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Stock assessment of ling (*Genypterus blacodes*) on the Chatham Rise (LIN 3&4) and in the Sub-Antarctic (LIN 5&6) for the 2011–12 fishing year

New Zealand Fisheries Assessment Report 2013/6.

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EXECUTIVE SUMMARY

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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 16 and 17 in Cook Strait). These stocks are subsequently referred to as LIN 3&4, LIN 5&6, LIN 6B, LIN 7WC, and LIN 7CK, respectively.

Updated Bayesian assessments are presented for the LIN 3&4 (Chatham Rise) and LIN 5&6 (Sub-Antarctic) stocks, using the general-purpose stock assessment program CASAL v2.22. The assessments incorporated all relevant biological parameters, the commercial catch histories, series of trawl survey estimates of relative abundance, 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 is estimated to be about 55% 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 all produced similar estimates of current stock status and size. A model excluding long line fishery data in favour of trawl survey data was used as the base case, giving primacy to fishery-independent data. That model estimated that B_0 was about 127 000 t, and was very unlikely to be lower than 110 000 t; B_{2011} was about 71 000 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.

The current status of the LIN 5&6 stock is estimated to be about 89% B_0, although the level of absolute biomass is uncertain because there is little contrast in any of the abundance indices. The assessment incorporates uncertainty in *M* by estimating an *M*-at-age relationship for this parameter in the model. The resulting relationship was biologically plausible. Four models were examined, and all produced similar estimates of current stock status and similar *M*-at-age relationships. The model fitting double-normal selectivity ogives to trawl data (surveys and commercial fishery) and logistic selectivity ogives to the line fishery data was considered the most realistic of those presented. That model estimates that B_0 was about 330 000 t, and was very unlikely to be lower than 220 000 t; B_{2011} is about 290 000 t. Current stock size of LIN 5&6 is estimated to be well above the management target of 40% B_0, and is likely to increase over the next five years at the most recent catch level or at the level of the TACC.

1. INTRODUCTION

This document reports the results of Ministry of Fisheries Project DEE201002LINA. The specific project objective was to carry out a descriptive analysis of the commercial catch and effort data, update the standardised catch and effort analyses from the ling fisheries, and conduct stock assessments, including estimating biomass and sustainable yields, for LIN 3 & 4 and LIN 5 & 6 in 2011–12. The assessments are reported in the main body of this document. The updated descriptive analysis is presented in Appendix A, and the CPUE updates are presented in Appendix B. Because the assessment of the Sub-Antarctic stock is reported here, a previously unpublished analysis of the distribution of ling biomass in LIN 5 and LIN 6 is presented in Appendix C.

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 16 and 17). These stocks are referred to as LIN 3&4, LIN 5&6, LIN 6B, LIN 7WC, and LIN 7CK, respectively. The most recently reported assessments of these stocks are as follows: LIN 3&4 and LIN 5&6 (Horn 2008), LIN 6B (Horn 2007b), LIN 7CK (Horn & Francis 2013), and LIN 7WC (Horn 2009).

The current assessments used CASAL v2.22, a generalised age- or length-structured fish stock assessment model (Bull et al. 2012). The LIN 3&4 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. The LIN 5&6 assessment incorporates two trawl survey biomass series, catch-at-age data from both research survey series and from line and trawl fisheries, catch-at-length data from the line fishery, and two line fishery CPUE series.

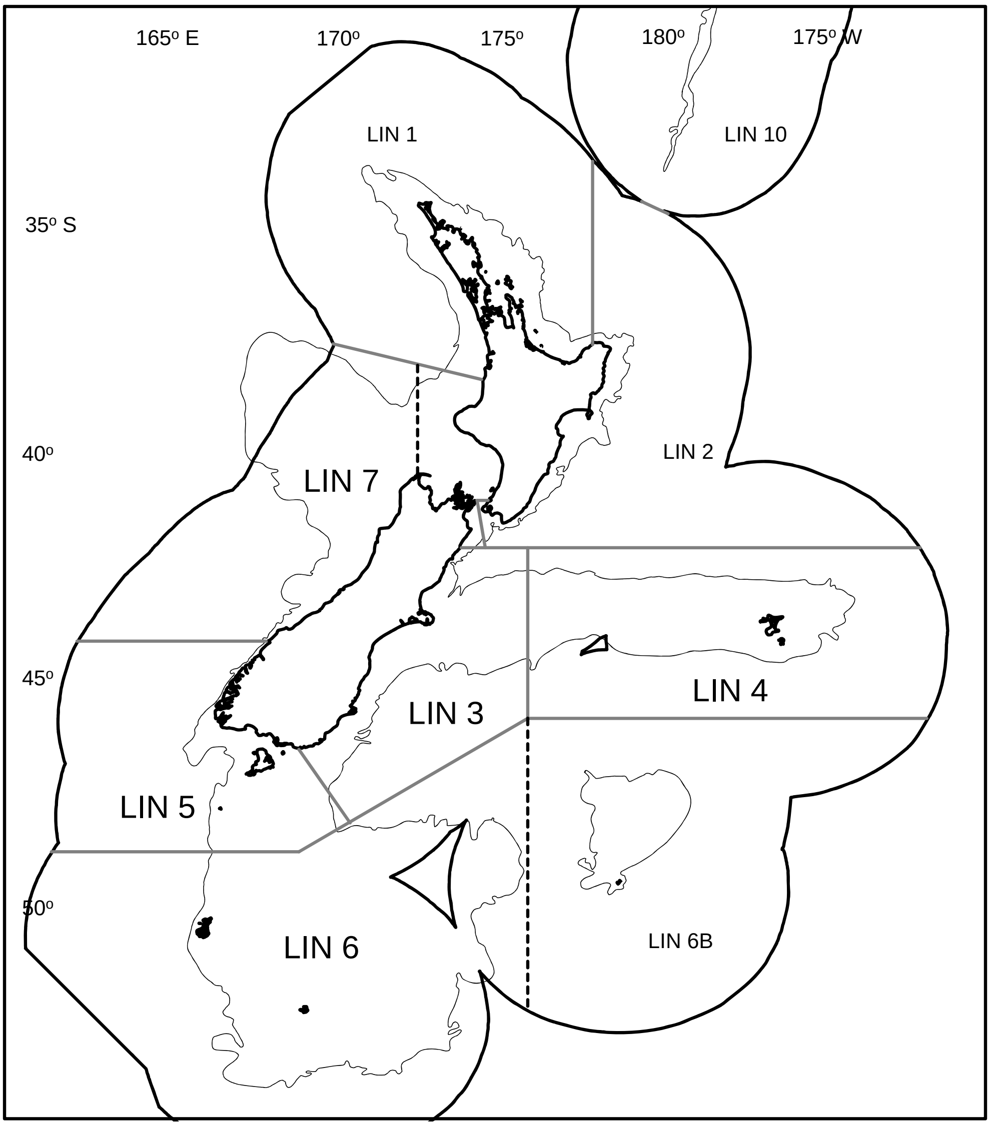

Figure 1: Area of Fishstocks LIN 3, 4, 5, 6, and 7. Adjacent ling fishstock areas are also shown, as is the 1000 m isobath. The boundaries used to separate biological stock LIN 6B from the rest of LIN 6, and the west coast South Island section of LIN 7 from the rest of LIN 7, are shown as broken lines.

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 (and to a lesser extent in other areas) 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, 4, 5, and 6 (Table 2), although since about 2000 there has been a decline in the line catch in most areas, but most markedly in LIN 5&6 (Appendix A). In some areas this decline in line catches was concurrent with an increase in trawl catches. Landings on the Bounty Plateau are taken almost exclusively by longline. A small, but important, quantity of ling is also taken by setnet in LIN 3 and LIN 7. In the west coast South Island section of LIN 7, about two-thirds of ling landings are taken as a trawl bycatch, primarily of the hoki fishery. In Cook Strait, about 75% of ling landings are taken as a bycatch of the hoki trawl fishery, with the remaining landings generally made by the target line fishery (Appendix A).

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 c.v. 10% or less) over the 5 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). Also under the AMP, the TACC for LIN 1 was increased to 400 t from 1 October 2002, within an overall TAC of 463 t.

TACCs for LIN 5 and 6 have been increased by about 20% to 3600 t and 8500 t, respectively, from 1 October 2004. This followed an assessment (Horn 2004a) indicating that the level of exploitation during the 1990s had little impact on the size of the Sub-Antarctic stock.

The TACC for LIN 7 has been consistently exceeded throughout the 1990s, sometimes by as much as 50%. It is strongly believed that landings of ling by trawlers off the west coast of South Island (WCSI) were under-reported in fishing years 1989–90 to 1992–93; an adjusted catch history is presented in Table 2. Dunn (2003a) investigated the extent of likely misreporting of hake from HAK 7 to other hake stocks from 1989–90 to 2000–01, and he extended this investigation to ling (Dunn 2003b). He concluded that any misreporting from LIN 7 to LIN 5&6 was minimal, but that the levels of misreporting from LIN 7 to LIN 3&4 could have been about 250–400 t annually in the three fishing years from 1997–98 to 1999–2000. However, the accuracy of these estimates is unknown.

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
Fishing Year	Domestic	Chartered	Total	(Japan + Korea)	Japan	Korea	USSR	Total	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 by Fishstock from 1983–84 to 2009–10 and actual TACCs (t) from 1986–87 to 2009–10. Estimated landings for LIN 7 from 1987–88 to 1992–93 include an adjustment for ling bycatch of hoki trawlers, based on records from vessels carrying observers.

Fishstock	LIN 1		LIN 2		LIN 3		LIN 4		LIN 5	
QMA (s)	1 & 9		2		3		4		5	
	Landings	TACC	Landings	TACC	Landings	TACC	Landings	TACC	Landings	TACC
1983–84*	141	–	594	–	1 306	–	352	–	2 605	–
1984–85*	94	–	391	–	1 067	–	356	–	1 824	–
1985–86*	88	–	316	–	1 243	–	280	–	2 089	–
1986–87#	77	200	254	910	1 311	1 850	465	4 300	1 859	2 500
1987–88#	68	237	124	918	1 562	1 909	280	4 400	2 213	2 506
1988–89#	216	237	570	955	1 665	1 917	232	4 400	2 375	2 506
1989–90#	121	265	736	977	1 876	2 137	587	4 401	2 277	2 706
1990–91#	210	265	951	977	2 419	2 160	2 372	4 401	2 285	2 706
1991–92#	241	265	818	977	2 430	2 160	4 716	4 401	3 863	2 706
1992–93#	253	265	944	980	2 246	2 162	4 100	4 401	2 546	2 706
1993–94#	241	265	779	980	2 171	2 167	3 920	4 401	2 460	2 706
1994–95#	261	265	848	980	2 679	2 810	5 072	5 720	2 557	3 001
1995–96#	245	265	1 042	980	2 956	2 810	4 632	5 720	3 137	3 001
1996–97#	313	265	1 187	982	2 963	2 810	4 087	5 720	3 438	3 001
1997–98#	303	265	1 032	982	2 916	2 810	5 215	5 720	3 321	3 001
1998–99#	208	265	1 070	982	2 706	2 810	4 642	5 720	2 937	3 001
1999–00#	313	265	983	982	2 799	2 810	4 402	5 720	3 136	3 001
2000–01#	296	265	1 104	982	2 330	2 060	3 861	4 200	3 430	3 001
2001–02#	303	265	1 034	982	2 164	2 060	3 602	4 200	3 294	3 001
2002–03#	246	400	996	982	2 528	2 060	2 997	4 200	2 936	3 001
2003–04#	249	400	1 044	982	1 990	2 060	2 617	4 200	2 899	3 001
2004–05#	283	400	936	982	1 597	2 060	2 758	4 200	3 584	3 595
2005–06#	364	400	780	982	1 710	2 060	1 769	4 200	3 522	3 595
2006–07#	301	400	874	982	2 089	2 060	2 113	4 200	3 731	3 595
2007–08#	381	400	792	982	1 778	2 060	2 383	4 200	4 145	3 595
2008–09#	320	400	634	982	1 751	2 060	2 000	4 200	3 232	3 595
2009–10#	386	400	584	982	1 715	2 060	2 026	4 200	3 034	3 595

Fishstock	LIN 6		LIN 7			LIN 10			
QMA (s)	6		7 & 8			10		Total	
	Landings	TACC	Reported Landings	Estimated Landings	TACC	Landings	TACC	Landings§	TACC
1983–84*	869	–	1 552	–	–	0	–	7 696	–
1984–85*	1 283	–	1 705	–	–	0	–	6 953	–
1985–86*	1 489	–	1 458	–	–	0	–	7 205	–
1986–87#	956	7 000	1 851	–	1 960	0	10	6 940	18 730
1987–88#	1 710	7 000	1 853	1 777	2 008	0	10	7 901	18 988
1988–89#	340	7 000	2 956	2 844	2 150	0	10	8 404	19 175
1989–90#	935	7 000	2 452	3 171	2 176	0	10	9 028	19 672
1990–91#	2 738	7 000	2 531	3 149	2 192	<1	10	13 506	19 711
1991–92#	3 459	7 000	2 251	2 728	2 192	0	10	17 778	19 711
1992–93#	6 501	7 000	2 475	2 817	2 212	<1	10	19 065	19 737
1993–94#	4 249	7 000	2 142	–	2 213	0	10	15 961	19 741
1994–95#	5 477	7 100	2 946	–	2 225	0	10	19 841	22 111
1995–96#	6 314	7 100	3 102	–	2 225	0	10	21 428	22 111
1996–97#	7 510	7 100	3 024	–	2 225	0	10	22 522	22 113
1997–98#	7 331	7 100	3 027	–	2 225	0	10	23 145	22 113
1998–99#	6 112	7 100	3 345	–	2 225	0	10	21 034	22 113
1999–00#	6 707	7 100	3 274	–	2 225	0	10	21 615	22 113
2000–01#	6 177	7 100	3 352	–	2 225	0	10	20 552	19 843
2001–02#	5 945	7 100	3 219	–	2 225	0	10	19 565	19 843
2002–03#	6 283	7 100	2 917	–	2 225	0	10	18 909	19 978
2003–04#	7 032	7 100	2 927	–	2 225	0	10	18 760	19 978
2004–05#	5 506	8 505	2 522	–	2 225	0	10	17 186	21 977
2005–06#	3 553	8 505	2 479	–	2 225	0	10	14 182	21 977
2006–07#	4 696	8 505	2 295	–	2 225	0	10	16 102	21 977
2007–08#	4 502	8 505	2 282	–	2 225	0	10	16 264	21 977
2008–09#	2 977	8 505	2 223	–	2 225	0	10	13 139	21 977
2009–10#	2 414	8 505	2 432	–	2 474	0	10	12 591	22 226

* FSU data.
\# QMS data.
§ Includes landings from unknown areas before 1986–87, and areas outside the EEZ since 1995–96.

3. RESEARCH RESULTS

3.1 Catch-at-age

New catch-at-age distributions from the following samples were created as part of Project MID201001A, and were reported by Horn & Sutton (2012). All the samples extend existing series of catch-at-age data.

LIN 3&4: Trawl survey (TAN1101), Jan 2011
LIN 3&4: Commercial longline, Jun – Oct 2010
LIN 3&4: Commercial trawl, Oct 2009 – May 2010
LIN 5&6: Commercial longline (spawning fishery), Oct–Dec 2009
LIN 5&6: Commercial longline (non-spawning fishery), Feb–Jul 2010
LIN 5&6: Commercial trawl, Sep 2009 – Apr 2010
Cook Strait: Commercial trawl, Jun–Sep 2010

For the second time since 1993 there were insufficient length data and otoliths collected from the LIN 7 commercial trawl fishery off WCSI to enable the estimation of catch-at-age from the winter fishery (i.e., Jun–Sep 2010).

3.2 Catch-at-length

The initial formulation of series of numbers-at-length for ling from various trawl and longline fisheries was described by Horn (2002b). These series have been included in some previous stock assessment models where a lack of age data precludes their input as catch-at-age. However, considerable volumes of catch-at-age data are now available for most fisheries (both trawl and line). The only catch-at-length data that are now used as model inputs were derived for the Chatham Rise (LIN 3&4) stock from a logbook scheme set up in 1995 by SeaFIC (Langley 2001). That programme essentially ceased to function from the end of the 2005–06 fishing year.

4. MODEL INPUTS, STRUCTURE, AND ESTIMATION

4.1 Model input data

Estimated commercial landings histories for the five stocks are listed in Table 3. Landings up to 1972 are assumed to be zero, although it is very likely that small quantities of ling were taken in various areas before then. The split between method (and pre-spawning and spawning seasons for the LIN 5&6 longline fishery) since 1983 was based on reported estimated landings per month, pro-rated to equal total reported landings. Landings before 1983 were split into method and season, based on anecdotal information of fishing patterns at the time, as no quantitative information is available.

Estimates of biological parameters and assumed values for model parameters used in the assessments are given in Table 4. Growth and length-weight relationships were revised most recently by Horn (2006). *M* was initially set at 0.18 for all stocks (Horn 2000), but was revised on a stock by stock basis by Horn (2008). The maturity ogive represents the proportion of fish (in the virgin stock) that are estimated to be mature at each age. Ogives for LIN 3&4, LIN 5&6, and LIN 7WC are from Horn (2005). The LIN 6B and LIN 7CK ogives are assumed to be the same as for LIN 3&4 and LIN 7WC, respectively, in the absence of any data to otherwise determine them. 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 0.9) was assumed. Variability in the von Bertalanffy age-length relationship was assumed to be lognormal with a constant c.v. of 0.1.

Standardised CPUE series for the longline fisheries in LIN 3&4 and LIN 5&6 are derived and listed in Appendix B. The most recently derived CPUE series for other ling stocks were reported by Horn &

Ballara (2012). CPUE indices were used as relative biomass indices, with associated c.v.s estimated from the generalised linear model used to estimate relative year effects. Series of research trawl survey indices were available for LIN 3&4, LIN 5&6, and LIN 7WC (Table 5). Biomass estimates from the trawl surveys are used as relative biomass indices, with associated c.v.s estimated from the survey analysis.

The *Tangaroa* trawl survey catch data from LIN 3&4 and LIN 5&6 were also available as estimates of catch-at-age. For LIN 3&4, LIN 5&6, LIN 6B, LIN 7WC, and LIN 7CK, various series of catch-at-age data from the commercial trawl and longline fisheries were available (see Horn & Sutton 2012). Catch-at-age data were fitted to the model as proportions-at-age, where estimates of the proportions-at-age and associated c.v.s 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. This replacement was because zero values cannot be used with the error distribution assumed for some proportions-at-age data (i.e., lognormal). Ageing error for the observed proportions-at-age data was assumed to have a discrete normal distribution with c.v.s as defined in Table 4. The c.v.s varied between stocks because of perceived differences between stocks in the difficulty of reading otoliths (author's unpublished data).

Catch-at-length data (for the LIN 3&4 assessment only) were fitted to the model as proportions-at-length with associated c.v.s by length class. These data were also estimated using the software described above. Zero values of proportion-at-length were replaced with 0.0001.

A summary of all input data series, by stock, is given in Table 6. 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.] The c.v.s applied to each data set would then give appropriate weight to the signal provided by each series.

Table 3: Estimated catch histories (t) for LIN 3&4 (Chatham Rise), LIN 5&6 (Campbell Plateau), LIN 6B (Bounty Platform), LIN 7WC (WCSI section of LIN 7), and LIN 7CK (Cook Strait sections of LIN 7 and LIN 2). Landings have been separated by fishing method (trawl or line), and, for the LIN 5&6 line fishery, by pre-spawning (Pre) and spawning (Spn) season. The 2011 values are required for the current assessment; they are estimated based on recent landings trends. For LIN 6B, all landings up to 1990 were taken by trawl, and over 97% of all landings after 1990 were taken by line.

Year	LIN 3&4		LIN 5&6			LIN 6B	LIN 7WC		LIN 7CK	
	trawl	line	trawl	line Pre	line Spn	line	trawl	line	trawl	line
1972	0	0	0	0	0	0	0	0	0	0
1973	250	0	500	0	0	0	85	20	45	45
1974	382	0	1 120	0	0	0	144	40	45	45
1975	953	8 439	900	118	192	0	401	800	48	48
1976	2 100	17 436	3 402	190	309	0	565	2 100	58	58
1977	2 055	23 994	3 100	301	490	0	715	4 300	68	68
1978	1 400	7 577	1 945	494	806	10	300	323	78	78
1979	2 380	821	3 707	1 022	1 668	0	539	360	83	83
1980	1 340	360	5 200	0	0	0	540	305	88	88
1981	673	160	4 427	0	0	10	492	300	98	98
1982	1 183	339	2 402	0	0	0	675	400	103	103
1983	1 210	326	2 778	5	1	10	1 040	710	97	97
1984	1 366	406	3 203	2	0	6	924	595	119	119
1985	1 351	401	4 480	25	3	2	1 156	302	116	116
1986	1 494	375	3 182	2	0	0	1 082	362	126	126
1987	1 313	306	3 962	0	0	0	1 105	370	97	97
1988	1 636	290	2 065	6	0	0	1 428	291	107	107
1989	1 397	488	2 923	10	2	9	1 959	370	255	85
1990	1 934	529	3 199	9	4	11	2 205	399	362	121
1991	2 563	2 228	4 534	392	97	172	2 163	364	488	163
1992	3 451	3 695	6 237	566	518	1 430	1 631	661	498	85
1993	2 375	3 971	7 335	1 238	474	1 575	1 609	716	307	114
1994	1 933	4 159	5 456	770	486	875	1 136	860	269	84
1995	2 222	5 530	5 348	2 355	338	387	1 750	1 032	344	70
1996	2 725	4 863	6 769	2 153	531	588	1 838	1 121	392	35
1997	3 003	4 047	6 923	3 412	614	333	1 749	1 077	417	89
1998	4 707	3 227	6 032	4 032	581	569	1 887	1 021	366	88
1999	3 282	3 818	5 593	2 721	489	771	2 146	1 069	316	216
2000	3 739	2 779	7 089	1 421	1 161	1 319	2 247	923	317	131
2001	3 467	2 724	6 629	818	1 007	1 153	2 304	977	258	80
2002	2 979	2 787	6 970	426	1 220	623	2 250	810	230	171
2003	3 375	2 150	7 205	183	892	932	1 980	807	280	180
2004	2 525	2 082	7 826	774	471	860	2 013	814	241	227
2005	1 913	2 440	7 870	276	894	50	1 558	871	200	282
2006	1 639	1 840	6 161	178	692	43	1 753	666	129	220
2007	2 322	1 880	7 504	34	651	237	1 306	933	107	189
2008	2 350	1 810	6 990	329	821	507	1 067	1 170	115	110
2009	1 534	2 217	5 225	276	432	275	1 089	1 009	108	39
2010	1 484	2 257	4 270	864	313	2	1 346	1 063	74	14
2011	1 500	2 200	4 500	450	450	–	–	–	–	–

Table 4: Biological and other input parameters used in the ling assessments.

1. Natural mortality (M)

	Female	Male
All stocks (average)	0.18	0.18
LIN 3&4	0.14	0.14
LIN 5&6	0.20	0.20
LIN 7WC	0.20	0.20
LIN 7CK	0.22	0.22

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

	Female		Male	
	a	*b*	*a*	*b*
LIN 3&4	0.00114	3.318	0.00100	3.354
LIN 5&6	0.00128	3.303	0.00208	3.190
LIN 6B	0.00114	3.318	0.00100	3.354
LIN 7WC	0.000934	3.368	0.001146	3.318
LIN 7CK[#]	0.000934	3.368	0.001146	3.318

[#] Parameters assumed to be the same as for LIN 7WC, in the absence of data from Cook Strait.

3. von Bertalanffy growth parameters (n, sample size)

	Male				Female			
	n	*k*	t_0	L_∞	*n*	*k*	t_0	L_∞
LIN 3&4	3 964	0.127	–0.70	113.9	4 133	0.083	–0.74	156.4
LIN 5&6	2 884	0.188	–0.67	93.2	4 093	0.124	–1.26	115.1
LIN 6B	296	0.141	0.02	120.5	386	0.101	–0.53	146.2
LIN 7WC	2 366	0.067	–2.37	159.9	2 320	0.078	–0.87	169.3
LIN 7CK	348	0.080	–1.94	158.9	332	0.097	–0.54	163.6

4. Maturity ogives (proportion mature at age)

Age	3	4	5	6	7	8	9	10	11	12	13	14	15
LIN 3&4 (and assumed for LIN 6B)													
Male	0.0	0.027	0.063	0.14	0.28	0.48	0.69	0.85	0.93	0.97	0.99	1.00	1.0
Female	0.0	0.001	0.003	0.006	0.014	0.033	0.08	0.16	0.31	0.54	0.76	0.93	1.0
LIN 5&6													
Male	0.0	0.022	0.084	0.27	0.61	0.86	0.96	0.99	1.00	1.0			
Female	0.0	0.001	0.004	0.015	0.06	0.22	0.55	0.84	0.96	1.0			
LIN 7WC (and assumed for LIN 7CK)													
Male	0.0	0.015	0.095	0.39	0.77	0.94	1.00	1.00	1.00	1.0			
Female	0.0	0.004	0.017	0.06	0.18	0.39	0.65	0.85	0.94	1.0			

5. Miscellaneous parameters

Stock	3&4	5&6	6B	7WC	7CK
Stock-recruitment steepness	0.9	0.9	0.9	0.9	0.9
Recruitment variability c.v.	0.6	0.6	1.0	0.6	0.7
Ageing error c.v.	0.05	0.06	0.05	0.05	0.07
Proportion by sex at birth	0.5	0.5	0.5	0.5	0.5
Proportion spawning	1.0	1.0	1.0	1.0	1.0
Maximum exploitation rate (U_{max})	0.6	0.6	0.6	0.6	0.6

Table 5: Series of relative biomass indices (t) from *Tangaroa* (TAN) and *Kaharoa* (KAH) trawl surveys (with coefficients of variation, c.v.) available for the assessment modelling.

Fishstock	Area	Trip code	Date	Biomass (t)	c.v. (%)
LIN 3&4	Chatham Rise	TAN9106	Jan-Feb 1992	8 930	5.8
		TAN9212	Jan-Feb 1993	9 360	7.9
		TAN9401	Jan 1994	10 130	6.5
		TAN9501	Jan 1995	7 360	7.9
		TAN9601	Jan 1996	8 420	8.2
		TAN9701	Jan 1997	8 540	9.8
		TAN9801	Jan 1998	7 310	8.3
		TAN9901	Jan 1999	10 310	16.1
		TAN0001	Jan 2000	8 350	7.8
		TAN0101	Jan 2001	9 350	7.5
		TAN0201	Jan 2002	9 440	7.8
		TAN0301	Jan 2003	7 260	9.9
		TAN0401	Jan 2004	8 250	6.0
		TAN0501	Jan 2005	8 930	9.4
		TAN0601	Jan 2006	9 300	7.4
		TAN0701	Jan 2007	7 800	7.2
		TAN0801	Jan 2008	7 500	6.8
		TAN0901	Jan 2009	10 620	11.5
		TAN1001	Jan 2010	8 850	10.0
		TAN1101	Jan 2011	7 030	13.8
LIN 5&6	Campbell Plateau	TAN9105	Nov-Dec 1991	24 090	6.8
		TAN9211	Nov-Dec 1992	21 370	6.2
		TAN9310	Nov-Dec 1993	29 750	11.5
		TAN0012	Dec 2000	33 020	6.9
		TAN0118	Dec 2001	25 060	6.5
		TAN0219	Dec 2002	25 630	10.0
		TAN0317	Nov-Dec 2003	22 170	9.0
		TAN0414	Dec 2004	23 790	12.2
		TAN0515	Dec 2005	19 700	9.0
		TAN0617	Dec 2006	19 640	12.0
		TAN0714	Dec 2007	26 490	8.0
		TAN0813	Dec 2008	22 840	9.5
		TAN0911	Dec 2009	22 710	9.6
LIN 5&6	Campbell Plateau	TAN9204	Mar-Apr 1992	42 330	5.8
		TAN9304	Apr-May 1993	33 550	5.4
		TAN9605	Mar-Apr 1996	32 130	7.8
		TAN9805	Apr-May 1998	30 780	8.8
LIN 7WC	WCSI	KAH9204	Mar-Apr 1992	286	19
		KAH9404	Mar-Apr 1994	261	20
		KAH9504	Mar-Apr 1995	367	16
		KAH9701	Mar-Apr 1997	151	30
		KAH0004	Mar-Apr 2000	95	46
		KAH0304	Mar-Apr 2003	150	33
		KAH0503	Mar-Apr 2005	274	37
		KAH0704	Mar-Apr 2007	180	27
		KAH0904	Mar-Apr 2009	291	37
		KAH1104	Mar-Apr 2011	235	43

Table 6: Summary of the relative abundance series available for the assessment modelling, including source years (Years). The process error that was added to the observation error in the stocks that were modelled is also listed.

Data series	Years	Process error c.v.
LIN 3&4		
Trawl survey proportion at age (*Amaltal Explorer*, Dec)	1990	Variable
Trawl survey biomass (*Tangaroa*, Jan)	1992–2011	0.2
Trawl survey proportion at age (*Tangaroa*, Jan)	1992–2011	Variable
CPUE (longline, all year)	1990–2010	0.15
Commercial longline proportion-at-age (Jun–Oct)	2002–10	Variable
Commercial longline length-frequency (Jun–Oct)	1995–2002	Variable
Commercial trawl proportion-at-age (Oct–May)	1992, 1994–2010	Variable
LIN 5&6		
Trawl survey proportion at age (*Amaltal Explorer*, Nov)	1990	0.15
Trawl survey biomass (*Tangaroa*, Nov–Dec)	1992–94, 2001–10	0.01
Trawl survey proportion at age (*Tangaroa*, Nov–Dec)	1992–94, 2001–10	0.15
Trawl survey biomass (*Tangaroa*, Mar–May)	1992–93, 1996, 1998	0.01
Trawl survey proportion at age (*Tangaroa*, Mar–May)	1992–93, 1996, 1998	0.01
CPUE (longline, spawning fishery)	1991–2010	0.18
CPUE (longline, non-spawning fishery)	1991–2010	0.18
Commercial longline proportion-at-age (spawning, Oct–Dec)	2000–08, 2010	0.3
Commercial longline proportion-at-age (non-spawn, Feb–Jul)	1999, 2001, 2003, 2005, 2009, 2010	0.3
Commercial trawl proportion-at-age (Sep–Apr)	1992–94, 1996, 1998, 2001–10	0.3
LIN 6B		
CPUE (longline, all year)	1992–2004, 2006, 2007–09	
Commercial longline proportion-at-age (Nov–Mar)	1993, 2000–01, 2004, 2008–09	
LIN 7CK		
CPUE (hoki trawl, Jun–Sep)	1990–2009	
CPUE (longline, all year)	1990–2009	
Commercial trawl proportion-at-age (Jun–Sep)	1999–2010	
Commercial longline proportion-at-age (May–Sep)	2006–2007	
LIN 7WC		
CPUE (hoki trawl, Jun–Sep)	1999–2009	
CPUE (longline, all year)	1990–2009	
Commercial trawl proportion-at-age (Jun–Sep)	1991, 1994–2008	
Commercial longline proportion-at-age	2003	
Commercial longline length-frequency	2006	
Trawl survey biomass (*Kaharoa*, Mar–Apr)	1992, 94, 95, 97, 2000, 03, 05, 07, 09, 11	
Trawl survey proportion-at-length (*Kaharoa*, Mar–Apr)	1992, 94, 95, 97, 2000, 03, 05, 07, 09, 11	
Trawl survey biomass (*Tangaroa*, July)	2000	

4.2 Model structure

The LIN 3&4 and LIN 5&6 stocks were assessed in 2011. The stock assessment model partitions 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 Campbell Plateau stock is similarly modelled except that there are three fisheries: a trawl fishery, and line fisheries in the spawning season and non-spawning season. The model's annual cycle for the stocks is described in Table 7.

The selectivity ogives for the commercial trawl and line fisheries were age-based and were estimated in the model, separately by sex. The trawl survey and trawl fishery ogives were estimated using either a double normal or logistic parameterisation; the estimated line fishery ogives were 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. 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 7: Annual cycles of the LIN 3&4 and LIN 5&6 stock models, 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	$\%Z^3$
LIN 3&4						
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	–	
LIN 5&6						
1	Dec–Aug	Recruitment Non-spawning fisheries (trawl & line)	0.75	0.4	Trawl survey (summer) Trawl survey (autumn) Line CPUE (non-spawn) Line (non-spawn) catch-at-age/length Trawl catch-at-age	0.1 0.5 0.7
2	Sep–Nov	Increment ages Spawning fishery (line)	0.25	0.0	Line CPUE (spawning) Line (spawning) catch-at-age/length	0.5

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.

4.3 Model estimation

Model parameters were estimated using Bayesian estimation implemented using the CASAL v2.22 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 c.v. of 0.2 was added to the trawl survey biomass index following Francis et al. (2001), and a process error c.v. for the line fishery CPUE was estimated at 0.15 following Francis (2011). The multinomial effective sample sizes for the at-age and at-length data were adjusted using the reweighting procedure of Francis (2011).

For LIN 5&6, lognormal errors, with known c.v.s, were assumed for all relative biomass and proportions-at-age observations. The c.v.s available for those observations of relative abundance and proportion-at-age allow for sampling error only. However, additional process variance, assumed to arise from differences between model simplifications and real world variation, was added to the sampling variance. Process error was added to CPUE series so that the final point c.v.s were approximately 0.2, as recommended by Francis et al. (2001). Process error for catch-at-age and catch-at-length series was estimated in early MPD runs of the model, using all available data. Hence, the overall c.v. assumed in the model runs for each observation was calculated by adding process error and observation error. The process errors added to each input series are listed in Table 6.

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).

5. MODEL ESTIMATES for LIN 3&4 (CHATHAM RISE)

5.1 Developing a base model

The previous assessment of the Chatham Rise ling stock found that estimated biomass was very sensitive to relatively small changes in *M* (Horn 2008). Catch-at-age data also indicated that the *M* for the Chatham Rise stock was probably lower than the 'default' value of 0.18 used in many previous ling assessments (Horn 2008). As a result, proportions-at-age data were included in all model runs in this assessment, and *M* estimated.

The investigative phase of the stock assessment resulted in a large number of alternative model runs, but these are not all detailed here. Instead, only aspects of the runs necessary to illustrate particular characteristics of the assessment have been included.

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 c.v. of the residuals of the fit of the smoother to the data. An appropriate c.v. is chosen from the resulting plots qualitatively, and is the largest c.v. that still gives a smooth and good fit to the data. For the longline CPUE index, a process error c.v. of 0.15 was considered appropriate (Figure 2).

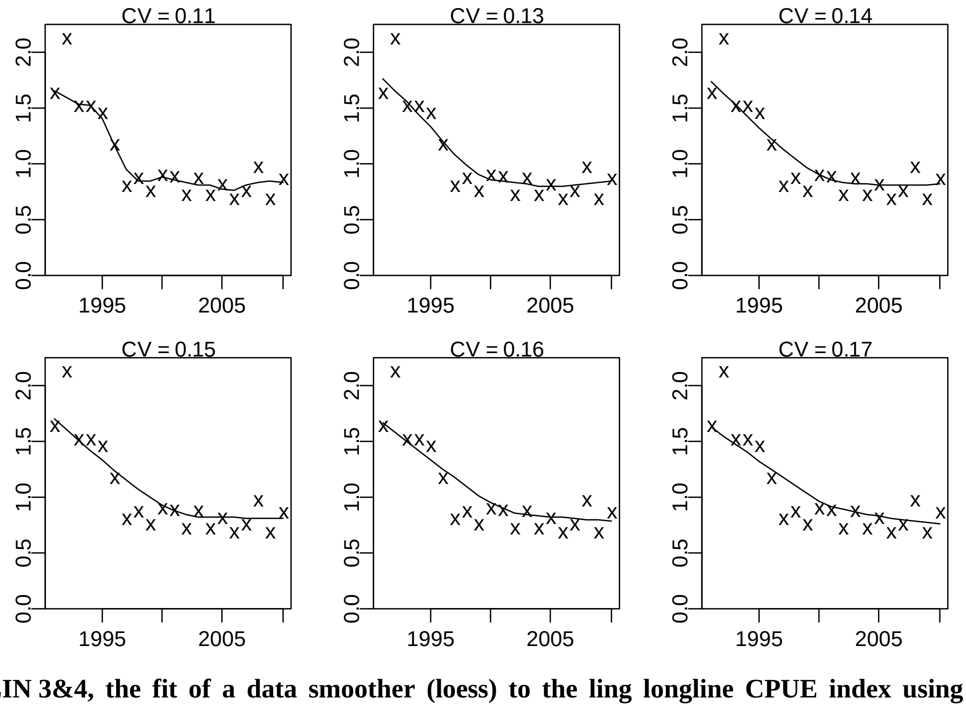

Figure 2: LIN 3&4, the fit of a data smoother (loess) to the ling longline CPUE index using different degrees of data smoothing. The c.v. increases as the degree of smoothing (here the "span" of the R function *loess*) increases.

The proportion-at-age samples from the trawl survey were persistently skewed slightly towards males, and those from the trawl fishery slightly towards females, and both of these could be adequately fitted by the model. The composition data for the trawl survey and fishery were therefore sexed in all model runs. However, there was a strong temporal trend in sex ratio in the composition data from the longline fishery, and this could not be fitted by any model run (Figure 3). The longline composition data for 1995–2001 were from length samples, and were predominantly female, whilst those from 2002–2009 were from age samples, and were predominantly male. The Middle Depth Fisheries Assessment Working Group noted that there were other possible biases in sex determination of the samples from the longline fishery, and concluded that, without corroborating evidence from other analyses, the best option was to treat the longline composition data as unsexed; this was done for the final base model and sensitivity runs.

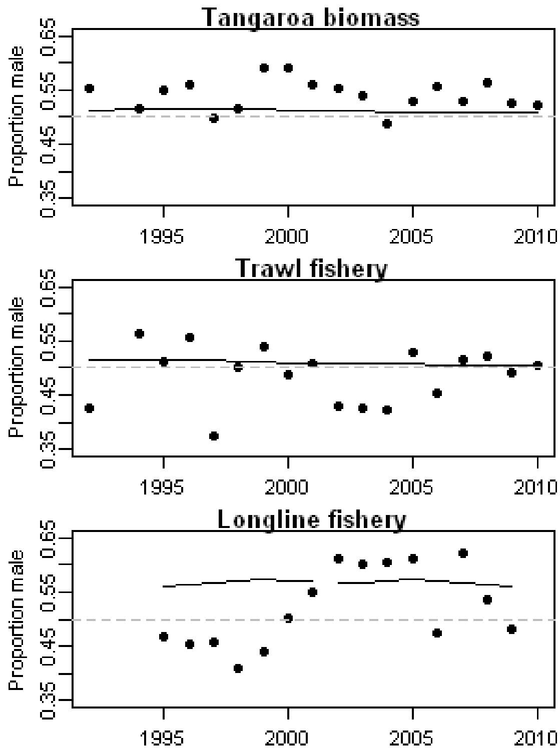

Figure 3: LIN 3&4, model fit (lines) to the sex ratio in the ling composition data for the trawl (*Tangaroa*) survey, trawl fishery, and longline fishery (points). The model fit shown here was the "best" overall fit to the composition data (as judged by likelihood scores), and assumed double normal selectivity ogives for the trawl survey and fishery, logistic selectivity for the longline fishery, and sex specific *M*-at-age relationships.

As in the previous assessment (Horn 2008), the base run for this assessment assumed double-normal selectivity ogives for the trawl survey and fishery, and a logistic selectivity ogive for the longline fishery, with the males ogives fitted relative to females. What the latter means is that "capped" ogives in CASAL were used (Bull et al. 2012), meaning that the maximum selectivity for males could be other than 1. Where this selectivity assumption was applied, males were typically more vulnerable than females (ogive asymptote greater than one) to the trawl survey, and less vulnerable than females (ogive asymptote less than one) to the trawl and longline fisheries. This allowed the model to modify the relative vulnerability of males and females, and change the sex ratio of the fishery catches and stock. Whether this is a reasonable assumption is unclear, but clear differences in sex ratio are apparent in the observed catch-at-age data. Model runs using length-based ogives, where the relative age of selectivity for males and females depends on the relative growth rates, were tried but gave worse fits to the data.

In this assessment the assumed errors for the composition data were multinomial; previous assessments have assumed lognormal distributions (Horn 2008). The effective sample sizes for the composition samples were estimated from a multinomial model fitted to a regression of log(proportion) against log(c.v.), where the c.v. was estimated by bootstrapping from the sample data (Bull & Dunn 2002). The effective sample sizes are given in Table 8.

Table 8: LIN 3&4, 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).

Fishing year	Initial EFS	Reweighted EFS
Trawl survey proportion-at-age		
1990	319	121
1992	439	166
1993	485	183
1994	503	190
1995	297	112
1996	375	142
1997	391	148
1998	405	153
1999	417	158
2000	521	197
2001	571	216
2002	522	197
2003	484	183
2004	482	182
2005	453	171
2006	532	201
2007	424	160
2008	397	150
2009	386	146
2010	378	143
2011	299	113
Longline proportion-at-length		
1995	1632	68
1996	1677	70
1997	1860	78
1998	1870	78
1999	1804	76
2000	2056	87
2001	1272	53

Fishing year	Initial EFS	Reweighted EFS
Trawl fishery proportion-at-age		
1992	319	43
1994	230	31
1995	123	16
1996	213	29
1997	132	18
1998	475	64
1999	485	65
2000	311	42
2001	366	49
2002	285	38
2003	267	36
2004	185	25
2005	260	35
2006	181	24
2007	309	41
2008	402	54
2009	227	30
2010	252	34
Longline proportion-at-age		
2002	411	88
2003	524	112
2004	409	88
2005	331	72
2006	115	24
2007	171	36
2008	223	48
2009	430	92

Reweighting of the composition data (proportion-at-length and proportion-at-age) followed Francis (2011). Figure 4 shows the 95% credible intervals for mean age for the four composition data sets using the initial effective sample sizes (Table 8). The predicted mean age from the model fit did not pass through all of the credible intervals. The Francis (2011) method reduced the effective sample sizes, and as a result inflated the uncertainty and credible intervals. The effective samples sizes were scaled down by factors between 0.458 and 0.045, with the greatest effect being on the longline proportion-at-length data set (Figure 4, Table 8). The reweighted model fit passed through almost all of the credible intervals (Figure 5).

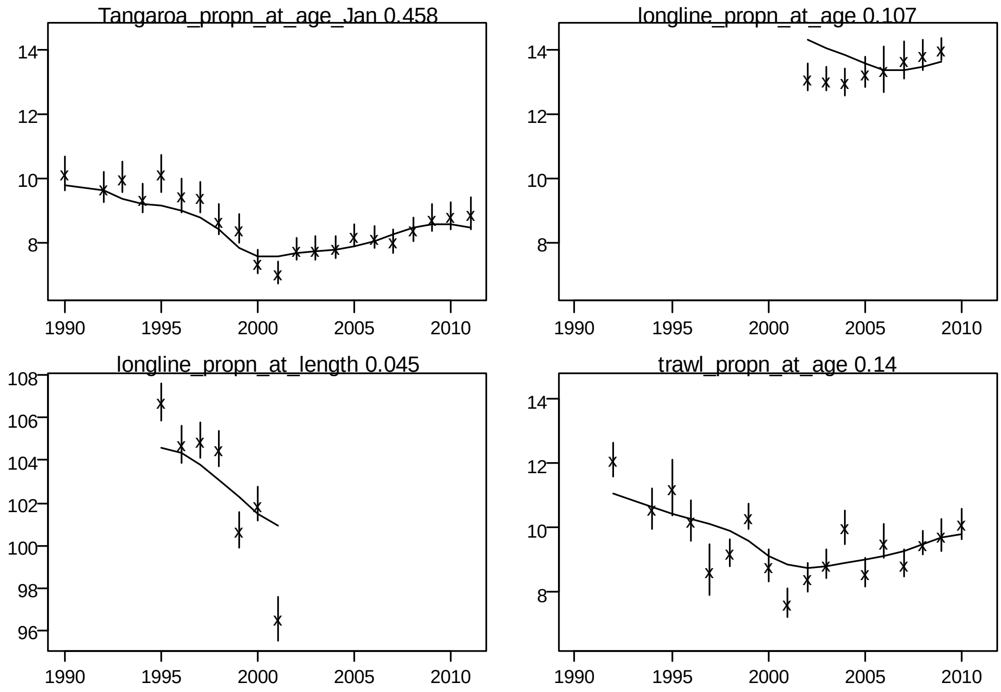

Figure 4: LIN 3&4, model fit (lines) to mean age of the four composition data sets (points), showing the observed mean age and 95% credible limits around mean age with the initial multinomial effective sample sizes (vertical lines). The figure titles indicate the data set, and the value by which the effective sample size for that data set should be multiplied (following method TA1.8 of Appendix A in Francis 2011).

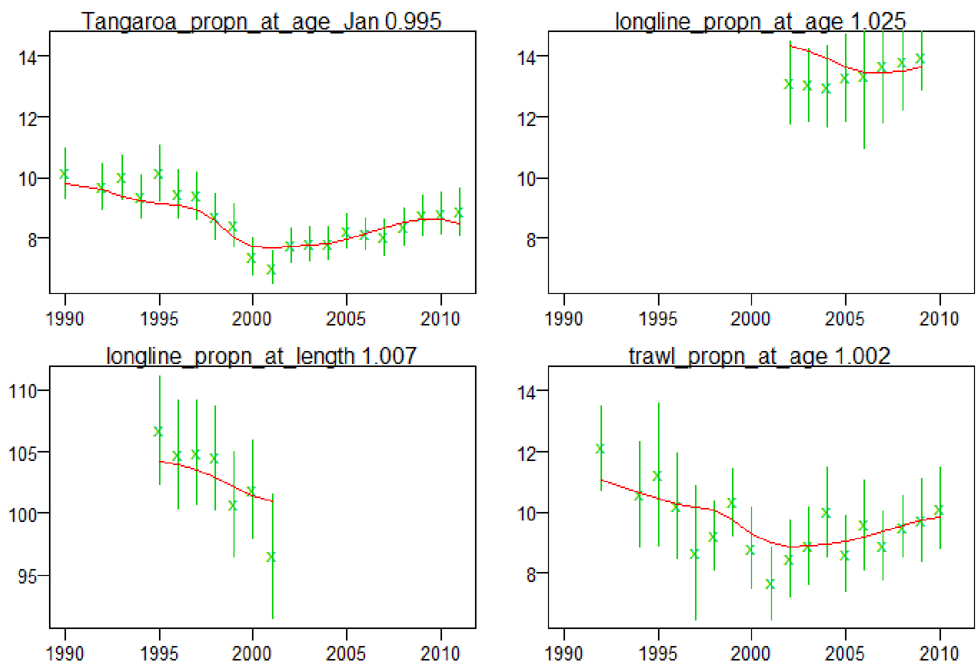

Figure 5: LIN 3&4, model fit (lines) to mean age of the four composition data sets (points), showing the observed mean age and 95% credible limits around mean age with the re-weighted multinomial effective sample sizes (vertical lines). The figure titles indicate the data set, and the value by which the effective sample size for that data set should be multiplied (following method TA1.8 of Appendix A in Francis 2011); values close to 1 indicate further re-weighting is not recommended.

The re-weighting example shown (Figures 4 and 5) included all data sets, and in model runs where data sets were excluded (see below), the model was reweighted.

There was a systematic misfit between the observed and fitted mean age for the longline proportion-at-age (Figure 4). However, this misfit was not investigated further because the longline data were considered the least reliable, and so fitting these data was not a principle concern, and because these data had little material influence on the result. With the re-weighted effective sample size doubled or halved the overall changes were small; B_0 changed by about 2%, B_{2011} by 8%, and $\%B_0$ by 4%.

In this assessment, the fit to the biomass indices was given primacy (Francis 2011). However, 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 6). An attempt was made to fit both biomass indices in the same model run. This seemed reasonable, because the trawl survey caught ling at a younger age than the longline fishery so, in principle, a decline in predominantly older ling could result in the different observed trends. However, attempts to fit both indices in the same model were not successful (Figure 6). The model runs investigated different assumed selectivities, including domed selectivity for the trawl survey but logistic for the longline fishery, also (alternatively) all logistic selectivity ogives but variable *M*-at-age relationships, and varying the relative weights of the data series.

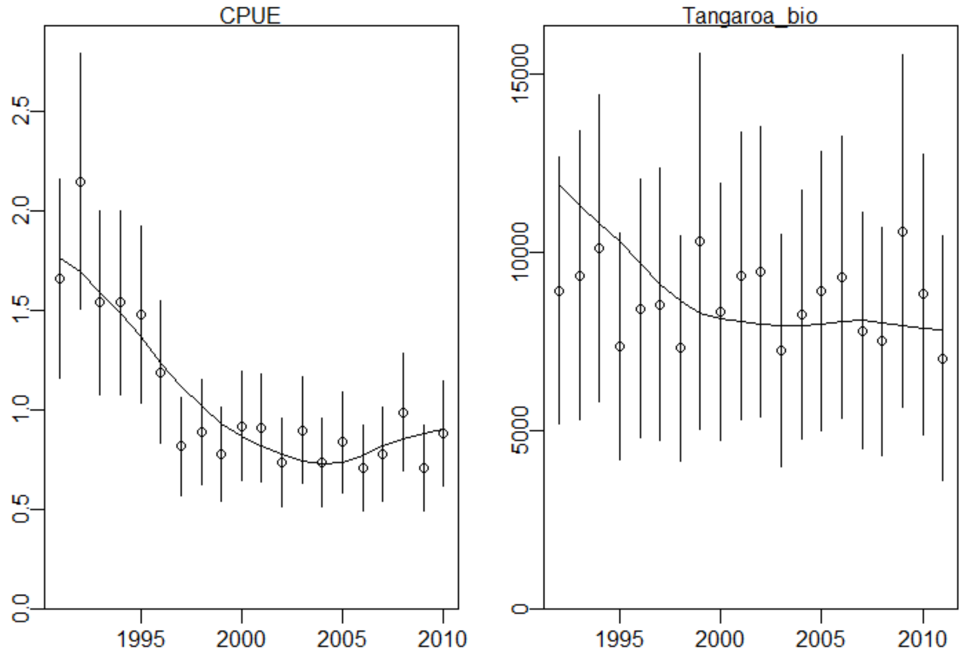

Figure 6: LIN 3&4, model fit to the biomass indices for longline CPUE (CPUE) and trawl survey (Tangaroa_bio). The model fit shown here was the "best" overall fit to the both biomass indices together (as judged by likelihood scores), and assumed all logistic selectivity ogives, and an *M*-at-age relationship (the COSH ogive; Bull et al. (2012)) by sex. Although the fit to the trawl survey was within all of the 95% credible intervals, there were still strong patterns in the residuals, with the first 7 points all below the fit.

The primary reason for the lack of fit to the trawl survey biomass index appeared to be a relatively strong biomass signal from the composition data, which happened to be consistent with the CPUE index (Figure 7). The trawl survey biomass index showed little contrast, and did not contain a strong biomass signal. A model run including just the composition data (i.e., no biomass indices) estimated B_0 at 122 200 t, and current biomass as $\%B_0$ at 47%, similar to the final model runs (see the Base and NoTrawl runs below). The strong influence of the composition data was noted in the previous assessment (Horn 2008), and apparently still occurred in this assessment despite substantial down-weighting of the composition data.

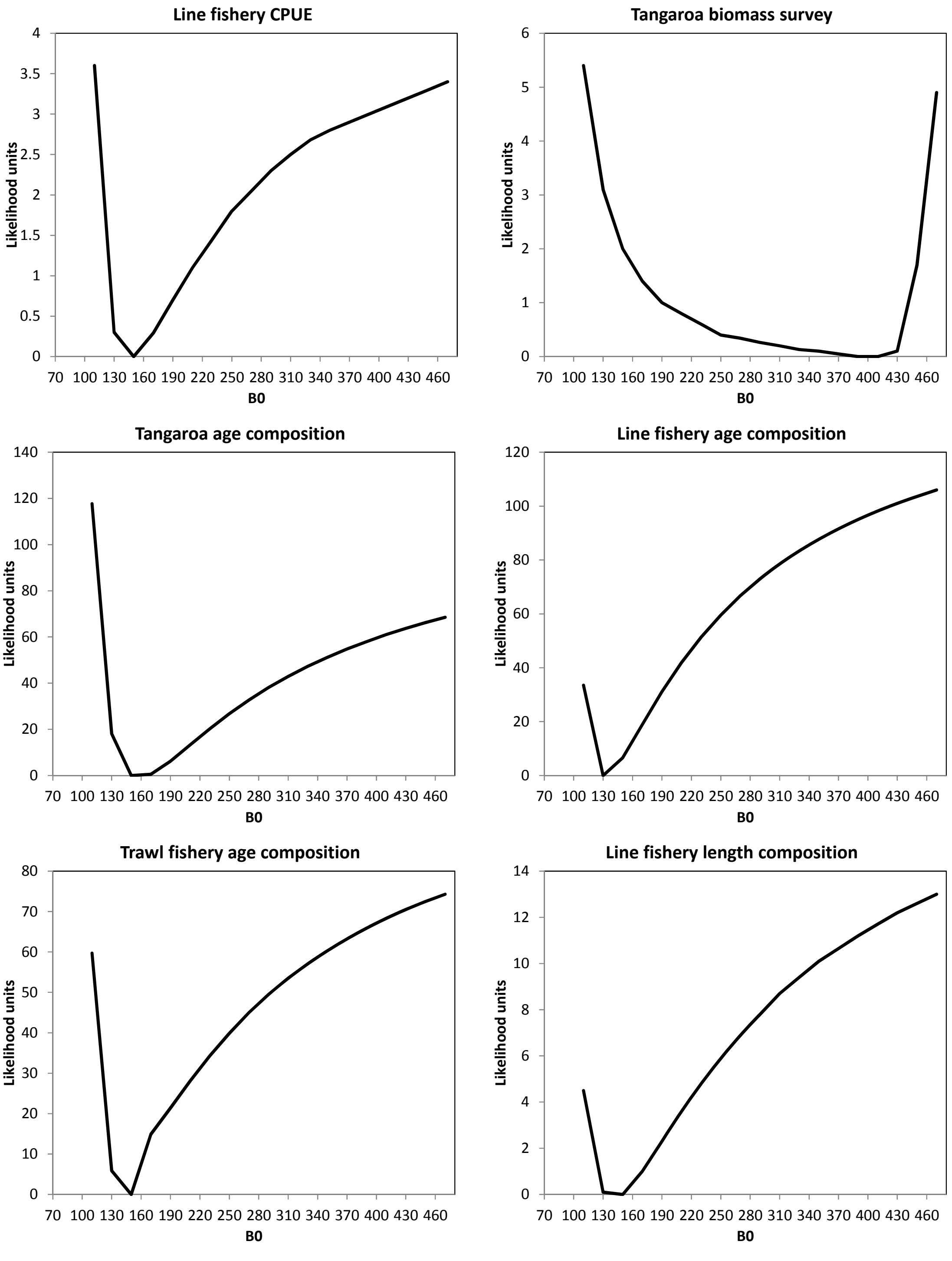

Figure 7: LIN 3&4, likelihood profiles for B_0, for the observational data sets. The profiles shown are from a model run assuming all logistic selectivity ogives and a constant *M*; profiles were broadly similar for other runs examined.

Therefore, to remove this conflict, the Middle Depth Fisheries Assessment Working Group agreed a base case model run (Base) that used all the observational data except those from the line fishery; the trawl survey biomass index being preferred in the base case because these data were fishery independent. A sensitivity run (NoTrawl) included the line fishery data, and excluded the trawl survey data. When the line fishery data were excluded in the Base run, the line fishery selectivity was set to that estimated from the NoTrawl run; in the NoTrawl run the survey selectivity was set to that estimated in the Base run.

There were no sensitivity runs associated with fits to the composition data, because the fits were broadly acceptable (Figures 8–13) and varied little between runs. Although the likelihoods of the fits to the composition data did vary a little between fits, visually the fits were essentially indistinguishable.

Overall, the assessment seemed to be quite robust, because a number of other sensitivity runs were completed but they did not produce materially different estimates of the key parameters of interest: stock size and status (Table 9).

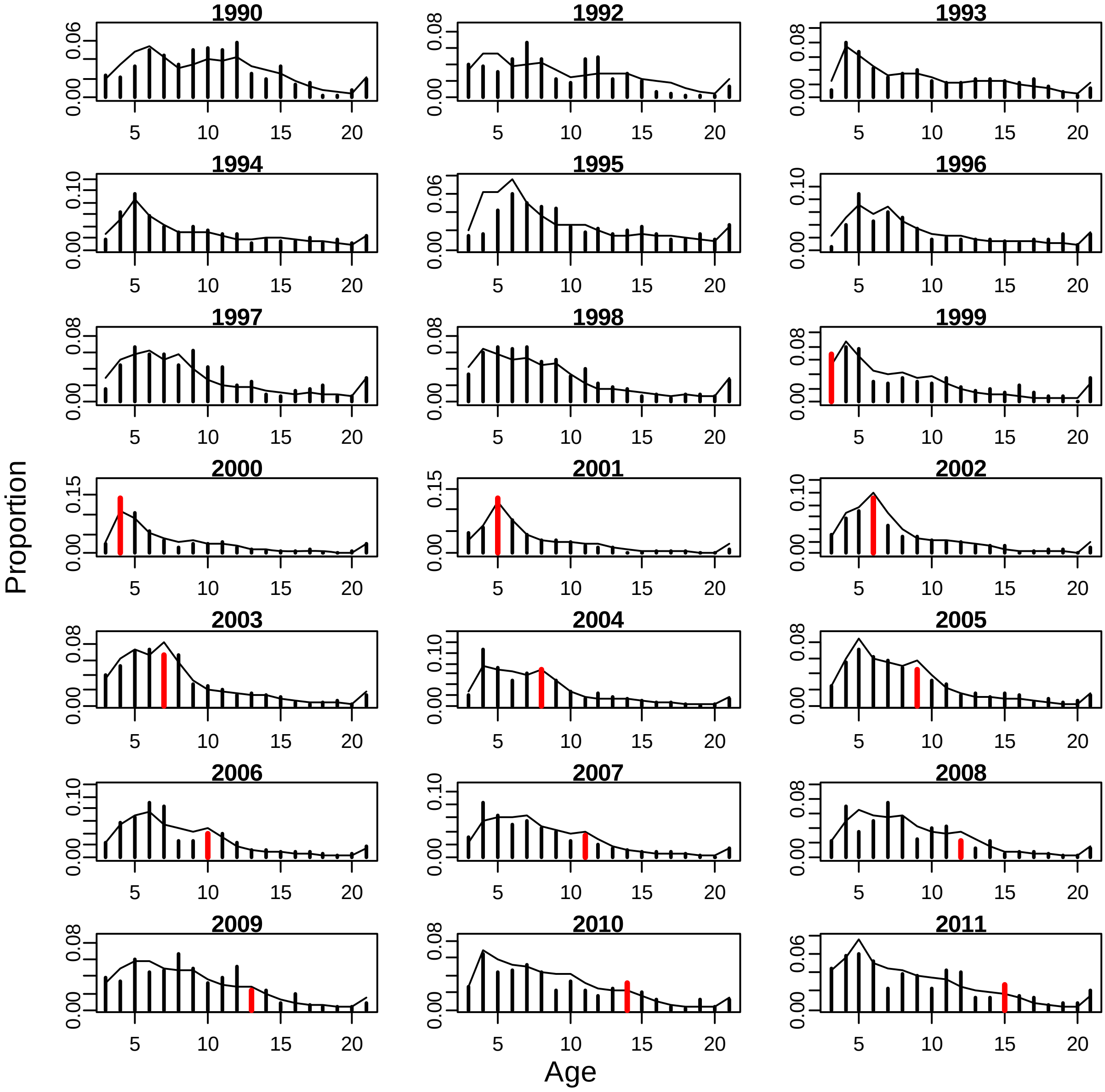

Figure 8: LIN 3&4, model run fit (lines) to observed proportion-at-age (bars) for male ling in the trawl survey. The fit shown is the MPD for the Base run. The red-shaded bar (age 4 in 2000) tracks a year class and is just for reference.

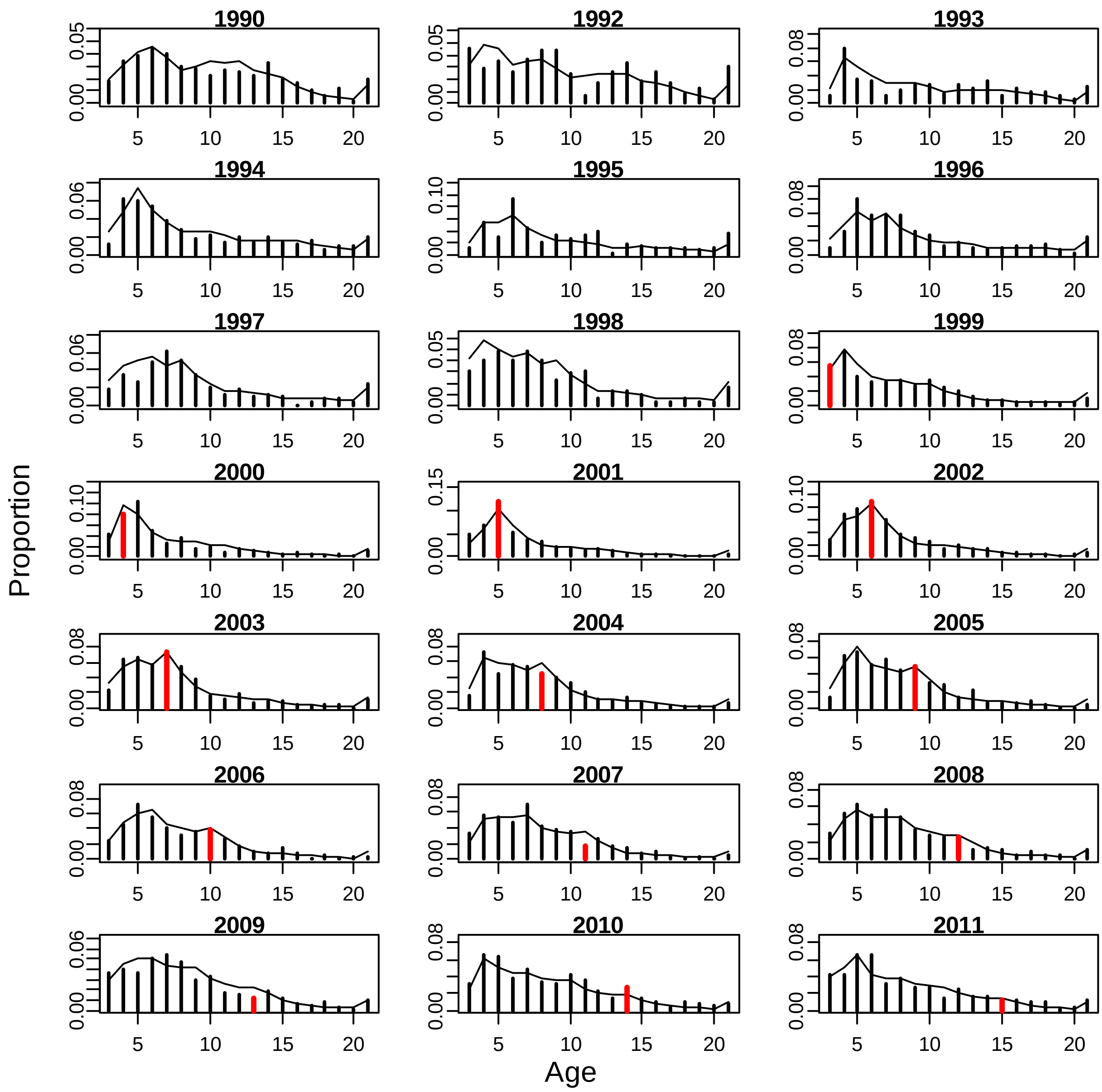

Figure 9: LIN 3&4, model run fit (lines) to observed proportion-at-age (bars) for female ling in the trawl survey. The fit shown is the MPD for the Base run. The red-shaded bar (age 4 in 2000) tracks a year class and is just for reference.

Table 9: LIN 3&4, examples of other sensitivity runs for the LIN 3&4 assessment model, showing the estimates for the key quantities B_0 and current biomass as a percentage of B_0 (%B_0). The key assumptions changed in each run are indicated; other setting were generally the same; all models estimated *M*. Runs 1–5 are MPD estimates, runs 6 and 7 are MCMC estimates.

Key run assumptions	B_0 (t)	%B_0
1. All logistic selectivity ogives, single sex *M*	120 100	54
2. All logistic selectivity ogives, *M* separate by sex	116 100	51
3. All logistic selectivity ogives, *M*-at-age relationship by sex	119 100	56
4. All logistic selectivity ogives, all observations unsexed	119 000	59
5. Selectivity double normal ogive for trawl survey and fishery, logistic for longline, single sex *M*	119 600	51
6. Base run (as 5 but no longline data)	122 200	47
7. NoTrawl run (as 5 but no trawl survey data)	113 800	50

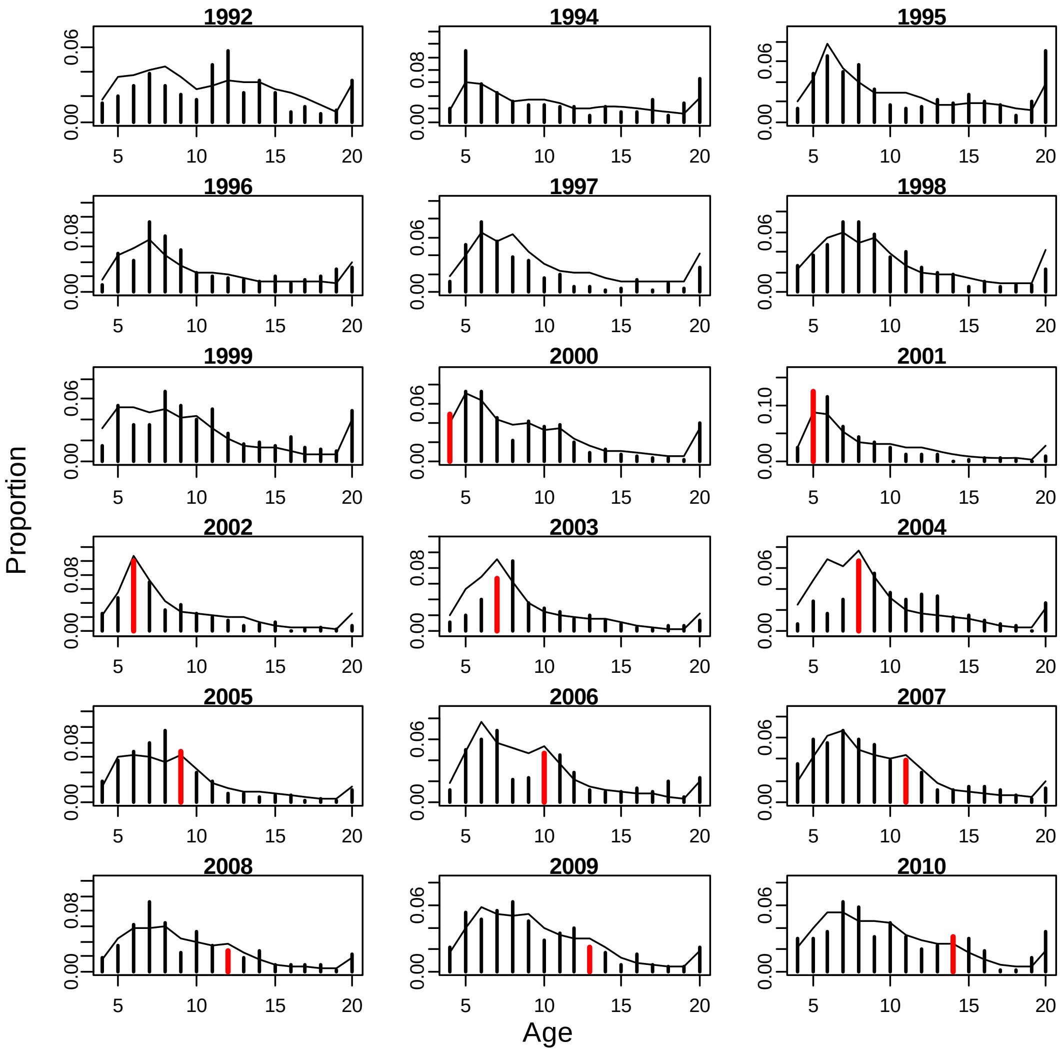

Figure 10: LIN 3&4, model run fit (lines) to observed proportion-at-age (bars) for male ling in the trawl fishery. The fit shown is the MPD for the Base run. The red-shaded bar (age 4 in 2000) tracks a year class and is just for reference.

5.2 Model estimation using MCMC

Model parameters were estimated using Bayesian estimation implemented using the CASAL software. For final runs, the full posterior distribution was sampled using Monte Carlo Markov Chain (MCMC) methods, based on the Metropolis-Hastings algorithm. MCMCs were estimated using 3×10^6 iterations, a burn-in length of 5×10^5 iterations, and with every 2500th sample kept from the final 2.5×10^6 iterations (i.e., a final sample of length 1000 was taken from the Bayesian posterior).

5.3 Prior distributions and penalty functions

The assumed prior distributions used in the assessment are given in Table 10. Most priors were intended to be uninformed, and were specified with wide bounds. The 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 c.v. 0.70, with bounds assumed to be 0.02 to 0.30.

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.

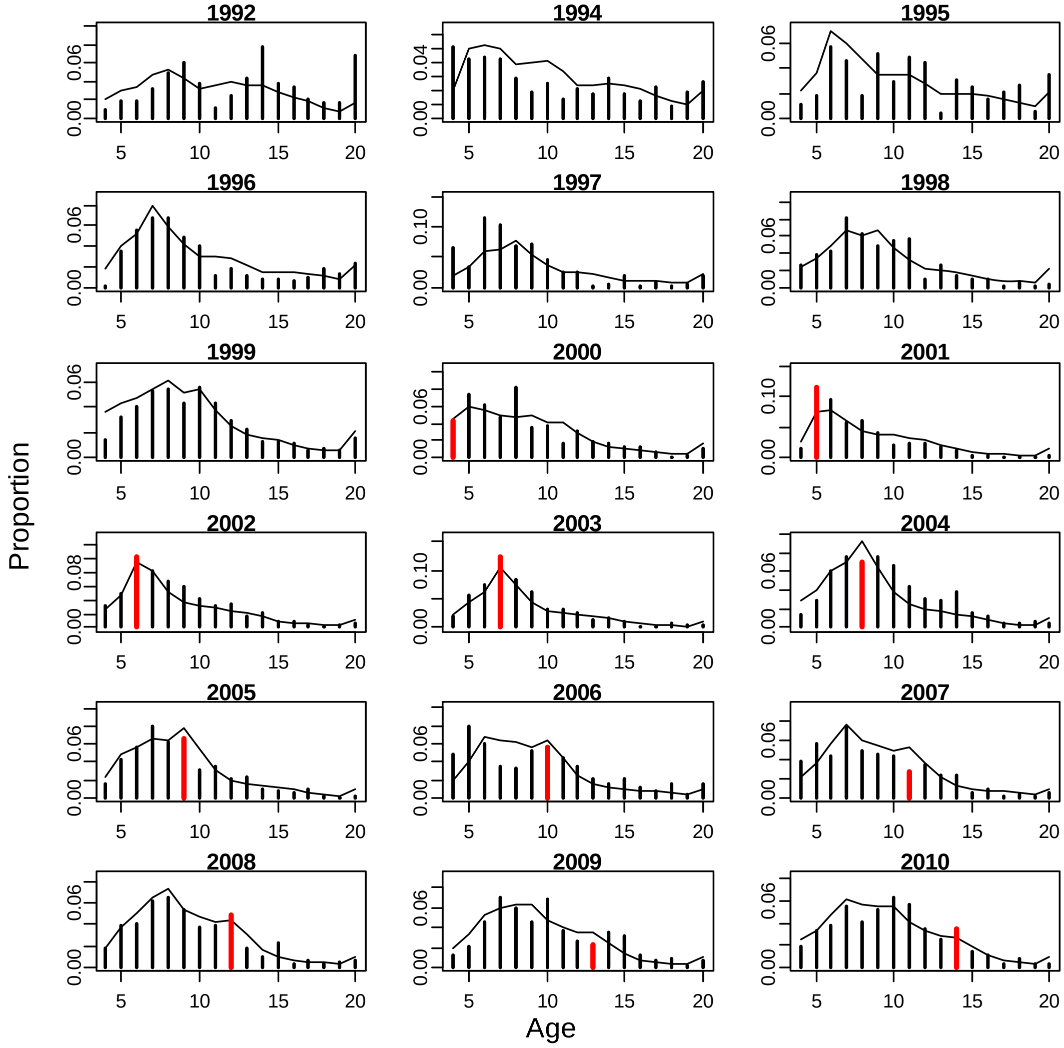

Figure 11: LIN 3&4, model run fit (lines) to observed proportion-at-age (bars) for female ling in the trawl fishery. The fit shown is the MPD for the Base run. The red-shaded bar (age 4 in 2000) tracks a year class and is just for reference.

Table 10: LIN 3&4, assumed prior distributions and bounds for estimated parameters in the assessment. Parameter values are mean (in natural space) and c.v. for lognormal. *n*, number of parameters estimated.

Parameter description	*n*	Distribution	Parameters		Bounds	
B_0	1	uniform-log	–	–	30 000	500 000
Year class strengths	34	Lognormal	1.0	0.70	0.01	100
Trawl survey *q*	1	Lognormal	0.13	0.70	0.02	0.3
CPUE *q*	1	uniform-log	–	–	1e-8	1e-3
Selectivities	9 or 14[1]	Uniform	–	–	0	20–200[2]
M	1	Uniform	–	–	0.01	0.6

[1] 14 for the Base run, and 9 for the NoTrawl run.
[2] A range of maximum values was used for the upper bound.

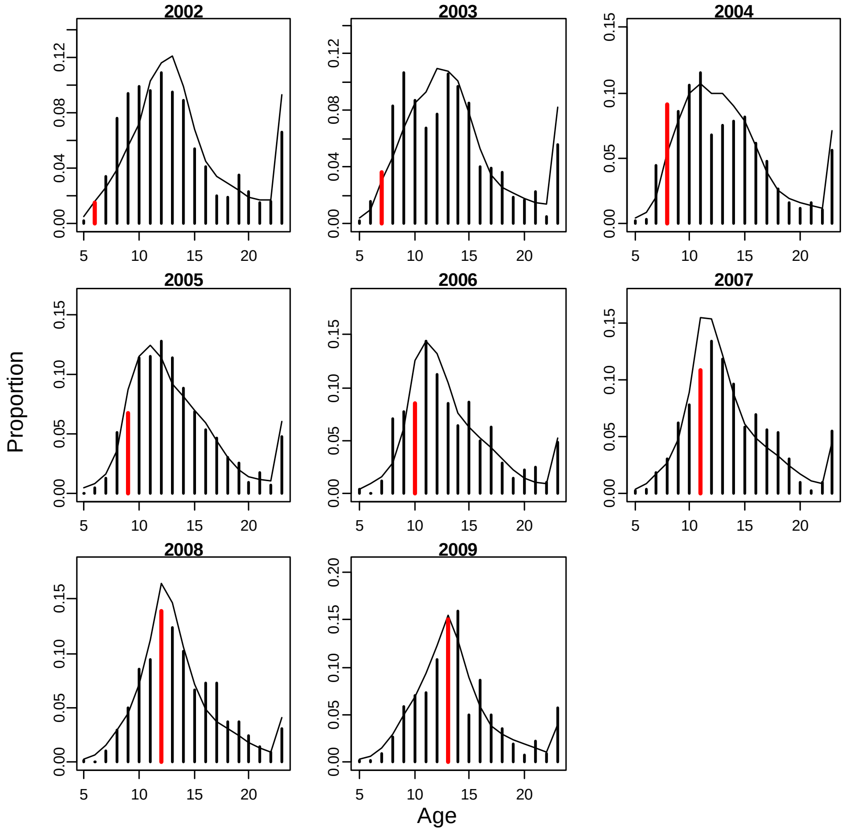

Figure 12: LIN 3&4, model run fit (lines) to observed proportion-at-age (bars) for unsexed ling in the trawl fishery. The fit shown is the MPD for the NoTrawl run. The red-shaded bar (age 4 in 2002) tracks a year class and is just for reference.

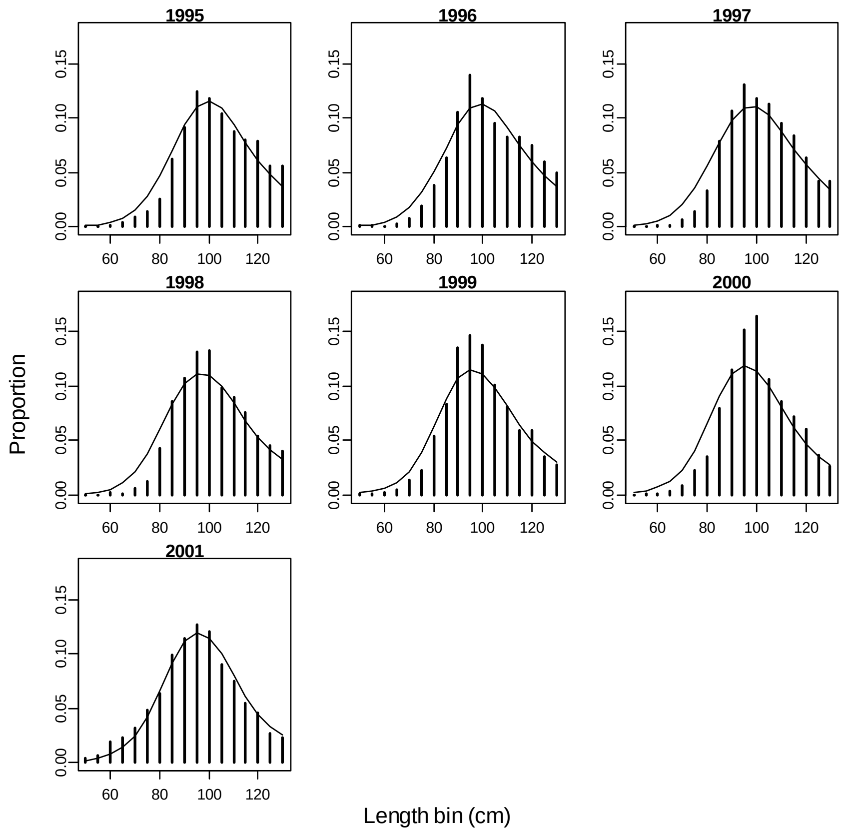

Figure 13: LIN 3&4, model run fit (lines) to observed proportion-at-length (bars) for unsexed ling in the trawl fishery. The fit shown is the MPD for the NoTrawl run.

5.4 MCMC estimates

MCMCs were completed only for the Base and NoTrawl runs. The chains looked reasonable (Figures 14 and 15), and the distributions of estimates of B_0 and B_{2011} (as $\%B_0$) from the Base run were fairly consistent between the first, middle, and last thirds of the chain (Figure 16), and hence convergence was probably adequate for stock-assessment purposes. Convergence of the NoTrawl chain was less convincing (Figure 17), but was still considered adequate as a sensitivity run to the stock assessment.

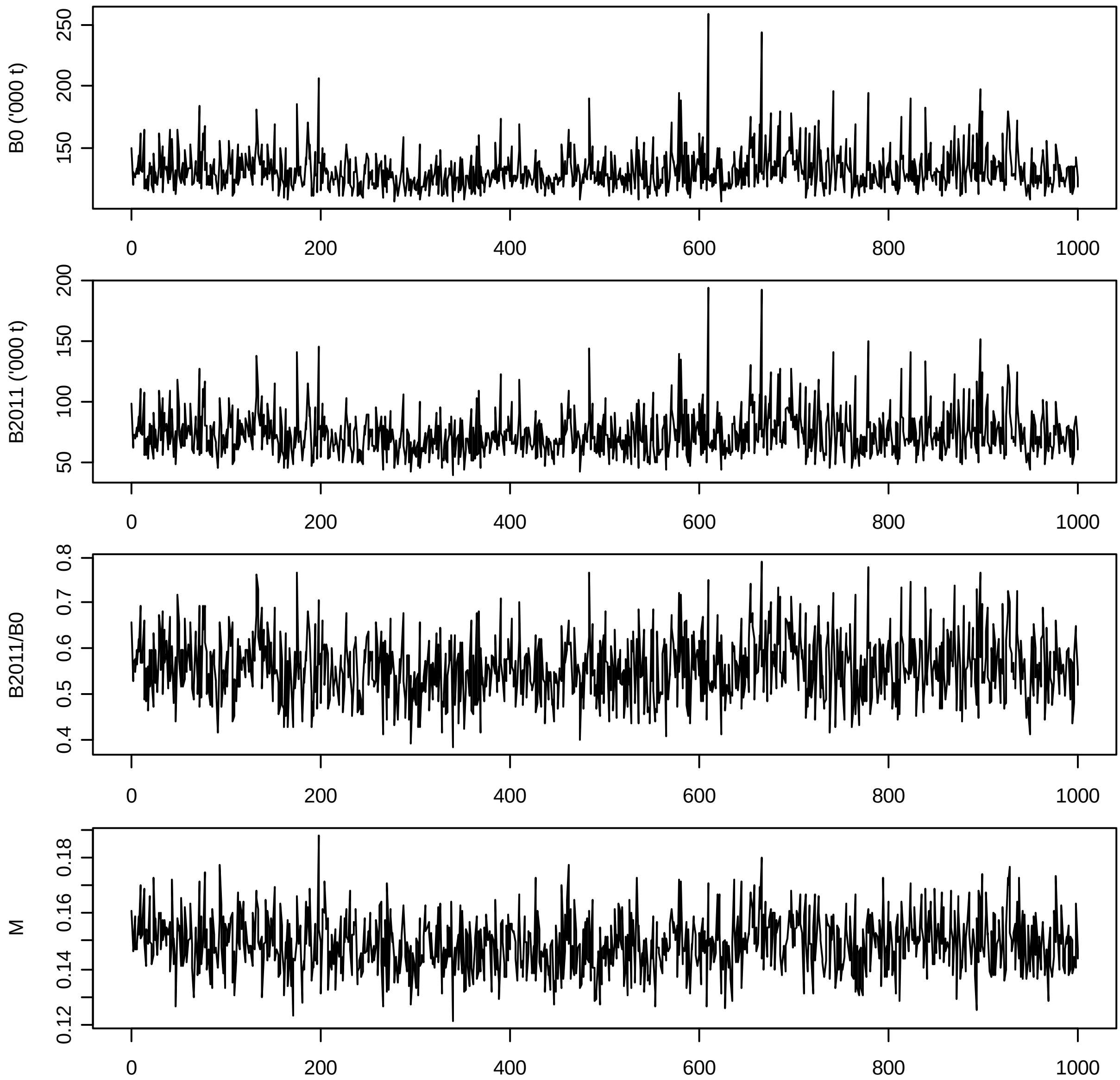

Figure 14: LIN 3&4, trace diagnostic plot of the MCMC chain for estimates of B_0, B_{2011}, B_{2011}/B_0 ($\%B_0$), and M, for the Base model run.

The MCMC for the Base run showed that the MPD was far in the tail of the posterior probability distribution. Whilst the MCMC for the Base run had a median B_0 of 127 400 t and $\%B_0$ of 55%, the MPD was at 277 000 t and 67% (Figure 18). Further investigations (e.g., different MPD start points, different MCMC settings) indicated that both the MPD and MCMC were valid estimates. As a result, it appeared that whilst the MPD had identified a minimum, almost all of the posterior probability distribution was elsewhere.

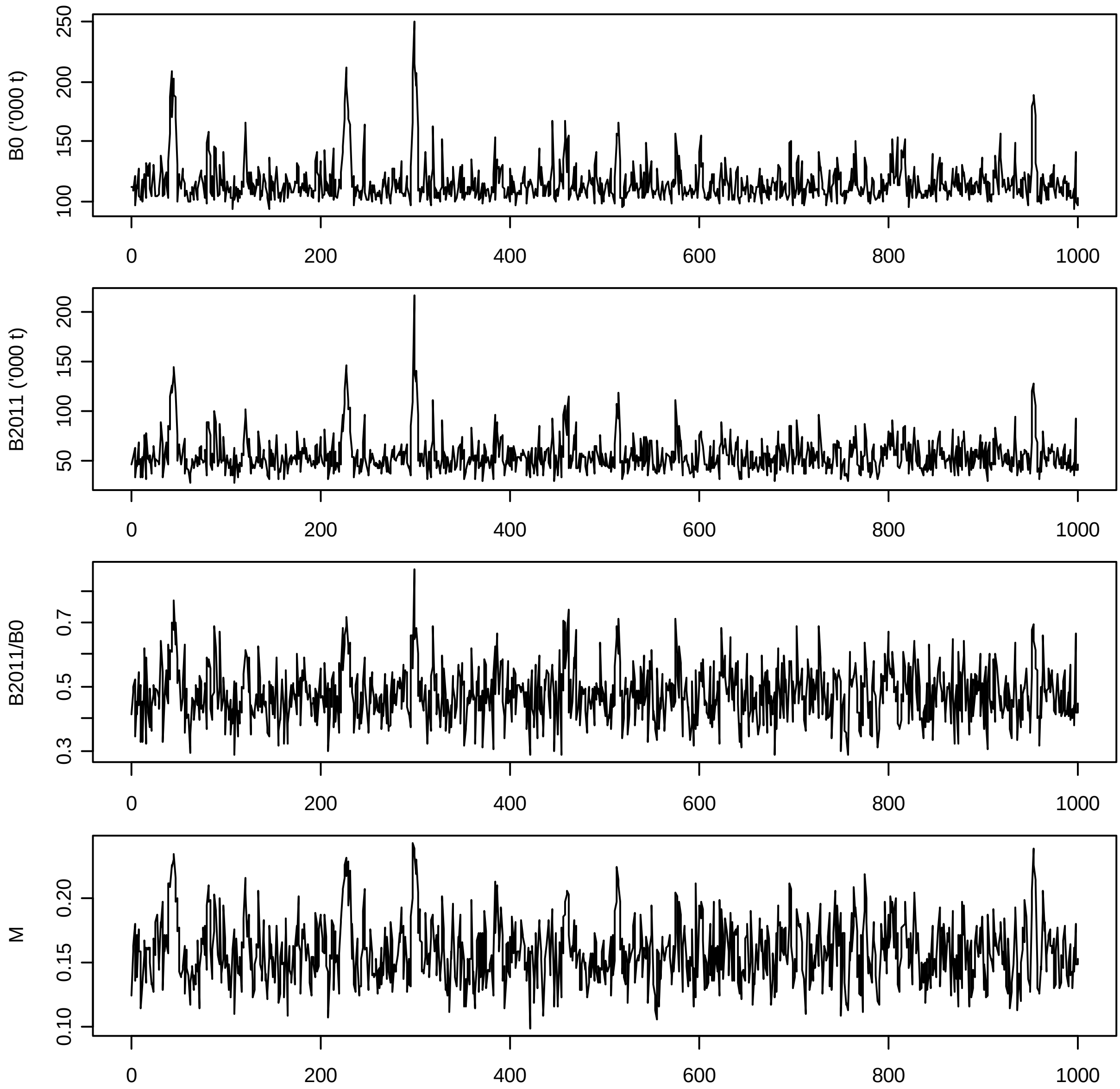

Figure 15: LIN 3&4, trace diagnostic plot of the MCMC chain for estimates of B_0, B_{2011}, B_{2011}/B_0 (%B_0), and M, for the NoTrawl model run.

The selectivity ogives were not tightly defined (Figures 19 and 20, Table 11). Fishing selectivities indicated that ling were fully selected by the trawl survey before the trawl fishery, and the trawl fishery before the line fishery (Table 11). Males and females were selected at a similar age in the trawl survey, but in the trawl and line fisheries males were selected at an earlier age. The trawl survey and fishery ogives were essentially logistic-shaped even though it was fitted using the double-normal parameterisation. The maximum selectivity (cap) was greater than 1 for males from the trawl survey, and less than 1 for females from the trawl survey; this allowed the model to fit the skew in the sex ratio (see Figure 3). There is no information outside the model that allows the shape of the estimated selectivity ogives to be verified.

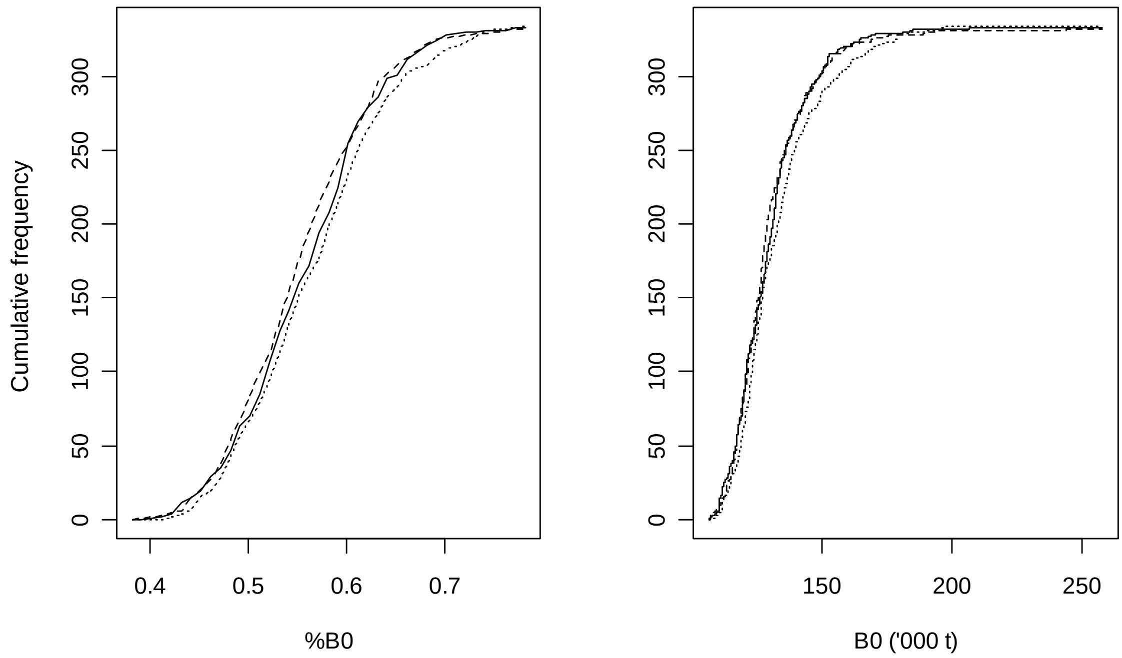

Figure 16: LIN 3&4, MCMC diagnostic plot showing the cumulative frequencies of B_0 and B_{2011} (%B_0) for the first (solid line), middle (dashed line), and last (dotted line) third of the MCMC chain for the Base run.

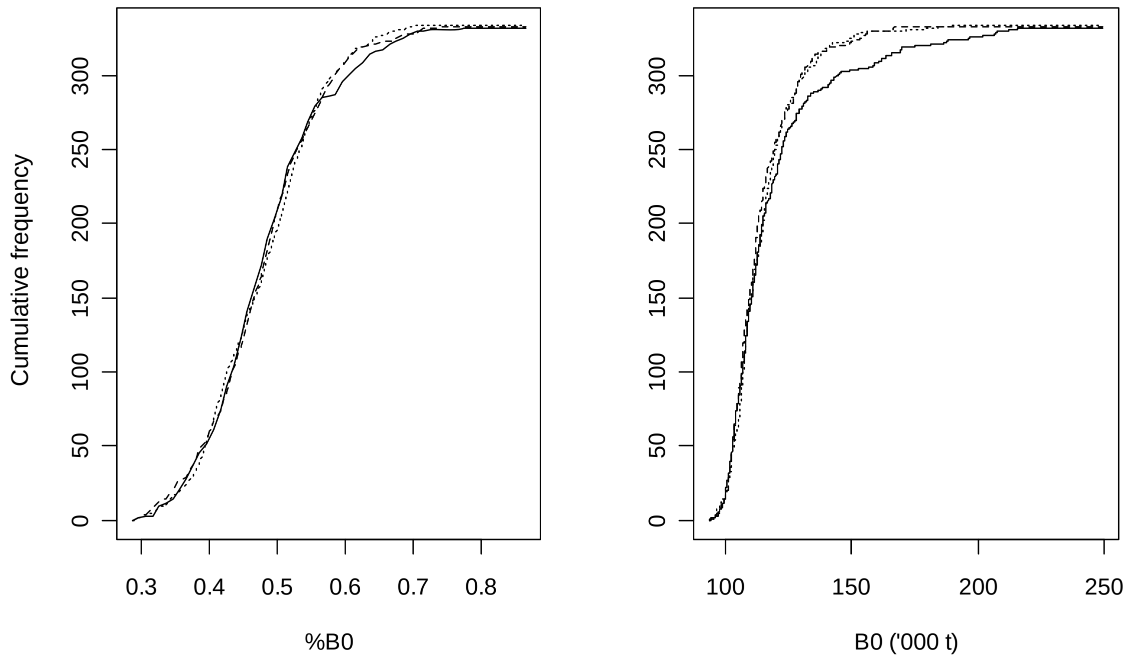

Figure 17: LIN 3&4, MCMC diagnostic plot showing the cumulative frequencies of B_0 and B_{2011} (%B_0) for the first (solid line), middle (dashed line), and last (dotted line) third of the MCMC chain for the NoTrawl run.

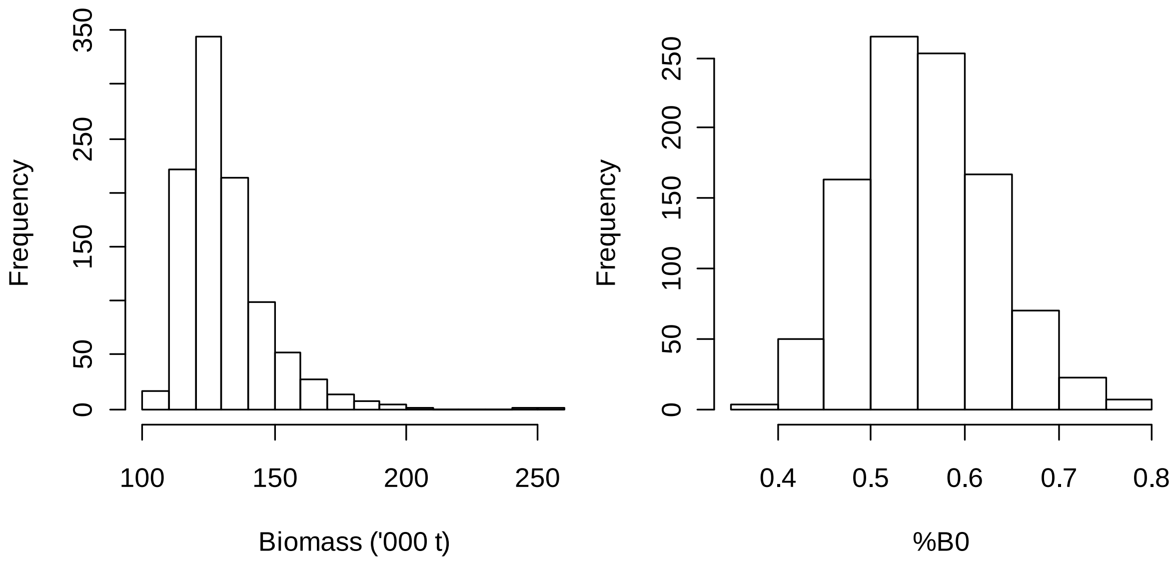

Figure 18: LIN 3&4, frequency histograms of posterior estimates of B_0 and B_{2011} (as $\%B_0$) from the Base run MCMC. The MPD estimate was at 277 000 t and 67% respectively.

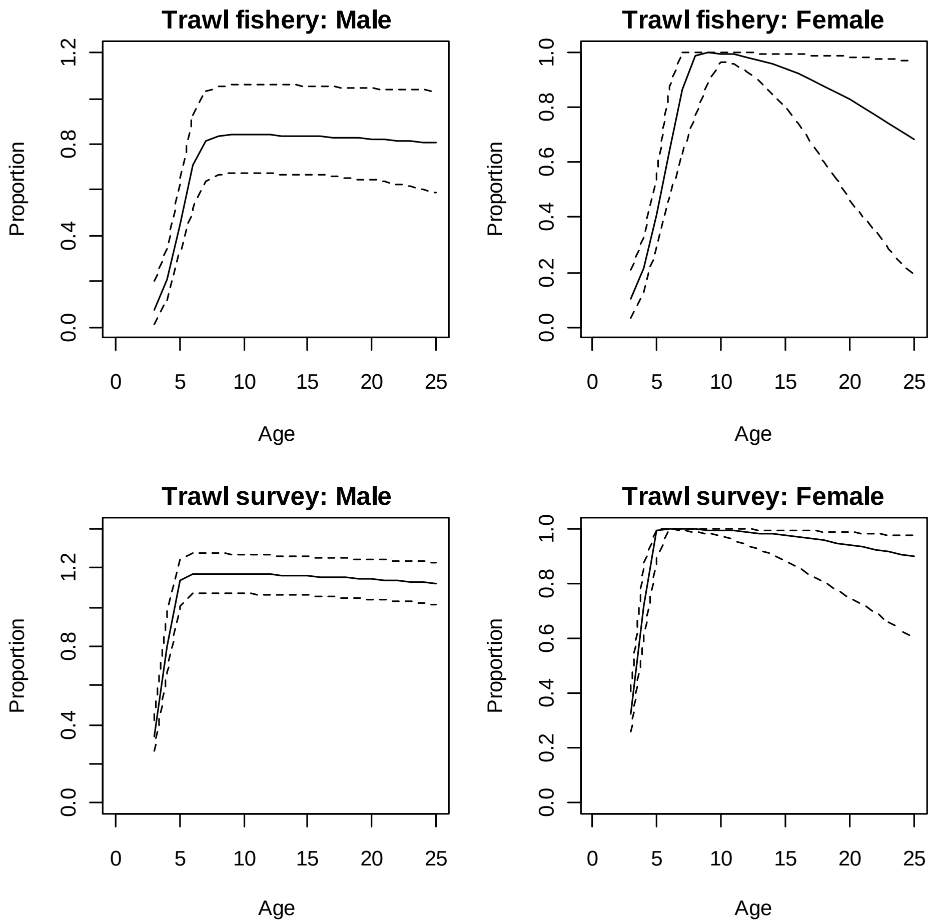

Figure 19: LIN 3&4 Base run, estimated median selectivity ogives (solid line) and 95% credible interval (dashed lines) for the trawl survey and fishery.

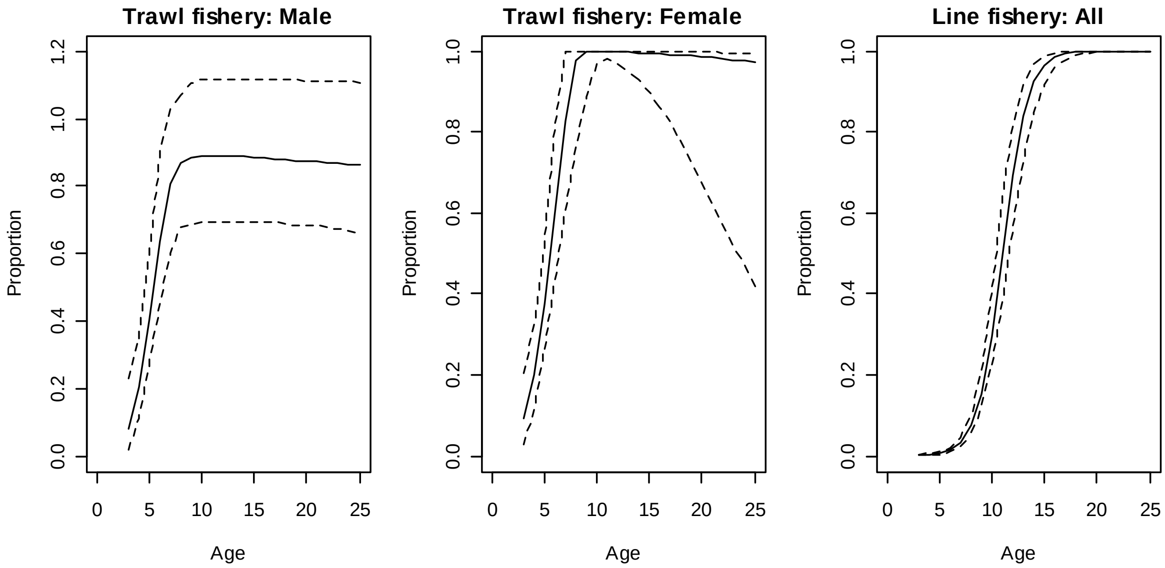

Figure 20: LIN 3&4 NoTrawl run, estimated median selectivity ogives (solid line) and 95% credible interval (dashed lines) for the trawl and line fisheries.

Table 11: LIN 3&4, estimated median and 95% credible interval (in parentheses) for parameters of selectivity ogives for the model runs Base and NoTrawl. The double-normal ogives had an A_{95} for the length hand side (LHS) and right hand side (RHS), and for males also an estimated maximum selectivity (cap).

Run	Source	Sex	A_{50}	A_{95} LHS	A_{95} RHS	Cap
Base	Trawl survey	Male	5.2 (4.6–6.0)	1.7 (1.2–2.3)	82.4 (47.9–145.0)	1.2 (1.1–1.3)
		Female	5.2 (4.6–6.1)	1.7 (1.2–2.6)	50.0 (22.7–99.3)	1.0[1]
	Trawl fishery	Male	7.1 (5.8–9.2)	2.2 (1.2–4.2)	87.4 (28.5–177.5)	0.8 (0.7–1.1)
		Female	8.3 (6.8–11.0)	2.9 (1.8–5.0)	22.6 (9.8–77.3)	1.0[1]
NoTrawl	Trawl fishery	Male	7.8 (6.1–8.8)	2.6 (1.3–3.4)	119.1 (30.7–167.9)	0.9 (0.7–1.0)
		Female	8.6 (7.0–9.5)	3.0 (1.8–3.7)	89.0 (13.5–158.0)	1.0[1]
	Line fishery	Unsexed	11.0 (10.4–11.3)	3.5 (3.0–3.8)	–	–

1. Fixed parameter (not estimated)

Year class strengths were not well estimated (and had wide credible bounds) for years where only older fish were available to determine age class strength (i.e., before 1980) or where there are few data (i.e., after 2004) (Figure 21); intermediate year class strengths appear well estimated. Since 1980, year class strengths were below average except for a period between 1994 and 1999, and in 2007. Estimated year class strengths were not widely variable, with all medians being between 0.5 and 2. The overall pattern of year class strength was similar for the Base and NoTrawl runs.

The Base model produced only a marginally improved fit to the trawl survey biomass index (Figure 22; compare with e.g., Figure 6), and whilst the fitted biomass was within the observation credible intervals the pattern in the residuals still indicated a poor to moderate fit. The NoTrawl run produced a moderate to good fit to the line CPUE index (Figure 23).

Estimated biomass for the Chatham Rise stock declined during the late 1970s as a result of high line fishery catches, but then recovered until the early 1990s, and then declined again during the 1990s as a result of increased catches and the recruitment of the relatively weak years classes spawned throughout the 1980s. Biomass has since increased following a reduction in fishing pressure, and the recruitment of average to strong year classes. Bounds around the median biomass estimates are wide (Table 12). The Base and NoTrawl model runs produced similar biomass trends (Figure 24).

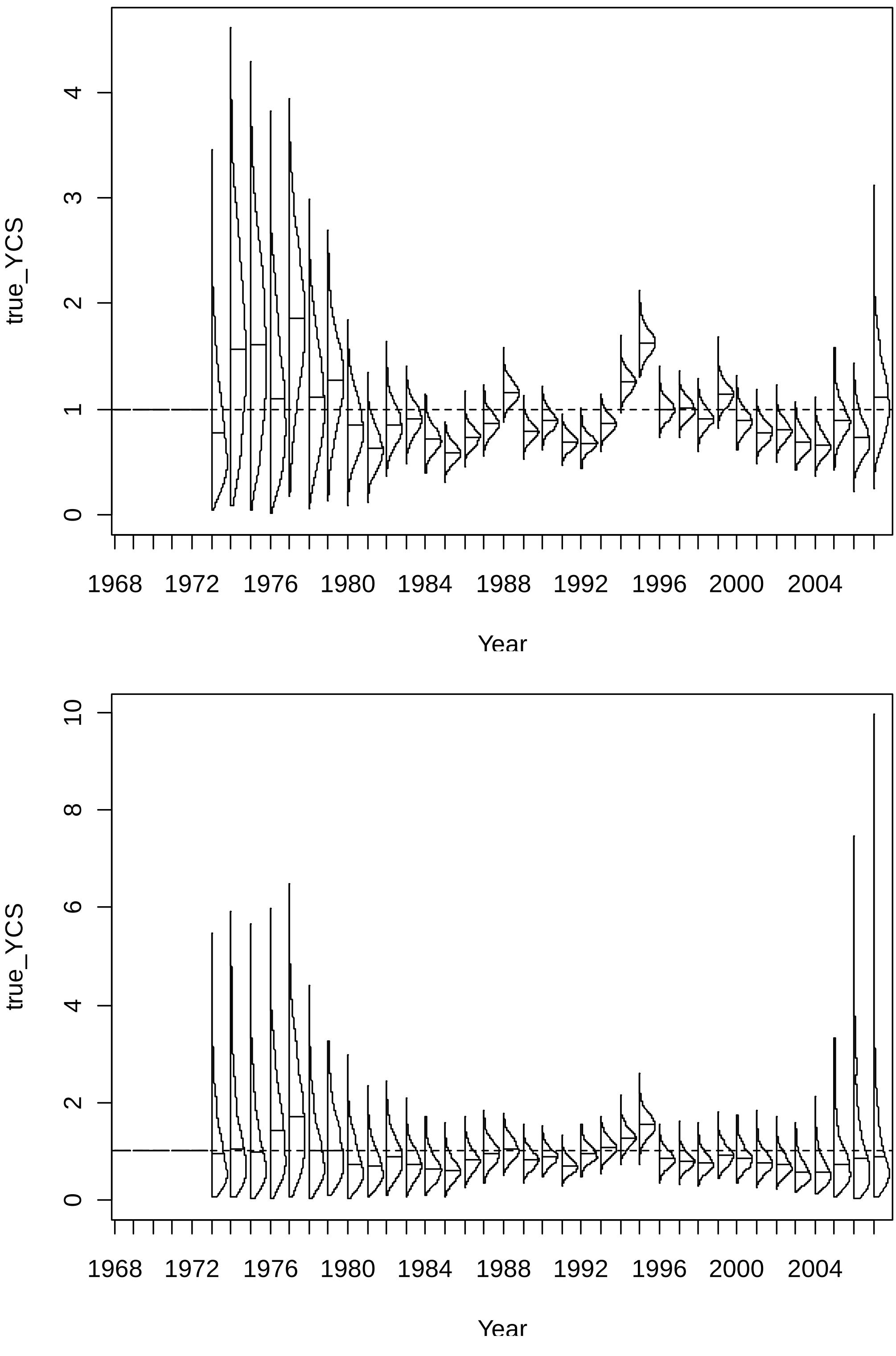

Figure 21: LIN 3&4 Base (top panel) and NoTrawl (bottom panel) model runs, estimated posterior distributions of year class strengths. The dashed horizontal line indicates the year class strength of one. Individual distributions are the marginal posteriors, with horizontal lines indicating the median.

Natural mortality was estimated to be 0.15 (95% credible intervals 0.13–0.17) for the Base run, and 0.16 (0.12–0.21) for the NoTrawl run. The Base run therefore estimated a slightly larger and less productive stock.

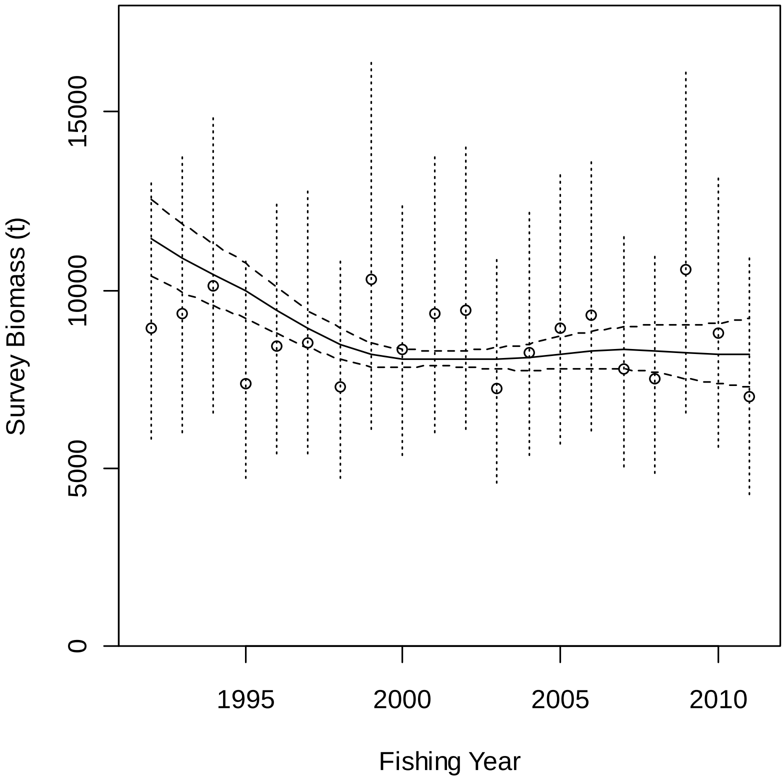

Figure 22: LIN 3&4, fit of the Base MCMC run (solid line, median; dashed lines, 95% credible intervals) to the trawl survey biomass index (points, 95% credible intervals as dotted vertical lines).

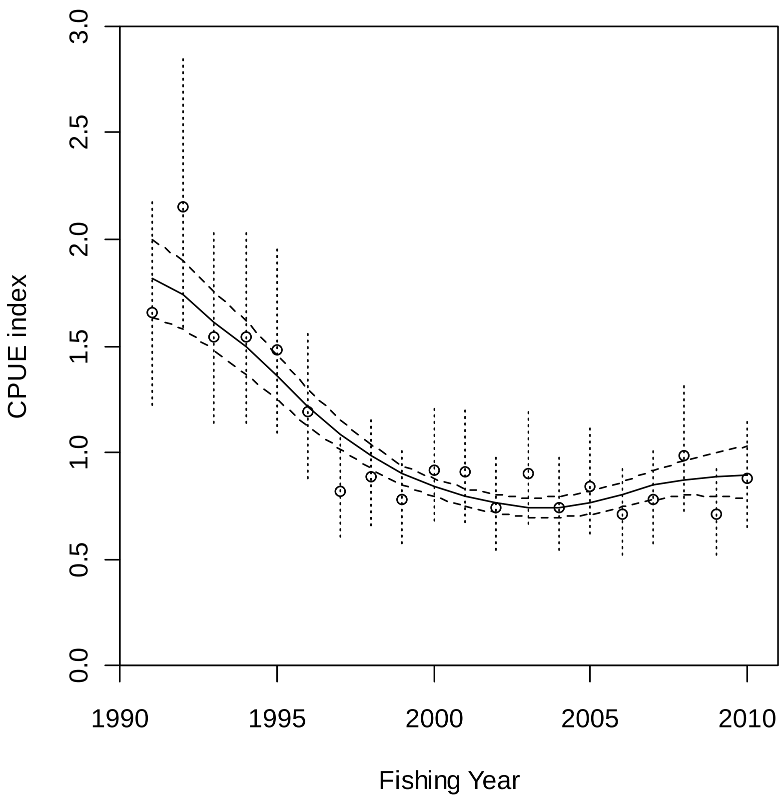

Figure 23: LIN 3&4, fit of the Base MCMC run (solid line, median; dashed lines, 95% credible intervals) to the line fishery CPUE index (points, 95% credible intervals as dotted vertical lines).

Table 12: LIN 3&4, Bayesian median and 95% credible intervals (in parentheses) of B_0 and B_{2011} (in tonnes), and B_{2011} as a percentage of B_0 for both model runs (%B_0).

Model run		B_0		B_{2011}		B_{2011} (%B_0)
Base	127 400	(110 400–170 300)	70 800	(48 600–121 900)	55	(44–71)
NoTrawl	111 400	(98 200–166 000)	52 900	(33 200–106 800)	48	(32–67)

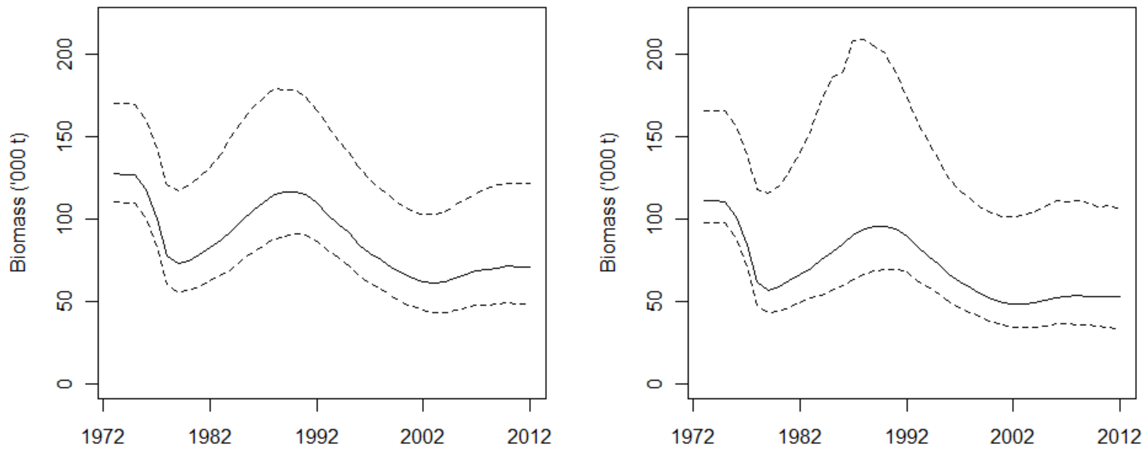

Figure 24: LIN 3&4, estimated posterior distributions of the biomass trajectory (in tonnes) from the Base (left panel) and NoTrawl (right panel) runs. Broken lines show the 95% credible intervals and the solid line the median.

5.5 Biomass projections

Biomass projections from the model were made under two assumed future catch scenarios. The first, lower catch scenario (1870 t by the trawl fishery and 2000 t by the line fishery) is the mean catch level reported from the last five years. The second, higher catch scenario (3000 t by the trawl fishery, 3260 t by the line fishery) assumes that the TACC is taken.

In the projections, relative year class strengths from 2012 onwards were selected randomly from the previously estimated year class strengths from 1980 to 2007.

Projections with both model runs suggested that the biomass in 2016 will be about the same as in 2011 under current catch scenarios (Table 13). If the TACC was caught, both model runs suggest that a decline in biomass would take place.

Table 13: LIN 3&4, Bayesian median and 95% credible intervals of projected B_{2016}, B_{2016} as a percentage of B_0, and B_{2016}/B_{2011} (%) for the model runs, under two future annual catch scenarios.

Model run	Future catch (t)		B_{2016}		B_{2016} (%B_0)		B_{2016}/B_{2011} (%)
Base model	3870	69 900	(45 500–122 000)	54.7	(40.9–72.1)	98.2	(87.1–111.4)
	6260	60 100	(35 000–111 200)	47.0	(31.5–65.6)	84.3	(68.6–100.8)
NoTrawl	3870	55 800	(28 700–123 100)	49.9	(29.1–80.3)	103.2	(77.1–164.0)
	6260	45 800	(18 500–112 500)	41.2	(18.4–71.6)	84.4	(50.1–149.1)

5.6 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 (the only run used to advise fishery management), in Table 14. It appears very unlikely (i.e., less than 1%) that

B_{2016} will be lower than the soft target of 20%B_0, but at the higher catch level there is a moderate probability (21%) that the stock will fall below the target level (40% B_0).

Table 14: Probabilities that current (B_{2011}) and projected (B_{2016}) biomass will be less than 40%, 20% or 10% of B_0. Projected biomass probabilities are presented for two scenarios of future annual catch (i.e., 3870 t, and 6260 t).

Model run	Biomass	Management reference points		
		40% B_0	20% B_0	10% B_0
Base	B_{2011}	0.000	0.000	0.000
	B_{2016}, 3870 t catch	0.017	0.000	0.000
	B_{2016}, 6260 t catch	0.210	0.000	0.000

6. MODEL ESTIMATES for LIN 5&6 (SUB-ANTARCTIC)

6.1 Developing a base model

The most recent previous assessment of the Sub-Antarctic ling stock found that estimated biomass was moderately sensitive to relatively small changes in *M* (Horn 2008). It also appeared likely that the true *M* for the Sub-Antarctic stock was slightly higher than the 'default' value of 0.18 that has been used in many previous ling assessments (Horn 2008). Consequently, there is a need to incorporate the effect of this uncertainty in *M* in the current assessment.

Past assessments have also produced relatively uncertain results because there is little contrast in any of the abundance series (i.e., trawl surveys and line fishery CPUE). This led to conclusions that the stock had been only lightly fished, but that absolute biomass estimates were poorly known.

An initial model was set up using the two research survey series (input as relative biomass and proportions-at-age) and fishery catch-at-age data (i.e., no CPUE indices), and allowing *M* to be estimated as an age-dependent relationship. Logistic selectivity ogives were estimated for each of the trawl survey series, and for the two line fisheries; a double-normal ogive was estimated for the trawl fishery. This model produced a biomass trajectory that showed an overall slight decline from the early 1970s to the late 1990s, followed by a rebuilding phase to the present. An examination of annual catch from the stock, and the pattern of estimated year class strengths (adjusted by 10 years to account for age at full recruitment into the fisheries), showed how these series influenced biomass (Figure 25). The slight biomass decline about 1980 corresponded with a period of moderate catches, followed by a period of low catches throughout the 1980s which, along with the recruitment of some strong year classes, resulted in a slight rebuild of biomass to 1990. Throughout the 1990s, catches increased to peak in 1997 and recruiting year classes were generally weak, resulting in a steady decline in the biomass trajectory to its minimum in 1999. During the 2000s, although catches remained high, there was a steady rebuild in biomass particularly in the early part of the decade when three very strong year classes would have recruited into the fishery.

The combination of catch and estimated year class strengths clearly support the trends in the estimated biomass trajectory (Figure 25). However, it is considered desirable to check that the pattern of estimated year class strengths is supported by the available data, and is not simply an artefact of the model to ensure that the relative abundance series are well fitted. Consequently, estimated proportion-at-age distributions (with sexes combined) were compiled by year from the trawl survey series (Figure 26) and the longline fisheries (Figure 27). Distributions were not created for the trawl fishery as the age-length keys used are derived from trawl survey otoliths, so the year class abundances would be quite similar.

The observed proportions in Figures 26 and 27 relating to the estimated strong year classes from 1993 to 1995 are often much greater than the proportions of older fish immediately following them, and sometimes very similar to the proportions immediately preceding them. These are characteristics of relatively abundant year classes. Three year classes estimated to be weak (1984, 1986 and 1987) are depicted as crosses on Figures 26 and 27, and these symbols are often followed by proportions that are similar or slightly higher than the 'weak' value. Although the patterns are not as clear-cut as for the strong year classes, many of the crosses still exhibit the characteristic of a relatively weak year class. So it is clear that the available data are supportive of the pattern of year class strengths estimated in Figure 25.

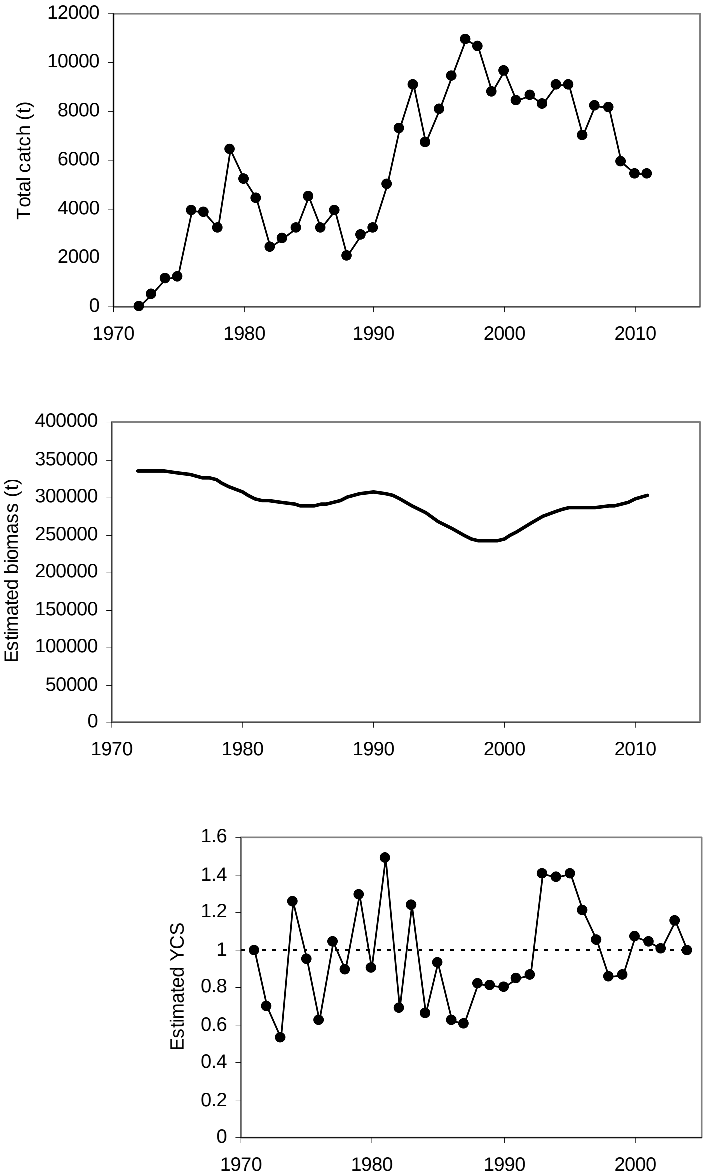

Figure 25: LIN 5&6 — Annual catch (t) by all fisheries combined, estimated biomass trajectory, and estimated year class strengths (YCS).

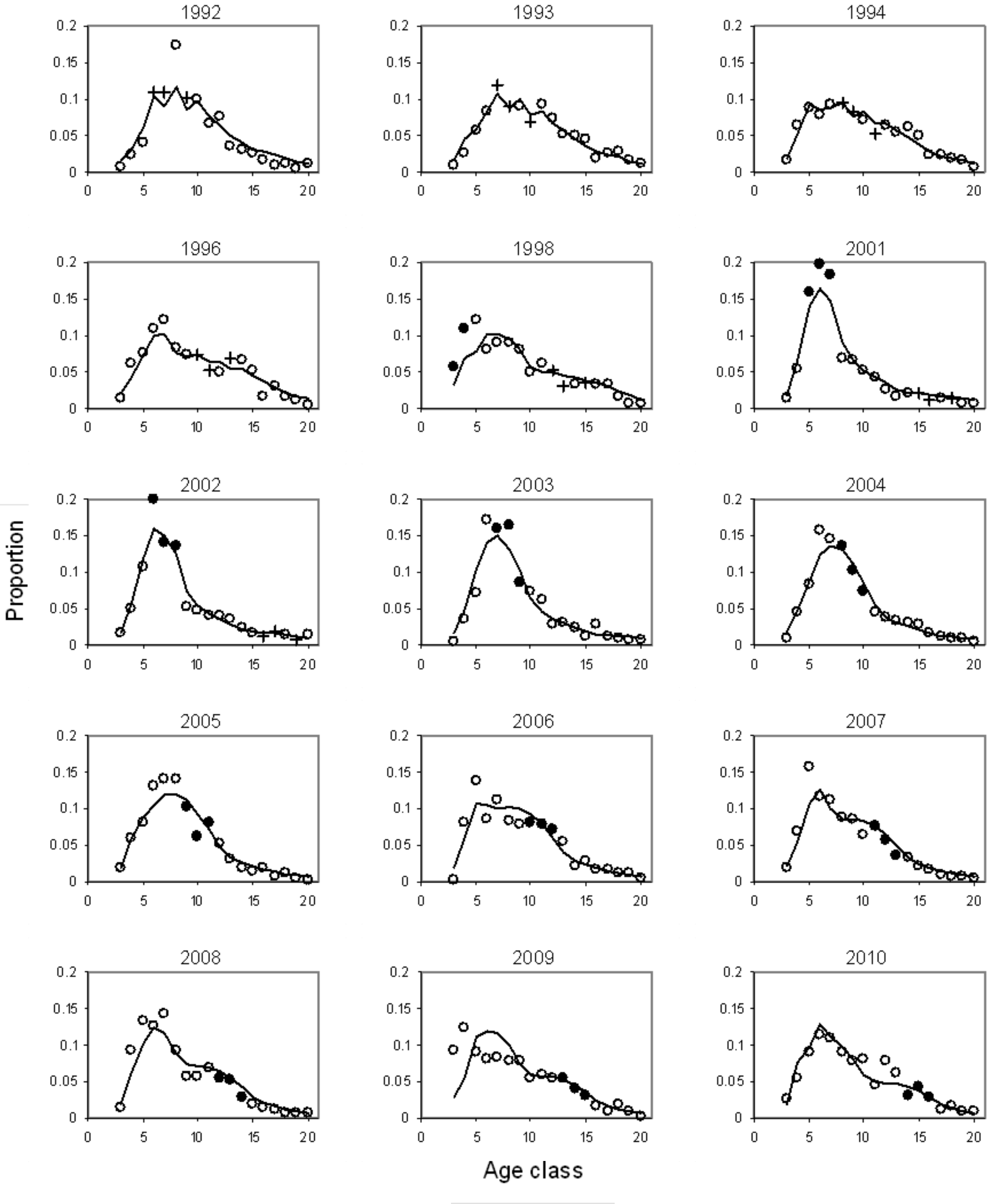

Figure 26: LIN 5&6 — Observed proportions-at-age with sexes combined (symbols), and the model estimated distribution (solid lines), by year, from the research surveys. Estimated strong year classes (1993–95) are shown as filled circles, weak year classes (1984, 1986–87) as crosses, and all other year classes as open circles.

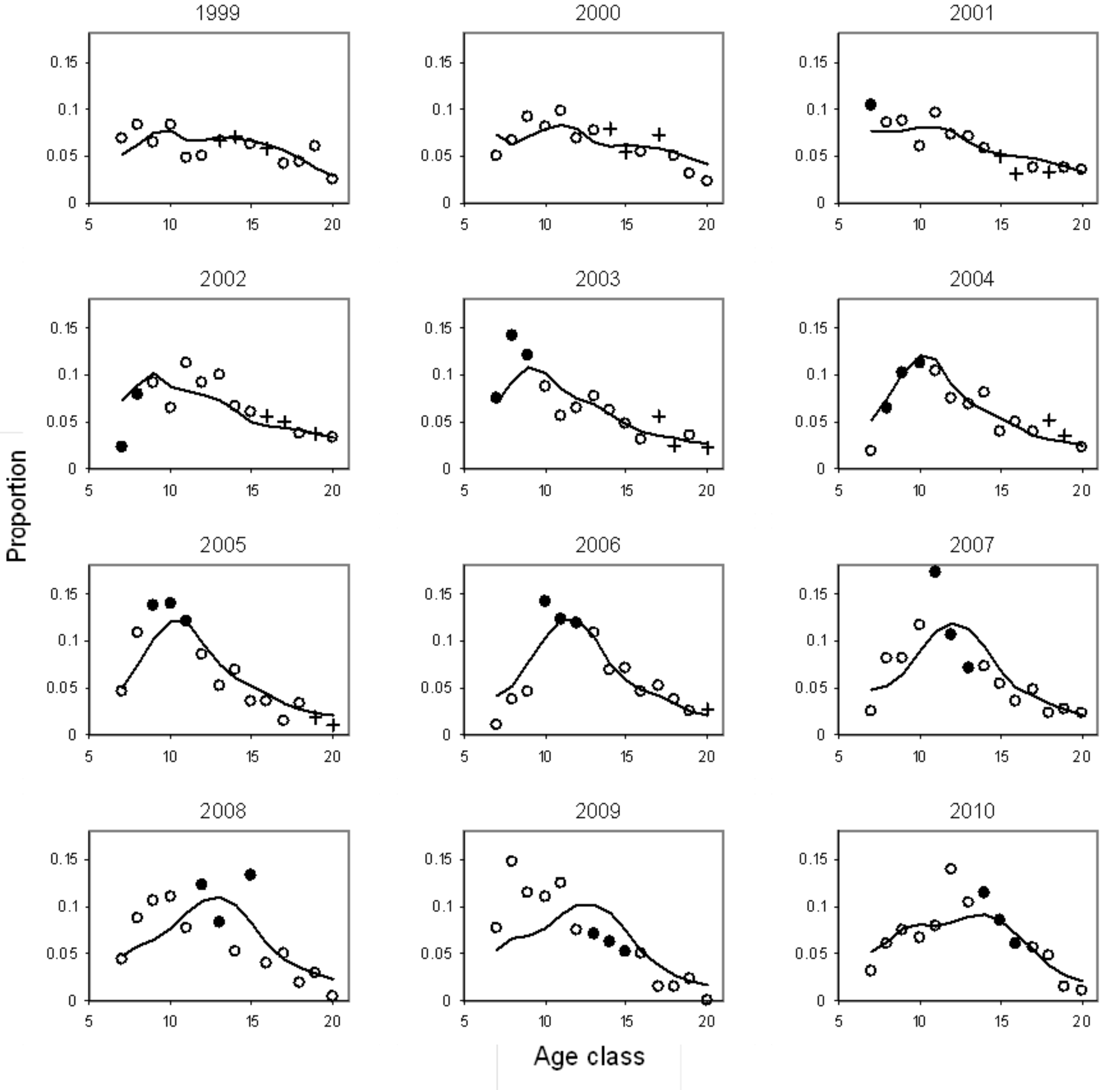

Figure 27: LIN 5&6 — Observed proportions-at-age with sexes combined (symbols), and the model estimated distribution (solid lines), by year, from the longline fisheries. Estimated strong year classes (1993–95) are shown as filled circles, weak year classes (1984, 1986–87) as crosses, and all other year classes as open circles.

The estimated biomass trajectory is also influenced by the series of relative abundance indices. If we assume that the relative abundance series is an accurate and unbiased index of relative abundance, then a good model will fit the series well. Two trawl survey biomass series are available for the LIN 5&6 stock (see Table 5). Fits to the two series are shown in Figure 28. The autumn series is relatively short, but appears to be well fitted. The summer series is not well fitted overall, although it could be argued that with the exception of the 2001 (and perhaps the 1994) point the fit is reasonable, and is indicative of a stock with a biomass that has changed little in the last two decades. The 2001 summer estimate has a c.v. of 6.9%, one of the lowest in the series; the 1994 estimate has one of the highest c.v.s in the series (11.5%). The low c.v. on the potentially aberrant 2001 survey estimate would strongly encourage the model to try to fit this point. A model run excluding the 2001 survey biomass point would probably be a useful investigation to gauge the influence of what may be an abnormal survey result.

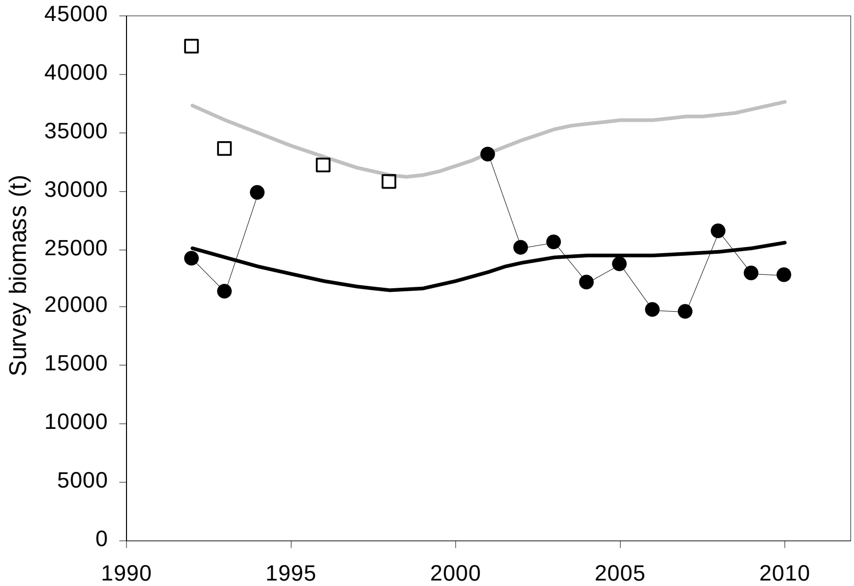

Figure 28: LIN 5&6 — Observed relative biomass from the autumn (open squares) and summer (filled circles) research trawl surveys. Survey biomass trajectories estimated in the model are also shown for the autumn (grey line) and summer (black line) surveys.

The instantaneous natural mortality (*M*) relationship (estimated using the double exponential parameterisation) from the initial model was logical with a minimum at age 14 (slightly higher than the estimated age at 100% maturity of 11 years), and a range from 0.13 to 0.39 (Figure 29). The various selectivity ogives that are estimated in the initial model will be confounded with the relationship for *M*. Specifying logistic ogives for all except the trawl fishery assumes that selectivity does not decline with age in either the line fisheries or the trawl surveys. No information is available to verify such an assumption. However, line fisheries consistently catch larger ling than trawl fisheries, and there is no reason to believe that the oldest (largest) ling are less likely to take a hook than younger fish, so logistic ogives are probably suitable for these fisheries. The trawl surveys comprehensively cover the range of depths where ling are most abundant, so applying logistic ogives to these series assumes that older (larger) fish are not better at avoiding the trawl than younger fish. The ogives estimated from the initial model (Figure 30) are plausible in that age at full selectivity increases from the trawl surveys (60 mm mesh codend), to the commercial trawl fishery (60–100 mm mesh codends), to the line fisheries.

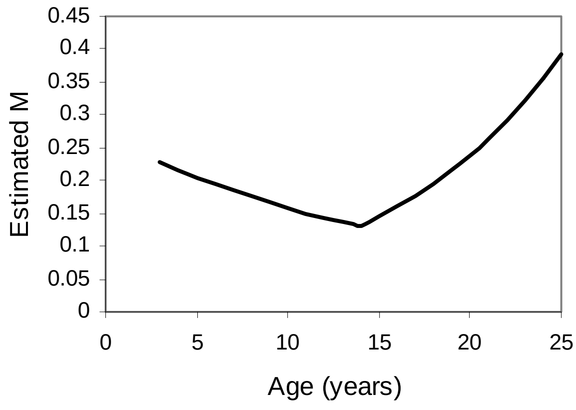

Figure 29: LIN 5&6 — Estimated age-dependent relationship for *M* for both sexes combined, over an age range from 3 to 25 years, from the initial model.

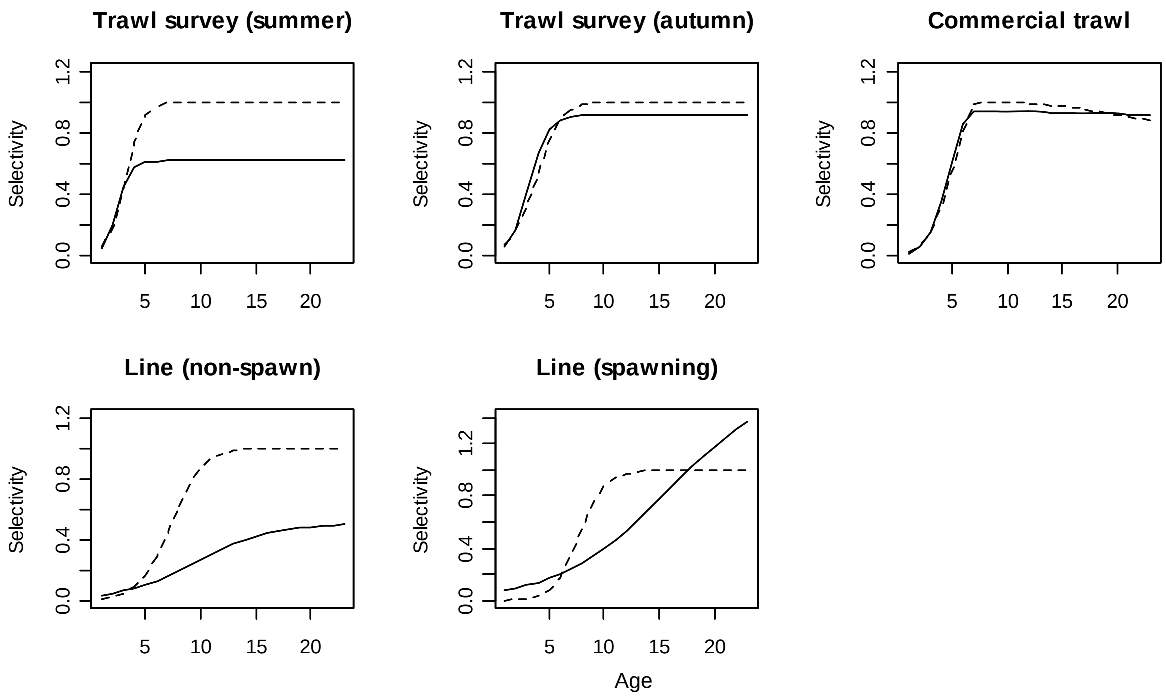

Figure 30: LIN 5&6 — Estimated selectivity ogives by survey and fishery, and sex (male, solid lines; female, dashed lines), from the initial model.

The effect of allowing the trawl survey ogives to be domed was examined in a second model. The estimated trawl survey and trawl fishery ogives all indicated a reduction in selectivity with age from about ages 5–7 (Figure 31). Again, these ogives would be confounded with the estimated age-dependent relationship for *M*, which had a much wider range than in the initial model particularly for young to middle aged fish, i.e., 0.72 to 0.05 for ages 3 to 12 (Figure 32). This range, and particularly the minimum value, is probably unrealistic for ling.

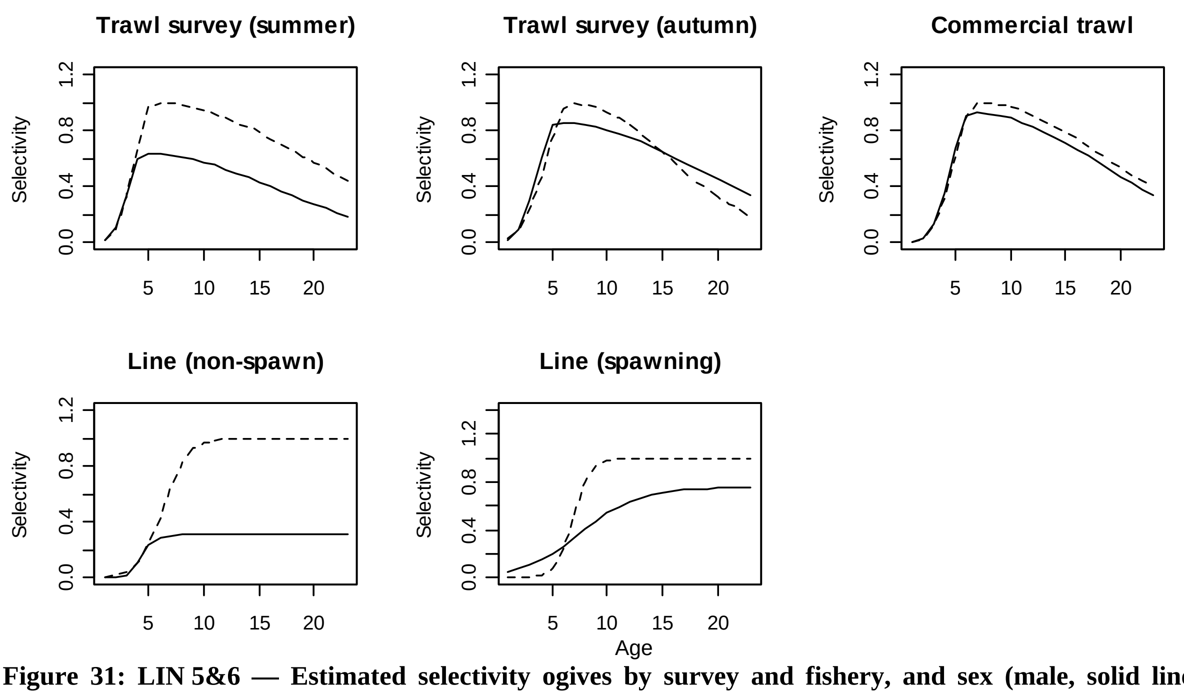

Figure 31: LIN 5&6 — Estimated selectivity ogives by survey and fishery, and sex (male, solid lines; female, dashed lines), from the model allowing double-normal trawl survey ogives.

Figure 32: LIN 5&6 — Estimated age-dependent relationship for *M* for both sexes combined, over an age range from 3 to 25 years, from the model allowing double-normal selectivity ogives for the trawl surveys.

As well as markedly altering the estimated *M*-at-age relationship, the domed trawl survey ogives indicate that fish become relatively less vulnerable to the trawl with increasing age (after age 6), producing a cryptic biomass in the survey area. The domed ogive model produced a lower estimate of B_0 (221 300 compared with 335 600 t) and a more pessimistic stock status (B_{cur} of 73% B_0 compared with 90% B_0). In combination, the lower estimated absolute biomass and the cryptic biomass result in survey *q* values that are much higher for the domed ogive model (0.18 and 0.27 for summer and autumn, respectively) than for the initial model (0.08 and 0.12, respectively), and also markedly higher than values for ling and hake caught with the same gear on the Chatham Rise (i.e., 0.06–0.16) estimated in assessments considered to be reasonably reliable (Horn 2008, Horn & Francis 2010). However, the overall fit for the model allowing domed trawl survey ogives was better than for the initial model, particularly for the at-age data (Table 15). There was little difference in the estimated year class strengths between models, although the domed model estimated slightly higher values for year classes before 1980. In summary, although the domed model provides an overall better fit to the data than the initial model, there is little difference between models in the year class strength estimates and the fits to the survey biomass series, but the domed model produces less realistic natural mortality estimates and relatively high *q* estimates. Consequently, it was concluded that the initial model is a better 'base case', but that an MCMC run of the domed model is worthy of investigation.

Table 15: Negative log likelihood of all data series for the initial model with logistic survey selectivities (Logistic) and the model allowing domed survey selectivities (Double-normal), showing how allowing domed selectivities improved the overall model fit.

Data series	Logistic	Double-normal	Gain
Survey biomass (autumn)	-7.5	-7.4	-0.1
Survey biomass (summer)	-6.9	-6.5	-0.4
Survey age (autumn)	-82.3	-86.3	4.0
Survey age (summer)	-259.4	-263.5	4.1
Line fishery age (non-spawn)	-25.2	-35.8	10.6
Line fishery age (spawning)	-47.9	-44.9	-3.0
Trawl fishery age	-111.1	-114.3	3.2
Priors & penalties	3.2	6.3	-4.1
Total log likelihood	-537.1	-552.4	15.3

Two CPUE series are available for the LIN 5&6 stock, one from each of the two line fisheries (see Appendix B). No obvious sources of bias are apparent for either of the series, but because they are fishery-dependent series they are considered to be less reliable as indices of relative abundance than trawl survey biomass. Fits to the two CPUE series when they were included in the initial model are shown in Figure 33. Although the CPUE series are quite spiky, the model fits appear reasonable and there are no obvious trends in the residuals.

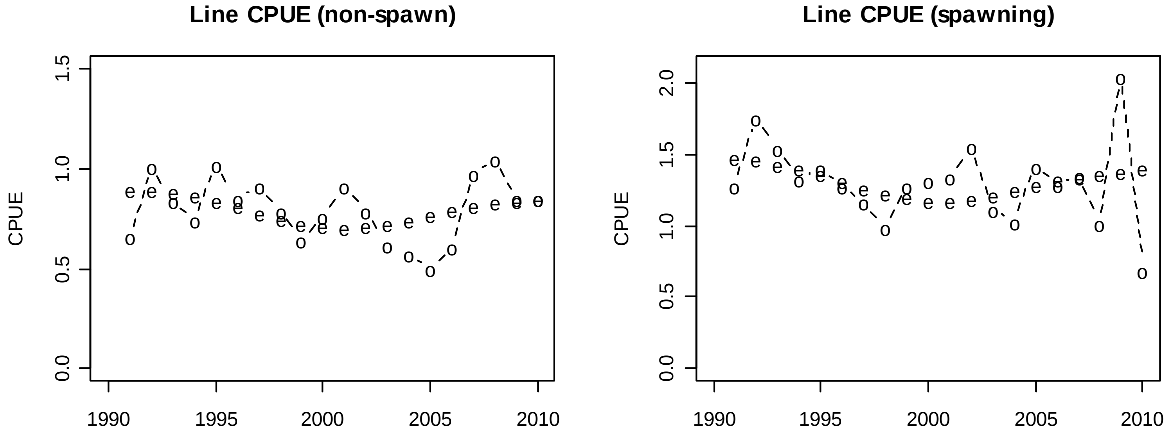

Figure 33: LIN 5&6 — MPD model fits (e) to observed (o) CPUE series from the non-spawning and spawning line fisheries.

Following the investigations above with MPD model fits it was concluded that the best base model for MCMC estimation was the initial model (hereafter called the 'logistic' model). Three additional models were also fully investigated as a sensitivity to the base case. Descriptions of all four models are as follows.

- Logistic (the base model) — catch history, trawl survey abundance, all available at-age data series, logistic selectivity ogives for the line fishery and the trawl survey series, double-normal ogives for the trawl fishery, and *M* estimated as a double-exponential age-dependent relationship.
- Exclude survey — the logistic model, but with the 2001 trawl survey biomass point excluded.
- CPUE — the logistic model, but including the two line fishery CPUE series.
- Double-normal — the logistic model, but estimating double-normal selectivity ogives for the trawl survey series.

6.2 Model estimation using MCMC

Model parameters were estimated using Bayesian estimation implemented using the CASAL software. For final runs, the full posterior distribution was sampled using Monte Carlo Markov Chain (MCMC) methods, based on the Metropolis-Hastings algorithm. MCMCs were estimated using 3×10^6 iterations, a burn-in length of 5×10^5 iterations, and with every 2500th sample kept from the final 2.5×10^6 iterations (i.e., a final sample of length 1000 was taken from the Bayesian posterior).

6.3 Prior distributions and penalty functions

The assumed prior distributions used in the assessment are given in Table 16. Most priors were intended to be uninformed, and were specified with wide bounds. The exception was the choice of informative priors for the trawl survey *q*. The priors on *q* for the *Tangaroa* trawl surveys were estimated assuming that the catchability constant was a product of areal availability (0.5–1.0), vertical availability (0.5–1.0), and vulnerability between the trawl doors (0.03–0.40). The resulting (approximately lognormal) distribution had mean 0.13 and c.v. 0.70, with bounds assumed to be 0.02 to 0.30.

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 16: Assumed prior distributions and bounds for estimated parameters in the LIN 5&6 assessment. Parameter values are mean (in natural space) and c.v. for lognormal.

Parameter description	Distribution	Parameters		Bounds	
B_0	uniform-log	–	–	50 000	800 000
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*
Process error c.v.	uniform-log	–	–	0.001	2
M (x_0, y_0, y_1, y_2)	Uniform	–	–	3, 0.01, 0.01, 0.01	15, 0.6, 1.0, 1.0

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

6.4 MCMC estimates

Model estimates of biomass, year class strengths, and *M* were derived using the fixed parameters (see Table 4) and the model input parameters described earlier. The logistic model and three sensitivity models were investigated. MCMC estimates of the posterior distributions are presented below. In addition, MCMC estimates of the median posterior and 95% percentile credible intervals are reported for the key output parameters. A comparison of the MCMC chains for estimates of B_0 from the four models shows that all have a clear concentration of estimates between about 250 000 and 600 000 t (Figure 34). Although no chain appears to be well converged in Figure 34, the distributions of estimates of B_0 and B_{2011} (as %B_0) from the logistic model are reasonably consistent between the first, middle, and last thirds of the chain (Figure 35), and hence convergence is probably adequate for stock-assessment purposes.

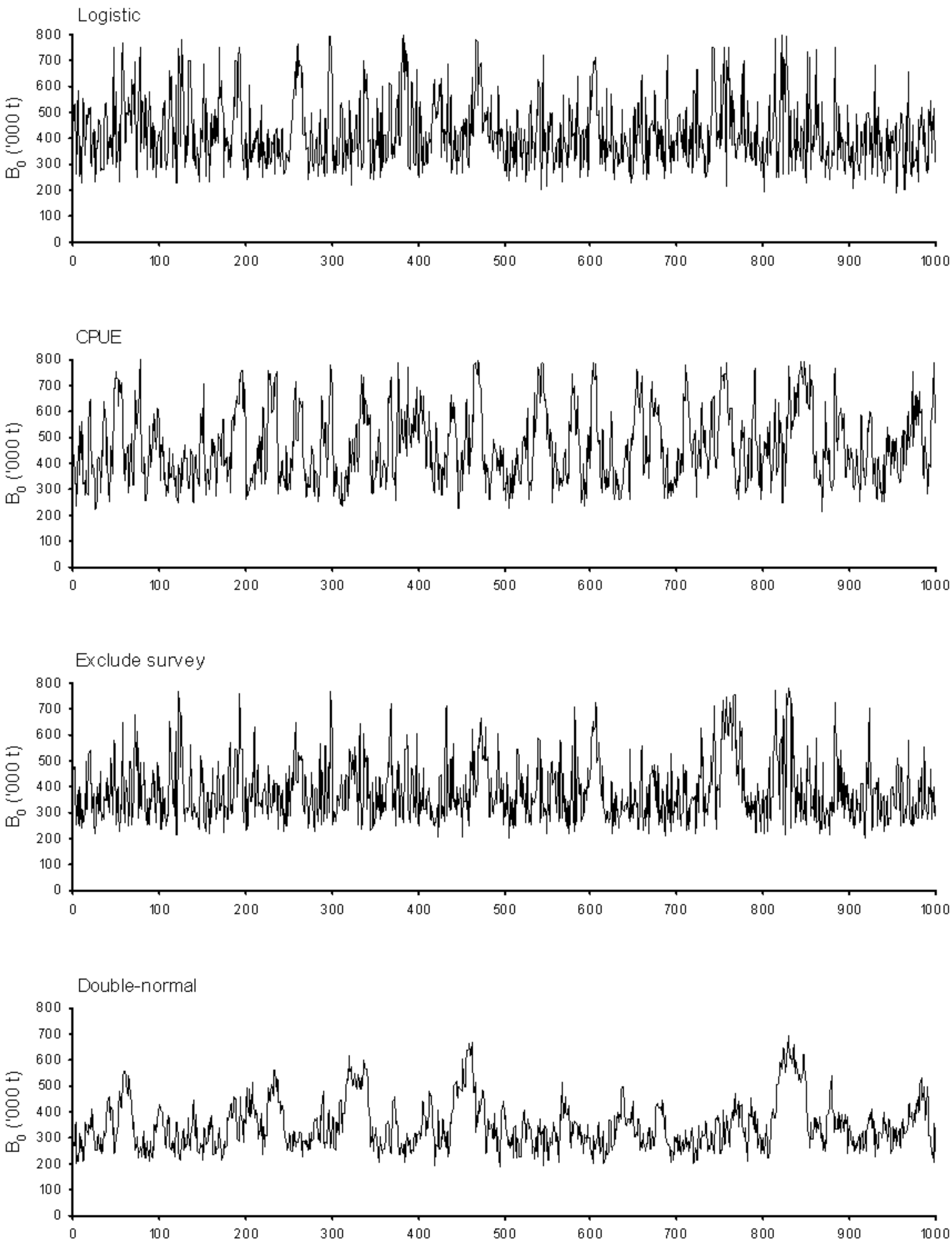

Figure 34: Trace diagnostic plot of the MCMC chains for estimates of B_0 for both the four Sub-Antarctic stock model runs.

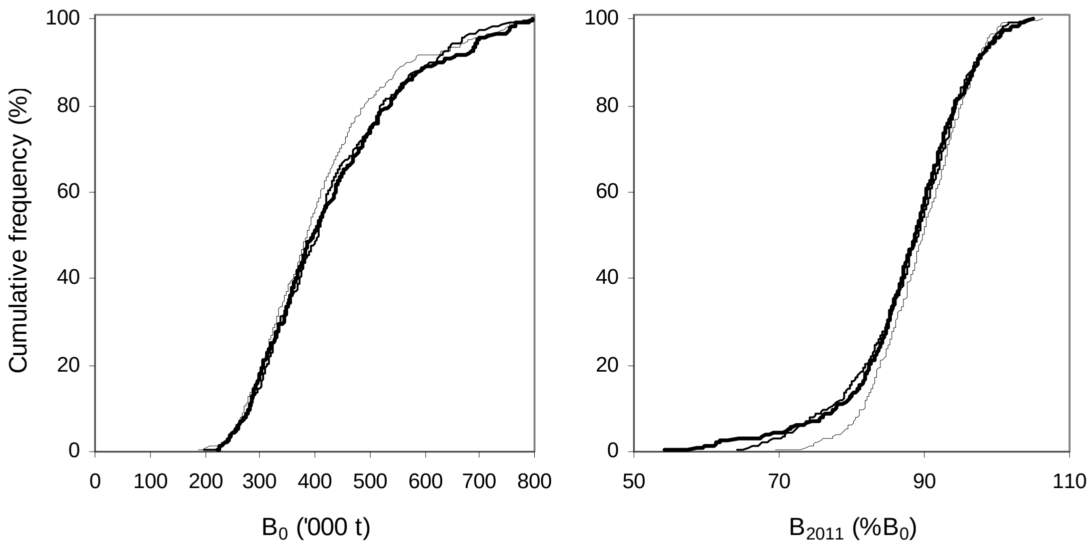

Figure 35: MCMC diagnostic plot showing the cumulative frequencies of B_0 and B_{2011} (%B_0) for the first (thick line), middle (medium line), and last (thin line) third of the MCMC chain for the logistic model.

The estimated MCMC marginal posterior distributions for selected parameters from the logistic model are shown in Figures 36–41. Instantaneous natural mortality (M) was estimated as an age-dependent relationship independent of sex (Figure 36). The relationship had a minimum of about 0.14 at 13 years, rising to about 0.4 at 25 years, and a relatively narrow 95% credible interval across most ages. However, the estimation of M will be confounded with the estimation of survey and fishery selectivities, so we cannot be confident that the true relationship has been determined here.

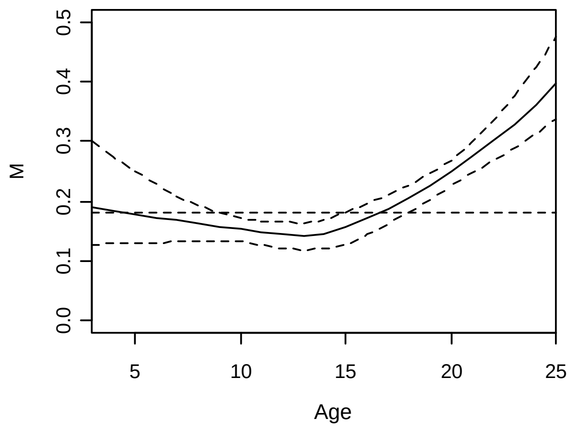

Figure 36: LIN 5&6 logistic model — Estimated median natural mortality age-dependent relationship (with 95% credible interval shown as dashed lines). The horizontal dashed line is at 0.18, a value that has been used as a fixed value for M in previous assessments.

The selectivity ogives were relatively tightly defined (Figure 37). Fishing selectivities indicated that ling were fully selected in the trawl fishery by about age 8–9 years, compared to age 13–15 (for females) in the line fisheries. This is consistent with selectivity ogives for other assessed ling stocks where age at full selectivity is higher in the line fishery relative to the trawl fishery (e.g., Horn 2008). In both fisheries, females appear to be fully selected at younger ages than males, which is consistent with selectivity by size as females are larger at age than males. The trawl fishery ogive is essentially logistic-shaped even though it was fitted using the double-normal parameterisation. There is no information outside the model that allows the shape of the estimated selectivity ogives to be verified.

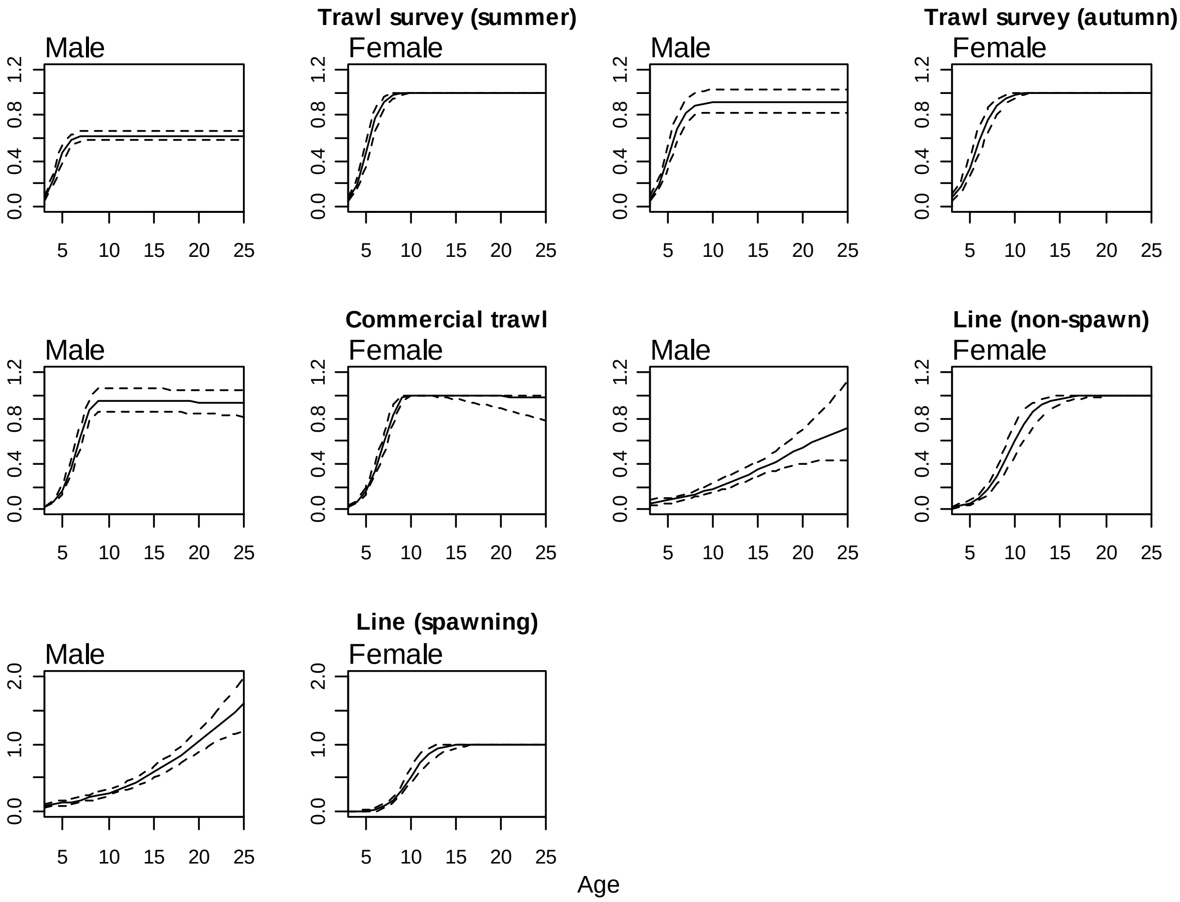

Figure 37: LIN 5&6 logistic model — Estimated median selectivity ogives (with 95% credible interval shown as dashed lines) for the two trawl survey series and the three commercial fisheries.

Year class strengths were not well estimated (and have wide credible bounds) for years where only older fish were available to determine age class strength (i.e., before 1982) or where there are few data (i.e., after 2004) (Figure 38). Intermediate year class strengths appear well estimated. Year classes were generally weak from 1982 to 1992, strong from 1993 to 1996, and average since then (although 2005 may be strong). Overall, estimated year class strengths were not widely variable, with all medians being between 0.5 and 2.

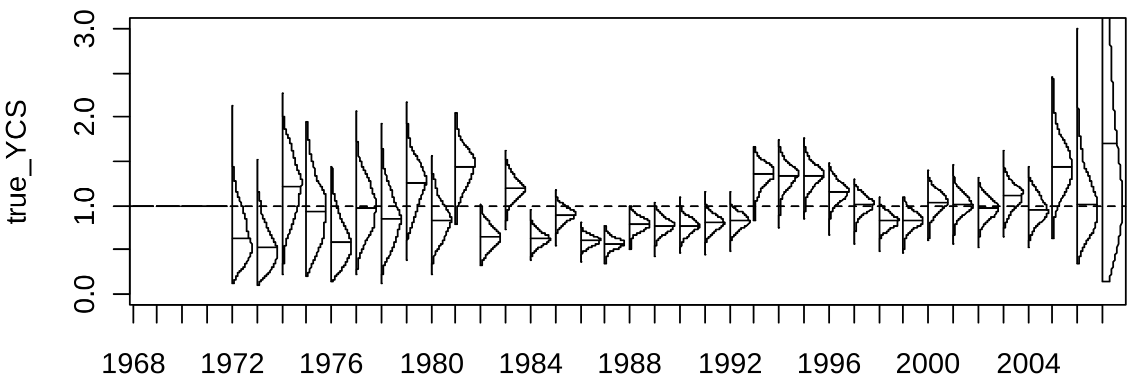

Figure 38: LIN 5&6 logistic model — Estimated posterior distributions of year class strengths. The dashed horizontal line indicates the year class strength of one. Individual distributions are the marginal posteriors, with horizontal lines indicating the median.

The model fits to the two trawl survey series were shown above (Figure 28): the autumn series points were well fitted, as were all but the 2001 point in the summer series. Estimated median catchability coefficients (*q*, with 95% credible intervals) are 0.07 (0.04–0.13) and 0.10 (0.05–0.18) for the summer and autumn surveys, respectively (Figure 39). As expected, the summer *q* is lower than the autumn value.

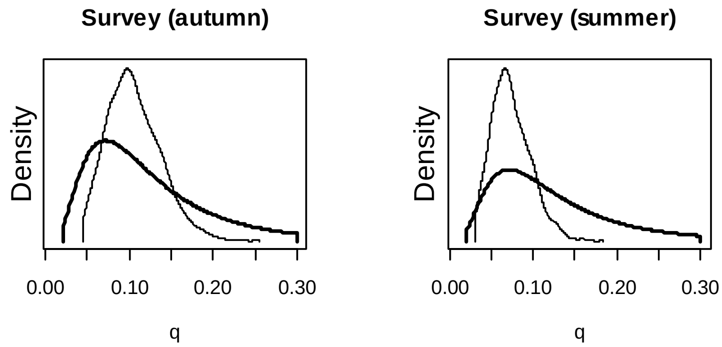

Figure 39: LIN 5&6 logistic model –– Estimated posterior distributions (thin lines) of the trawl survey *q*, and distributions of priors (thick lines), for the autumn and summer trawl survey series.

Estimated biomass for the Sub-Antarctic stock declined slightly throughout the 1980s owing to fishing, but more steeply throughout the 1990s owing to increased fishing pressure and the recruitment of the relatively weak years classes spawned throughout the 1980s (Figures 40 and 41). Biomass has since increased following a reduction in fishing pressure and the recruitment of average to strong year classes. Bounds around the median biomass estimates are wide. Current stock size is estimated to be about 89% of B_0 (95% credible interval 70–101%) (see Figure 40 and Table 17.) Exploitation rates (catch over vulnerable biomass) were very low up to the late 1980s, and have been low (up to about 0.04 yr^{-1}) since then (Figure 41).

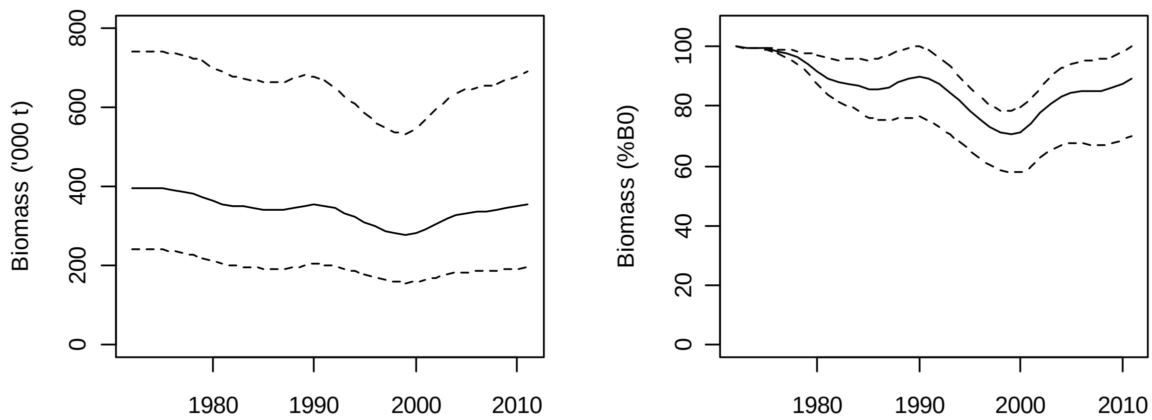

Figure 40: LIN 5&6 logistic model — Estimated median trajectories (with 95% credible intervals shown as dashed lines) for absolute biomass and biomass as a percentage of B_0.

Table 17: Bayesian median and 95% credible intervals of B_0, B_{2011}, and B_{2010} as a percentage of B_0 for the Sub-Antarctic (LIN 5&6) model runs.

Model run	B_0	B_{2011}	B_{2011} (%B_0)
Logistic	394 700 (240 200–740 800)	355 200 (195 400–690 000)	89 (70–101)
CPUE	442 400 (258 000–763 200)	399 300 (214 300–703 600)	90 (74–100)
Exclude survey	352 900 (229 300–691 100)	314 000 (182 900–614 700)	89 (70–101)
Double-normal	328 500 (220 800–590 400)	292 400 (173 600–553 200)	87 (76–98)

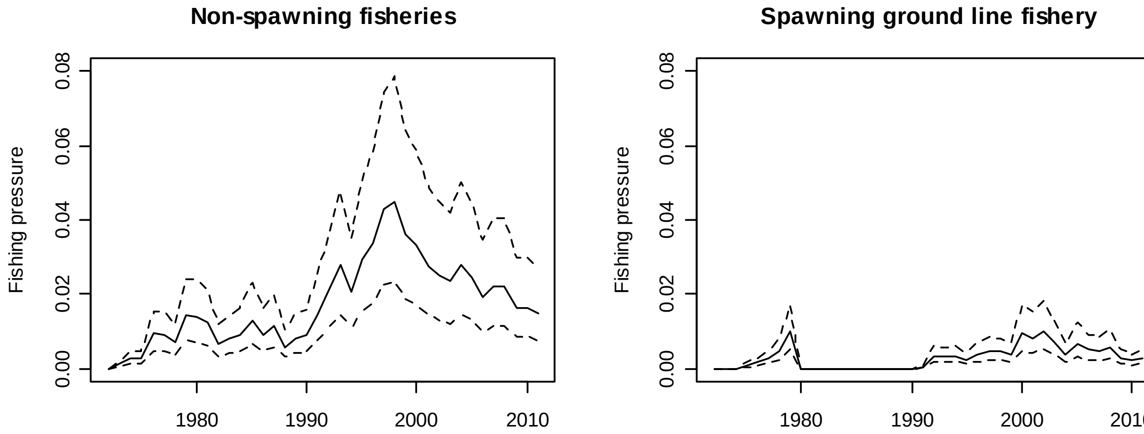

Figure 41: LIN 5&6 logistic model — Estimated median trajectories (with 95% credible intervals shown as dashed lines) of fishery exploitation rates.

The sensitivity model including the two line fishery CPUE series produced a stock status little different to the logistic model, but with slightly higher estimates of absolute biomass (Table 17). The fits to the CPUE series were reasonably good (see Figure 33) with no obvious trends in the residuals. The estimated selectivity ogives, M-at-age relationship, year class strengths, and biomass trajectory (%B_0) were virtually identical to those from the logistic model. The fits to the trawl survey indices were also little different (Figure 42).

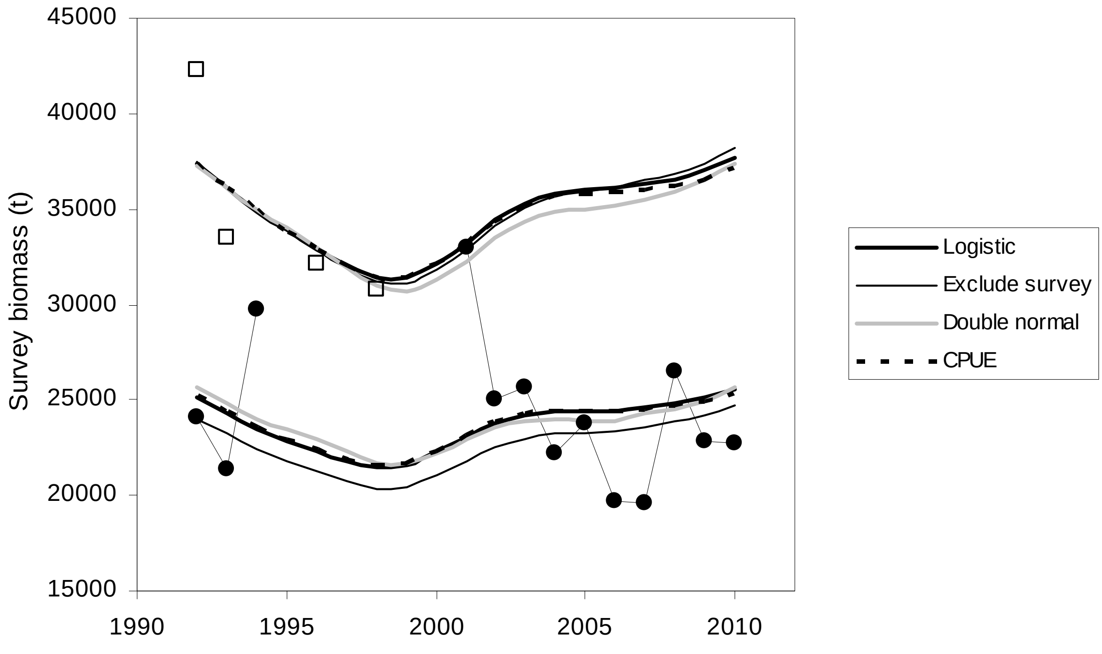

Figure 42: LIN 5&6 — Observed relative biomass from the autumn (open squares) and summer (filled circles) research trawl surveys. Survey biomass trajectories estimated in the model are also shown for the autumn (upper set of lines) and summer (lower set of lines) surveys.

The sensitivity model excluding the 2001 summer survey biomass point from the logistic model also produced a stock status little different to the logistic model, but with slightly lower estimates of absolute biomass (Table 17). The fits to the autumn survey series were little changed, while the fit to the summer series was lower, but with an even reduction across the entire series (see Figure 42). The estimated selectivity ogives, *M*-at-age relationship, year class strengths, and biomass trajectory (%B_0) were virtually identical to those from the logistic model.

The sensitivity model allowing the selectivity ogives for the trawl survey series to be fitted using the double-normal parameterisation also produced a stock status little different to the logistic model, but had the lowest estimates of absolute biomass of all the models (Table 17). Based on the initial MPD runs of this model, it was expected that the selectivity ogives (and, consequently, the *M*-at-age relationship) would be quite different to those of the logistic model (see Figures 31 and 32). However, only the autumn trawl survey ogive for females differs markedly; fish older than about 15–20 years are less selected (Figure 43). The natural mortality relationship (Figure 44) is little different to that estimated in the logistic model. The fits to the trawl survey series were also little changed (see Figure 42), and *q* values (with 95% credible intervals) were lower than in the MPD run, i.e., 0.09 (0.05–0.14) and 0.13 (0.07–0.21) for the summer and autumn surveys, respectively, but higher than in the logistic model (Figure 45). The year class strengths and biomass trajectory (%B_0) were virtually identical to those from the logistic model, and the 95% credible intervals around these estimated quantities were narrower than for the other models (see Table 17).

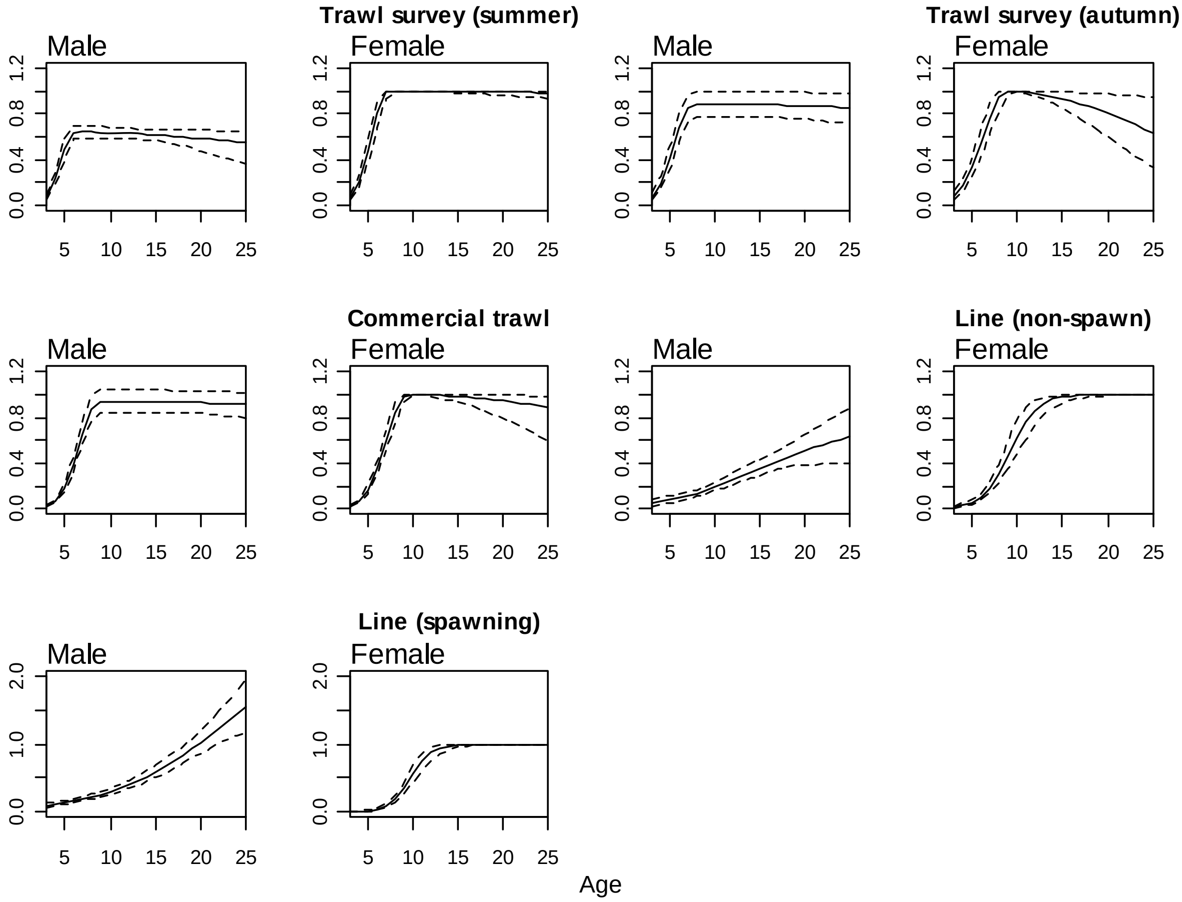

Figure 43: LIN 5&6 double-normal model — Estimated median selectivity ogives (with 95% credible interval shown as dashed lines) for the two trawl survey series and the three commercial fisheries.

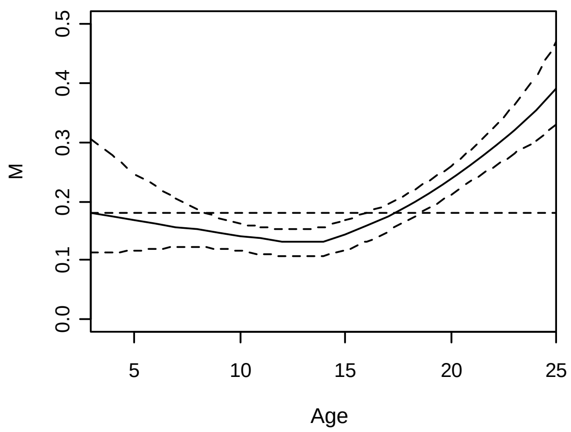

Figure 44: LIN 5&6 double-normal model — Estimated median age-dependent natural mortality relationship (with 95% credible interval shown as dashed lines). The horizontal dashed line is at 0.18, a value that has been used as a fixed value for M in previous assessments.

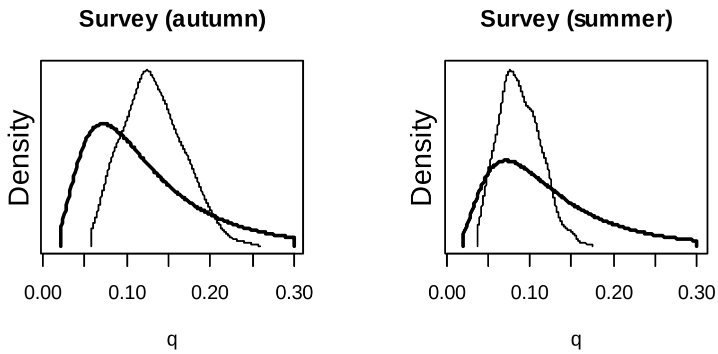

Figure 45: LIN 5&6 double-normal model — Estimated posterior distributions (thin lines) of the trawl survey *q*, and distributions of priors (thick lines), for the autumn and summer trawl survey series.

6.5 Biomass projections

Biomass projections from the logistic and double-normal models were made under two assumed future catch scenarios (5900 t or 12 100 t annually from 2012 to 2016). The low catch scenario (5000 t by the trawl fishery and 450 t by each line fishery) approximates the catch level from recent years. The high catch scenario (9000 t by the trawl fishery, 1500 t by the line non-spawning fishery, and 1600 t by the line spawning fishery) assumes that the TACC is taken. Biomass projections from the CPUE and exclude survey models were made under the low catch scenario only.

In the projections, relative year class strengths from 2008 onwards were selected randomly from the previously estimated year class strengths from 1980 to 2006.

Projections from all models suggested that biomass in 2011 will increase to about the level of B_0 under the lower catch scenario by 2016 (Table 18, Figure 46). Under the higher catch scenario, biomass was still projected to increase, but to a level slightly less than B_0 by 2016.

Table 18: Bayesian median and 95% credible intervals of projected B_{2016}, B_{2016} as a percentage of B_0, and B_{2016}/B_{2011} (%) for the Sub-Antarctic (LIN 5&6) model runs, under two future annual catch scenarios.

Model run	Future catch (t)	B_{2016}	B_{2016} (%B_0)	B_{2016}/B_{2011} (%)
Logistic	5 900	409 400 (210 400–963 700)	103 (84–149)	114 (94–211)
	12 100	386 700 (184 000–964 500)	97 (75–145)	107 (85–201)
CPUE	5 900	464 300 (213 800–973 900)	104 (85–141)	114 (94–181)
Exclude survey	5 900	365 300 (197 000–913 000)	103 (84–153)	114 (95–216)
Double-normal	5 900	327 400 (183 700–684 500)	98 (81–127)	111 (94–155)
	12 100	304 600 (160 500–659 100)	91 (72–121)	102 (85–148)

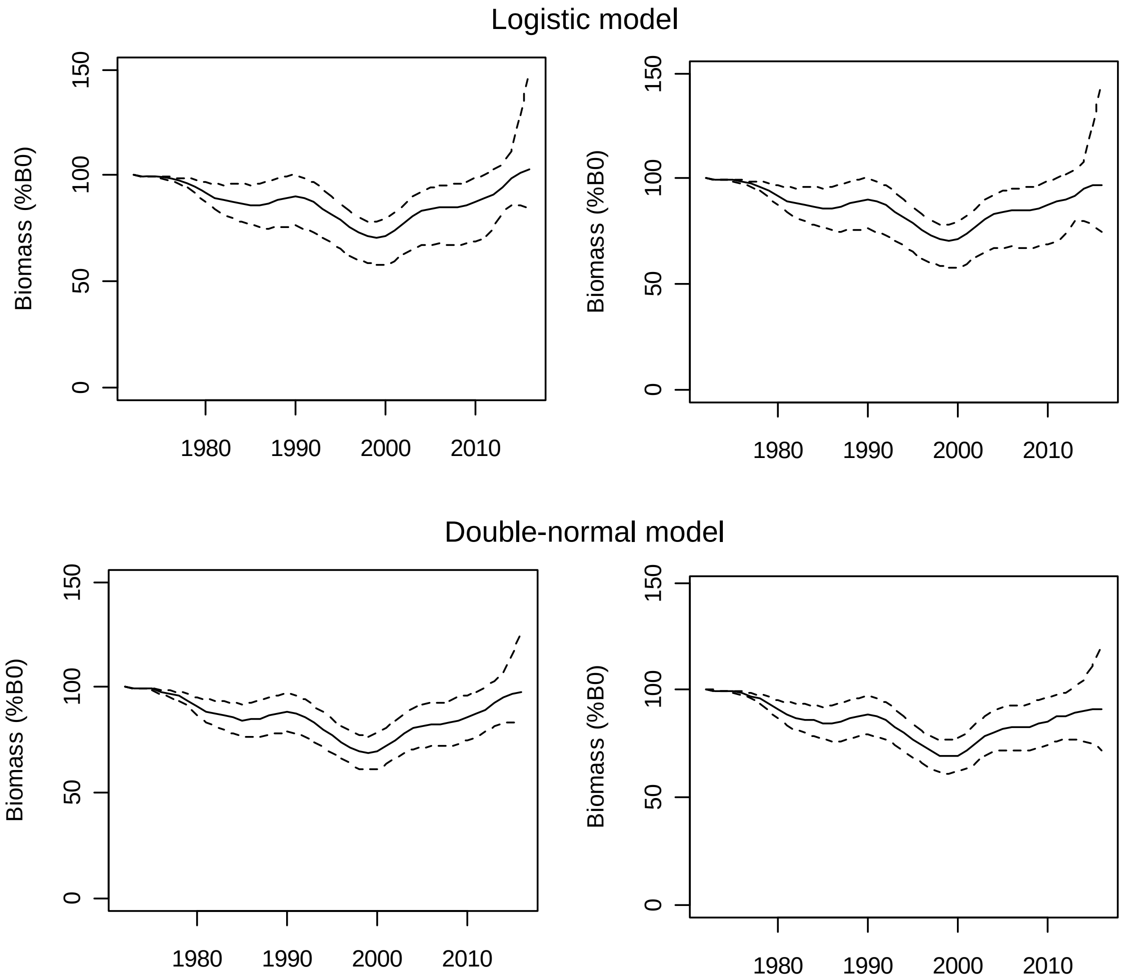

Figure 46: LIN 5&6 biomass projections — Estimated median trajectories (with 95% credible intervals shown as dashed lines) for biomass as a percentage of B_0, projected to 2016 under the logistic and double-normal models, with future catches assumed to be 5900 t (left panel) or 12 100 t (right panel) annually.

6.6 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 logistic and double-normal model runs, in Table 19. It appears extremely unlikely (i.e., less than 0.1%) that B_{2016} will be lower than the target of 40%B_0.

Table 19: Probabilities that current (B_{2011}) and projected (B_{2016}) biomass will be less than 40%, 20% or 10% of B_0. Projected biomass probabilities are presented for two scenarios of future annual catch (i.e., 5900 t, and 12 100 t).

Model	Biomass	Management reference points		
		40% B_0	20% B_0	10% B_0
Logistic	B_{2011}	0.000	0.000	0.000
	B_{2016}, 5900 t catch	0.000	0.000	0.000
	B_{2016}, 12 100 t catch	0.000	0.000	0.000
Double-normal	B_{2011}	0.000	0.000	0.000
	B_{2016}, 5900 t catch	0.000	0.000	0.000
	B_{2016}, 12 100 t catch	0.000	0.000	0.000

7. DISCUSSION

7.1 LIN 3&4 (Chatham Rise)

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 likely to be about 55% of B_0, within relatively wide bounds of 44 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. It seems possible that these results are not incompatible, and in the last assessment both indices were included in the base model run (Horn 2008). In the 2011 assessment, however, the difference between the two biomass indices was considered too great and two alternative model runs were completed. It seems the degree of conflict between these two indices is somewhat subjective. It still seems possible that changes to selectivity might help to resolve the differences between the two biomass indices, through changing the availability of different ages of fish, but this was not resolved within the present assessment.

The present assessment estimated *M*, following the recommendations of the previous assessment (Horn 2008). Future models might investigate assuming length-based selectivity ogives only, but still in an age-based model. A couple of sensitivity runs were done assuming length-based ogives in 2011, but this assumption was not fully investigated; it seems possible it might be a simpler and better base model assumption. It may also be prudent to look more closely at sex ratios within the observational data, and in particular (a) whether they have leverage on the model estimates (in particular B_0 and $\%B_0$), and (b) whether they are likely to be real or just sampling biases; if the former, then we should try to fit them. Concerns about the veracity of composition data, and especially those from the line fishery, were raised during the assessment review process. Concern was also raised about the line fishery CPUE index (see Appendix B), where it was suggested that changes in fishing behaviour or fleet composition might have caused the apparent decline in CPUE. Finally, the MPD for the Base model run was in the tail of the MCMC posterior probability distribution.

7.2 LIN 5&6 (Campbell Plateau)

Previous modelling of Sub-Antarctic ling, as well as other stocks, has shown the assessments to be relatively sensitive to small changes in *M*, and has also indicated that *M* probably varies between stocks (Horn 2008). Consequently, it was considered prudent to estimate *M* in the model, fitted as a double exponential relationship. The derived relationships from all model runs were very similar and were biologically sensible, with *M* being greater for very old (*M* about 0.4) and very young (about 0.2) fish, and lowest (about 0.15) at age 13 years. Ideally, it might be expected that the minimum *M* would be nearer the age at 50% maturity (i.e., about 7–9 years for Sub-Antarctic ling), this being a proxy for the age of peak fitness. It must be remembered, however, that the selectivity ogives and the age-dependent relationship for *M* will be confounded, so although the assessment takes account of the uncertainly around *M*, the estimated *M* relationship may not be a true representation of this biological parameter. But despite the confounding of *M* with selectivity, it is pleasing to find that the *M* relationship differs little when the research survey ogives are fitted with either the logistic or double-normal parameterisation.

The four model runs presented have very consistent estimates of current stock status (i.e., median estimates ranging from 87 to 90% B_0), although median estimates of absolute biomass in 2011 are relatively more variable (i.e., 292 000 to 399 000 t). Incorporating the line fishery CPUE series encourages higher levels of absolute biomass, while removing the possibly aberrant 2001 research survey biomass estimate encourages lower levels. Allowing double-normal research survey ogives also encourages lower levels of absolute biomass. From the results of the MPD runs, it was concluded that the logistic model was preferable to the double-normal mode because of its more realistic *M*-at-age relationship. However, the MCMC results show both models to produce similar *M* relationships. Given the lower log-likelihood of the double-normal run (see Table 15), this is probably the best ‘base’ model.

Under all model runs, current biomass was estimated to be 89% of B_0, with 95% credible intervals no broader than 70–101% B_0. Stock size is projected to increase in the next five years with catches at current levels or at the level of the TACC (i.e., more than twice current levels). The four abundance series (two from surveys, and two from CPUE) were generally well fitted. However, the assessment of the LIN 5&6 stock is moderately uncertain, mainly because there is not enough contrast in the abundance indices to clearly indicate absolute biomass levels. Results from the model run considered most realistic (double-normal) indicate a virgin biomass of about 330 000 t. However, there seems little doubt that the stock has experienced relatively low levels of exploitation, that current biomass is very likely to be well above the management target level of 40% B_0, and that future catches even double those from recent years will have little impact on current stock size.

It is recommended that future assessments of the LIN 5&6 stock maintain the estimation of an age-dependent relationship for *M*, as this is believed to provide a greater degree of biological reality for a parameter that is known to have a marked influence on biomass estimation (Horn 2008).

It should be noted that the LIN 6 administrative stock also includes a separate biological ling stock on the Bounty Plateau. This stock and landings from it have been excluded from the current analysis, as in previous assessments. The Bounty stock is relatively small, being perhaps about 5% of the size of the LIN 5&6 stock (Horn 2007b). Landings from it have fluctuated markedly since the beginning of the longline fishery there in 1991 (see Table 3); since 1992, 0–16% (mean = 7%) of the combined LIN 5 and LIN 6 landings have been taken from the Bounty Plateau.

Another factor that may be pertinent to this assessment is that the Sub-Antarctic biological stock is spread across two administrative fishstocks. An analysis presented in Appendix C shows that although it is likely that the current TACCs allow the harvest of biomass in proportion to its abundance in these two administrative fishstocks, the actual proportion of the available ling biomass harvested from LIN 5 each year is probably much greater than the proportion of available biomass taken from LIN 6. This is because the LIN 6 TACC is usually under-caught (and the catch from the separate Bounty Plateau biological stock is also included in this QMA), whilst the LIN 5 TACC is often fully caught. Much of the LIN 5 catch is from spawning aggregations.

8. ACKNOWLEDGMENTS

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APPENDIX A. Updated descriptive analysis of ling fisheries

Previous descriptive analyses of commercial catch and effort data for ling were completed for the fishing years 1989–90 to 1998–99 (Horn 2001) and 1989–90 to 2004–05 (Horn 2007a). These were both comprehensive reports showing how the ling fisheries in the New Zealand EEZ had evolved and operated. They also aimed to define seasonal and areal patterns of fish distribution. The work presented here simply updates tables A2 and A3 of Horn & Ballara (2012), i.e., catch by area, by method, to indicate whether any marked changes have occurred in the fisheries in the last year.

For a detailed description of the methods used to extract and summarise the landings data, see Horn (2007a). Commercial catch and effort data for all landings of ling from fishing years 1989–90 to 2009–10 had previously been extracted from the MFish catch and effort database, and groomed. The data extracted were reported by fishers on CELR (Catch, Effort, and Landing Return), LCER (Lining Catch Effort Return), LTCER (Lining Trip Catch Effort Return), NCELR (Netting Catch Effort Landing Return), TCER (Trawl Catch Effort Return), or TCEPR (Trawl, Catch, Effort, and Processing Return) forms. The fishing methods examined were: deepwater bottom trawl, deepwater midwater trawl, inshore bottom trawl, inshore midwater trawl, line, setnet, and fish pots. The distinction between deepwater and inshore trawls is not based on depth or position, but rather on the form type that the catch is reported on. TCEPR records are classified as deepwater; CELR and TCER records are classified as inshore.

The catch data from the statistical areas were combined so that the groupings generally approximated the various administrative ling stocks, with two major exceptions. The Bounty Platform section of LIN 6 was examined separately as it is believed to contain a distinct biological stock (Horn 2005), and a Cook Strait area comprising parts of LIN 2 and LIN 7 was created. The areas are: East North Island (East NI), East South Island (East SI), Chatham, Southland, Sub-Antarctic, Bounty, West South Island (West SI), and Cook Strait (Table A1).

All landings data

Annual estimated landings by area, from all methods combined, are listed in Table A2. The estimated totals for each year amount to between 85 and 93% of the actual reported landings. Significant landings have been taken in all areas. Most landings are taken in five areas around the South Island: East SI, Chatham, Southland, Sub-Antarctic, and West SI. This pattern of landings is consistent with ling distributions derived from research trawls (Anderson et al. 1998). There are some changes in the proportions of landings contributed by some areas before and after 2000. Landings from the Sub-Antarctic increased in the latter period (although have been relatively low in the last two years), while those from Chatham declined. There are also some changes between the 2008–09 and 2009–10 fishing years. Line-caught landings from Cook Strait are lower than in any other year analysed, and the Bounty Plateau are negligible and lower than in any year since target line fishing began in that area (Table A3b). In contrast, Sub-Antarctic line-caught landings are higher than in any year since 2001. Trawl fishery landings are generally similar by area in the last two years (Table A3a). Total landings from the EEZ were slightly lower than in 2008–09, and consequently were lower than in any year since 1990 (Table A2).

Landings summaries by fishing method and area

Ling are taken by a variety of fishing methods in each of the areas. Summaries of catch by fishing method, by area and fishing year, are presented in Tables A3a–c.

The inshore bottom trawl fishery (Table A3a) produces low levels of landings (i.e., generally less than 100 t annually) in all areas except Sub-Antarctic, Chatham, and Bounty, where catches are negligible or zero. However, there is some indication of an increasing West SI catch by this method. The deepwater bottom trawl fishery (Table A3a) is still important in the Southland and Sub-Antarctic areas (despite the reductions relative to 2007–08), with annual landings generally in excess of 2000 t. Landings in the Sub-Antarctic increased from the late 1990s to peak at more than 4700 t in 2003–04, but only 1300 t was reported in 2008–09 and 1500 t in 2009–10.

Landings from the inshore midwater trawl fishery (Table A3a) are negligible in all areas except West SI and Cook Strait; catches from 2009–10 in both those areas are low relative to recent previous years. Total landings from the deepwater midwater trawl fishery (Table A3b) in 2009–10 are low relative to most years since 1989–90.

The line fishery (Table A3b) is significant in all areas, but can vary markedly by area between years. The total catch was similar to recent years, but with a marked decline apparent in Cook Strait, and essentially no fishery on Bounty in 2009–10. Relative to 2008–09, only East SI and Sub-Antarctic produced markedly higher landings. The Chatham area is still the most productive, but its recent landings are only about a third of those taken at its peak in the mid 1990s.

Setnet fishery landings (Table A3b) have long been negligible in all areas except East SI and West SI. The 2008–09 landings in these two areas were similar to those of the previous year. Landings from fish pots (Table A3c) are generally recorded only from East SI and Southland, but they average about 20 t annually. The 2009–10 landings are moderately high.

Conclusions

In summary, the overall 2009–10 ling catch from the EEZ is slightly lower than the previous year, and markedly lower than in any other year since 1990–91. The distribution and size of trawl fishery landings changed little in the last year, but trawl landings were markedly lower than those taken by this method during the early to mid 2000s. The overall line fishery catch was also quite similar to the previous year. This is markedly lower than in the most productive years (i.e., 1992–2002), but relatively consistent with the pattern of landings since 2003. The negligible line fishery landings from the Bounty Plateau were more than offset by increased line landings from the Sub-Antarctic.

Table A1: Definitions of geographical areas used in the analysis (based on statistical areas), and the administrative ling stocks they approximate. For a plot of statistical areas, see Figure 1.

Area	Statistical areas	Approximate ling stock
East NI	11–15, 201–206	LIN 2
East SI	18–24, 301	LIN 3
Chatham	49–52, 401–412	LIN 4
Southland	25–31, 302, 303, 501–504	LIN 5
Sub-Antarctic	601–606, 610–612, 616–620, 623–625	Part of LIN 6
Bounty	607–609, 613–615, 621, 622	Part of LIN 6
West SI	32–36, 701–706	Part of LIN 7
Cook Strait	16, 17, 37–40	Parts of LIN 2 & 7

Table A2: Total estimated ling landings (t) as reported on TCEPR, TCER, CELR, NCER, and LCER returns, by fishing year, by area. Fishing year 1989–90 is denoted as "1990", etc. The percentage of total landings taken over two distinct periods (1990–1999 and 2000–2010) from each area is also presented (Percentage). Total estimated landings by year (Total) can be compared with actual reported landings from Fishstocks LIN 2–7 (Landings).

Area										Fishing year	Percentage
	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	1990–99
East NI	268	425	451	512	501	508	509	478	562	423	2.9
East SI	1 220	1 934	1 808	1 612	1 571	1 948	2 320	2 034	2 031	1 939	11.5
Chatham	513	2 157	4 360	3 649	3 755	4 839	4 151	3 814	4 343	3 926	22.2
Southland	2 143	2 105	3 841	2 890	3 259	3 646	4 537	4 445	4 123	3 549	21.6
Sub-Antarctic	1 189	2 673	2 390	5 038	2 270	3 653	3 591	4 951	5 382	4 284	22.1
Bounty	12	32	907	969	1 149	382	387	351	394	563	3.2
West SI	2 322	1 946	1 854	1 864	1 765	2 399	2 595	2 536	2 745	2 975	14.4
Cook Strait	415	527	314	324	252	319	369	381	276	344	2.2
Total	8 083	11 800	15 925	16 859	14 524	17 695	18 459	18 990	19 855	18 004	
Landings	8 907	13 296	17 537	18 812	15 720	19 580	21 183	22 209	22 841	20 811	
% of landings	90.7	88.8	90.8	89.6	92.4	90.4	87.1	85.5	86.9	86.5	

Area											Fishing year	Percentage
	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2000–10
East NI	461	557	582	481	507	393	416	512	492	474	442	3.2
East SI	2 098	1 681	1 571	1 842	1 475	1 213	1 202	1 592	1 421	1 389	1 373	10.0
Chatham	3 969	3 412	3 214	2 723	2 379	2 570	1 667	1 947	2 308	1 817	1 844	16.6
Southland	3 423	3 557	3 349	3 143	3 350	4 294	3 918	4 492	4 562	3 478	3 238	24.3
Sub-Antarctic	4 716	4 469	5 326	5 052	5 658	4 678	2 935	3 613	3 503	1 526	2 272	26.1
Bounty	990	1 064	629	922	853	49	43	236	503	232	2	3.3
West SI	2 685	3 068	2 630	2 344	2 406	2 057	2 051	1 797	1 791	1 845	1 957	14.7
Cook Strait	332	395	289	346	360	373	299	241	182	127	75	1.8
Total	18 674	18 203	17 591	16 852	16 990	15 628	12 531	14 430	14 760	10 887	11 204	
Landings	21 300	20 255	19 255	18 654	18 506	16 894	13 814	15 798	15 881	12 792	12 205	
% of landings	87.7	89.9	91.4	90.3	91.8	92.5	90.7	91.3	92.9	85.1	91.8	

Table A3a: Catch of ling (t) by area, by fishing year, for various fishing methods: inshore bottom trawl, deepwater bottom trawl, inshore midwater trawl. Fishing year 1989–90 is denoted as "1990", etc. Values have been rounded to the nearest tonne, so "0" represents estimated landings of less than 0.5 t, and "–" indicates nil reported landings.

Method &																					Fishing year
Area	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Inshore bottom trawl																					
East NI	25	25	21	17	22	18	24	17	7	5	7	6	4	8	3	2	2	15	11	11	14
East SI	148	197	145	109	64	66	50	62	46	51	80	75	106	91	88	99	46	49	71	39	66
Chatham	4	5	2	–	1	2	3	0	0	0	–	0	1	1	0	1	10	1	–	–	–
Southland	47	63	54	94	78	83	50	56	28	66	67	99	89	166	137	136	106	100	10	121	180
West SI	148	150	192	218	111	107	190	166	105	157	129	51	54	69	55	130	127	101	239	252	277
Cook Strait	4	9	3	10	22	78	83	72	25	25	20	15	17	8	4	7	3	4	6	31	26
Total	376	450	418	447	297	354	400	373	211	304	303	245	270	342	287	375	294	269	437	455	563
Deepwater bottom trawl																					
East NI	59	117	88	75	74	79	126	153	131	163	157	206	207	113	74	51	40	71	19	37	23
East SI	599	817	936	802	726	824	1 084	1 019	1 158	972	857	956	855	1 127	810	589	599	944	827	700	548
Chatham	500	1 236	1 344	1 010	443	818	729	771	2 254	1 841	1 889	1 461	1 217	1 317	1 062	798	567	854	1 183	498	539
Southland	1 980	2 008	3 376	2 182	2 096	2 507	3 929	3 407	2 921	2 650	2 396	2 095	2 133	1 944	2 431	3 157	2 971	3 534	3 571	2 951	2 607
Sub-Antarctic	1 148	2 445	2 045	4 104	1 758	2 013	2 297	2 661	2 990	2 344	3 496	3 540	4 447	4 655	4 764	4 223	2 598	3 495	3 154	1 304	1 475
Bounty	4	7	35	–	4	0	1	–	–	3	1	0	1	1	1	9	4	–	–	8	0
West SI	370	260	306	476	385	486	370	518	496	876	761	1 018	1 133	838	823	763	993	703	525	556	603
Cook Strait	7	13	4	2	48	58	96	126	77	111	88	39	72	35	38	30	21	19	40	21	7
Total	4 666	6 901	8 133	8 650	5 534	6 786	8 632	8 655	10 026	8 961	9 645	9 315	10 063	10 029	10 004	9 620	7 794	9 620	9 321	6 076	5 803
Inshore midwater trawl																					
East NI	1	0	1	2	0	0	0	–	0	–	0	1	–	–	0	0	–	–	–	–	0
East SI	3	9	6	0	1	0	2	7	4	8	7	7	2	30	13	1	2	0	1	–	1
West SI	2	–	2	4	3	10	24	25	57	83	206	180	82	113	67	70	63	34	6	33	40
Cook Strait	42	125	37	30	11	6	16	22	13	9	18	30	14	36	29	23	21	18	14	14	8
Total	48	134	45	35	14	17	43	54	74	100	231	218	98	178	110	93	86	52	20	48	49

Table A3b: Catch of ling (t) by area, by fishing year, for various fishing methods: deepwater midwater trawl, line, setnet. Fishing year 1989–90 is denoted as "1990", etc. Values have been rounded to the nearest tonne, so "0" represents estimated landings of less than 0.5 t, and "–" indicates nil reported landings.

Method &																					Fishing year
Area	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Deepwater midwater trawl																					
East NI	0	12	1	4	1	0	2	2	12	7	4	5	1	4	4	1	3	1	2	2	1
East SI	72	57	62	35	39	34	87	111	198	213	213	81	103	88	79	65	24	6	10	3	18
Chatham	–	69	11	44	39	54	59	52	44	45	30	44	38	20	60	15	2	1	0	–	0
Southland	116	29	121	173	271	398	274	133	79	57	100	380	139	169	197	139	161	175	84	6	36
Sub-Antarctic	42	11	19	48	11	11	22	5	5	6	15	200	225	183	239	157	165	118	3	6	8
Bounty	8	19	38	4	3	3	2	–	7	11	7	0	1	–	2	6	1	2	1	2	0
West SI	1 261	740	402	340	353	803	857	725	997	768	713	855	651	587	759	335	268	123	87	80	127
Cook Strait	260	326	200	179	107	117	119	141	105	91	107	147	74	137	119	96	65	45	33	25	22
Total	1 759	1 261	854	828	824	1 421	1 421	1 168	1 446	1 197	1 189	1 713	1 233	1 188	1 460	815	690	471	220	124	213
Line																					
East NI	135	186	300	389	401	409	353	278	401	248	292	339	370	356	425	339	365	425	459	419	404
East SI	185	613	475	488	550	816	913	593	382	512	748	426	379	400	360	370	430	492	502	579	638
Chatham	8	846	3 003	2 595	3 272	3 966	3 360	2 991	2 045	2 039	2 050	1 907	1 958	1 386	1 257	1 757	1 088	1 092	1 124	1 316	1 303
Southland	0	2	288	439	813	653	280	845	1 090	775	850	960	972	850	583	860	676	678	796	382	401
Sub-Antarctic	–	217	326	886	501	1 630	1 273	2 285	2 388	1 934	1 204	728	655	214	655	298	172	–	345	216	789
Bounty	–	7	834	965	1 142	378	384	351	386	549	982	1 063	627	921	850	34	38	234	502	222	1
West SI	197	428	686	698	761	891	983	975	963	990	782	913	648	688	678	729	562	745	934	887	864
Cook Strait	66	56	70	100	63	59	53	20	56	107	98	163	112	130	169	216	189	155	89	34	11
Total	591	2 357	5 982	6 560	7 503	8 801	7 598	8 337	7 710	7 154	7 007	6 499	5 721	4 945	4 976	4 602	3 520	3 820	4 751	4 055	4 411
Setnet																					
East NI	48	85	40	25	4	1	4	27	12	1	1	1	–	0	1	0	5	0	–	5	0
East SI	210	227	145	164	180	199	180	205	201	147	171	132	124	104	120	79	51	47	6	58	62
Chatham	0	–	0	–	–	–	–	–	–	–	–	–	–	0	–	0	–	–	–	2	2
Southland	0	2	1	1	0	1	0	2	2	0	0	0	1	0	1	1	1	2	1	6	4
West SI	345	368	266	129	154	103	170	126	129	103	94	49	62	50	24	31	39	91	0	36	47
Cook Strait	36	0	1	3	1	1	1	1	0	0	0	2	0	0	0	1	0	0	0	0	0
Total	639	681	452	322	339	305	356	361	343	251	266	184	186	155	147	112	96	140	7	108	115

Table A3c: Catch of ling (t) by area, by fishing year, for various fishing methods: fish pots. Fishing year 1989–90 is denoted as "1990", etc. Values have been rounded to the nearest tonne, so "0" represents estimated landings of less than 0.5 t, and "–" indicates nil reported landings.

Method &																					Fishing year
Area	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Fish pots																					
East NI	–	–	–	–	–	0	–	0	–	–	–	–	–	–	–	–	0	–	–	–	0
East SI	2	14	39	15	12	8	4	38	41	36	21	4	3	1	4	10	49	53	4	10	41
Chatham	0	0	0	0	0	–	–	–	–	–	–	–	–	–	–	–	–	–	–	0	–
Southland	1	1	1	1	1	2	4	2	3	0	10	24	16	13	0	0	3	3	1	11	8
West SI	–	–	0	–	–	–	0	0	0	–	–	1	–	–	0	–	–	–	–	0	0
Cook Strait	–	0	0	0	–	–	–	–	–	–	0	–	–	–	1	–	–	–	–	–	–
Total	3	16	40	16	13	10	8	40	44	36	31	29	19	14	5	10	52	57	5	21	49

APPENDIX B. Estimation of CPUE from line fisheries in LIN 3&4 and LIN 5&6

This Appendix reports on an analysis to update series of CPUE indices from target line fisheries for ling on the Chatham Rise (LIN 3&4) and Sub-Antarctic (LIN 5&6). CPUE analyses of these fisheries were most recently reported by Horn & Ballara (2012). These CPUE series are used as inputs into stock assessments reported elsewhere in this document.

Methods

Data grooming

Catch and effort data, extracted from the fishery statistics database managed by the Ministry of Fisheries (MFish), were used in the line fishery analyses. All catch-effort-and-landing-return (CELR), lining-catch-effort-return (LCER), net-catch-effort-and-landing-return (NCELR), trawl-catch-effort-return (TCER), lining-trip-catch-effort-return (LTCER), and trawl-catch-effort-and-processing-return (TCEPR) records where ling were targeted or caught from anywhere in the New Zealand EEZ were extracted and groomed to rectify as many errors as possible. The catch and effort data were requested from the Ministry of Fisheries catch-effort database "warehou" as extract 7922A. The data consist of all fishing and landing events associated with a set of fishing trips that reported a positive catch or landing of hake, hoki, or ling between 1 October 1989 and 30 December 2010.

Data were checked for errors, using simple checking and imputation algorithms similar to those used by Ballara & O'Driscoll (2012). Individual tow or set locations were investigated and errors were corrected using median imputation for start/finish latitude or longitude, fishing method, target species, tow speed, net depth, bottom depth, wingspread, duration, and headline height for each fishing day for a vessel. Range checks were defined for the remaining attributes to identify outliers in the data. The outliers were checked and corrected if possible with mean imputation on larger ranges of data such as vessel, target species and fishing method for a year or month, or the record was removed from the data set. Statistical areas were calculated from positions where these were available. Transposition of some data was carried out (e.g., bottom depth and depth of net, or number of hooks and number of sets).

Variables

Variables used in the analysis are described in Table B1 and are generally similar to those used in previous analyses (e.g., Horn & Ballara 2012). Longline CPUE was defined as catch per day (i.e., daily estimated catch in kilograms by a vessel in a particular statistical area), and number of hooks set per day was offered as an explanatory variable. Catch per day (rather than catch per hook) was used as the unit of CPUE because it has been shown (Horn 2002a) that the relationship between catch per hook and the number of hooks set per day is non-linear. *Total hooks* per day and *number of sets* per day were offered as an untransformed number and as log-transformed data. *Year* was a categorical variable and was defined as the calendar year. Season variables of both *month* and *day of year*, and statistical area (*statarea*) variables were offered to the model. Individual vessel details were checked for consistency each year as it is apparent that more than one vessel can have the same vessel identification number. Records with no vessel identification data were excluded from further analyses. *Vessel* was incorporated into the CPUE standardisation to allow for possible differences in fishing between vessels.

Data selection

Data for the Chatham Rise and Sub-Antarctic were grouped by statistical area as follows: Chatham Rise (LIN 3&4): 018–024, 049–052, 301, 401–412, and Sub-Antarctic (LIN 5&6): 025–031, 302, 303, 501–504, 601–606, 610–612, 616–620, 623–625. Note that these analyses were carried out on the basis of presumed biological stocks, rather than administrative (QMA) stocks. Consequently, the grouping of some statistical areas may appear erroneous, but has been done in a way that best approximates biological stocks. For example, Statistical Areas 302, 303, and most of 026 are in LIN 3, but they have been included in the Sub-Antarctic analysis, as ling in these areas probably derive from the Sub-Antarctic stock because the Stewart-Snares shelf and Campbell Plateau are the closest submarine shelves to these statistical areas.

Data were available from 1 October 1989, but were analysed by calendar year rather than fishing year because of a seasonal trend of higher catch rates in most ling line fisheries running from about June to December (see Horn 2007a). This ensured that all catches in a particular season peak were included in a single year, rather than being spread between two (fishing) years.

Some line vessels had been recording individual set data on CELR forms (whereas for most vessels, a single record constitutes a day's fishing). If uncorrected, this would cause bias in CPUE analyses as those vessels would contribute about four times as many records per day fishing as other vessels. Consequently, all longline data were condensed (catches, hooks, and sets summed over vessel, day, and statistical area) to ensure that each record represented total catch and effort per statistical area per day.

To ensure that the longline data to be analysed were within plausible ranges and related to vessels that had consistently targeted and caught significant landings of ling (and so were likely to truly represent experienced and competent ling fishers), data were accepted if all the following constraints were met:

- catch was by bottom longline
- catch was between 1 and 35 000 kg per day,
- number of hooks was between 50–50 000 per day (Chatham Rise), and 3000–50 000 per day (Sub-Antarctic)
- number of records for a vessel was: greater than 100 for the Chatham Rise; greater than 50 for the Sub-Antarctic; and all vessels included in any particular stock analysis had fished in more than 1 year,
- target species was reported as ling.

Examination of the zero catch records indicated that most represented either duplicated records (two records for a particular day, one with and one without catches) or obvious mistakes (two or three days fishing with no ling catch). Because of the relatively high number of hooks fished in any set, a zero catch of ling in any set that is genuinely targeting ling is likely to result either from some gear malfunction or from exploratory fishing. The removal of such data points from the analysis will not bias the index of relative abundance of ling on known fishing grounds. Consequently, as in previous analyses, all zero observations were removed. There were 626 and 46 records of zero ling catch from the Chatham Rise and Sub-Antarctic, respectively, making up 3.4% and 0.8% of the data.

The Sub-Antarctic line fishery data were also analysed as two fisheries within the Sub-Antarctic stock using all the data records that were accepted into the 'whole stock' analysis. The two fisheries were: spawning (Statistical Area 030 for the months September to December), and non-spawning (all other statistical areas and all months). This is consistent with the assessment model structure for this stock which incorporates a spawning fishery at Puysegur and a non-spawning fishery in other areas (Horn 2008).

The model

The lognormal linear model was used for all analyses. A forward stepwise Generalised Linear Model (Chambers & Hastie 1991) implemented in R code (R Development Core Team 2011) was used to select variables in the model. *Year* was forced into the model as the first term, and the algorithm added variables based on changes in residual deviance. The explanatory power of a particular model is described by the reduction in residual deviance relative to the null deviance defined by a simple intercept model. Variables were added to the model until an improvement of less than 1% of residual deviance explained was seen following inclusion of an additional variable. Variables are either categorical or continuous, with model fits to continuous variables being made as third-order polynomials. The standardised indices were calculated using GLM, with associated standard errors. Indices are presented using the canonical form (Francis 1999) so that the year effects for a particular stock were standardised to have a geometric mean of 1. The c.v.s represent the ratio of the standard error to the index. The 95% confidence intervals are also calculated for each index.

For the longline CPUE series estimated for subareas within the Sub-Antarctic stock a *year:fishery* interaction effect was forced into the model. This produced a CPUE series for each of the two fisheries within the stock, but with all other expected variable effects being the same over the fisheries. Apart from the *year:fishery* interaction in the Sub-Antarctic two fishery model, interaction terms and nested terms were not used, as in the past their inclusion resulted in some implausible *vessel* coefficients, so they were excluded (Horn & Ballara 2012).

Unstandardised CPUE was also derived for each year and Fishstock from the available data sets. The annual indices were calculated as the mean of the individual daily catch (kg) for longline.

Model predictions for all variables selected into the final model were plotted against a vertical axis representing the expected (non-zero) catch. To calculate the *y*-values for a particular variable, all other model predictors must be fixed. These fixed values were chosen to be 'typical' values (see Francis (2001) for further discussion of this method). Note that if different fixed values were chosen, the values on the *y*-axis would change but the appearance of the plots would be unchanged.

Results

Chatham Rise (LIN 3&4)
The Chatham Rise final analysis included 14 400 records of days fished throughout the 21 years analysed (Table B2a). The estimated landings from this effort represented more than 90% of the total estimated landings by line fishing for this stock. Line fishing has accounted for about half of the LIN 3&4 landings since 1990, although the line fishery produced 59–72% of the catch annually from 1993 to 1997 (Appendix A, Tables A2 and A3). None of the 28 vessels included in this analysis had fished in all years, but 14 vessels had fished in six or more years (Figure B1). Chatham Rise line fisheries catch ling throughout the year, but more catch is taken from July to November (Figure B2a). Over 99% of the catch is taken by the bottom longline method and from target ling lines. Most of the line catch is taken in Statistical Areas 020–021, 049, 052, 401–404, and 410. Statistical Areas 301, 406, 411, and 412 had an insignificant number of sets (0.1% of days over 21 years), and these were probably attributable to reporting errors or exploratory fishing so were removed from the final analysis.

For the lognormal model, four variables were selected with vessel explaining 62% (from a total of 75%) of total variance (Table B3). Other variables selected included *log(total hooks)* and *month*.

The standardised year effects (Table B4, Figure B3a) show a steady decline from 1990 to 1997, followed by a relatively constant signal since then. The decline in standardised index does not match the increases in the raw index seen in the early 1990s, but does follow the trend in the raw index from 1995 to 2010. The overall trend is similar to the previous analysis of Horn & Ballara (2012). A similar analysis done on fishing year rather than calendar year also showed a similar overall (Figure B4a).

The predicted values indicated higher expected catch rates with increased total hooks, and that the highest catch rates tend to occur from August to December (the probable spawning season), but the best monthly catch rate is less than double the worst (Figure B5a). Vessels catching the most ling had higher expected catches (but not the highest expected catches) and had lower variability. Data from 28 vessels are incorporated in the model; the difference between the best and worst of all but one of these is less than a factor of 6. This level of between-vessel difference is not great given the inclusion in the analysis of auto-longliners and smaller hand-baiting inshore vessels.

The model shows no marked patterns in the residuals (Figure B6a) although the diagnostics for the lognormal model were poor; the quantile-quantile plots indicated a deviation from the normal distribution of the residuals at both the lower and upper ends, suggesting that very small and very large catch rates were not well modelled. The poorly estimated points (i.e., those with residuals less than –2 or greater than 2) made up a small fraction (1.7%) of the total data set, with residuals less than –3 making up a very small fraction (0.3%) of the total data.

Sub-Antarctic (LIN 5&6)

The Sub-Antarctic analysis included 5864 records of days fished throughout the 21 years analysed (Table B2b), with 1713 from the spawning fishery, and 4151 from the non-spawning fishery (Tables B2c,d). The spawning fishery had 30–151 days fished in each year; the non-spawning fishery had more data, particularly through the middle part of the series (52–542 days per year), although 2007 had only 8 days fished. This effort produced more than 94% of the total estimated landings by line fishing for this stock. From 1993 to 2002 when the auto-longline fishery was at its peak, line fishing accounted for about 17–37% of the LIN 5&6 landings (excluding the Bounty Plateau). The percentage of line catch was lower from 2003 to 2009 (8–14% of the landings), but was again relatively high (22%) in 2010 (Appendix A, Tables A2 and A3). Data from 12 vessels were included in the final analysis. No vessel had fished the entire series, but seven had fished in six or more years (Figure B1).

Sub-Antarctic line fisheries catch ling throughout the year, although very little catch is taken in August and September (Figure B2b). Most Puysegur (Statistical Area 030) catch was taken from October to December, and non-Puysegur catch from January to July, and in December (Figure B2c). Most of the Sub-Antarctic line catch is taken by bottom longline (98% of days), and ling targeting (93.5% of days), so only data from this method and target were included in the analysis. Most of the line catch was taken in Statistical Areas 030, 602–605, 610–611, 618, and 619. Statistical Areas 025–029, 031, 302–303, 502, 504, 601, 606, 612, 616–617 and 624 all had few days fished (i.e., less than 50) throughout the 21 years (overall 3.4% of days), and these were probably attributable to reporting errors or exploratory fishing, so were removed from the final analysis.

For the lognormal model, the variables entering the final model were *log(total hooks)*, *statarea*, and *vessel*. About 51% of the variance was explained by the *log(total hooks)* variable, and total explained variance was 61% (Table B3).

The standardised year effects (Table B4, Figure B3a) showed a variable series with no clear trend. The trend in standardised index follows the trend in the raw index. The overall trend is similar to the previous analysis of Horn & Ballara (2012). A similar analysis done using fishing year rather than calendar year showed a similar overall trend, but it was lagged by one year, showing that the trend in the last three months of the year is important in the Sub-Antarctic indices (Figure B4c).

The predicted values indicated higher expected catch rates with increased total hooks (Figure B5b). The highest expected catch rates occurred in Statistical Area 030, but rates varied by a factor of less than 2 over all areas. Vessels catching the most ling had higher expected catch rates and lower variability, although catch rate by vessel varied by a factor of less than 3.

The model shows no marked patterns in the residuals (Figure B6a) although the diagnostics were poor with the quantile-quantile plots showing a deviation from the normal distribution of the residuals at the lower end. The poorly estimated points (i.e., those with residuals less than –2) made up only 0.4% of the total data set.

The variables selected into the two-fishery model were the same as for the single fishery model, except that *statarea* was not selected (Table B3). The variable *log(total hooks)* explained most of the variance (60%), and with *vessel* included, 62% of total variance was explained.

For both the spawning and non-spawning fisheries, the standardised indices showed variable indices with no overall trend (Table B4, Figure B3b). There were similar trends between series although the indices in the spawning fishery were higher than in the non-spawning fishery (Figure B4b). The highest indices in each series (2007 for non-spawning and 2009 for spawning) are based on the lowest numbers of days fishing and both have very wide confidence bounds. The trend in the standardised indices follows the trend in the raw indices for both fisheries. The overall trend is similar to the previous analysis of Horn & Ballara (2012). A similar analysis, but using fishing year instead of calendar year as the dependent variable, had a similar overall trend but again with the lag in indices (Figure B4c).

The two-fishery model showed no marked patterns in the residuals (Figure B6) although the diagnostics were poor with the quantile-quantile plots showing a deviation from the normal distribution of the residuals especially at the lower end.

Conclusions

In recent assessments of ling stocks around the South Island, series of CPUE indices derived from commercial fisheries have been used as indices of abundance (e.g., Horn 2007b, 2008, 2009). CPUE is used in conjunction with indices from trawl survey series for LIN 3&4 and LIN 5&6. Horn (2002a) showed that most of the ling line CPUE series appeared to perform well in relation to the four criteria raised by Dunn et al. (2000), and so were probably reasonable indices of abundance (for that part of the population targeted by the line fishery).

As would be expected, the trends in the indices, and the variables selected into the models, have not changed markedly between the previous (Horn & Ballara 2012) and current analyses. The longline fisheries examined here target a single species using the same method, so the sets of variables selected into the model for each stock might be expected to have some similarities. In all the analyses, *log(total hooks)* and *vessel* were selected into the model. *Month* was accepted into the Chatham Rise model, and *statarea* into the single fishery Sub-Antarctic model. With the CPUE unit being 'kg per day', it would be expected that the number of hooks set per day would be a very influential variable. This is certainly the case for LIN 3&4, and LIN 5&6, where *log(total hooks)* is the most influential variable, accounting for the largest proportion of the explained variance. Skill levels and/or gear efficiency will vary between vessels so the selection of a *vessel* variable in each model would be expected. Clearly, catch rates vary throughout the year, probably in relation to the spawning season for ling. Hence, *month* was an important explanatory variable.

It is apparent from Figure B1 that the fleet dynamics in the line fisheries have changed quite considerably, with periods when several vessels ceased to operate and new ones entered the fishery. However, Horn (2004b) completed separate analyses for shorter time series of data and compared the results with the "all years" indices to show that the change in fleet dynamics has not biased the CPUE. It is also considered unlikely that CPUE series have been seriously biased by any changes in fishing practice over the durations of the fisheries (Horn 2004c), although data on some potentially influential factors are either unavailable before 2004 (e.g., hook spacing) or would be difficult to incorporate into analyses (e.g., vessel skipper, learning by fishers).

One clearly apparent change in recent fishing seasons is the reduction in effort on the Campbell Plateau (see Table B2b). This reduction is attributable in part to the diversion of autoline vessels to the Ross Sea toothfish fishery, but also to the permanent removal from the New Zealand fleet of some large line vessels, and to a recent reduction in overseas demand for New Zealand ling.

The line fishery CPUE analyses presented here for LIN 3&4 and LIN 5&6 provide sets of indices that are probably valid as relative abundance series (for that section of the population exploited by the fisheries) in stock assessment models for ling. Since the early 1990s, ling stocks targeted by line fisheries have been relatively constant in the Sub-Antarctic, but have declined to about half their original level on the Chatham Rise.

Analyses done on fishing year rather than calendar year showed a similar overall trend for the Chatham Rise but a lag of one year for the Sub-Antarctic. Clearly, the trend in the Sub-Antarctic fisheries is markedly influenced by fishing in the last three months of the year.

Table B1: Summary of the variables offered in the CPUE models for the line fisheries.

Variable	Type	Description
Year	Categorical	Calendar year
Month	Categorical	Month of year
Statistical area	Categorical	Statistical area for the set or tow
Vessel	Categorical	Unique vessel identifier
Day of year	Continuous	Julian day, starting at 1 on 1 January
Total hooks	Continuous	Number of hooks set per day in a statistical area
Log(Total hooks)	Continuous	Logarithm of variable Total hooks
Number of sets	Continuous	Number of set per day in a statistical area
Log(Number of sets)	Continuous	Logarithm of variable Number of sets
CPUE	Continuous	Ling catch (kg) per day in a statistical area

Table B2: Summary of data for all vessels and for vessels included in the final datasets, by year. Data include: number of unique vessels fishing (Vessels), number of vessel-days overall for non-zero and zero ling catches (Days), proportion of vessel-days that caught zero catch (Zeros), estimated catch, and unstandardised CPUE from non-zero catches from the tow-by-tow data.

(a) Chatham Rise

	All data					Final CPUE data				
Year	Vessels	Days	Zeros	Catch (t)	CPUE	Vessels	Days	Zeros	Catch (t)	CPUE
1990	29	528	0.01	309.0	0.59	–	–	–	–	–
1991	33	1 109	0.01	1 982.4	1.81	7	556	0	1 684.3	3.03
1992	27	935	0.02	2 969.9	3.23	9	660	0	2 804.9	4.25
1993	28	955	0.01	3 364.0	3.54	9	745	0	3 200.5	4.30
1994	26	1 208	0.00	3 966.0	3.29	9	765	0	3 490.2	4.56
1995	28	1 249	0.03	4 563.7	3.75	8	754	0	3 704.1	4.91
1996	33	1 350	0.07	3 938.0	3.14	8	777	0	3 307.3	4.26
1997	26	1 589	0.05	3 478.1	2.31	8	886	0	3 019.1	3.41
1998	24	1 022	0.10	2 476.1	2.70	9	596	0	2 348.9	3.94
1999	21	1 201	0.11	2 434.7	2.28	10	720	0	2 291.4	3.18
2000	22	975	0.10	2 333.3	2.66	10	677	0	2 297.2	3.39
2001	15	761	0.06	2 435.7	3.40	8	679	0	2 414.5	3.56
2002	14	1 043	0.04	2 105.2	2.11	10	883	0	2 087.6	2.36
2003	21	831	0.01	1 860.1	2.27	9	642	0	1 823.3	2.84
2004	25	1 047	0.01	1 668.0	1.62	11	709	0	1 554.0	2.19
2005	23	1 494	0.00	2 112.5	1.42	9	883	0	1 967.9	2.23
2006	25	1 156	0.00	1 502.0	1.30	8	664	0	1 401.0	2.11
2007	27	1 467	0.01	1 557.5	1.07	11	763	0	1 407.9	1.85
2008	29	1 260	0.01	1 915.7	1.54	11	592	0	1 539.2	2.60
2009	19	1 125	0.00	1 860.2	1.66	7	737	0	1 757.0	2.38
2010	21	1 201	0.00	1 828.9	1.52	8	722	0	1 683.6	2.33
Total	160	23 506		50 660.8		28	14 410		45 784.0	

Table B2 continued.

(b) Sub-Antarctic, single fishery

	All data					Final CPUE data				
Year	Vessels	Days	Zeros	Catch (t)	CPUE	Vessels	Days	Zeros	Catch (t)	CPUE
1990	1	1	0.00	0.1	0.10	–	–	–	–	–
1991	6	127	0.01	467.3	3.71	2	116	0	464.9	4.01
1992	10	276	0.00	1 089.5	3.95	2	237	0	1 072.4	4.52
1993	16	374	0.01	1 315.3	3.54	4	233	0	1 106.7	4.75
1994	11	369	0.00	1 447.1	3.92	3	280	0	1 264.7	4.52
1995	12	400	0.02	1 912.9	4.89	4	332	0	1 819.2	5.48
1996	13	401	0.01	1 925.4	4.87	5	356	0	1 884.5	5.29
1997	11	711	0.01	3 287.0	4.69	5	618	0	3 116.7	5.04
1998	11	766	0.04	3 140.8	4.28	5	616	0	2 803.1	4.55
1999	14	736	0.04	2 808.0	3.97	5	649	0	2 665.2	4.11
2000	9	483	0.00	2 223.5	4.62	4	462	0	2 206.6	4.78
2001	12	363	0.00	1 772.3	4.88	5	285	0	1 592.5	5.59
2002	10	244	0.00	1 299.7	5.33	5	217	0	1 265.9	5.83
2003	10	192	0.00	639.5	3.33	5	159	0	634.2	3.99
2004	9	448	0.00	1 656.3	3.70	4	410	0	1 633.3	3.98
2005	10	210	0.00	948.8	4.54	2	175	0	936.0	5.35
2006	10	161	0.00	818.6	5.08	3	140	0	814.5	5.82
2007	11	170	0.00	847.2	4.98	3	110	0	812.0	7.38
2008	10	271	0.00	691.7	2.55	3	196	0	632.9	3.23
2009	9	139	0.01	550.4	3.99	2	84	0	527.2	6.28
2010	10	269	0.00	1 008.7	3.75	2	189	0	924.3	4.89
Total	82	7 111		29 850.2		12	5 864		28 177.2	

(c) Sub-Antarctic, spawning fishery (Puysegur, October–December)

	All data					Final CPUE data				
Year	Vessels	Days	Zeros	Catch (t)	CPUE	Vessels	Days	Zeros	Catch (t)	CPUE
1990	–	–	–	–	–	–	–	–	–	–
1991	3	37	0.00	195.7	5.29	2	35	0	195.4	5.58
1992	5	68	0.00	377.7	5.55	2	56	0	374.4	6.69
1993	5	107	0.00	683.0	6.38	2	95	0	659.5	6.94
1994	5	107	0.00	680.3	6.36	2	98	0	677.7	6.92
1995	4	45	0.04	246.9	5.49	2	35	0	230.8	6.59
1996	4	107	0.02	757.5	7.35	2	97	0	745.2	7.68
1997	3	142	0.01	901.9	6.49	2	128	0	889.4	6.95
1998	3	140	0.00	745.6	5.36	2	117	0	732.2	6.26
1999	3	108	0.00	848.0	7.85	3	107	0	832.9	7.78
2000	3	117	0.00	911.7	7.79	3	117	0	911.7	7.79
2001	4	125	0.00	937.4	7.50	3	119	0	924.9	7.77
2002	3	102	0.00	849.0	8.32	3	102	0	849.0	8.32
2003	4	81	0.00	442.4	5.46	3	75	0	442.0	5.89
2004	3	151	0.00	953.3	6.31	3	151	0	953.3	6.31
2005	2	80	0.00	667.7	8.35	2	80	0	667.7	8.35
2006	3	88	0.00	642.7	7.30	3	88	0	642.7	7.30
2007	3	102	0.00	773.3	7.58	3	102	0	773.3	7.58
2008	3	71	0.00	358.9	5.05	1	54	0	326.3	6.04
2009	2	35	0.00	317.0	9.06	1	27	0	311.6	11.54
2010	3	33	0.00	135.4	4.10	1	30	0	135.2	4.51
Total	23	1 846		12 425.5		8	1 713		12 275.3	

Table B2 continued.

(d) Sub-Antarctic, non-spawning fishery (i.e. non-Puysegur, all year)

	All data					Final CPUE data				
Year	Vessels	Days	Zeros	Catch (t)	CPUE	Vessels	Days	Zeros	Catch (t)	CPUE
1990	1	1	0.00	0.1	0.10	–	–	–	–	–
1991	5	90	0.01	271.6	3.05	1	81	0	269.4	3.33
1992	8	208	0.00	711.8	3.42	2	181	0	698.0	3.86
1993	15	267	0.01	632.4	2.39	3	138	0	447.2	3.24
1994	10	262	0.00	766.8	2.93	3	182	0	587.0	3.23
1995	12	355	0.03	1 666.1	4.82	4	297	0	1 588.5	5.35
1996	12	294	0.01	1 167.9	4.00	5	259	0	1 139.3	4.40
1997	11	569	0.01	2 385.1	4.24	5	490	0	2 227.3	4.55
1998	10	626	0.05	2 395.2	4.03	5	499	0	2 070.9	4.15
1999	14	628	0.04	1 960.0	3.27	5	542	0	1 832.4	3.38
2000	9	366	0.01	1 311.8	3.60	4	345	0	1 294.9	3.75
2001	12	238	0.00	834.9	3.51	4	166	0	667.6	4.02
2002	10	142	0.00	450.7	3.17	5	115	0	416.9	3.63
2003	9	111	0.00	197.0	1.77	4	84	0	192.2	2.29
2004	9	297	0.00	703.0	2.37	3	259	0	680.1	2.63
2005	9	130	0.01	281.1	2.18	1	95	0	268.3	2.82
2006	8	73	0.00	175.9	2.41	1	52	0	171.9	3.31
2007	9	68	0.00	73.9	1.09	1	8	0	38.7	4.84
2008	9	200	0.00	332.8	1.66	2	142	0	306.6	2.16
2009	9	104	0.01	233.4	2.27	2	57	0	215.6	3.78
2010	9	236	0.00	873.3	3.70	2	159	0	789.1	4.96
Total	76	5 265		17 424.7		12	4 151		15 901.9	

Table B3: Variables retained in order of decreasing explanatory value by each model for each area, with the corresponding total r^2 value.

Lognormal	
Variable	r^2
Chatham Rise	
Year	5.1
Vessel	62.0
Log (Total hooks)	73.0
Month	75.2
Sub-Antarctic, single fishery	
Year	5.3
Log (Total hooks)	51.3
Statarea	59.2
Vessel	61.1
Sub-Antarctic, two fisheries	
Year	26.2
Log (Total hooks)	60.1
Vessel	62.2

Table B4: Lognormal CPUE standardised indices (with 95% confidence intervals and c.v.s) for the target ling line fisheries.

	Chatham Rise			Sub-Antarctic single fishery		
Year	Index	95% CI	c.v.	Index	95% CI	c.v.
1991	1.66	1.66–1.48	0.06	0.90	0.73–1.11	0.10
1992	2.15	2.15–1.93	0.05	1.25	1.06–1.47	0.08
1993	1.54	1.54–1.40	0.05	1.18	1.01–1.38	0.08
1994	1.54	1.54–1.40	0.05	0.99	0.86–1.15	0.07
1995	1.48	1.48–1.35	0.05	1.28	1.11–1.48	0.07
1996	1.19	1.19–1.09	0.04	1.06	0.93–1.22	0.07
1997	0.82	0.82–0.76	0.04	1.13	1.01–1.27	0.06
1998	0.89	0.89–0.82	0.04	0.97	0.88–1.08	0.05
1999	0.78	0.78–0.72	0.04	0.80	0.73–0.89	0.05
2000	0.92	0.92–0.85	0.04	0.97	0.87–1.09	0.06
2001	0.91	0.91–0.83	0.04	1.09	0.95–1.24	0.07
2002	0.74	0.74–0.68	0.04	1.07	0.93–1.24	0.07
2003	0.90	0.90–0.83	0.04	0.81	0.68–0.96	0.09
2004	0.74	0.74–0.68	0.04	0.76	0.66–0.87	0.07
2005	0.84	0.84–0.78	0.04	0.83	0.68–1.00	0.10
2006	0.71	0.71–0.65	0.04	0.90	0.75–1.08	0.09
2007	0.78	0.78–0.71	0.04	1.07	0.87–1.31	0.10
2008	0.99	0.99–0.90	0.05	1.04	0.87–1.24	0.09
2009	0.71	0.71–0.65	0.04	1.19	0.95–1.48	0.11
2010	0.88	0.88–0.81	0.04	0.92	0.78–1.09	0.08

	Sub-Antarctic spawning fishery			Sub-Antarctic non-spawn fishery		
Year	Index	95% CI	c.v.	Index	95% CI	c.v.
1991	1.28	0.91–1.80	0.17	0.66	0.51–0.84	0.12
1992	1.75	1.32–2.32	0.14	1.01	0.85–1.21	0.09
1993	1.54	1.22–1.93	0.11	0.84	0.68–1.03	0.10
1994	1.33	1.07–1.66	0.11	0.74	0.62–0.89	0.09
1995	1.40	0.99–1.98	0.17	1.02	0.88–1.19	0.08
1996	1.28	1.03–1.61	0.11	0.85	0.73–1.00	0.08
1997	1.16	0.94–1.42	0.10	0.91	0.80–1.03	0.06
1998	0.99	0.80–1.22	0.11	0.79	0.71–0.89	0.06
1999	1.28	1.04–1.57	0.10	0.64	0.58–0.71	0.05
2000	1.32	1.08–1.60	0.10	0.76	0.67–0.87	0.07
2001	1.34	1.10–1.63	0.10	0.91	0.77–1.09	0.09
2002	1.55	1.26–1.90	0.10	0.79	0.65–0.96	0.10
2003	1.12	0.88–1.43	0.12	0.62	0.49–0.78	0.12
2004	1.03	0.86–1.24	0.09	0.57	0.48–0.69	0.09
2005	1.42	1.11–1.82	0.12	0.50	0.38–0.65	0.13
2006	1.29	1.02–1.62	0.12	0.61	0.46–0.81	0.14
2007	1.35	1.08–1.68	0.11	0.98	0.49–1.96	0.36
2008	1.02	0.77–1.36	0.14	1.05	0.84–1.33	0.12
2009	2.05	1.39–3.01	0.19	0.85	0.65–1.12	0.13
2010	0.69	0.48–1.00	0.18	0.85	0.71–1.02	0.09

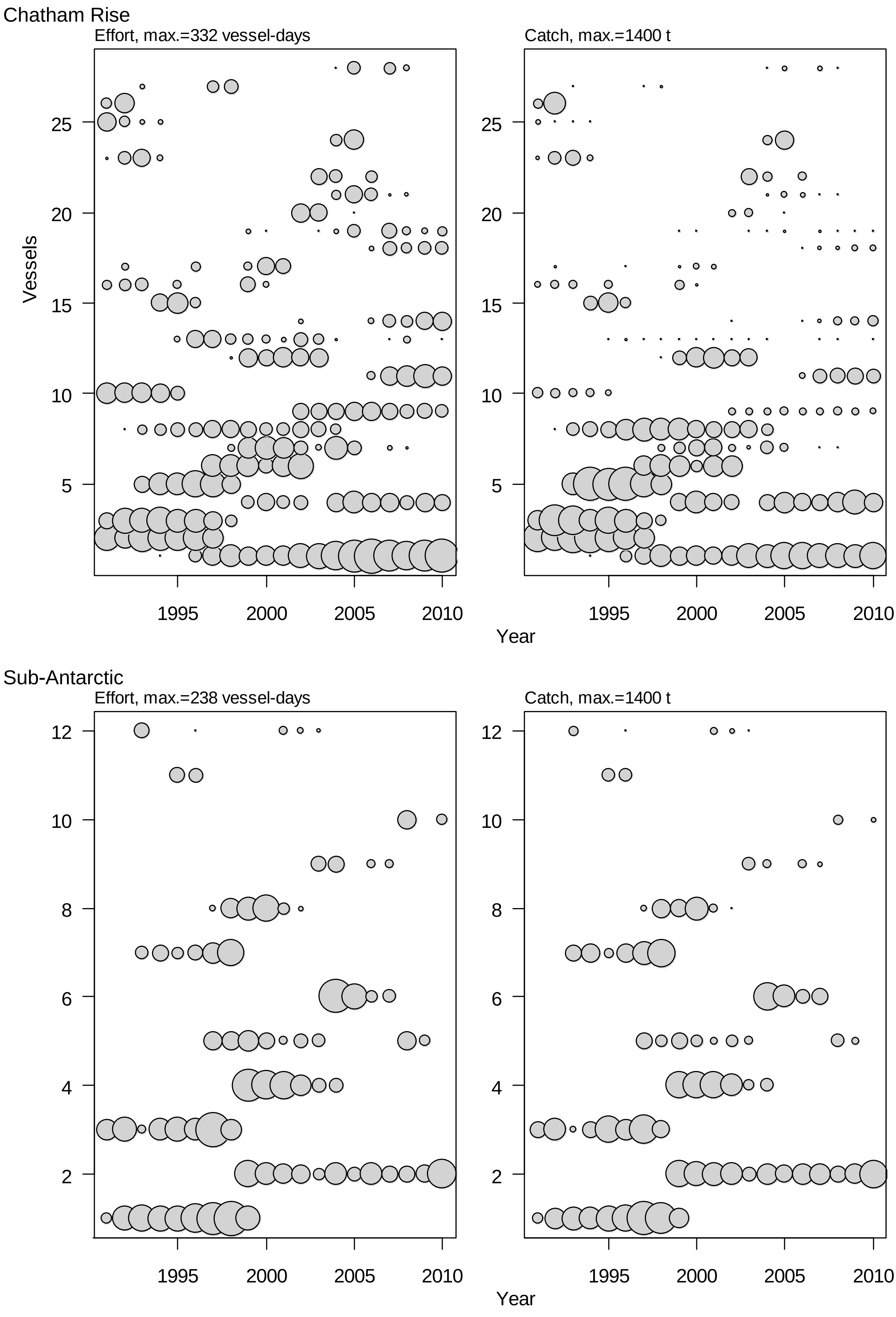


Figure B1: Line fishing effort and catches (where circle area is proportional to the effort or catch) by year for individual vessels (denoted anonymously by number on the *y*-axis) in final CPUE analyses for the Chatham Rise and Sub-Antarctic.

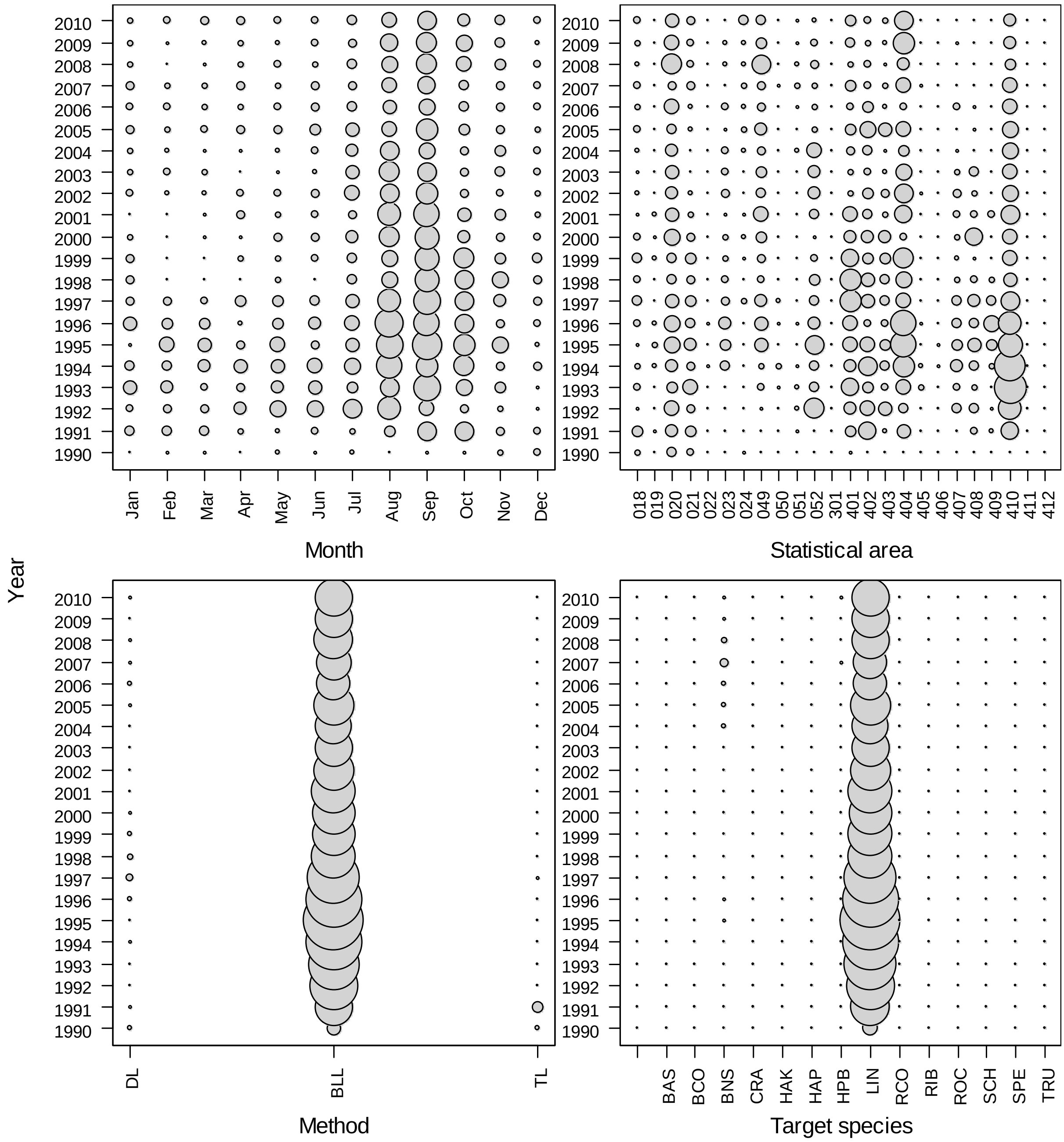


Figure B2a: Distribution of Chatham Rise ling line catch by month, target species, method, and statarea for 1990 to 2010 calendar years. Circle size is proportional to catch; maximum circle size is 1200 t in this plot. Method definitions: BLL, bottom longline; DL, dahn line; TL, trot line.

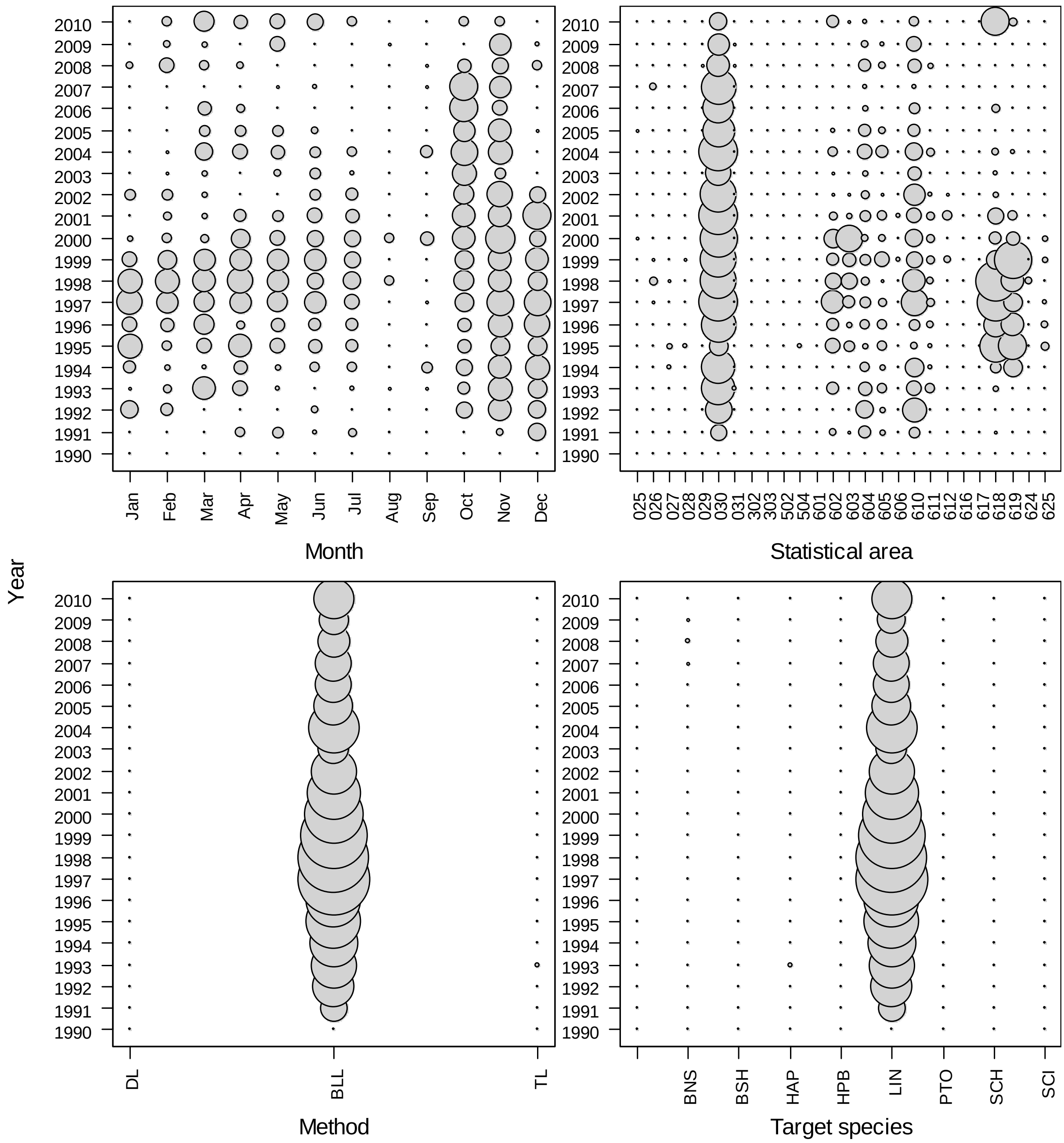


Figure B2b: Distribution of Sub-Antarctic single fishery ling line catch by month, target species, method, and statarea for 1990 to 2010 calendar years. Circle size is proportional to catch; maximum circle size is 600 t in this plot. Method definitions: BLL, bottom longline; DL, dahn line; TL, trot line.

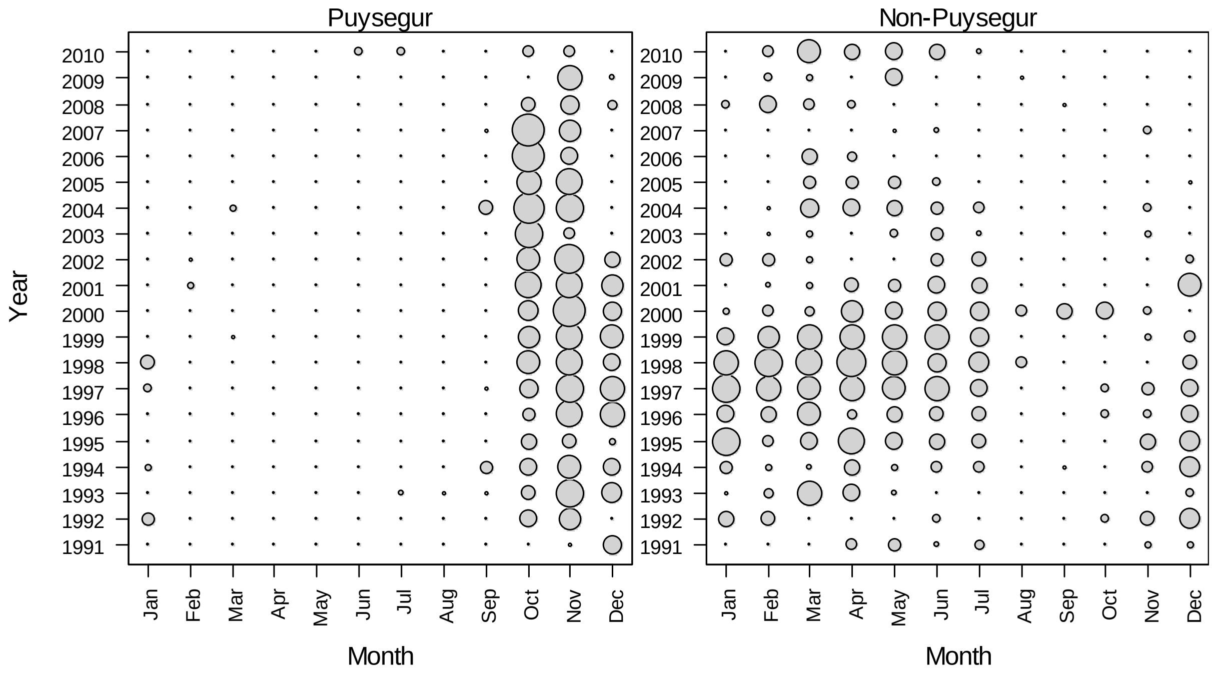


Figure B2c: Distribution of Sub-Antarctic ling line catch by month for Puysegur (statistical area 030) and non-Puysegur for the 1990 to 2010 calendar years. Circle size is proportional to catch; maximum circle size is 600 t in this plot.

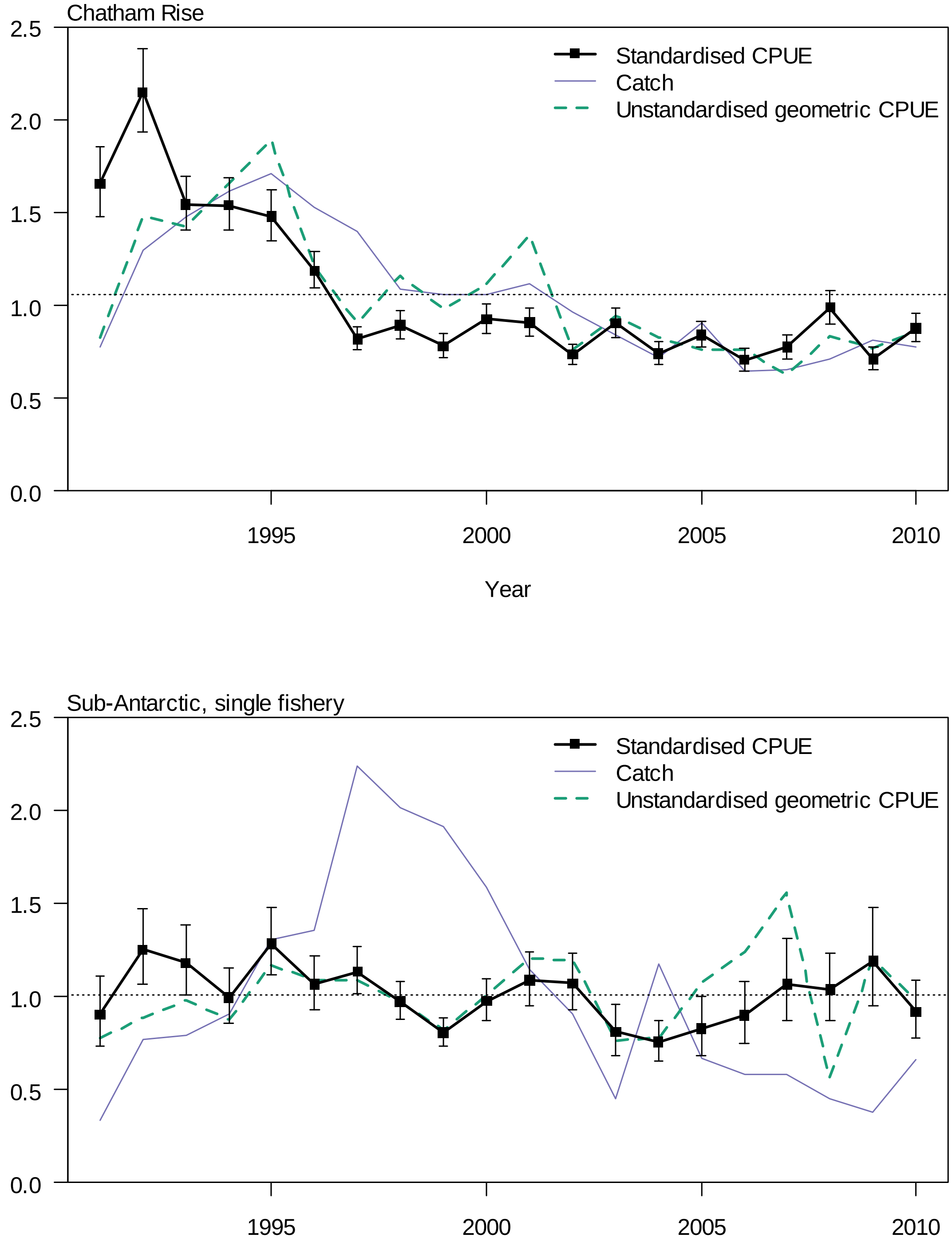


Figure B3a: CPUE from the lognormal model for the Chatham Rise fishery and the Sub-Antarctic single fishery line data, 1990–2010. Bars indicate 95% confidence intervals.

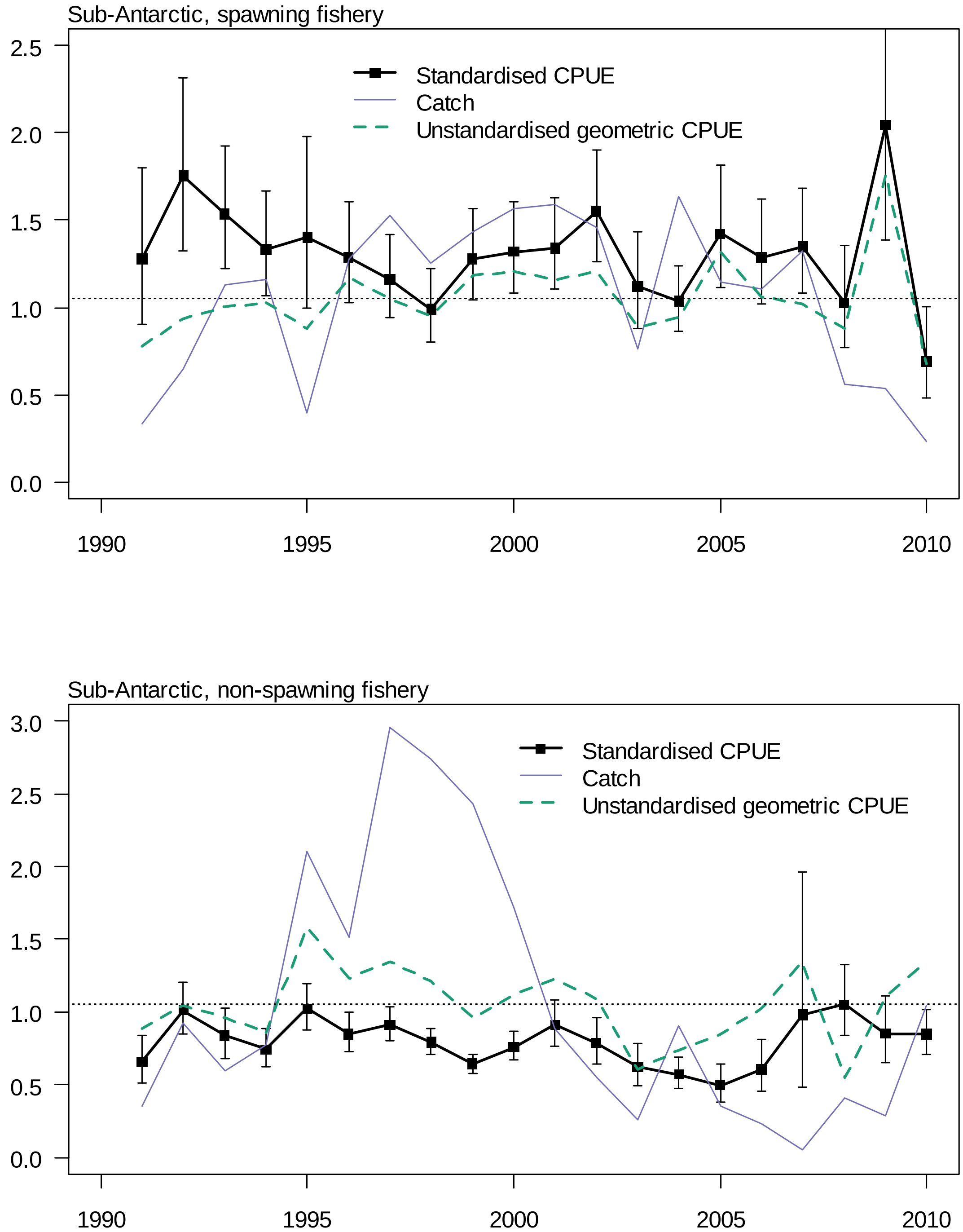


Figure B3b: CPUE from the lognormal model for the Sub-Antarctic two fishery model, 1991–2010. Bars indicate 95% confidence intervals.

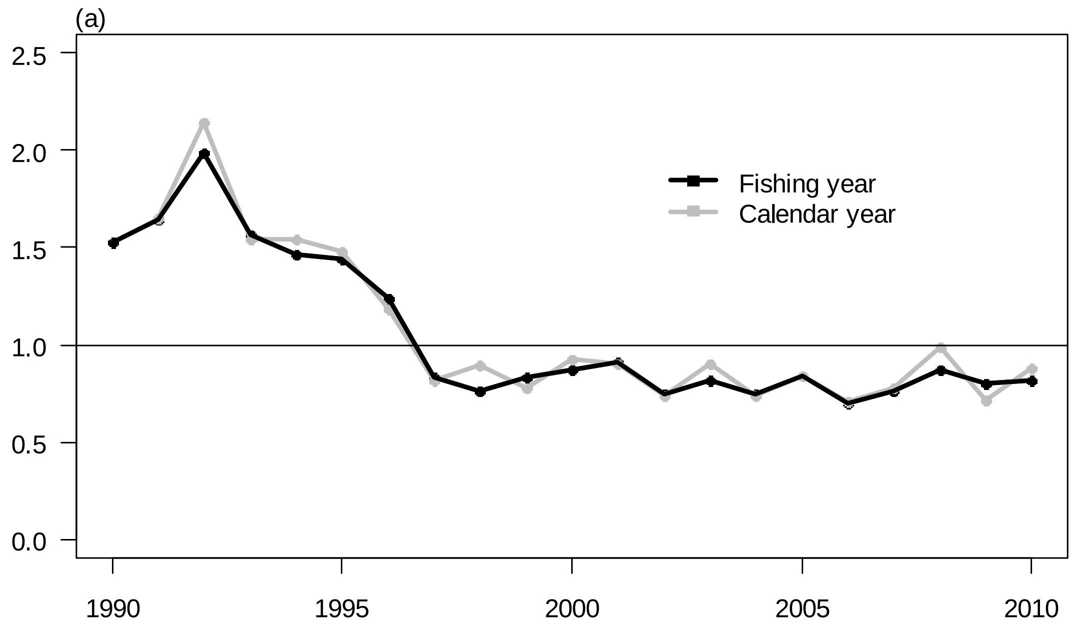


Figure B4a: Comparison of CPUE indices for the lognormal model for the Chatham Rise fishery models, by calendar year and fishing year for 1991–2010.

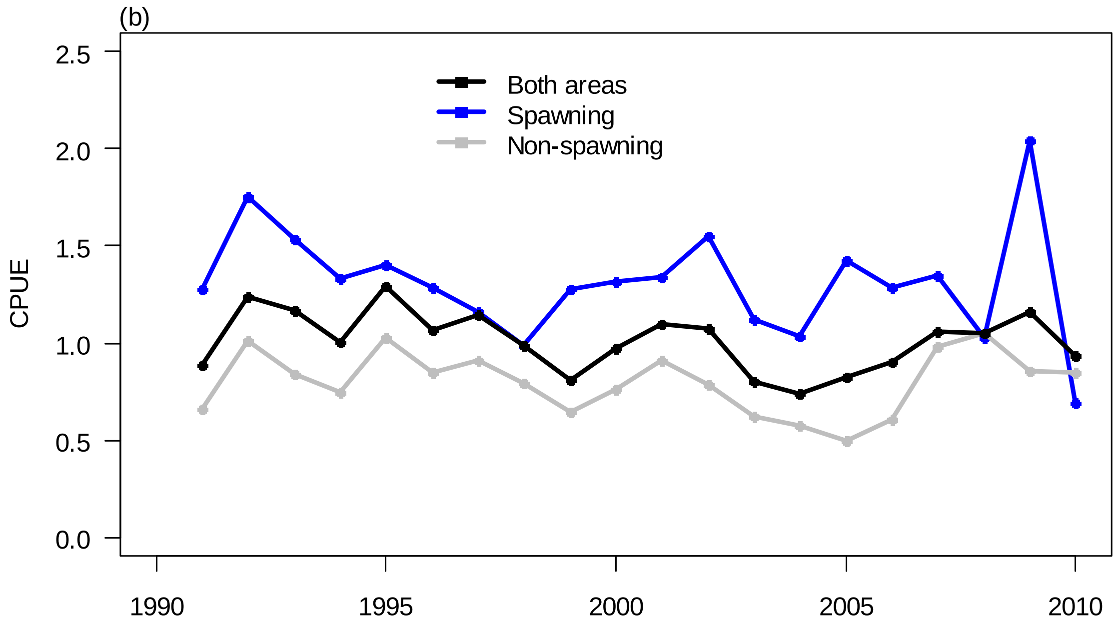


Figure B4b: Comparison of CPUE indices for the lognormal model for the Sub-Antarctic single (both areas) and two fishery (Spawning and non-spawning) models, 1991–2010.

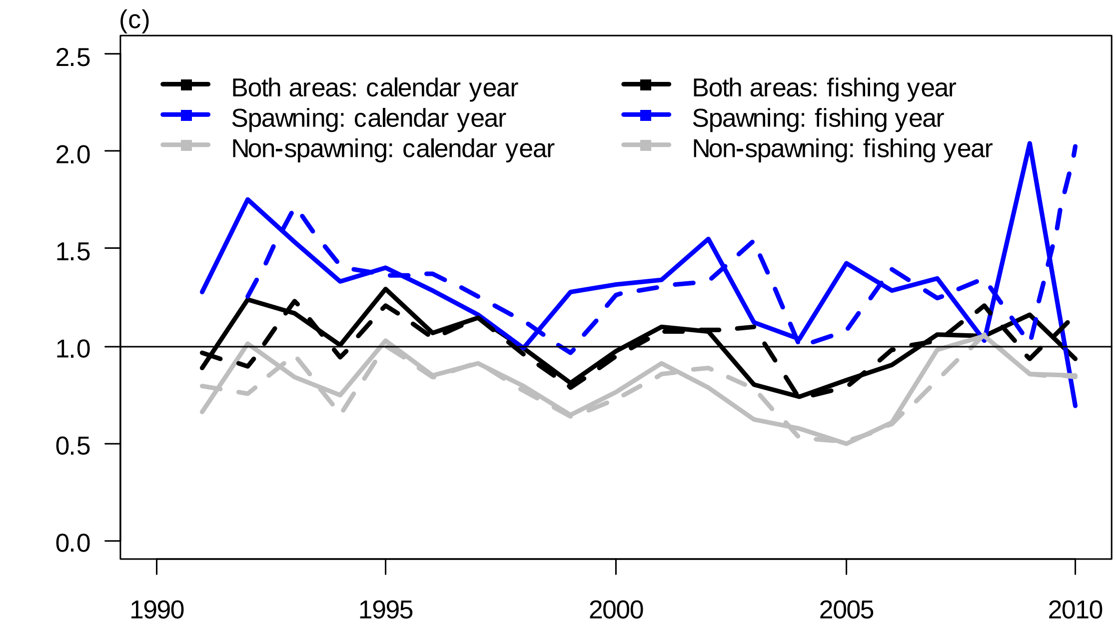


Figure B4c: Comparison of CPUE indices for the lognormal model for the Sub-Antarctic single (both areas) and two fishery (Spawning and non-spawning) models, by calendar and fishing year 1991–2010.

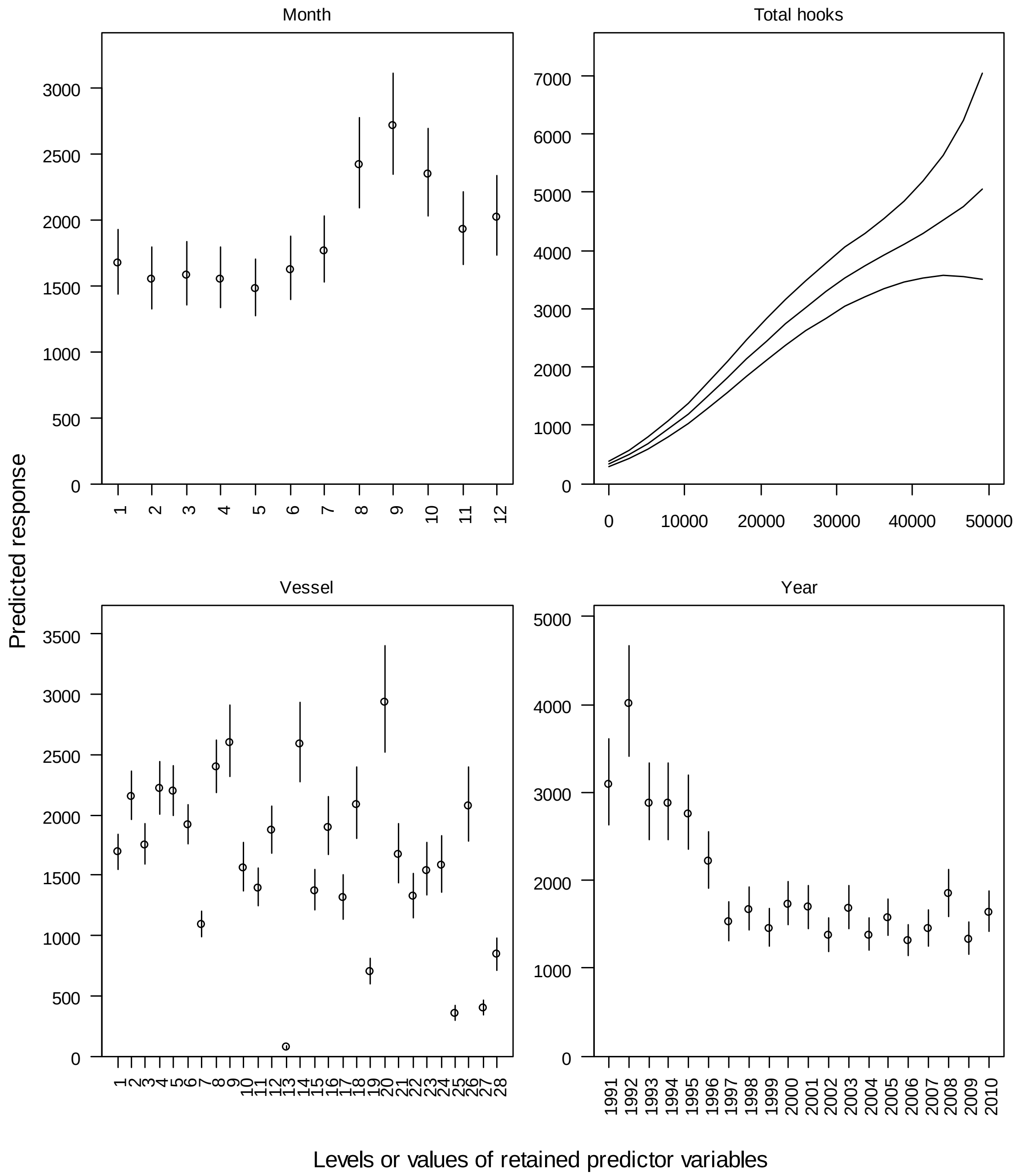


Figure B5a: Expected variable effects for variables selected into the CPUE lognormal model for the Chatham Rise line fishery, 1990–2010. The 95% confidence intervals are shown as bars for categorical variables and as upper and lower lines for continuous variables.

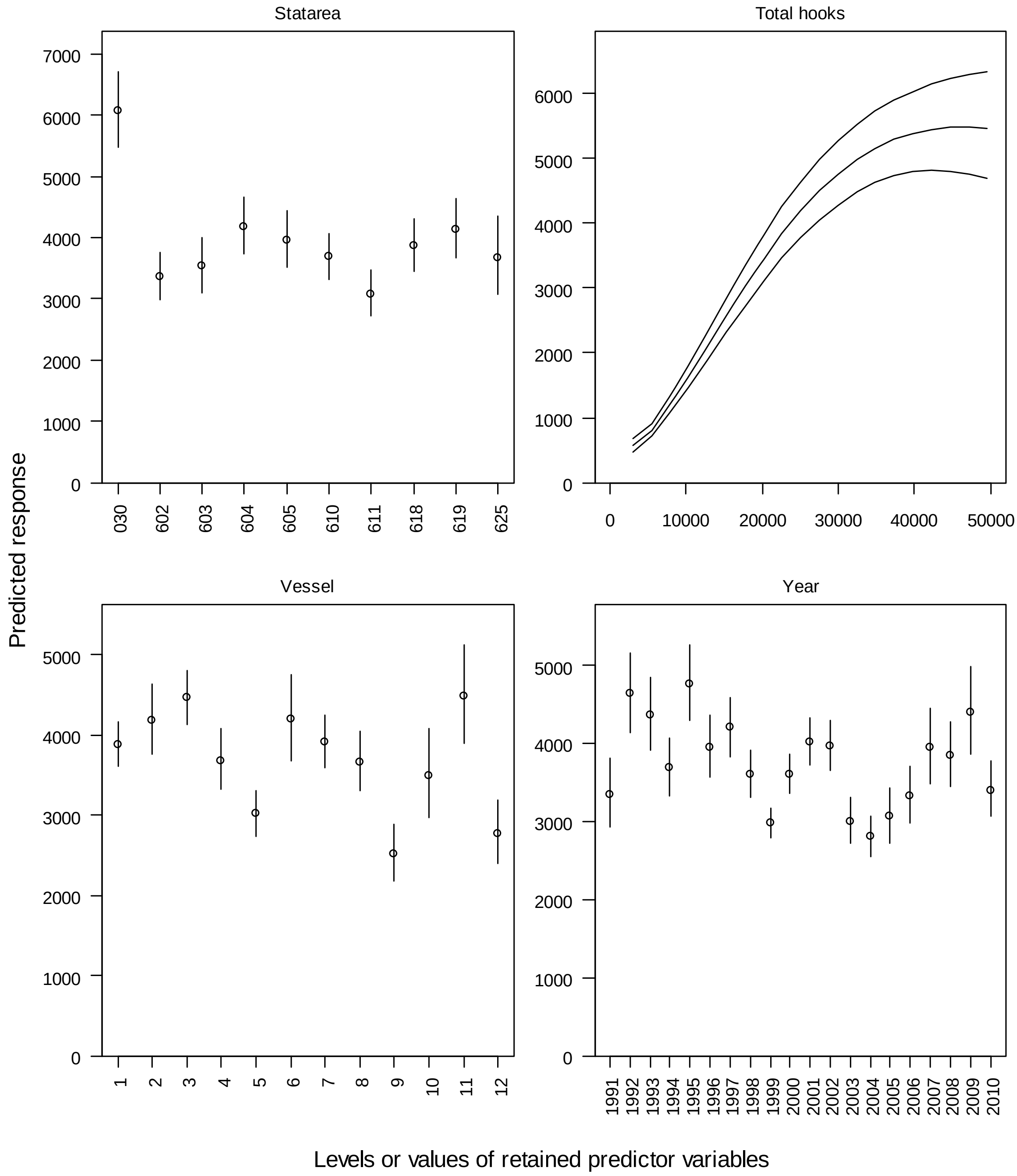


Figure B5b: Expected variable effects for variables selected into the CPUE lognormal model for the Sub-Antarctic single fishery line fishery, 1990–2010. The 95% confidence intervals are shown as bars for categorical variables and as upper and lower lines for continuous variables.

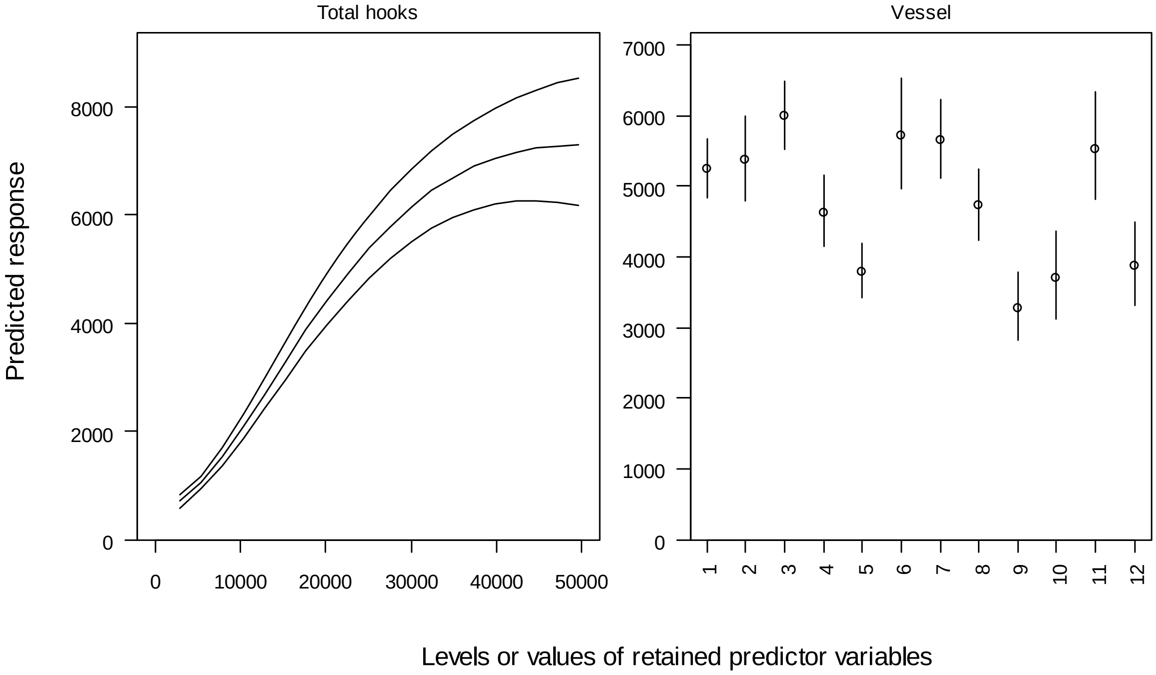
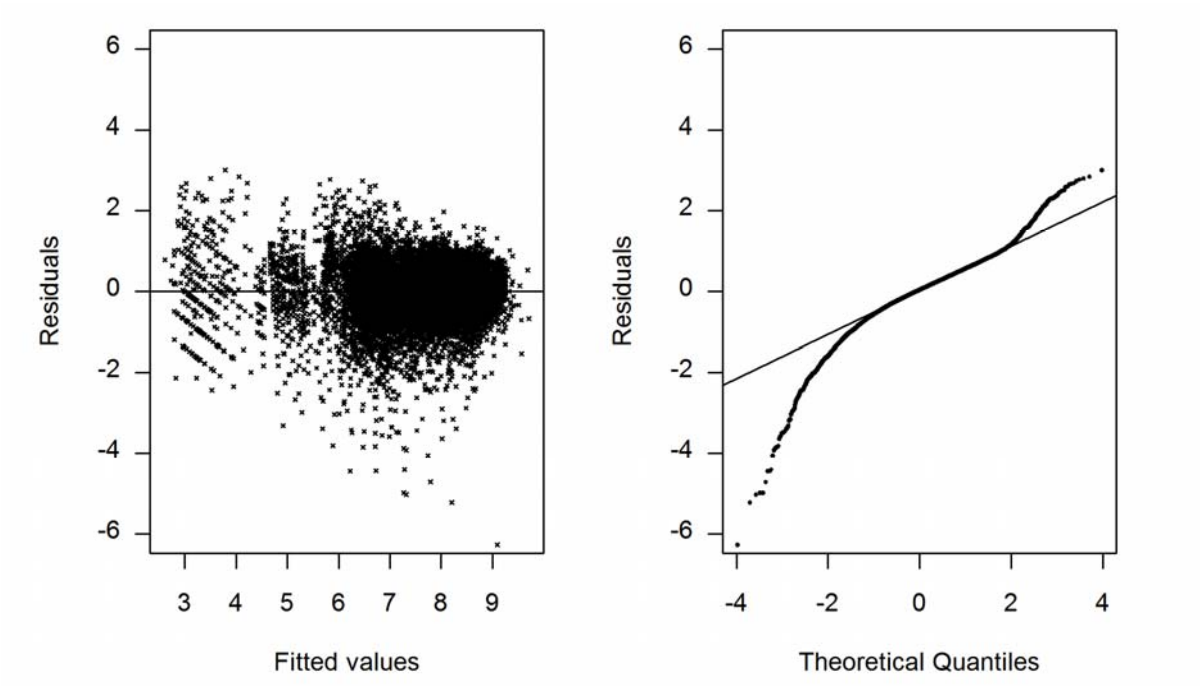


Figure B5c: Expected variable effects for variables selected into the CPUE lognormal model of the Sub-Antarctic two fishery model, 1991–2010. The 95% confidence intervals are shown as bars for categorical variables and as upper and lower lines for continuous variables.

Chatham Rise fishery



Sub-Antarctic single fishery

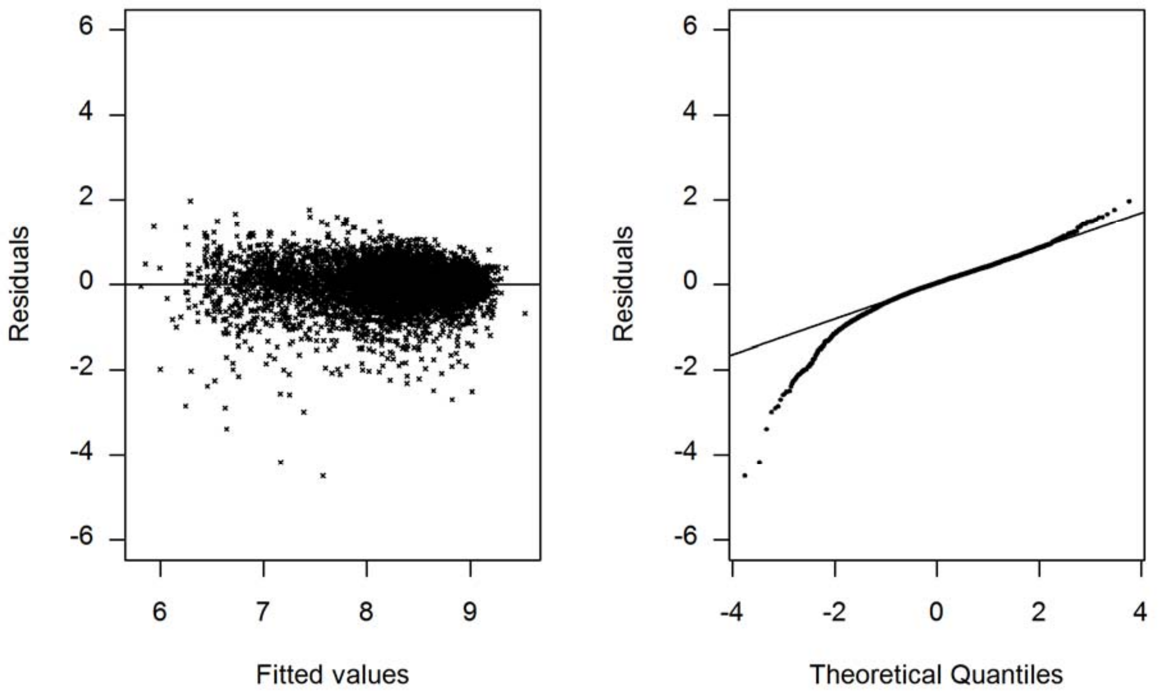


Figure B6a: Diagnostic plots for the CPUE model of the Chatham Rise and Sub-Antarctic single fishery models.

Sub-Antarctic two fishery model

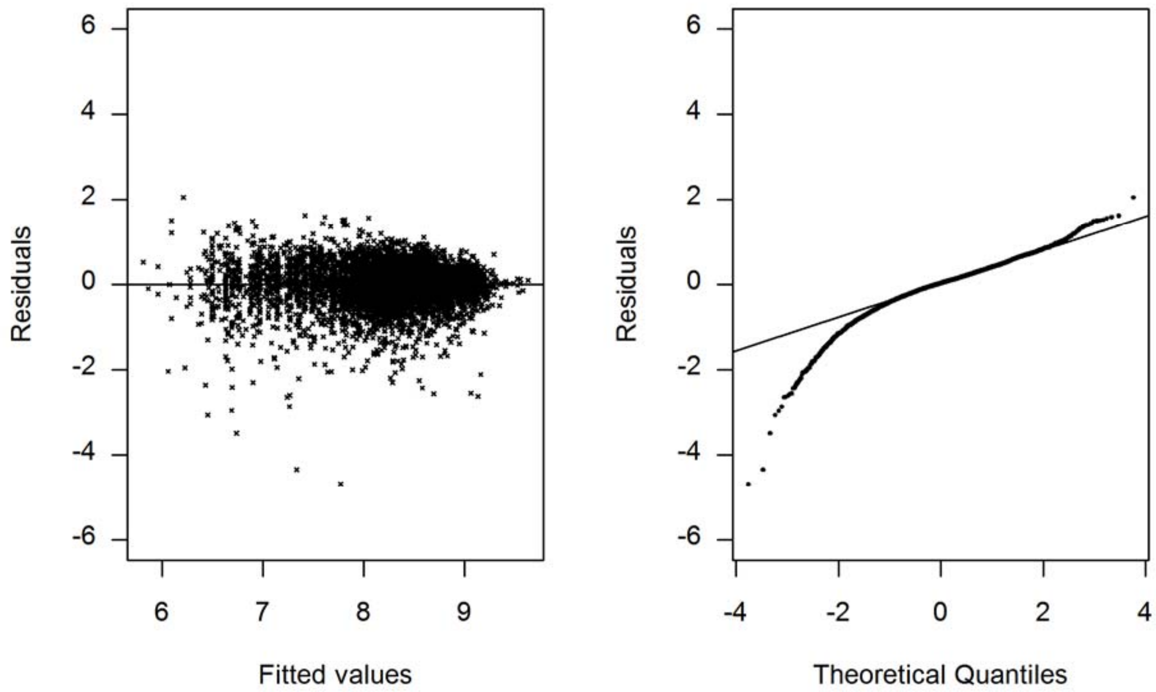


Figure B6b: Diagnostic plots for the CPUE model of the Sub-Antarctic two fishery model.

APPENDIX C. Biomass distribution in LIN 5 and LIN 6

This Appendix examines whether the distribution of trawl survey biomass in the Sub-Antarctic biological stock (i.e., LIN 5 and 6, excluding the Bounty Plateau) matches the quota allocations in LIN 5 and LIN 6. This work, funded by the Ministry of Fisheries under project LIN2007-01B, was reported in a Final Research Report (Horn 2010). Because an assessment of the Sub-Antarctic ling stock is reported above, the results of this earlier unpublished work would be usefully incorporated here.

Ling from the Campbell Plateau, Stewart-Snares shelf, and Puysegur area comprise a single biological stock (the 'Sub-Antarctic' stock), based primarily on growth and reproductive data. The growth rate of ling is consistent throughout this area, but significantly different to populations of ling in other areas (Horn 2005). The stock has two relatively distinct spawning areas (Horn 2005): Puysegur to Solander Island in LIN 5, and southern Stewart-Snares shelf to Auckland Islands across the LIN 5 and LIN 6 boundary. Some sporadic spawning activity does occur on the wider Campbell Plateau (in LIN 6). Consequently, this biological stock is believed to extend across two Fishstock areas (LIN 5 and LIN 6), although the Bounty Plateau area of LIN 6 is believed to hold another distinct biological stock.

There have been reporting issues along the LIN 5–LIN 6 boundary. Ling caught in LIN 5 have been reported as being caught just over the boundary line in LIN 6. The catch history shows that the LIN 5 TACC was often limiting, while the LIN 6 TACC is usually significantly under-caught (Table 2). This analysis of the distribution of biomass in the Sub-Antarctic biological stock, aimed to see whether the biomass matched the quota allocations in LIN 5 and LIN 6. Data are available from various trawl biomass surveys conducted since the late 1980s. Biomass was examined for three separate areas: Puysegur, Southland (i.e., all of FMA 5 excluding Puysegur), and Campbell (i.e., all of FMA 6 excluding the Bounty Plateau).

Available data

Trawl surveys of LIN 5 and 6 have been conducted in various seasons and years since late 1989 (Table C1). In the current analysis, survey area and depths were standardised wherever possible. This generally meant removing any strata deeper than 800 m (which usually removed less than 2% of total estimated ling biomass). The surveys were conducted by two vessels. Net design was consistent across all *Tangaroa* (tan) surveys, but varied between the *Amaltal Explorer* (aex) surveys.

Table C1: List of available trawl surveys, showing survey timing and depth range. Notes indicate any modifications made to the available data.

Trip	Season	Months	Depth	Notes
aex8902	summer	Oct–Nov	200–800m	300–800m around Auckland Is
aex9002	summer	Nov–Dec	300–800m	excl. Puys 1000m
tan9105	summer	Nov–Dec	300–800m	excl. Puys 1000m
tan9211	summer	Nov–Dec	300–800m	excl. Puys 1000m
tan9310	summer	Nov–Dec	300–800m	excl. Puys 1000m
tan0012	summer	Nov–Dec	300–800m	excl. Puys 1000m
tan0118	summer	Nov–Dec	300–800m	excl. Puys 1000m
tan0219	summer	Nov–Dec	300–800m	excl. Puys 1000m
tan0317	summer	Nov–Dec	300–800m	excl. Puys 1000m
tan0414	summer	Nov–Dec	300–800m	excl. Puys 1000m
tan0515	summer	Nov–Dec	300–800m	excl. Puys 1000m
tan0617	summer	Nov–Dec	300–800m	excl. Puys 1000m
tan0714	summer	Nov–Dec	300–800m	excl. Puys 1000m
tan0813	summer	Nov–Dec	300–800m	excl. Puys 1000m
tan9204	autumn	Apr–May	300–800m	
tan9304	autumn	May–Jun	300–800m	
tan9605	autumn	Mar–Apr	300–800m	excl. Puys 1000m
tan9805	autumn	Apr–May	300–800m	excl. Puys 1000m
aex9001	winter	Jul–Aug	300–800m	
tan9209	spring	Sep–Oct	300–800m	

Surveyed strata are shown in Figure C1. Strata combined to produce the three areas for the analysis are as follows:

- 'Puysegur' = strata 1 and 2
- 'Southland' = strata 3A, 3B, and 4 (including those parts in FMA 3)
- 'Campbell' = all remaining strata

However, it should be noted that there are some minor inconsistencies for strata 3B, 4, and 5A (i.e., small sections of these strata occur in both LIN 5 and LIN 6).

An additional boundary separating the eastern and western parts of the Campbell area was used in the analyses below. This boundary (denoted approximately by longitude 170° E) separated strata 5–10, from strata 11–15 (see Figure C1).

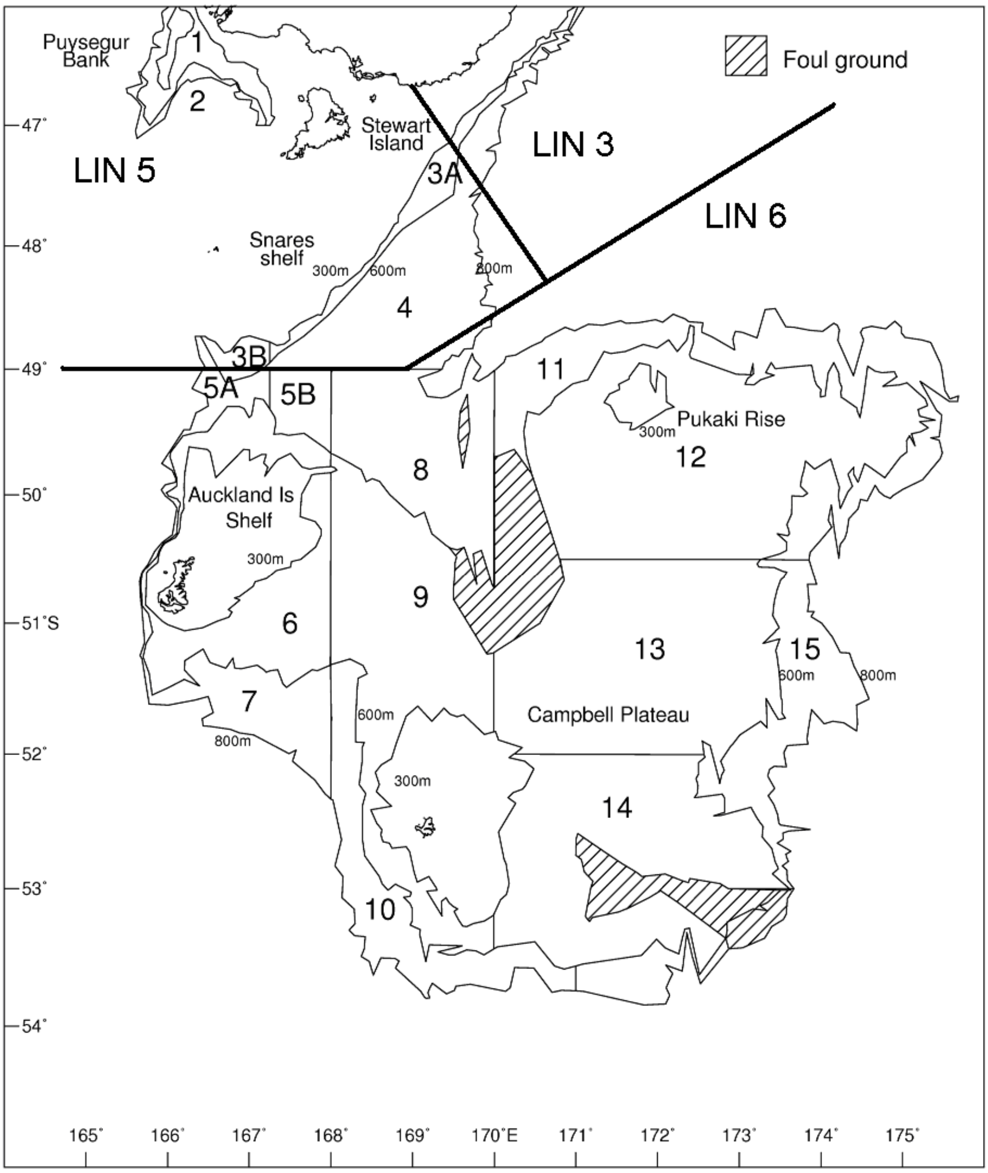


Figure C1: Trawl survey area, and strata, with FMA boundaries overlaid. The boundary between east and west Campbell is denoted approximately by longitude 170° E.

Biomass and sex ratios by area

Estimated biomass by area for each survey is shown in Figure C2. Most biomass (usually more than 80%) occurs in the Campbell area all year round. Where it is possible to examine trends across years but within seasons (i.e., in the summer and autumn series), it is apparent that biomass within an area is relatively consistent. However, there are some clear between-season differences. Biomass at Puysegur is particularly low in autumn relative to summer; a similar, but less marked trend is apparent for Southland ling. In contrast, autumn biomass on Campbell is consistently higher than summer biomass. There is also a seasonal trend across the Campbell area. Biomass is relatively high in the east and low in the west during autumn-winter, but more balanced during summer.

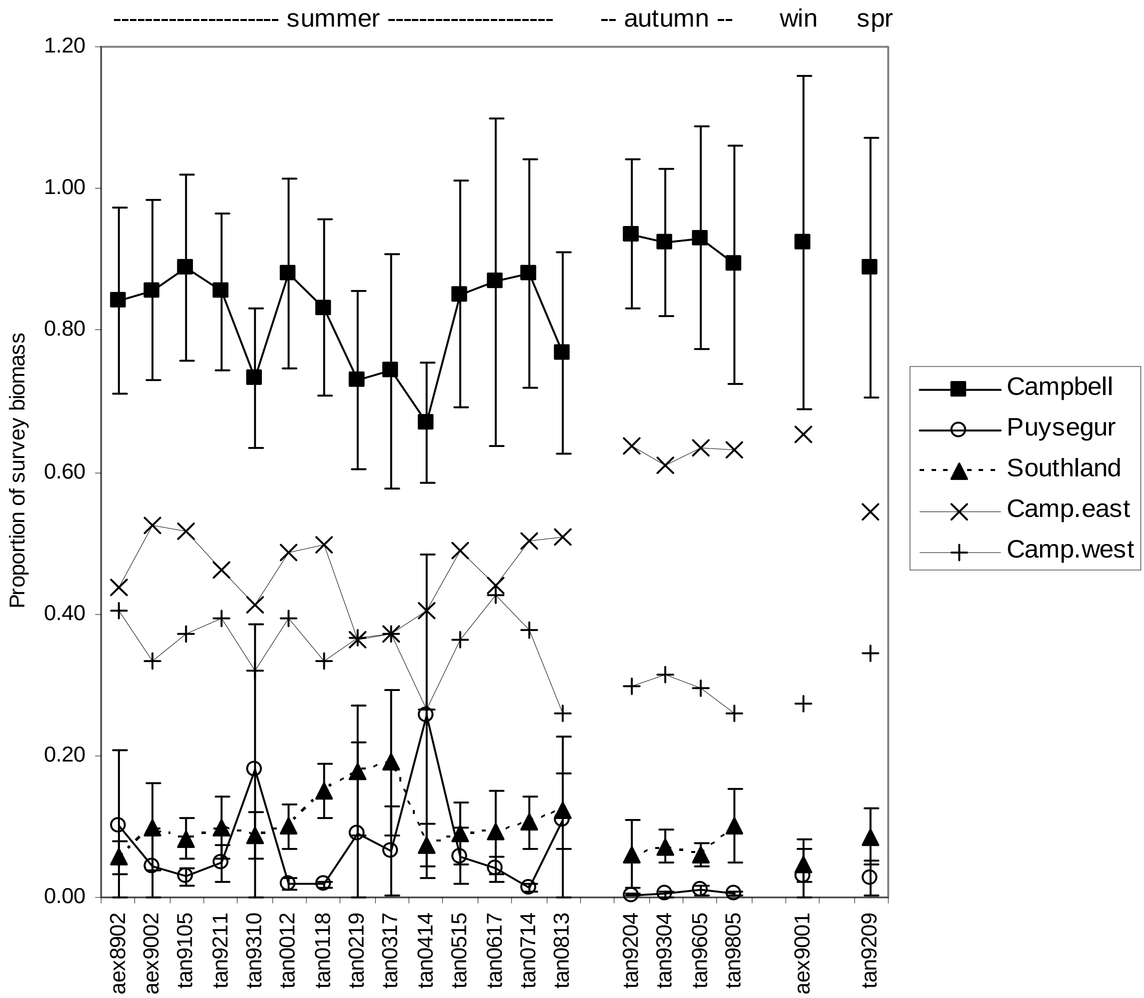


Figure C2: Areal distribution of ling biomass, by survey, grouped by season (summer, autumn, winter [win], spring [spr]). Vertical bars indicate 95% confidence intervals.

Biomass by sex and area is shown in Figure C3. Note that these plots show biomass, not numbers. On average, females are larger than males (2.7 kg compared to 1.7 kg), so there will be fewer females than males per unit biomass. However, the Campbell population is strongly female biased, particularly during the spring-summer spawning season (average 71% female biomass, or 62% females by number), but less so during autumn non-spawning (59% female biomass). This may indicate that many females do not go to spawn, or that they spend less time on the spawning ground than males. In contrast, the Puysegur population is strongly male biased throughout the year (average 59% male biomass, or 70% males by number). The Southland biomass is slightly female biased (i.e., 58% during the spawning season, and 51% during autumn non-spawning), but this equates to a numerical dominance of males in both seasons (53% and 60% males by number, respectively). There are no obvious trends of any within-area changes in sex-ratios over time in the summer series.

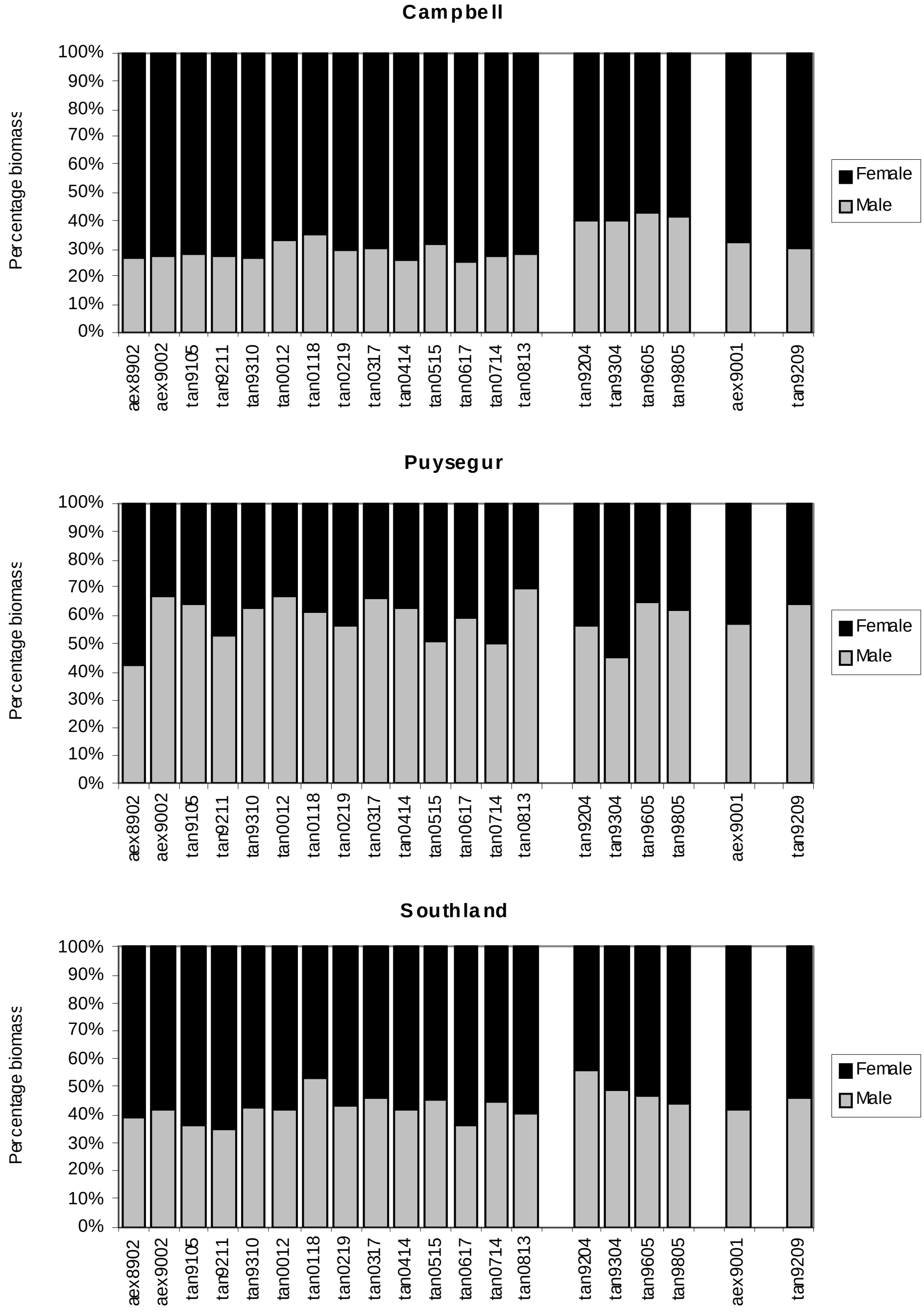


Figure C3: Ling biomass by sex and area, grouped by season.

Comparison of biomass and TACC by area

The distribution of the estimated ling biomass by area can be compared with the current TACCs in Table C2. Fishstock LIN 6 holds most of the Sub-Antarctic biological stock biomass (about 80–90%) but only 70% of the TACC. Also, it should be noted that catches for the Bounty Plateau biological stock must be reported against the LIN 6 TACC. However, the LIN 6 TACC has been caught or nearly caught in only three years (1996–97, 1997–98, and 2003–04), and is often markedly under-caught (see Table 2). FMA 5 holds a relatively low proportion of the Sub-Antarctic biological stock biomass (about 10–20%), but accounts for 30% of the TACC. LIN 5 reported landings have been close to the TACC in most years since the early 1990s (i.e., generally within ±12% of the TACC).

Table C2: Estimated ling biomass distribution by area and administrative fishstock, and TACCs associated with the LIN 5 and LIN 6 fishstocks.

Area	Average biomass		TACC
	Summer	Autumn	
Campbell	81%	92%	LIN 6: 8505 t (70%)
Puysegur	8%	1%	
Southland	11%	7%	LIN 5: 3595 t (30%)

However, it should be noted that ling occur in areas of both LIN 5 and LIN 6 that were not surveyed or included in the analyses used to derive the percentages in Table C2. It is known that ling biomass deeper than 800 m is likely to be negligible in all areas. However, the biomass shallower than 300 m could be significant. In a trawl survey series of depths 50–600 m in the Puysegur-Southland region about 60% of ling biomass occurred shallower than 200 m (Hurst & Bagley 1997).

The area between 50 and 300 m deep is considerable in both LIN 5 and LIN 6. However, when considered as a proportion of all area between 50 and 800 m, the shallow (50–300 m) ground is much more significant in LIN 5. Consequently, the ling biomass on shallower ground that would have been excluded from the current analysis is likely to be greater as a proportion of total biomass in LIN 5 than LIN 6. If this cryptic biomass was able to be used to recalculate the percentages in Table C2, then the Puysegur and Southland values would probably increase, and the Campbell values would decrease. Hence, the current TACC split (i.e., 70:30 between LIN 6 and LIN 5) may be quite close to the mean proportions of biomass in the two areas.

Trends in length distributions by area

Trends in the length-frequency distributions from the summer survey series only were examined. The data were analysed by area (i.e., Campbell, Puysegur, and Southland), and by sex. To examine trends over time, average cumulative length-frequency distributions were produced for three time periods: 1989–1993 (5 surveys), 2000–2004 (5 surveys), and 2005–2008 (4 surveys) (Figure C4).

Trends between areas were generally similar. In the Campbell area, males were, on average, smallest during the latter two periods (2000–04 and 2005–08), and largest in 1989–93. Females were, on average, smallest during the latter two periods (2000–04 and 2005–08), and largest in 1989–93. Males were relatively most abundant in 2000–04 and least abundant in 1989–93.

At Puysegur, males were, on average, smallest in 2000–04, and largest in 1989–93. Females were, on average, smallest during the latter two periods (2000–04 and 2005–08), and largest in 1989–93. Males were relatively most abundant in 2000–04 and least abundant in 1989–93 and 2005–08.

In the Southland area, males were, on average, smallest in 2000–04, and largest in 1989–93. Females were, on average, smallest in 2000–04, and largest in 1989–93. Males were relatively most abundant in 2000–04 and least abundant in 1989–93.

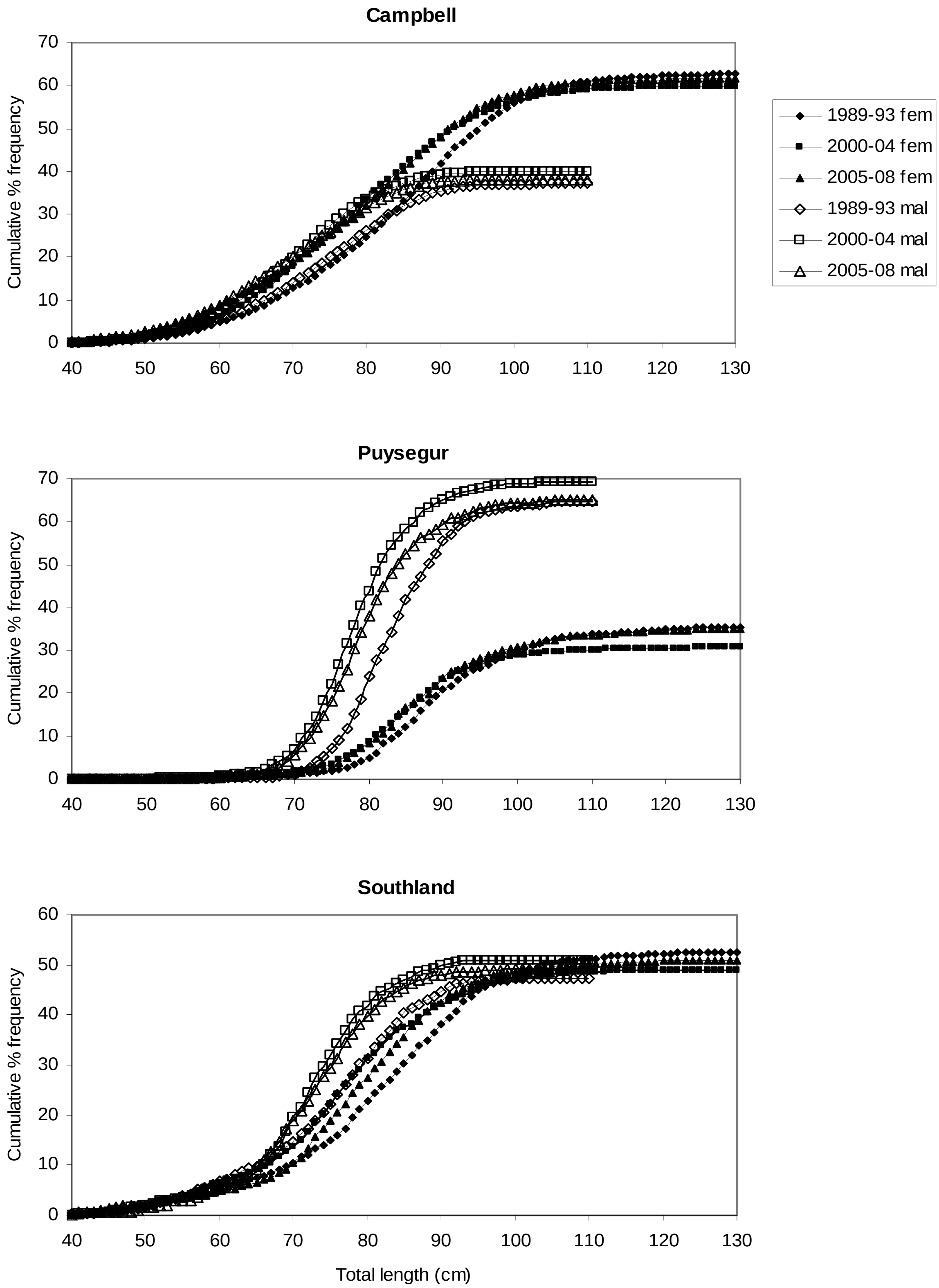


Figure C4: Cumulative length-frequency distributions, by sex, area, and time period. fem, female; mal, male.

Conclusions relating to LIN 5 and 6 biomass

The similar trends in cumulative length-frequency distributions between areas and sexes (i.e., fish were generally smaller but with a greater proportion of males in 2000–04, and larger but with relatively fewer males in 1989–93) provides further support for a single biological stock in the Campbell-Puysegur area. Sex ratios do vary between the three areas analysed, and seasonally within areas, but the differences are relatively constant over time. This is indicative of patterns of sex-related movement of ling that have been consistent over time.

The areal trends in biomass identified above are indicative of ling moving towards, and concentrating in, the north-western spawning grounds during spring and summer, then migrating back east (particularly out of Puysegur and onto the eastern Campbell Plateau) during autumn and winter. However, significant quantities of ling occur in the Southland and Campbell (east and west) areas throughout the year. There are several possible reasons for this:

- A sizable proportion of the ling population does not spawn annually, and so does not travel to the spawning grounds in spring-summer.
- Residence time on the spawning grounds is short relative to the length of the spawning season, so there are always abundant pre- or post-spawn fish in the non-spawning areas.
- Spawning occurs widely throughout FMAs 5 and 6, but is concentrated in two areas. (Running ripe female ling have been recorded sporadically across the Campbell Plateau, mainly from October to December (Horn 2005).)

It appears that the only clearly undesirable time-area combination for ling is Puysegur during autumn (see Figure C2). Biomass at Puysegur was negligible in all four of the autumn surveys.

The current TACCs may be proportionally quite similar to biomasses in FMA 5 and FMA 6. Although 80–90% of the middle depth survey biomass was estimated to occur in LIN 6, the value would probably be lower if the area shallower than 300 m could be included. The TACC for LIN 6 accounts for 70% of the combined LIN 5 and 6 TACC. However, the LIN 6 TACC is usually under-caught, and the catch from the Bounty Plateau stock is also included in this administrative fishstock. In contrast, the LIN 5 TACC is often fully caught. So although the current TACCs probably allow the harvest of biomass in proportion to its abundance in the two administrative fishstocks, the actual proportion of the available ling biomass harvested from LIN 5 each year is probably much greater than the proportion of available biomass taken from LIN 6.