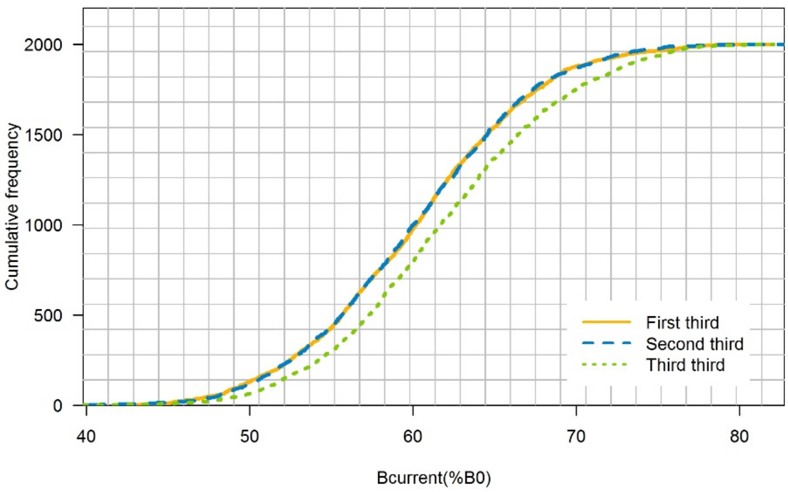

Figure B28: MCMC cumulative frequencies of $B_{current}$(%B_0) for the first (solid gold line), second (dashed blue line) and third (dotted green line) third of the MCMC chain for M model run with free *q*.

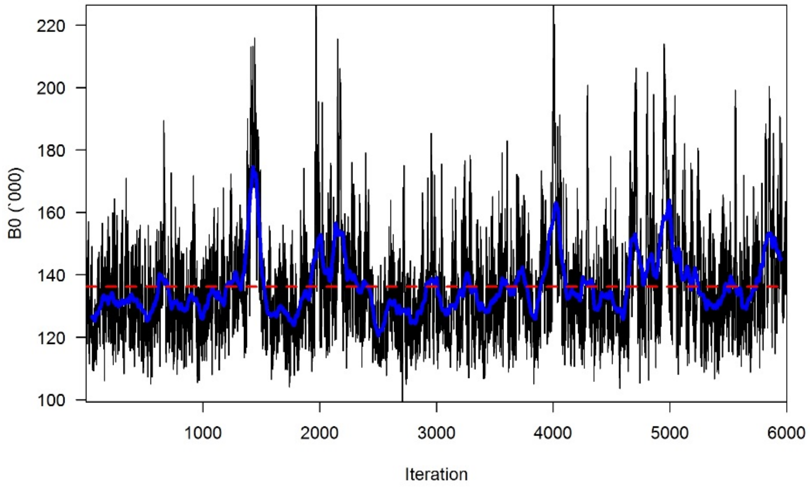

Figure B29: Trace diagnostic plot of the MCMC chain for B_0 in the M model run with free *q*. The red dashed line is the mean of the entire chain, the blue line is the moving mean of 100 points of the chain.

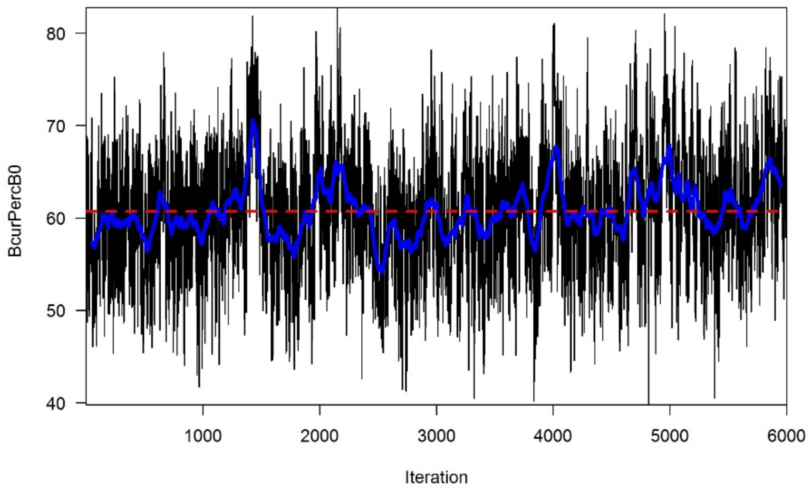

Figure B30: Trace diagnostic plot of the MCMC chain for $B_{current}$(%B_0) in the M model run with free *q*. The red dashed line is the mean of the entire chain, the blue line is the moving mean of 100 points of the chain.

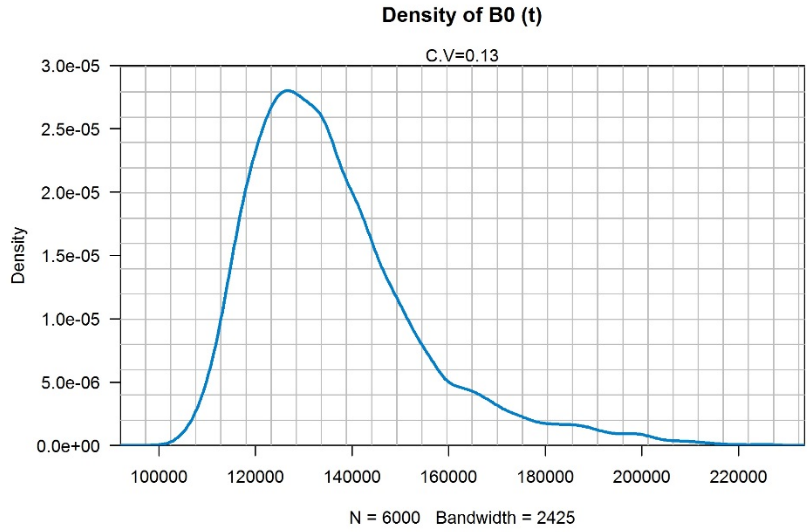

Figure B31: Estimated posterior distribution for B_0 in M model run.

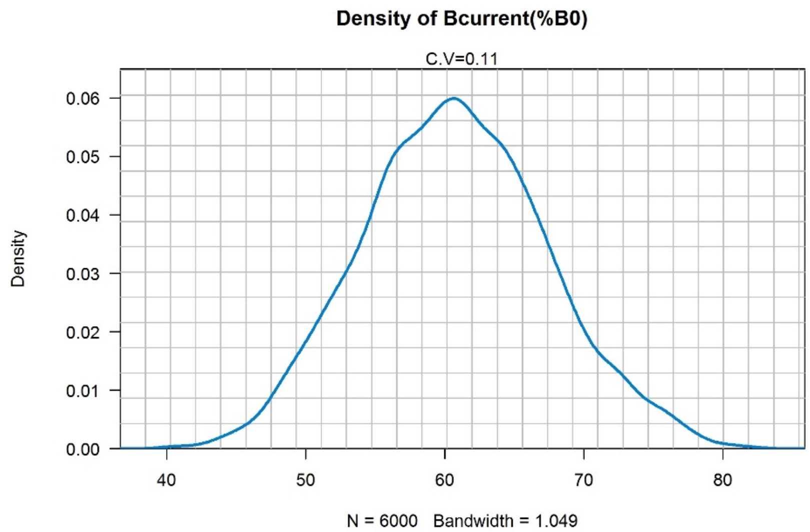

Figure B32: Estimated posterior distribution for $B_{current}(\%B_0)$ in M model run.