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Stock assessment of ling (*Genypterus blacodes*) in Cook Strait and off the West Coast South Island (LIN 7), and a descriptive analysis of all ling fisheries, for the 2012–13 fishing year

New Zealand Fisheries Assessment Report 2013/63

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EXECUTIVE SUMMARY

Dunn, M.R.; Edwards, C.T.T.; Ballara, S.L.; Horn, P.L. (2013). Stock assessment of ling (*Genypterus blacodes*) in Cook Strait and off the West Coast South Island (LIN 7), and a descriptive analysis of all ling fisheries, for the 2012–13 fishing year.

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Updated descriptive analyses for all New Zealand ling fisheries are presented incorporating data up to the 2010–11 fishing year. The overall 2010–11 ling catch from the EEZ was slightly lower than the previous year, and markedly lower than catches from 1991–92 to 2007–08. The distribution and size of trawl fishery landings changed little in 2010–11, with slight decreases in catch in East SI, Chatham, Sub-Antarctic, and slight increases in Southland and West SI, but overall trawl landings were markedly lower than those taken by this method during the early to mid 2000s. The 2010–11 overall longline fishery catch distribution was also quite similar to the previous year, but with decreases in catch for Chatham, Southland, and Sub-Antarctic, and negligible catches in Bounty Plateau and Cook Strait. This is markedly lower than 1992–2002, but relatively consistent with the pattern of landings since 2003.

Updated Bayesian assessments are presented for the LIN 7CK (Cook Strait, those parts of LIN 2 and LIN 7 making up Statistical Areas 016 and 017) and LIN 7WC (west coast South Island, LIN 7 west of Cape Farewell) stocks, using the general-purpose stock assessment program CASAL v2.30. The assessments incorporated all relevant biological parameters, the commercial catch histories, updated CPUE series, and catch-at-age data from research surveys and 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 7CK stock was not estimated satisfactorily. It was considered desirable to estimate the natural mortality rate (M) in the model because it is believed that M for the Cook Strait stock is higher than the 'default' value of 0.18, and so the effect of this uncertainty in M should be incorporated in the assessment. However, the simultaneous estimation of absolute virgin biomass and M was not successful owing to the adoption of a multinomial likelihood (rather than lognormal) method for estimating proportions-at-age. Consequently, models with fixed M values were run, and although the age data were reasonably well fitted, the model failed to accurately represent declines in abundance observed in CPUE values since 2001. Hence, the model presented here was considered unsuitable for providing management advice.

The current status of the LIN 7WC stock was highly uncertain, although the absolute virgin biomass was highly likely to have been greater than 50 000 t, and the exploitation rate was not high. The data were not very informative about biomass, with the priors contributing as much as the data to the biomass estimates. The model was sensitive to the choice of M, and runs were completed fixing or estimating M. When estimated, it was necessary to constrain M using a new informed prior. A model partitioned by sex provided poor fits to observed data, and sex was excluded in final model runs. In all final model runs, current stock size was estimated to be well above the management target of 40% B_0.

1. INTRODUCTION

This document reports the results of Ministry for Primary Industries Project DEE201002LINB. 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 7 (west coast South Island and Cook Strait) in 2012–13. The assessments are reported in the main body of this report. The updated descriptive analysis is presented in Appendix A, and the CPUE updates are presented in Appendix B.

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 the New Zealand 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 Plateau, the west coast of the South Island (WCSI), and Cook Strait.

In the stock assessment process, the same five biological stocks of ling are recognised, and are defined as follows: Chatham Rise (LIN 3 and LIN 4), Sub-Antarctic incorporating Campbell Plateau and Stewart-Snares shelf (LIN 5, and LIN 6 west of 176º E), Bounty Plateau (LIN 6 east of 176º E), west coast South Island (LIN 7 west of Cape Farewell), and Cook Strait (those parts of LIN 2 and LIN 7 between latitudes 41° and 42° S and longitudes 174° and 175.4° E, equating approximately to Statistical Areas 016 and 017). These stocks are referred to as LIN 3&4, LIN 5&6, LIN 6B, LIN 7WC, and LIN 7CK, respectively. The most recent previous assessments of these stocks were: LIN 3&4 and LIN 5&6 (Horn et al. 2013), LIN 6B (Horn 2007b), LIN 7CK (Horn & Francis 2013), and LIN 7WC (Horn 2009).

The assessments used CASAL v2.30, a generalised age- or length-structured fish stock assessment model (Bull et al. 2012). The LIN 7WC assessment incorporates a research trawl survey abundance series, catch-at-age data from the research survey series and from commercial line and trawl fisheries, catch-at-length data from the line fishery, and CPUE series from the line and trawl fisheries. The LIN 7CK assessment incorporates catch-at-age data, and CPUE series from the commercial line and trawl fisheries.

This report fulfils all objectives of Project DEE201002LINB “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 7WC and LIN 7CS in 2012-13”, funded by the Ministry for Primary Industries. Revised catch histories for all ling stocks are reported here, as are any new model input data and research results. Although some of these data are not relevant to the assessments reported here, they are included to provide in one place an up-to-date summary of the available knowledge and literature on ling in New Zealand waters.

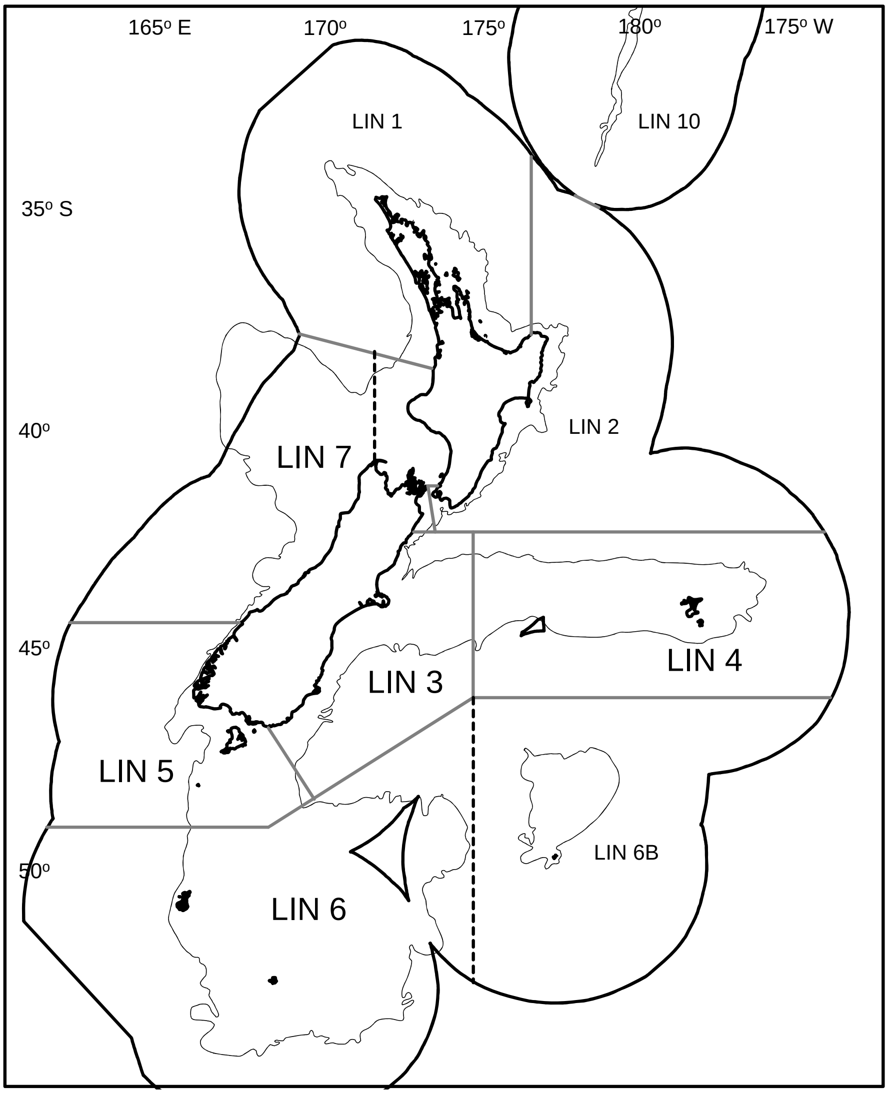


Figure 1: Ling fishstocks, and the 1000 m isobath. The boundaries used to separate biological stock LIN 6B from the rest of LIN 6, and the west coast South Island section of LIN 7 from the rest of LIN 7, are shown as broken lines.

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, 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 were taken almost exclusively by longline. A small, but important, quantity of ling was 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 were taken as a trawl bycatch, primarily of the hoki fishery. In Cook Strait, about 75% of ling landings were 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 CV 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. The TACCs for LIN 3 and LIN 4 were reduced to 2060 t and 4200 t, respectively, from 1 October 2000 following a decline in catch rates (from analysis of longline CPUE data) and assessment model results that estimated current biomass at 25–30% of B_0,. 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 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 the 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 Ministry of Agriculture and Fisheries; data from 1983–84 to 1985–86 from Fisheries Statistics Unit; data from 1986–87 and 1987–88 from QMS.

	New Zealand			Foreign licensed					
				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 2010–11 and actual TACCs (t) from 1986–87 to 2010–11. Estimated landings for LIN 7 from 1987–88 to 1992–93 include an adjustment for ling bycatch from 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
2010–11#	438	400	670	982	1 665	2 060	1 572	4 200	3 856	3 595

Fishstock	LIN 6		LIN 7			LIN 10		Total	
QMA (s)	6		7 & 8			10			
	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
2010–11#	2 047	8 505	2 771	–	2 474	0	10	12 953	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

New catch-at-age distributions relevant to the LIN 7WC assessment were created as part of Project MID201001C, and are reported elsewhere (Horn & Sutton in prep.). The distributions were for ling caught on the research surveys in July 2000 (TAN0007) and July 2012 (TAN1210), and during the commercial longline and commercial trawl fisheries in 2011–12. No catch-at-age distributions are available for the LIN 7CK stock since the 2009–10 fishing year.

4. MODEL INPUT DATA

Estimated commercial landings histories for the five stocks are listed in Table 3. Landings up to 1972 were assumed to be zero, although it is very likely that small quantities of ling were taken in various areas before then. The split of catches between fishing 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 by 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 (2006b). *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 by sex for LIN 3&4, LIN 5&6, and LIN 7WC are from Horn (2005). The LIN 6B and LIN 7CK ogives were assumed to be the same as for LIN 3&4 and LIN 7WC, respectively, in the absence of any data to 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) was assumed. Variability in size-at-age around the von Bertalanffy age-length model was assumed to be normal with a constant CV of 0.15.

Standardised CPUE series for the trawl and longline fisheries in LIN 7WC and LIN 7CK were derived and are listed in Appendix B. An evaluation of the available series by the Deepwater Fisheries Assessment Working Group (DWFAWG) resulted in only the trawl fishery indices being used in the assessment modelling (Table 5). The WCSI series was derived from data collected at sea by observers from 1987 to 2011. The Cook Strait series was derived from a subset of the available TCEPR data. Data from before 1994 were excluded as the fleet structure changed markedly at this time. The most recently derived CPUE series for other ling stocks were reported by Horn & Ballara (2012) and Horn et al. (2013). CPUE indices were used as relative abundance indices, with associated CVs estimated from the generalised linear model used to estimate relative year effects.

Series of research trawl survey indices are available for LIN 3&4, LIN 5&6, and LIN 7WC (Table 6). Biomass estimates from the trawl surveys were used as relative biomass indices, with associated CVs estimated from the survey analysis.

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 2013). Catch-at-age data were fitted to the model as proportions-at-age, where estimates of the proportions-at-age and associated CVs by age were estimated using the NIWA catch-at-age software by bootstrapping (Bull & Dunn 2002). Zero values of proportion-at-age were replaced with 0.0001. 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 CVs as defined in Table 4. The CVs varied between stocks because of perceived differences in the difficulty of reading otoliths between stocks (author Horn's unpublished data).

A summary of all input data series, by stock, is given in Table 7. Data from trawl surveys could be input either as a) biomass and proportions-at-age, or b) numbers-at-age. Francis et al. (2003) presented an argument for the use of proportions-at-age, rather than numbers-at-age, for hoki from trawl surveys. 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.

Table 3: Estimated catch histories (t) for LIN 3&4 (Chatham Rise), LIN 5&6 (Campbell Plateau), LIN 6B (Bounty Plateau), LIN 7WC (WCSI section of LIN 7), and LIN 7CK (Cook Strait sections of LIN 7 and LIN 2). Landings were separated by fishing method (trawl or line), and, for the LIN 5&6 line fishery, by pre-spawning (Pre) and spawning (Spn) season. The 2012 values were estimated for the current assessment 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. –, not estimated.

Year	LIN 3&4		LIN 5&6			LIN 6B	LIN 7WC		LIN 7CK	
	Trawl	Line	Trawl	Line		Line	Trawl	Line	Trawl	Line
				Pre	Spn					
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	–	1 597	1 046	111	38
2012	–	–	–	–	–	–	1 300	1 050	100	40

Table 4: Biological and other input parameters used in the ling assessments. – not estimated.

1. Natural mortality (M)

	Female	Male	Combined
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	0.18
LIN 7CK	0.22	0.22	–

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

	Female		Male		Combined	
	a	*b*	*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	0.001040	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	2 463	0.103	-0.88	149.8	2 358	0.112	0.08	163.1

	Combined			
	n	*k*	t_0	L_∞
LIN 7WC	4 686	0.077	-1.37	150.8

4. Maturity ogives (proportion mature at age)

Age (years)	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			
Combined	0.0	0.010	0.056	0.23	0.48	0.67	0.83	0.93	0.97	1.0			

5. Miscellaneous parameters

Stock	3&4	5&6	6B	7WC	7CK
Stock-recruitment steepness	0.9	0.9	0.9	0.84	0.9
Recruitment variability CV	0.6	0.6	1.0	0.6	0.7
Ageing error CV	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: Trawl fishery CPUE series (with CVs for individual points) accepted for inclusion in the assessment modelling of the WCSI and Cook Strait ling stocks. See Appendix B for derivation of these indices. –, not estimated.

	WCSI		Cook Strait	
Year	Index	CV	Index	CV
1987	0.49	0.07	–	–
1988	0.92	0.06	–	–
1989	1.33	0.06	–	–
1990	1.27	0.06	–	–
1991	0.81	0.06	–	–
1992	0.76	0.07	–	–
1993	1.04	0.06	–	–
1994	0.91	0.05	1.25	0.05
1995	1.31	0.06	1.16	0.04
1996	1.73	0.05	1.12	0.04
1997	1.40	0.06	1.00	0.04
1998	1.36	0.05	1.01	0.04
1999	1.59	0.05	1.02	0.03
2000	1.23	0.04	1.27	0.04
2001	0.94	0.04	1.46	0.04
2002	1.27	0.04	1.27	0.05
2003	0.71	0.05	1.27	0.04
2004	1.12	0.04	1.13	0.04
2005	0.79	0.04	1.18	0.04
2006	0.73	0.04	1.10	0.05
2007	0.55	0.06	0.73	0.06
2008	0.54	0.06	0.90	0.06
2009	0.48	0.06	0.44	0.07
2010	0.63	0.06	0.44	0.07
2011	1.06	0.06	0.23	0.09

Table 6: Series of relative biomass indices (t) from *Tangaroa* (TAN) trawl surveys (with coefficients of variation, CV) available for the assessment modelling.

Fishstock	Area	Trip code	Date	Biomass (t)	CV (%)
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
		TAN1201	Jan 2012	8 098	7.4
		TAN1301	Jan 2013	8 714	10.1
LIN 5&6	Sub-Antarctic	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
		TAN1117	Dec 2011	23 178	11.8
		TAN1215	Dec 2012	27 036	11.3
LIN 5&6	Sub-Antarctic	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	TAN0007	Jul–Aug 2000	1 861	16
		TAN1210	Jul–Aug 2012	2 169	14

Table 7: Summary of the relative abundance series available for the assessment modelling, including source years (Years).

Data series	Years
LIN 3&4	
Trawl survey proportion at age (*Amaltal Explorer*, Dec)	1990
Trawl survey biomass (*Tangaroa*, Jan)	1992–2012
Trawl survey proportion at age (*Tangaroa*, Jan)	1992–2012
CPUE (longline, all year)	1990–2010
Commercial longline proportion-at-age (Jun–Oct)	2002–10
Commercial longline length-frequency (Jun–Oct)	1995–2002
Commercial trawl proportion-at-age (Oct–May)	1992, 1994–2011
LIN 5&6	
Trawl survey proportion at age (*Amaltal Explorer*, Nov)	1990
Trawl survey biomass (*Tangaroa*, Nov–Dec)	1992–94, 2001–10, 2012
Trawl survey proportion at age (*Tangaroa*, Nov–Dec)	1992–94, 2001–10, 2012
Trawl survey biomass (*Tangaroa*, Mar–May)	1992–93, 1996, 1998
Trawl survey proportion at age (*Tangaroa*, Mar–May)	1992–93, 1996, 1998
CPUE (longline, spawning fishery)	1991–2010
CPUE (longline, non-spawning fishery)	1991–2010
Commercial longline proportion-at-age (spawning, Oct–Dec)	2000–08, 2010
Commercial longline proportion-at-age (non-spawn, Feb–Jul)	1999, 2001, 2003, 2005, 2009–11
Commercial trawl proportion-at-age (Sep–Apr)	1992–94, 1996, 1998, 2001–11
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)	1994–2011
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)	1987–2011
Commercial trawl proportion-at-age (Jun–Sep)	1991, 1994–2008
Commercial longline proportion-at-age	2003, 2012
Trawl survey biomass (*Tangaroa*, July)	2000, 2012
Trawl survey proportion-at-age (*Tangaroa*, July)	2000, 2012

5. ASSESSMENT MODELLING FOR LIN 7CK (COOK STRAIT)

5.1 Model structure

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

The selectivity ogives for the commercial trawl and line fisheries were age-based and estimated in the model, separately by sex. The trawl fishery ogives were estimated using a double normal parameterisation; the estimated line fishery ogives were assumed to be logistic. In all cases, male selectivity curves were estimated relative to female selectivity, which had a fixed maximum selectivity of one. The parameterisations of the double normal and logistic curves are given by Bull et al. (2012). In both 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 the stock. The choice of the maximum exploitation rate has the effect of determining the minimum possible virgin biomass allowed by the model. This value was set relatively high as there was little external information from which to determine it.

Table 8: Annual cycles of the LIN 7CK stock assessment model, showing the processes taking place at each time step, their sequence within each time step, and the available observations. Fishing and natural mortality that occur within a time step occur after all other processes, with half of the natural mortality for that time step occurring before and half after the fishing mortality.

					Observations	
Step	Period	Processes	M^1	Age[2]	Description	$\%Z^3$
1	Oct–May	recruitment fishery (line)	0.67	0.5	 Line catch-at-age	0.5
2	Jun–Sep	increment ages fishery (trawl)	0.33	0	Trawl CPUE Trawl catch-at-age	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 occur in 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.

5.2 Model estimation

Model parameters were estimated using Bayesian estimation implemented within the CASAL v2.30 software. Full details of the CASAL algorithms, software, and methods are detailed by Bull et al. (2012). Lognormal error, with known CVs per year, was assumed for the trawl CPUE relative abundance index. The CVs were obtained from the CPUE standardisation and represent sampling (observation) error. These were typically small, being of the order of 0.05. An additional process variance, assumed to arise from differences between model simplifications and real world variation, was added to the sampling variance. A process error CV of 0.2 was therefore added to the CPUE series, chosen using methods described in Francis (2011). For the proportions-at-age observations from the trawl and line fisheries, a multinomial error distribution was assumed. Process errors for the catch-at-age series were captured by the effective sample sizes per year, used in the multinomial likelihood, which were estimated iteratively using method TA1.8 described in Francis (2011). A small ageing error component was also added, which was normal with a CV of 0.07. These ensured that all the 95% confidence intervals around observed mean ages overlapped with the expected mean age from model outputs.

Year class strengths were assumed known (and equal to the long term average) for years before 1983 and after 2006, when inadequate or no catch-at-age data were available. Otherwise, relative year class strengths were estimated under the assumption that the estimates from the model must average 1. The Haist parameterisation for year class multipliers was used (see Bull et al. 2012).

Only maximum posterior density (MPD) fits were reported, as the DWFAWG considered the assessment too unreliable to warrant a full MCMC run. For the same reason, yields (MCY or CAY) were not calculated in this assessment.

The assumed prior distributions used in the assessment are given in Table 9. Most priors were intended to be relatively uninformative, and were specified with wide bounds. The priors for natural mortality assumed that *M* can vary between stocks, but is very probably between 0.1 and 0.3 for all stocks (following Horn 2008). Consequently, the chosen prior distribution was lognormal with a mean at 0.18 (the value previously used as *M* for all stocks) and a moderately high CV (Table 9).

Table 9: Assumed prior distributions and bounds for estimated parameters in the assessment. Parameter values are mean estimates (in natural space) and CV –, not estimated

Parameter description	Distribution	Parameters		Bounds	
B_0	uniform-log	–	–	2 000	60 000
Year class strengths	lognormal	1.0	0.9	0.01	100
CPUE *q*	uniform-log	–	–	1e-8	1e-2
Selectivities	uniform	–	–	0	20–200*
Process error CV	uniform-log	–	–	0.001	2
M	lognormal	0.18	0.16	0.1	0.3

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

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

5.3 Developing an assessment model

Recent previous assessment of the Cook Strait ling stock found that estimated biomass was sensitive to changes in *M* (Horn 2008, Horn & Francis 2013). It also appears likely that the true *M* for the Cook Strait stock is higher than the 'default' value of 0.18 that has been used in many previous ling assessments (Horn 2008). Consequently, there was a need to incorporate the effect of this uncertainty in *M* in the current assessment.

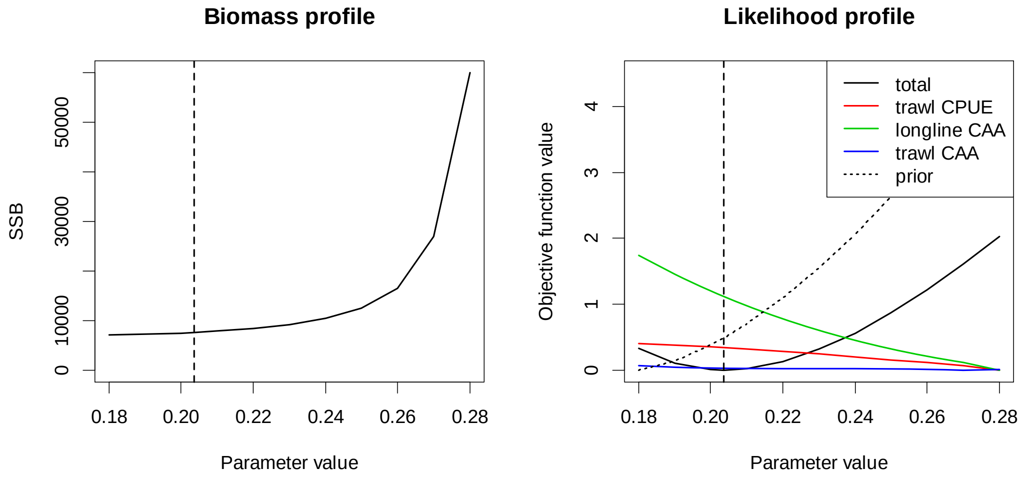
There were also some possible problems with the three available CPUE series for Cook Strait ling (see Tables 5 and 6), and this was critical as these series were the only available indices of relative abundance. The line fishery series was data poor and may be biased upwards owing to the potential to post-select the target species after the catch is on board (Horn & Ballara 2012). The observer trawl series was also data poor. The TCEPR trawl series appeared to suffer from some changes in fleet fishing or reporting behaviour between 1993 and 1994, which the model cannot standardise for. Consequently, Horn & Ballara (2012) recommended that TCEPR trawl indices from 1994 to 2009 only be used in any stock modelling. This recommendation was followed here, with the TCEPR CPUE series now extending from 1994 to 2011.

In the previous assessment (Horn & Francis 2013), *M* was estimated as approximately 0.21. However during the current assessment *M* could not be adequately estimated. A variety of model modifications were made which differentiate the current assessment from its previous iteration, mostly consisting of additional data, but there were also changes in the likelihood assumptions. The changes were added sequentially to the assessment of Horn & Francis (2013) to better identify why *M* could not be estimated.

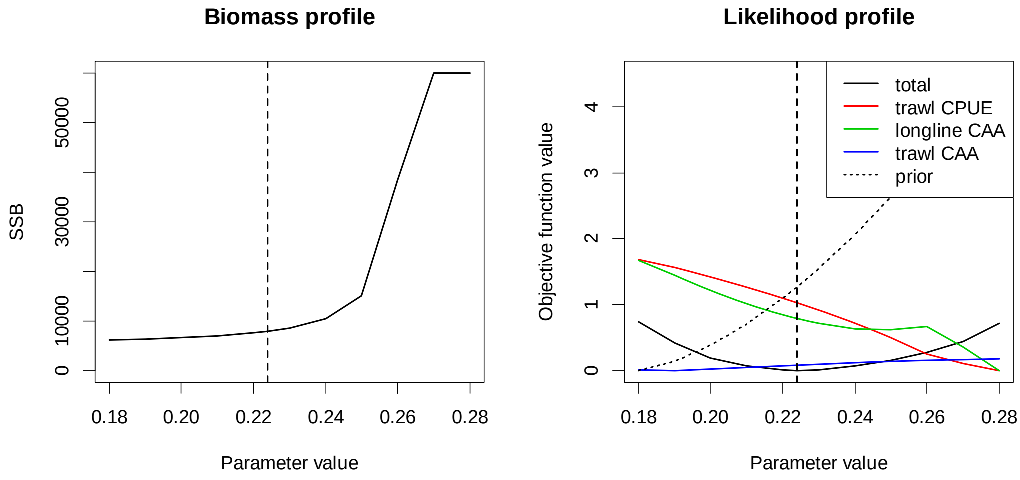
The sequential changes in each of the models run were as follows:

Run 1. Replication of previous assessment
Run 2. Add new catch and CPUE data
Run 3. Add new trawl proportions-at-age data
Run 4. Add new line proportions-at-age data
Run 5. Add multinomial likelihood for proportions-at-age data
Run 6. Add re-weighted effective sample sizes for proportions-at-age data
Run 7. Add new, re-estimated growth curve

At each step the likelihood profile for *M* was plotted, alongside the relationship between *M* and spawning stock biomass (B_0) (Figure 2).

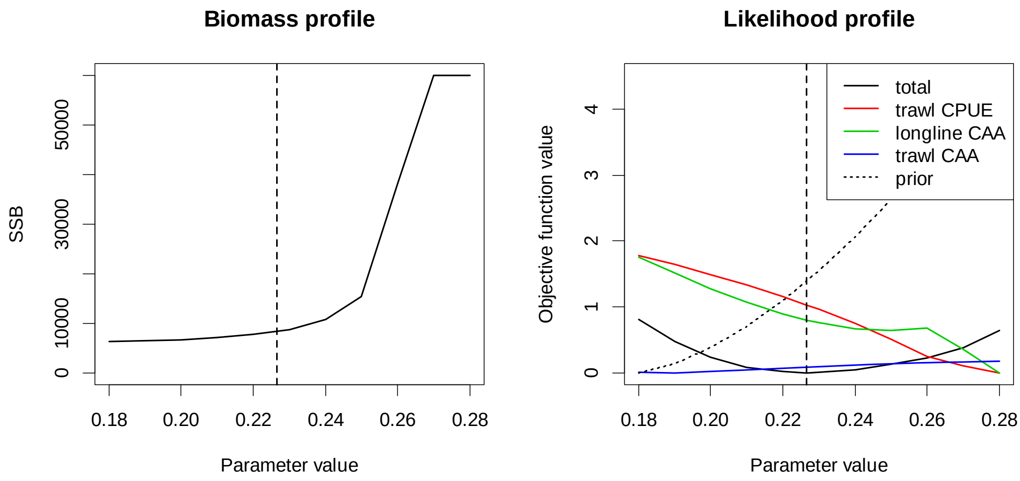


(a) Run 1: Replication of previous assessment.

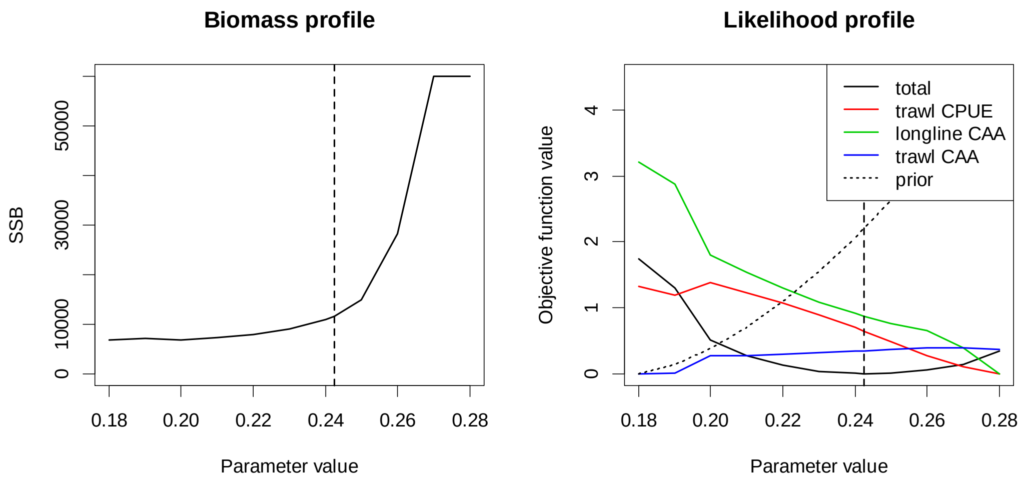


(b) Run 2: Add new catch and CPUE data.

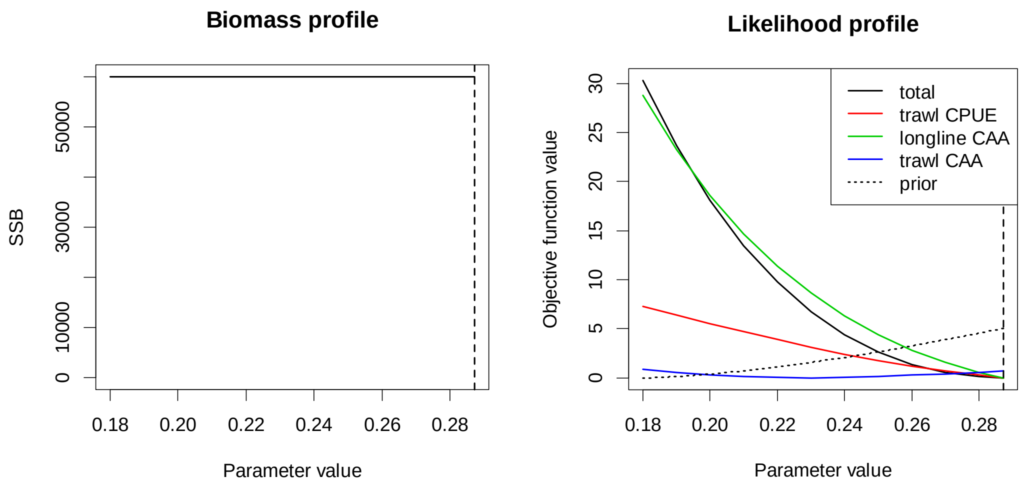
Figure 2: Likelihood profiles for *M*, alongside biomass profiles of B_0 against *M*, for different model fits. Dashed vertical line is the value of M estimated by the model.



(c) Run 3: Add new trawl proportions-at-age data.

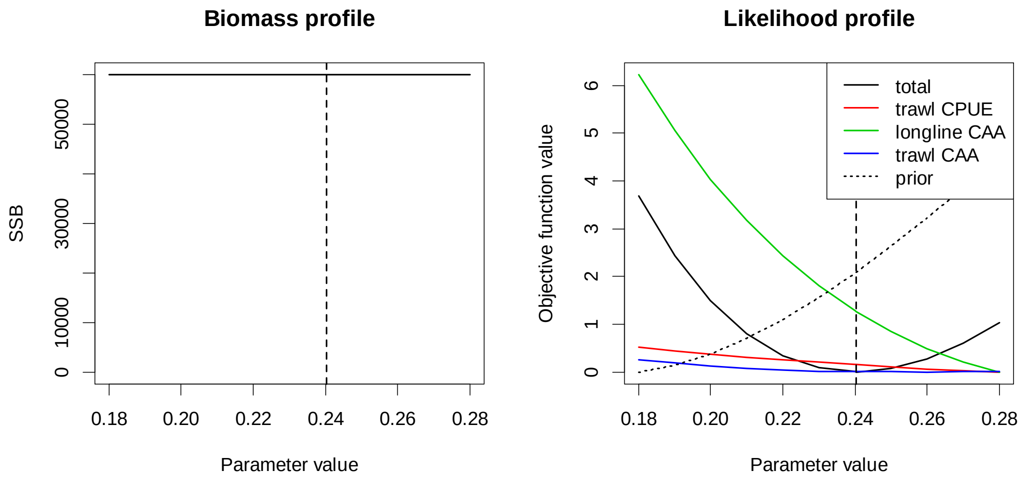


(d) Run 4: Add new line proportions-at-age data.

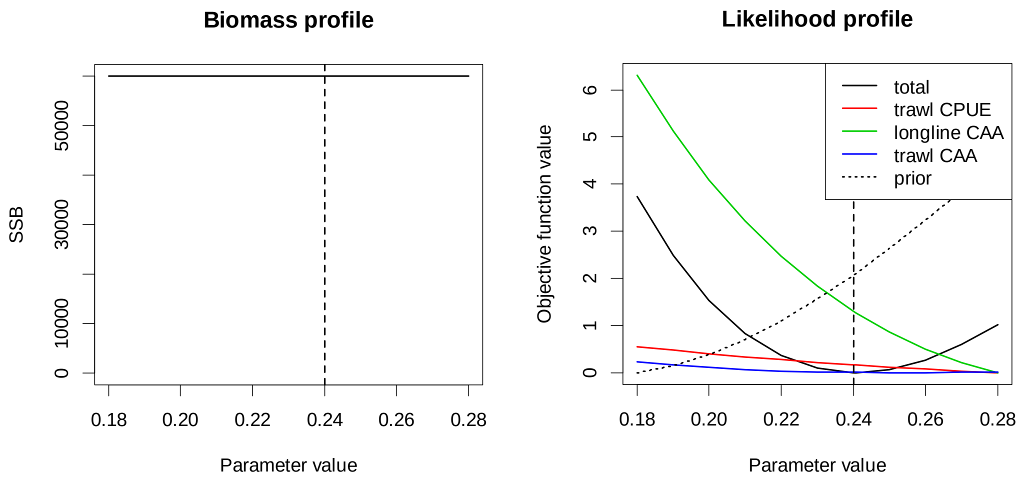


(e) Run 5: Add multinomial likelihood for proportions-at-age data.

Figure 2 (cont.): Likelihood profiles for *M*, alongside biomass profiles of B_0 against *M*, for different model fits. Dashed vertical line is the value of M estimated by the model.



(f) Run 6: Add re-weighted effective sample sizes for proportions-at-age data.



(g) Run 7: Add new, re-estimated growth curve.

Figure 2 (cont.): Likelihood profiles for *M*, alongside biomass profiles of B_0 against *M*, for different model fits. Dashed vertical line is the value of M estimated by the model.

From this auditing process, it was concluded that the inability to estimate *M* was not due to the new data, but rather to the addition of a multinomial likelihood for proportions-at-age. This prevented simultaneous estimation of B_0 and *M*. These results are further summarised in Table 10. The multinomial was considered the best available error structure for the proportions-at-age data. There were few data available to estimate *M* (in principle only the line fishery proportions-at-age). Therefore the multinomial likelihood for composition data was kept, and *M* was fixed, in subsequent runs, choosing values of M = 0.18, 0.20, 0.22, which accounted for the perception that *M* in the Cook Strait was higher than the value of 0.18 assumed in other assessments (Horn 2008). Higher fixed values of *M* were associated with model runs that hit the upper bound allowed for the B_0 estimate (Table 10). B_0 estimates at or about 60 000 t were not considered plausible for this stock.

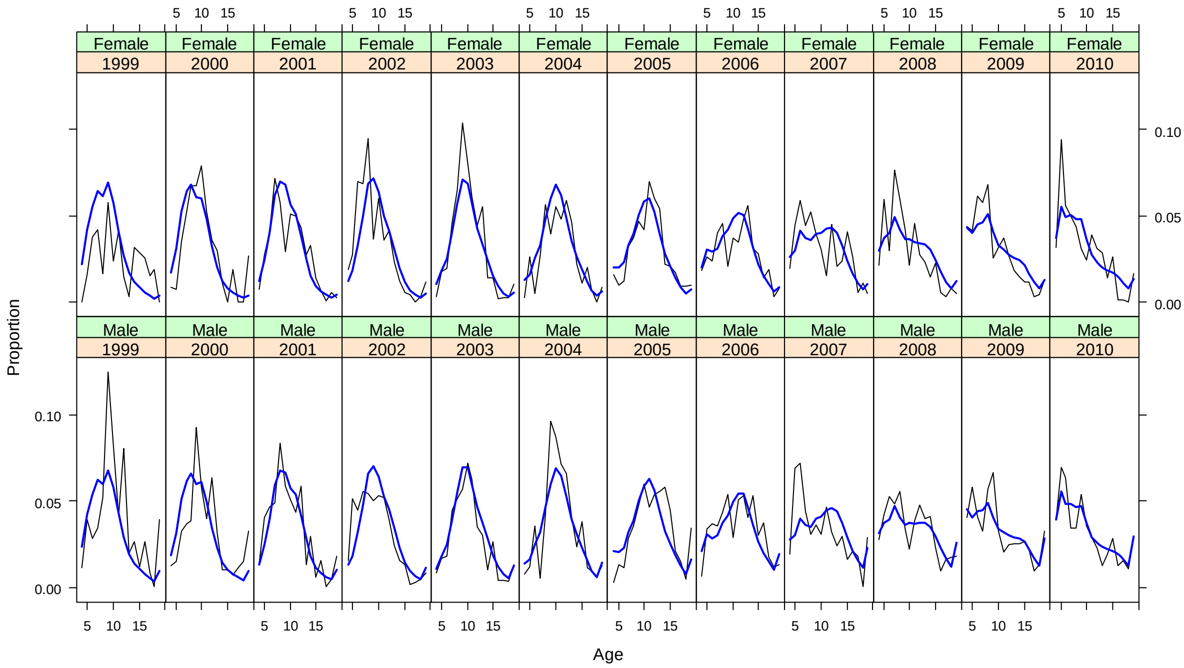
Table 10: Estimates of *M* and B_0 from sequential runs of the 2010 assessment model (Horn & Francis 2013), with additional data and model assumptions. Results with an assumed fixed *M* are also shown.

Model	M	B_0	B_{cur}	Depletion
2010 assessment	0.204	7 560	3 599	0.48
+ catch + cpue	0.224	7 871	3 735	0.47
+ trawl CAA	0.227	8 276	4 046	0.49
+ line CAA	0.243	11 592	6 497	0.56
+ MN CAA lk	0.240	60 000*	41 889	0.70
+ new growth curve	0.241	60 000*	41 497	0.69
Fixed M	0.18	6 152	2 040	0.33
Fixed M	0.20	7 101	3 021	0.43
Fixed M	0.22	10 692	5 875	0.55
Fixed M	0.24	60 000*	41 552	0.69

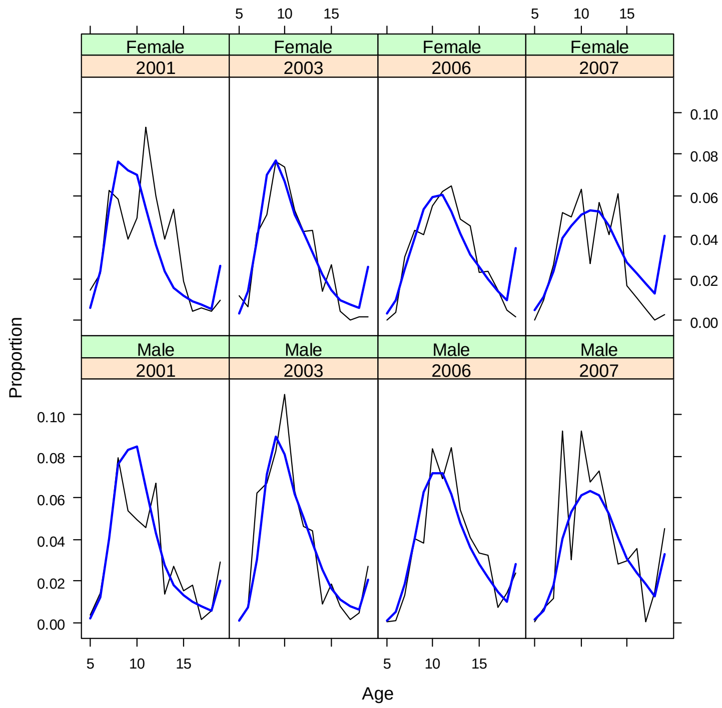
* bound

5.4 Maximum Posterior Density runs

For reasons described above, natural mortality was fixed at M = 0.18, 0.20, 0.22 and the assessment model fitted to the complete data set, assuming a multinomial error distribution for the proportions-at-age and the newly estimated growth curve. In all cases, B_0 was well estimated and fits to the proportions-at-age were good (Figure 3). However, fits to the CPUE were all poor, as shown in Figure 4.



(a) Trawl fishery



(b) Line fishery

Figure 3: Model fits to proportions-at-age data. For clarity of presentation, only a single run with *M*=0.18 is shown.

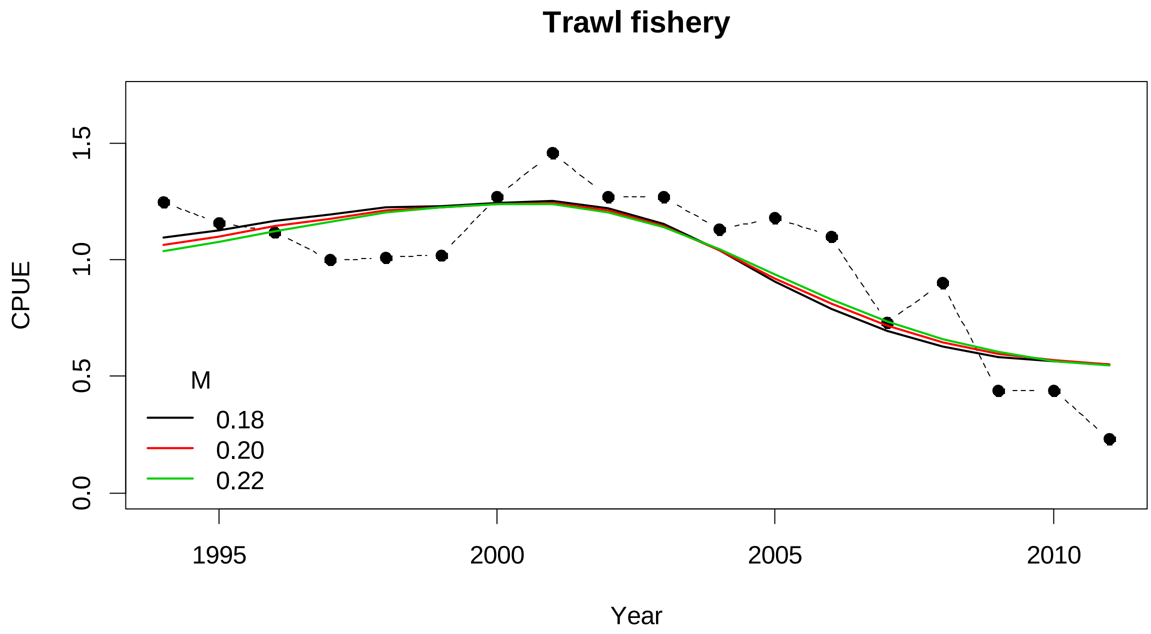


Figure 4: Model fits (black, red and green lines, representing models with different values of *M*) to the CPUE series from the trawl fishery (black dots connected by a dashed line).

Fits to the mean age, and sex ratio data, are shown in Figures 5 and 6.

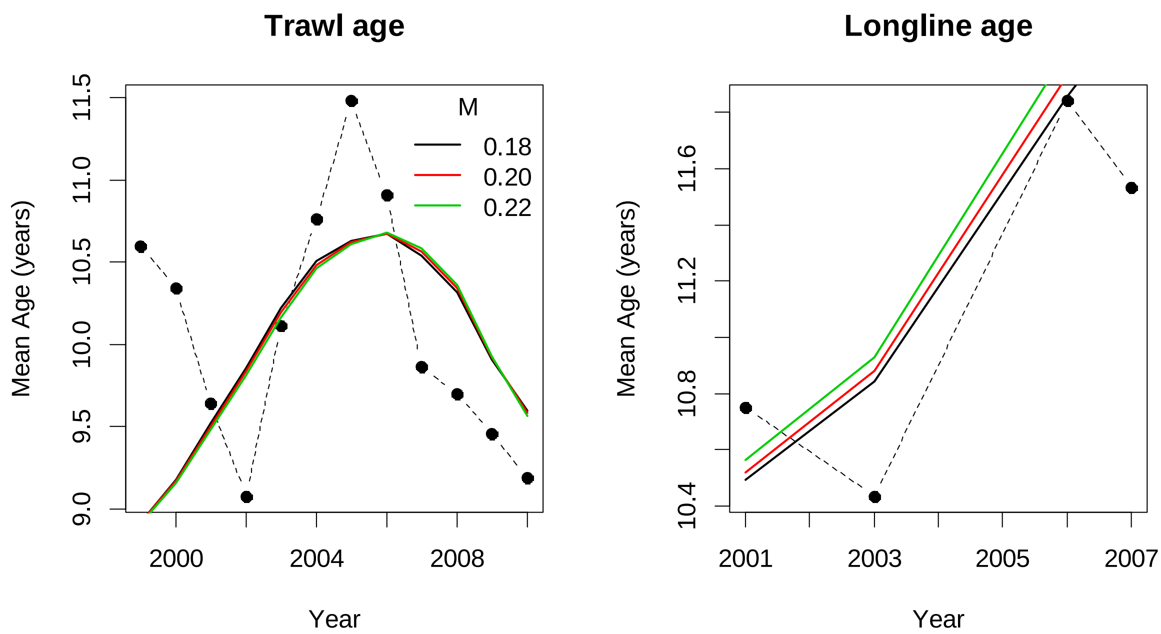
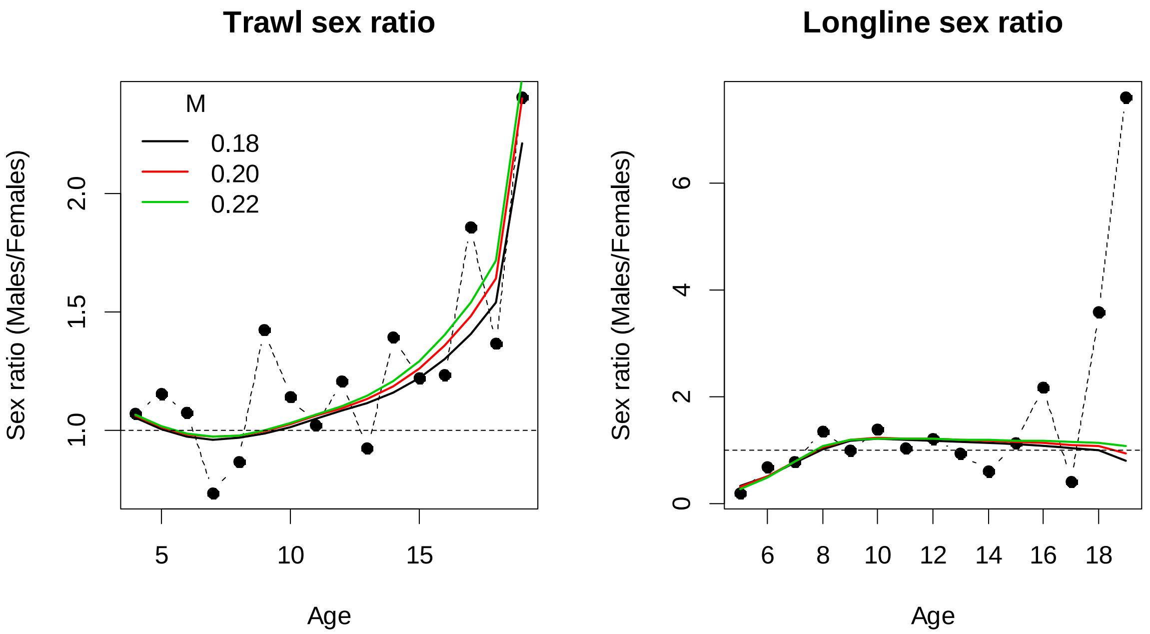
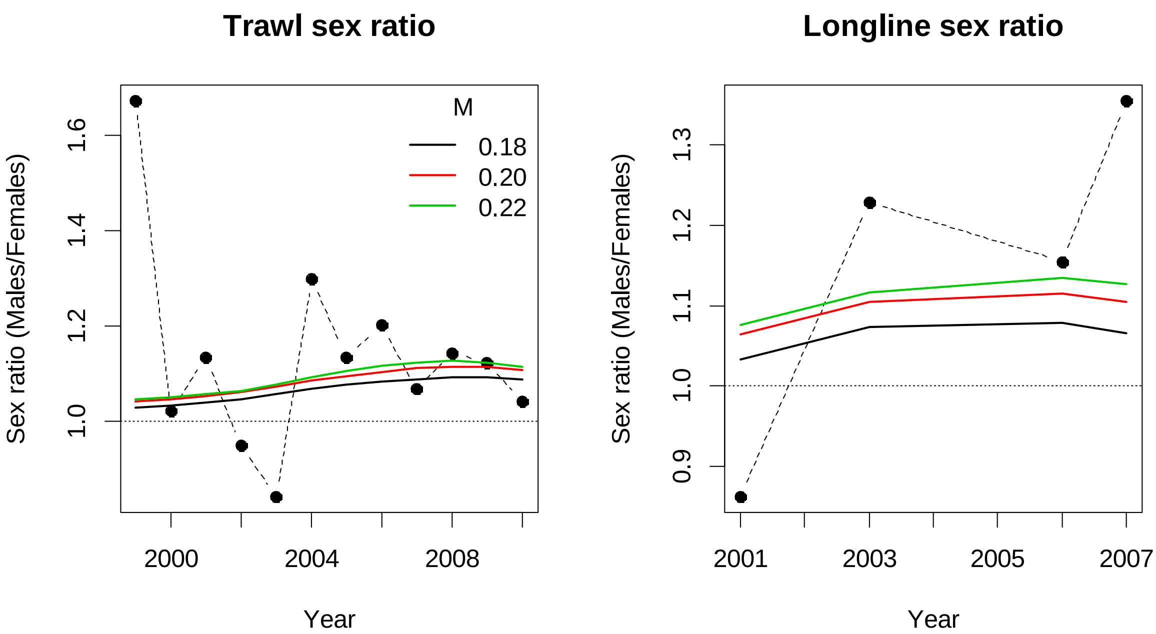


Figure 5: Model fits (black, red and green lines, representing models with different values of *M*) to the mean age (black dots connected by a dashed line).



(a) Sex-ratio at age



(b) Sex-ratio over time

Figure 6. Model fits (black, red and green lines, representing models with different values of *M*) to the sex-ratio (black dots connected by a dashed line, estimated from the proportions-at-age data).

Overall, model fits to the data were considered poor by the DFAWG. In particular, the DFAWG considered that the model failed to give a satisfactory fit to the decline in abundance evident in CPUE. As a consequence, the model was considered unsuitable for providing management advice.

5.5 Model estimates

The CASAL model developed here was considered unreliable and therefore was not used to provide estimates of stock status. The previous assessment (Horn & Francis 2013) therefore provides the most recent accepted stock assessment advice; this indicated a depletion of approximately 50% (Table 12 in Horn & Francis 2013). However the Horn & Francis (2013) assessment was considered too unreliable to provide estimates of sustainable yield (i.e., MCY or CAY).

6. ASSESSMENT MODELLING FOR LIN 7WC (WCSI)

6.1 Model structure and investigative runs

The initial stock assessment model partitioned the WCSI population into sex and age groups (3–28, with a plus group). The stock was assumed to reside in a single area. There were two fisheries, trawl and longline. The model's annual cycle for the stock is described in Table 11.

Table 11: Annual cycles of the LIN 7WC stock model, showing the processes taking place at each time step, their sequence within each time step, and the available observations. Fishing and natural mortality that occur within a time step occur after all other processes, with half of the natural mortality for that time step occurring before and half after the fishing mortality.

					Observations	
Time step	Period	Processes	M^1	Age[2]	Description	$\%Z^3$
1	Oct–May	Maturation Recruitment Fishery (line)	0.75	0.5	Line catch-at-age	0.5
2	Jun–Sep	Spawning Increment ages Fishery (trawl)	0.25	0	Trawl CPUE Trawl catch-at-age *Tangaroa* survey data	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 occur in that time step. In time step 1, the mean size of 2-year-old fish is calculated as if they were age 2.5
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.

Fish length at age (Von Bertalanffy growth formula), length-weight relationship, and maturity at age were all estimated outside the model and assumed to be constant.

The selectivity ogives for the *Tangaroa* trawl survey and commercial trawl and line fisheries were age-based and estimated in the model. The *Tangaroa* survey and trawl fishery ogives were estimated using a double normal parameterisation, and the line fishery ogives were assumed to be logistic (Bull et al. 2012). When sex was included in the partition, the male selectivity curves were estimated relative to female selectivity, which had a fixed maximum of one. Selectivities were assumed to be constant. Natural mortality rate was estimated in the model. The maximum exploitation rate allowed by the model was assumed to be 0.6.

Lognormal error, with known CVs per year, was assumed for the CPUE and *Tangaroa* survey indices. The proportions-at-age observations from trawl and line fisheries were assumed to have a multinomial error distribution. A process error CV of 0.2 was added to the *Tangaroa* survey and CPUE series, following Francis (2011). For the trawl fishery catch-at-age frequencies, effective sample sizes for the catch-at-age series were estimated iteratively using method TA1.8 described in Francis (2011). The effective sample sizes for the longline fishery and *Tangaroa* survey series were both estimated by rule-of-thumb. The effective sample size of the samples from the longline fishery was based upon the relative number of trips and sets or tows sampled, and set to be about one third of the mean of the trawl fishery effective sample sizes. The *Tangaroa* survey was considered to be the best data set, and was given effective sample sizes that were one third of the number of otoliths read (Table 12).

Table 12: Statistics and multinomial effective sample sizes for combined-sex age frequency distributions used in the LIN 7WC stock assessment model, from the longline fishery, trawl fishery, and *Tangaroa* trawl surveys.

Source	Year	No. otoliths read	No. sets or no. tows sampled	No. trips sampled	Assumed effective sample size
Longline fishery	2003	462	24	3	4
	2012	557	30	1	9
Trawl fishery	1991	396	65	8	13
	1994	393	141	13	15
	1995	506	111	8	20
	1996	448	83	9	12
	1997	841	173	13	29
	1998	628	155	14	22
	1999	548	221	11	22
	2000	533	168	16	17
	2001	563	178	23	17
	2002	604	332	15	31
	2003	595	286	13	26
	2004	595	334	17	34
	2005	637	184	11	26
	2006	637	154	14	14
	2007	306	65	13	8
	2008	460	98	11	18
Tangaroa survey	2000	560	44	1	185
	2012	613	48	1	202

A small ageing error was also added, which was normal with a CV of 0.07. Year class strengths were assumed known (and equal to 1) for years before 1974 and after 2008, when inadequate or no catch-at-age data were available. Otherwise, year class strengths were estimated under the assumption that the estimates from the model must average 1. The steepness of the Beverton-Holt recruitment model was assumed to be 0.84 (Shertzer & Conn 2012).

The assumed prior distributions used in the assessment are given in Table 13. Most priors were intended to be relatively uninformative, and were specified with wide bounds. The exception was the choice of informative prior for the *Tangaroa* trawl survey *q*, and for *M*. Priors on *q* for the *Tangaroa* trawl surveys of the Chatham Rise and Sub-Antarctic 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), and the resulting (approximately lognormal) distribution had mean 0.13 and CV 0.70, with bounds assumed to be 0.02 to 0.30 (Horn et al. 2013). However, the WCSI survey area in the 200–800 m depth range in strata 0004 A–C and 0012 A–C comprised 12 928 km^2, whereas the seabed area in that depth range in the entire LIN 7 biological stock area (excluding the Challenger Plateau) was estimated to be about 24 000 km^2. Because biomass from only 54% of the WCSI ling habitat was included in the index, the prior on μ was modified accordingly (i.e., $0.13 \times 0.54 = 0.07$), and the bounds were reduced from [0.02, 0.30] to [0.01, 0.20].

Table 13: LIN 7WC assumed prior distributions and bounds for estimated parameters in the assessment. Parameter values are mean estimates (in natural space) and CV for lognormal, and mean and standard deviation for normal.–, not estimated.

Parameter description	Distribution	Parameters		Bounds	
B_0	Uniform-log	–	–	10 000	500 000
Year class strengths	Lognormal	1.0	0.7	0.01	100
Tangaroa survey *q*	Lognormal	0.07	0.7	0.01	0.2
CPUE *q*	Uniform-log	–	–	1e-8	1e-2
Selectivities	Uniform	–	–	0	20–200*
M	Normal	0.2	0.025	0.1	0.3

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

Penalty functions were used to constrain the model so that any combination of parameters that did not allow the historical catch to be taken was strongly penalised. A small penalty was applied to the estimates of year class strengths to encourage estimates that averaged to 1. Initial runs were maximum posterior density (MPD) runs. For final runs, the full posterior distribution was sampled using Monte Carlo Markov Chain (MCMC) methods. MCMCs were run for 6×10^6 iterations, with sampling of every 5000^{th} sample after a burn-in length of 1×10^6 iterations.

Initial model runs included sex in the partition, but a skew and trend in sex ratio (Figure 7) resulted in selectivities with strong sex differences (Figure 8). For example, the model estimated that only about 1 male ling was captured for every 5 female ling in the longline fishery (Figure 8).

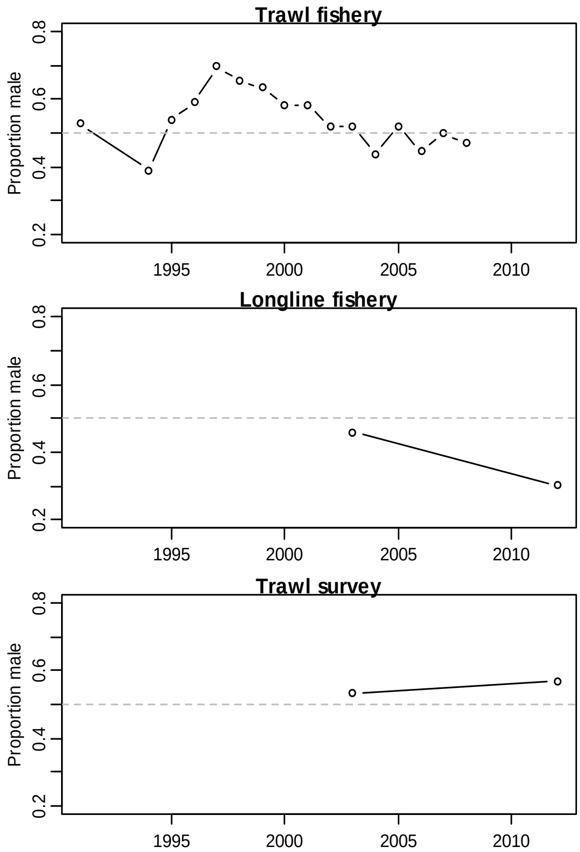


Figure 7: LIN 7WC sex ratio in age frequency observations (as proportion male).

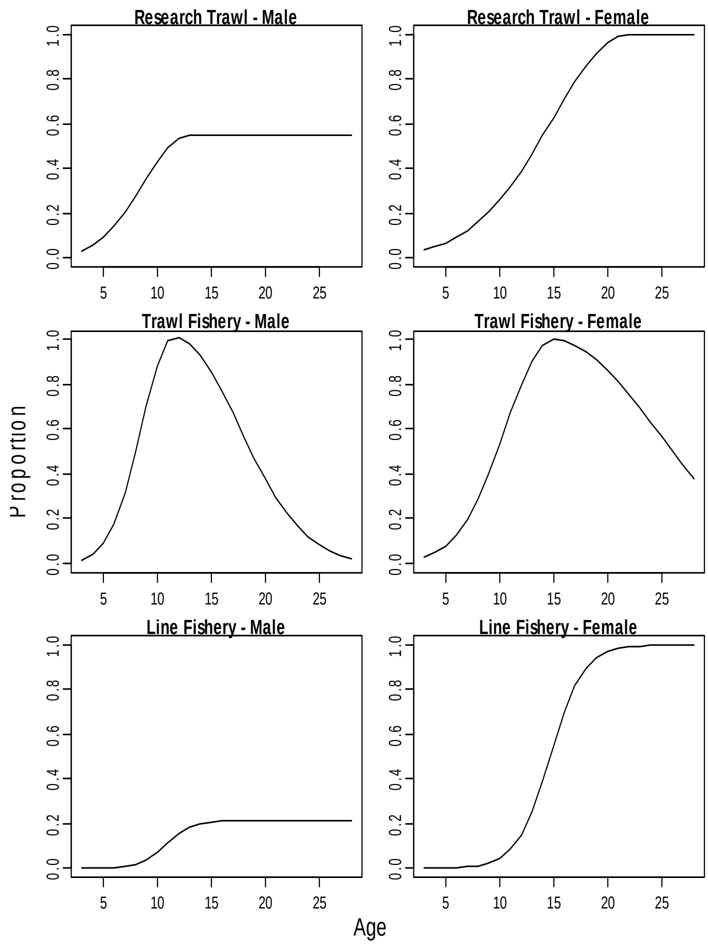


Figure 8: LIN 7WC selectivities estimated by the model when sex was included in the partition (MPD run).

The DFAWG considered the strong trends in observed sex ratio, and resulting shapes of selectivity ogives, to be doubtful, and recommended that sex be excluded from the observations and model partition. The final model therefore did not have sex in the partition, and all observations (age frequencies) and associated parameters (selectivities), and biological parameters (growth, maturity etc), were all unsexed.

Initial model runs estimated a relatively high *M*, at about 0.3 (Figure 9). The working group considered that this was too high to be reasonable for ling, and therefore an informative prior should be added (Table 13). This prior was informed by expert opinion, to be centred around 0.2 with 95% confidence intervals of 0.15–0.25.

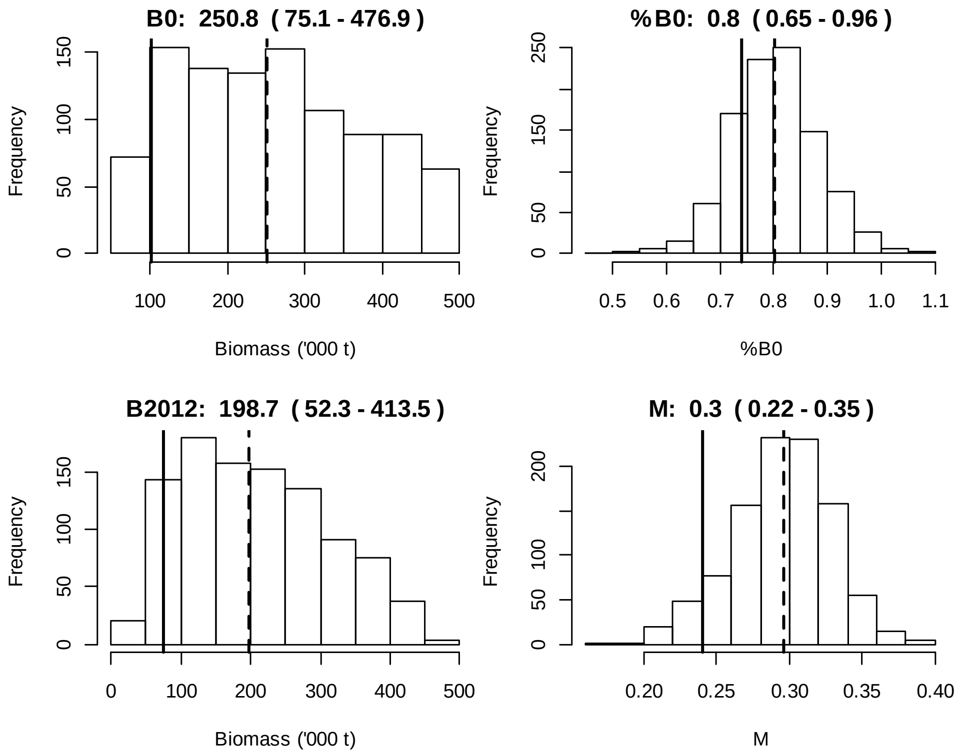


Figure 9: LIN 7WC parameter estimates from MCMC for a "base" model with sex not in the partition, shown as histograms of parameter frequency. B0, virgin biomass; %B0, biomass in 2012 as a proportion of virgin biomass; B2012, biomass in 2012 (the last year in the estimation model); M, natural mortality rate. The estimates are the median of the MCMC posterior, with 95% credible intervals given in parentheses. Solid vertical lines indicate the estimate from the MPD, and broken vertical lines the median of the MCMC posterior distribution.

6.2 Final model runs

As a result of preliminary investigations, a "base" model run was determined that included all observational data, was single sex (excluded sex from the partition), and included the informative prior on *M*.

The fit of the base run to the primary biomass index (CPUE) was not good, with a trend in residuals, and a relatively high standard deviation of normalised residuals (SDNR) (Figure 10). Both biomass indices provided information on the minimum biomass of the stock (B_{min}), but no information on the upper limit (Figure 11). In the base run, the information on the upper limit to estimated stock biomass came as much from priors as from observational data; from the prior on *q* for the *Tangaroa* survey series, the prior on *M*, and the proportions-at-age data from the trawl fishery and *Tangaroa* survey series (Figure 11).

The fits of the base run to the proportions-at-age observations were reasonable (Figures 12–14). The model run fits to proportions-at-age were relatively poor for early years of the trawl fishery, and for the *Tangaroa* survey in 2012. Inconsistency across observations meant that fits to the proportions-at-age could never be good, for example, the relatively large cohort observed at age six in the 2003 trawl fishery sample was of about average strength at age seven (2004) and then weak at age eight (2005), and this cohort was only of average strength in the 2003 longline fishery sample. The fits to ages three and four in the *Tangaro*a survey sample for 2012 were poor, but on average the combined year class strengths were similar to the observations (this misfit is considered further below).

For the base case model run, the prior had a strong influence on the estimate of *M*. All observational data sets other than the trawl fish proportions-at-age indicated an *M* greater than 0.21, and overall greater than 0.23 (Figure 15). Although suggesting an *M* of around 0.18, the trawl fishery proportions-at-age actually contained no real information about *M* as they were fitted with a domed selectivity (thus *M* and selectivity were confounded). Because of the lack of information in the model about this key parameter, a sensitivity run was completed with *M* set at 0.18.

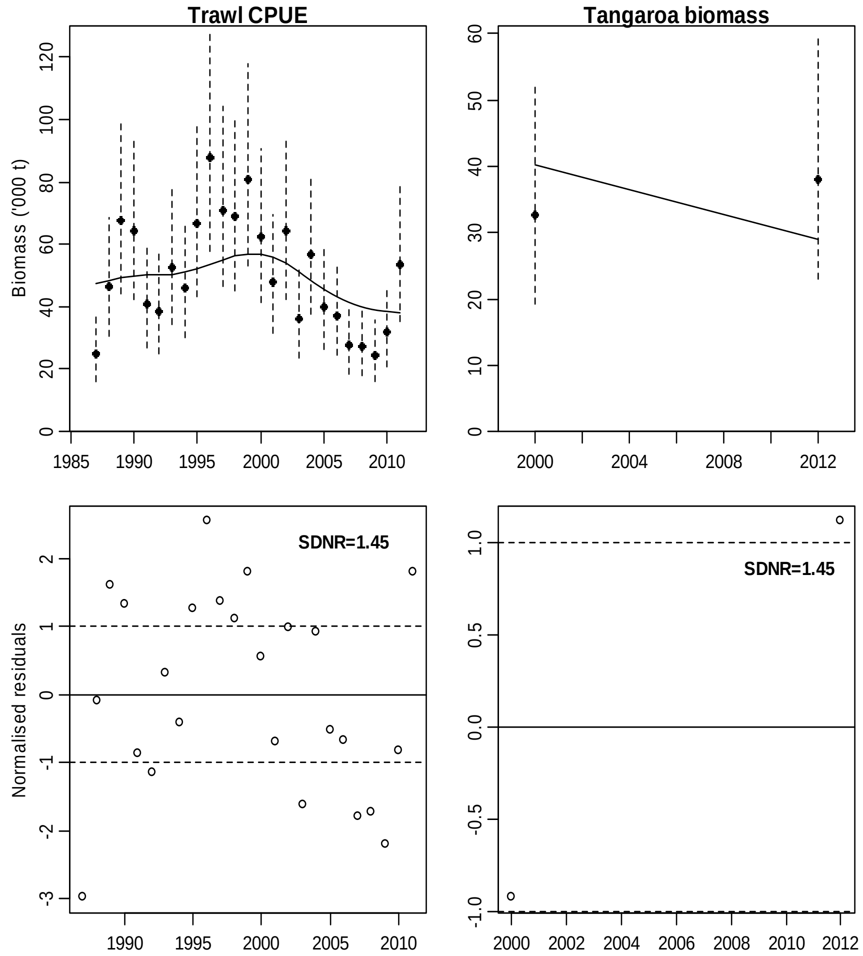


Figure 10: LIN 7WC fits of the MPD model run to the biomass indices in the top panels, and normalised residuals (and standard deviation of normalised residuals). In the top panels, vertical lines indicate the 95% confidence intervals; fits and observations are as estimated biomass; observations are scaled by the estimated catchability.

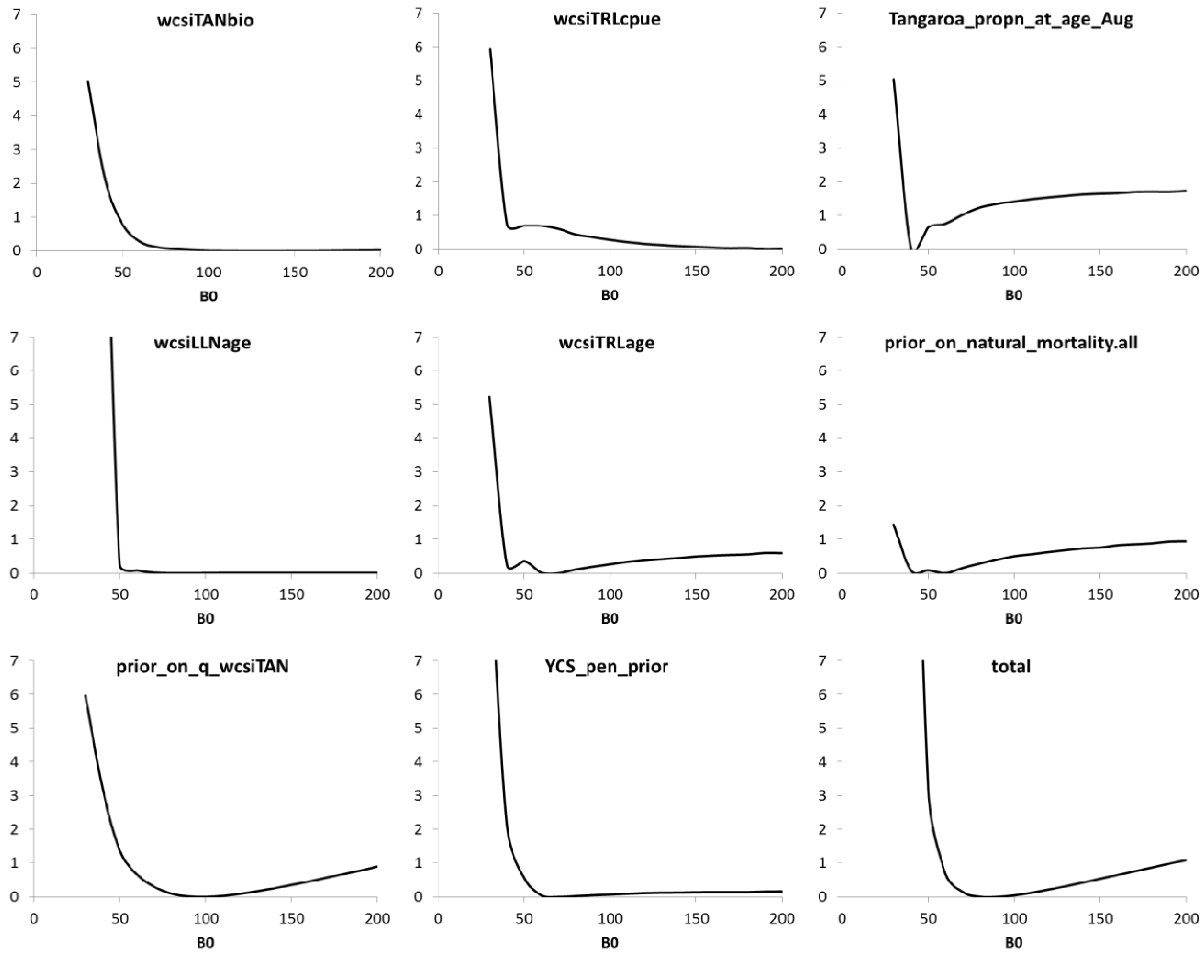


Figure 11: LIN 7WC likelihood profiles for virgin biomass (B_0), by likelihood component.

The MCMC analyses for the base model run performed well, with traces appearing stable (Figure 16), and good convergence indicated by strong overlap between estimates of quantities from each third of the chain (Figure 17). The biomass estimates were skewed, with wide credible intervals (Figure 18).

The selectivities were logistic for the longline fishery, and double-normal but effectively logistic for the *Tangaroa* survey series (Figure 19). The selectivity was slightly domed for the trawl fishery, with high uncertainty around the shape of the right-hand side. The parameter estimates (95% credible intervals in parentheses) for the longline fishery selectivity ogive were a50 = 15.04 (9.83–16.27) and a95 = 6.49 (2.04–7.65); the parameter estimates for the trawl fishery were a1 = 12.51 (10.95–12.78), a95 LHS = 4.03 (3.19–4.19), and a95 RHS = 39.8 (6.24–76.67); and for the *Tangaroa* survey a1 = 18.32 (13.68–18.91); a95 LHS = 7.33 (5.25–7.61), a95 RHS = 185.8 (150.8–89.6). This is equivalent to selectivity first in the trawl fishery (a50 at 8.48 years), then the *Tangaroa* survey (a50 = 10.99), and finally in the longline fishery (a50 = 15.04). The veracity of these estimates was questioned by the DFAWG, because the *Tangaroa* survey was expected to catch ling earlier than the trawl fishery.

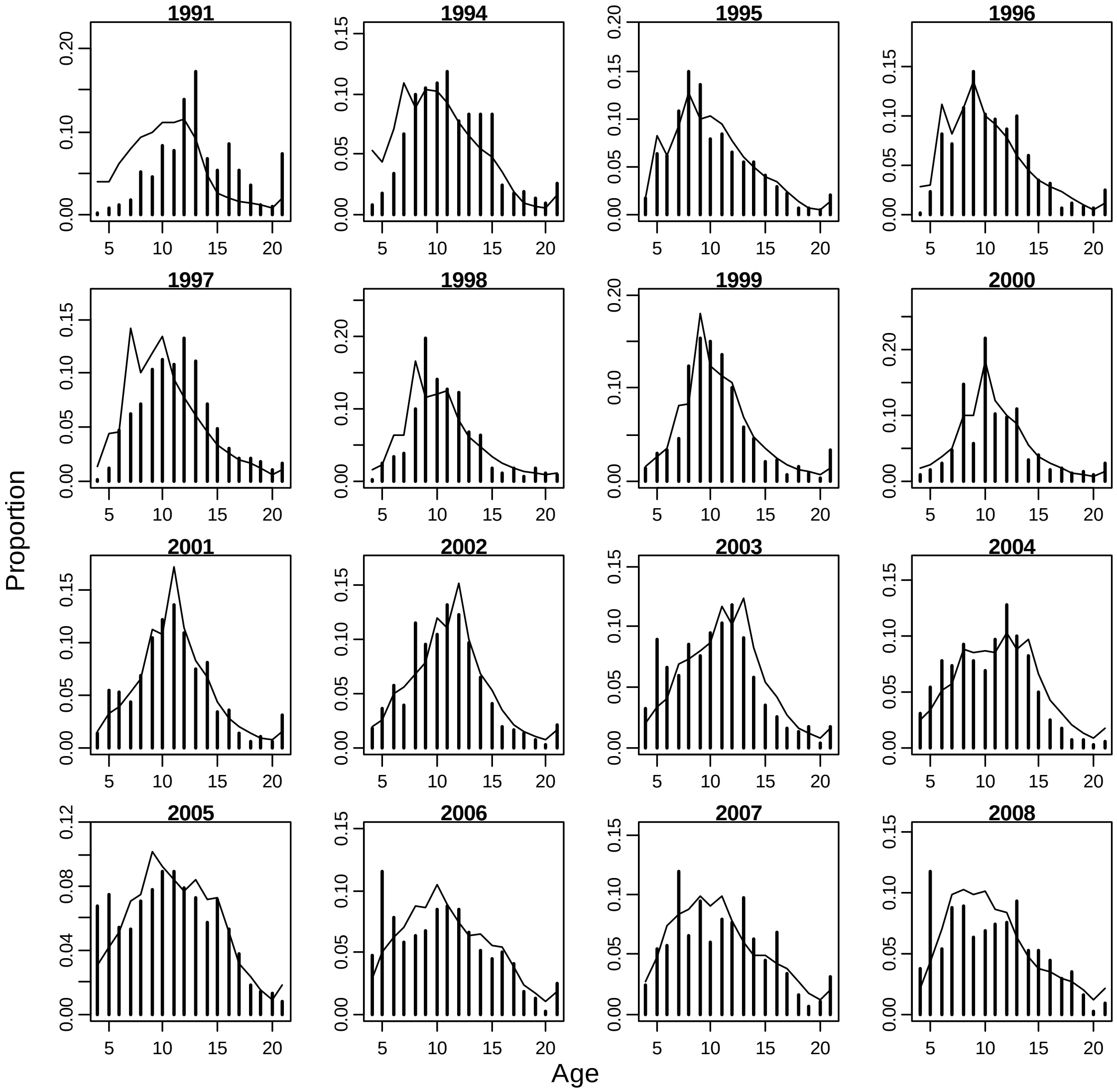


Figure 12: LIN 7WC fits (lines) of the MPD model run to the proportions-at-age in the trawl fishery (bars).

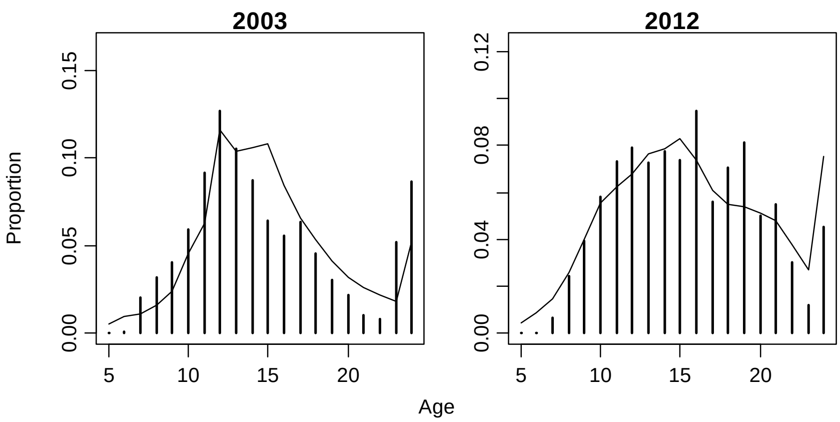


Figure 13: LIN 7WC fits (lines) of the MPD model run to the proportions-at-age in the longline fishery (bars).

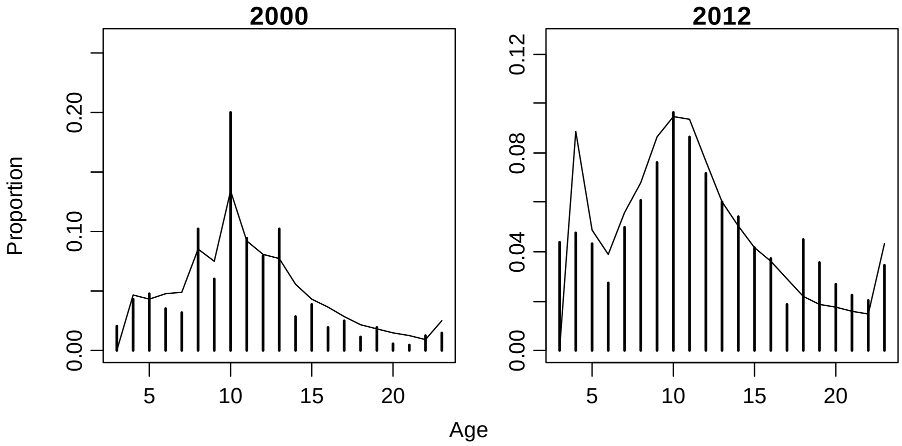


Figure 14: LIN 7WC fits (lines) of the MPD model run to the proportions-at-age in the *Tangaroa* trawl survey series (bars).

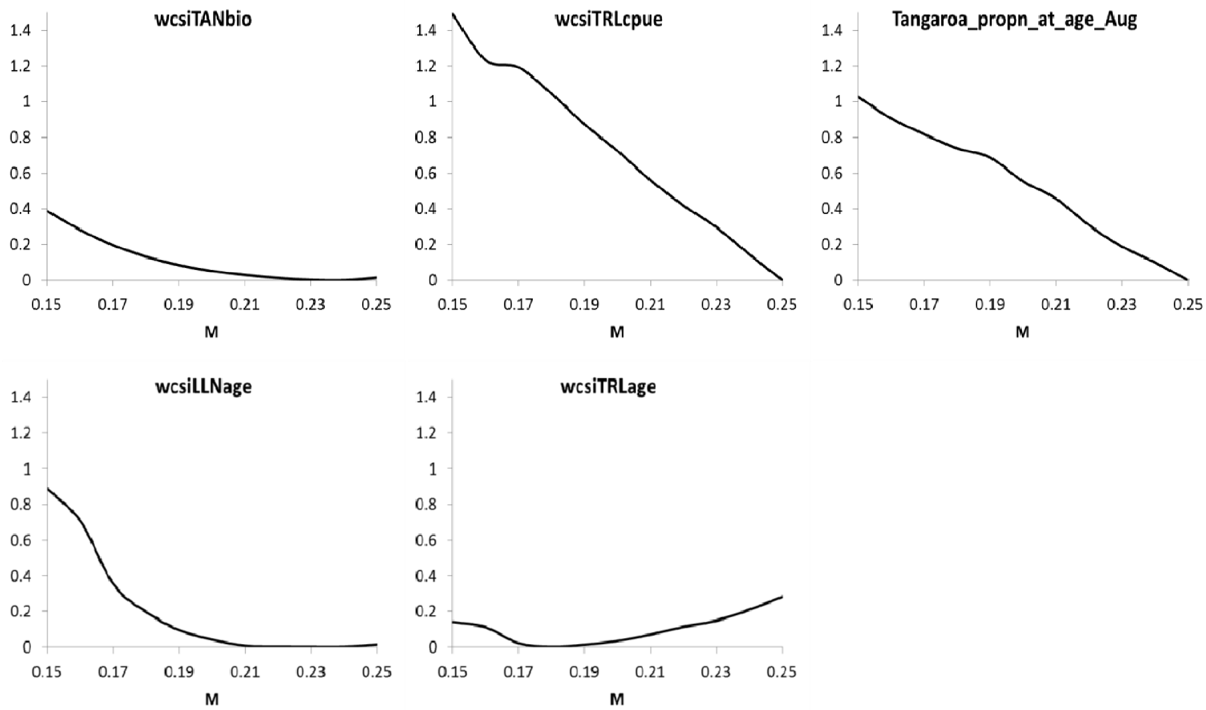


Figure 15: LIN 7WC likelihood profiles for natural mortality, for the observational data sets.

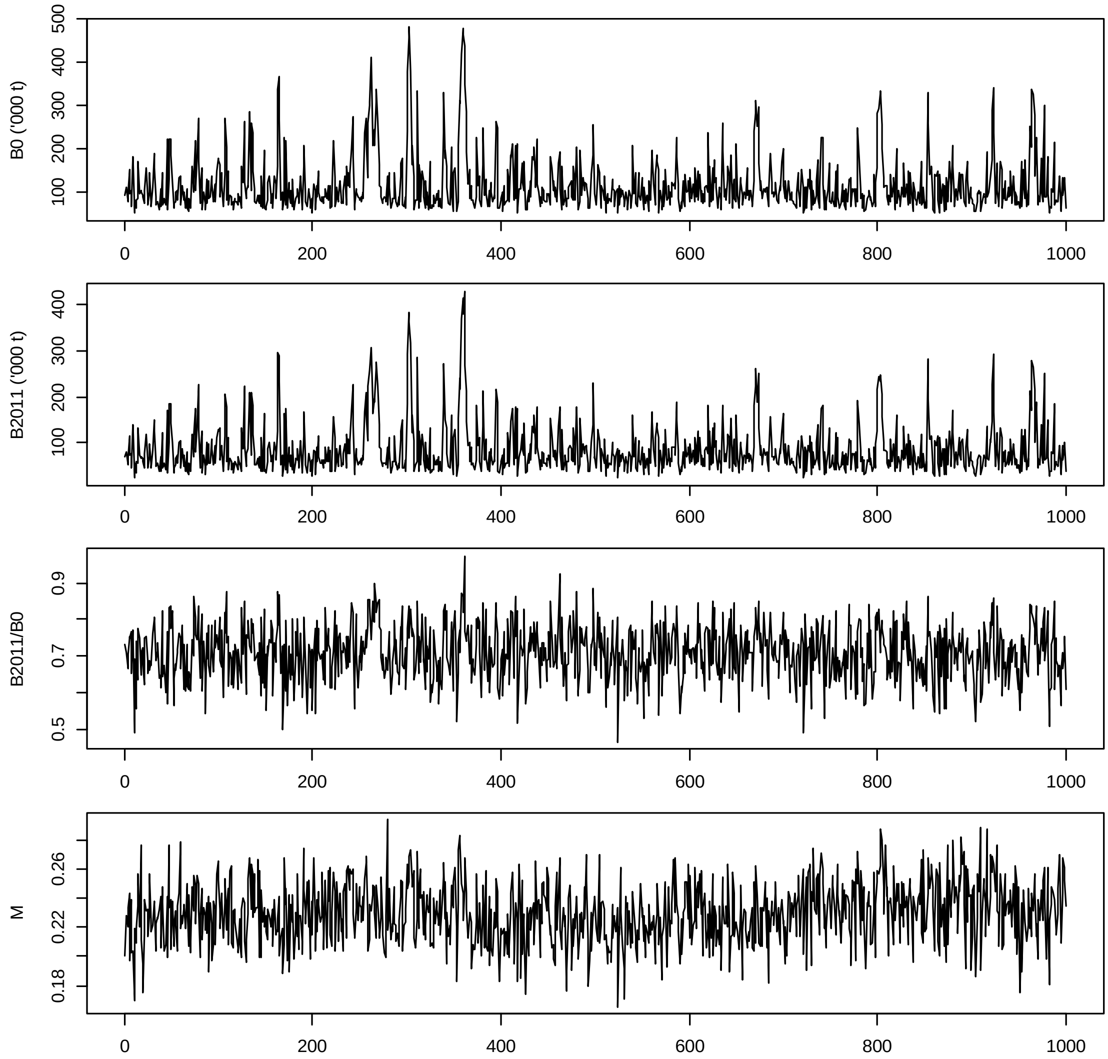


Figure 16: LIN 7WC samples from the base model run MCMC for key parameters and derived quantities.

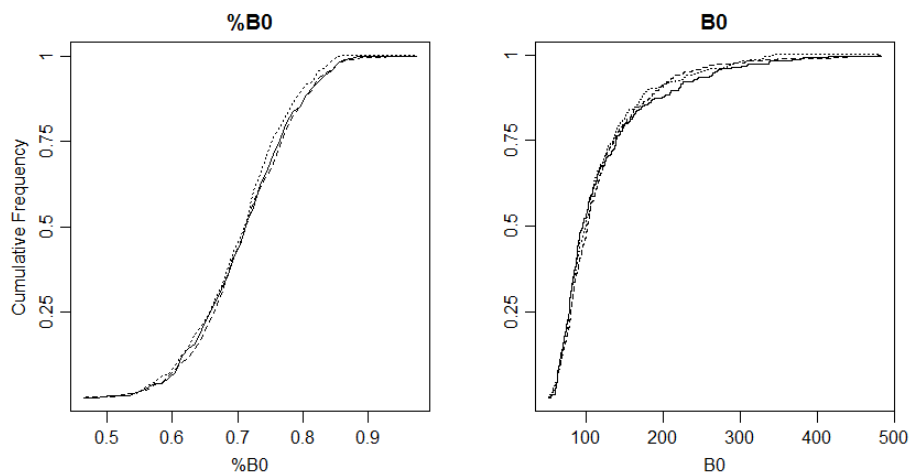


Figure 17: LIN 7WC base model run MCMC for virgin biomas (B0) and current biomass as a proportion of virgin biomass (% B0), cumulative frequency curves for the the first, middle, and last thirds of the samples from the MCMC chain.

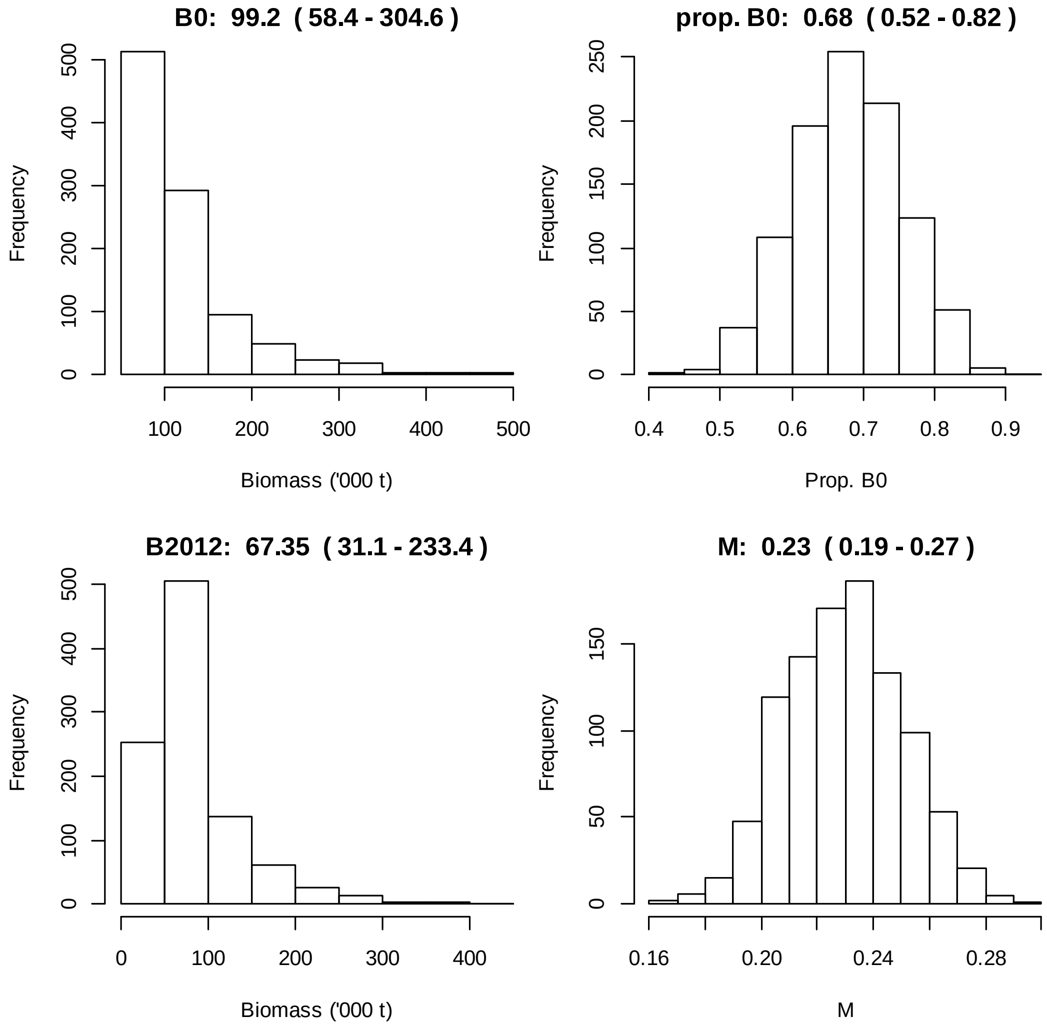


Figure 18: LIN 7WC parameter estimates from MCMC for the base model run, shown as histograms of parameter frequency. B0, virgin biomass; prop. B0, biomass in 2012 as a prioprtion of virgin biomass; B2012, biomass in 2012 (the last year in the estimation model); M, natural mortality rate. The estimates are the median of the MCMC posterior distribution, with 95% credible intervals given in parentheses.

A lack of information in the model about biomass was expected from examination of the input data, where the catch history and CPUE index were found to be broadly correlated (Figure 20). This suggested that the fishery was probably not driving fluctuations in stock biomass, but it was the converse. In this model structure, fluctuations in stock biomass would be caused by changes in recruitment (year class strength). Year class strength was estimated to be about average up until 1986, above average until 1990, below average until 2007, with the final cohort (2008) estimates just above average (Figure 21). This would be consistent with relatively large cohorts from the late 1980s producing relative high biomass and CPUE in the trawl fishery in the late 1990s.

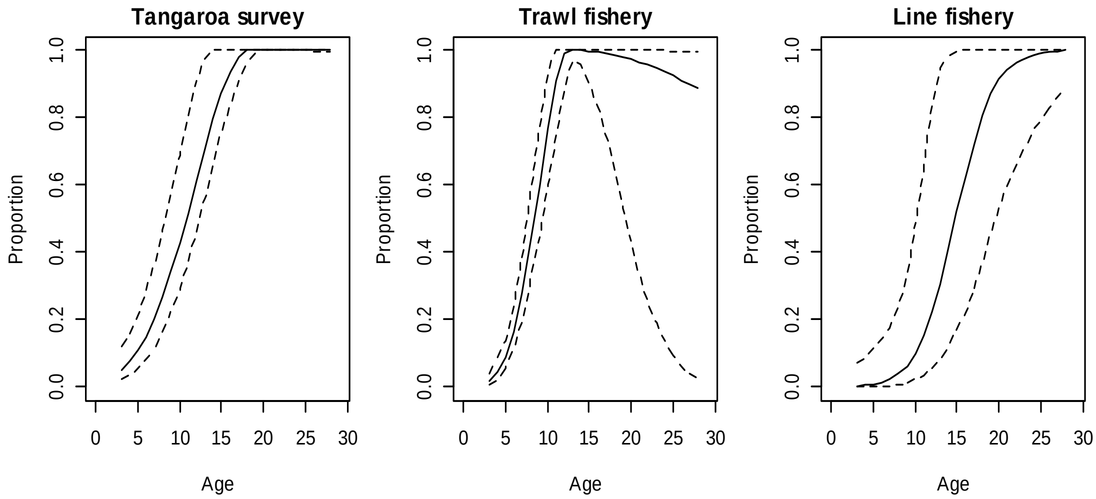


Figure 19: LIN 7WC selectivities from the MCMC of the base model run.

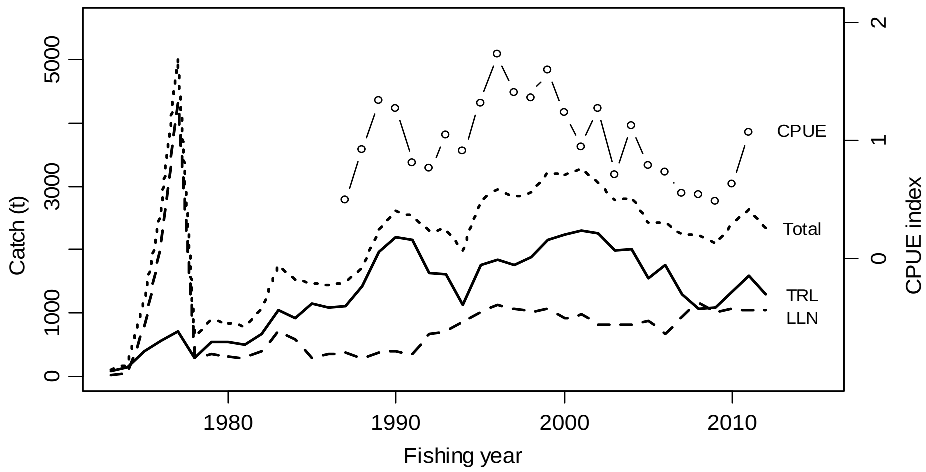


Figure 20: LIN 7WC catches by the longline fishery (dashed line), trawl fishery (solid line), and total catch (dotted line), against the CPUE index (points).

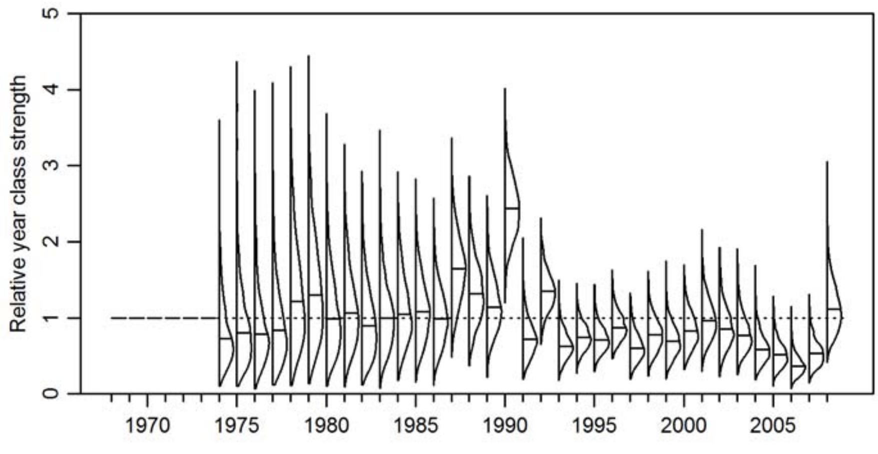


Figure 21: LIN 7WC recruitment deviates estimated from the MCMC of the base model run.

Sensitivities to the base run found that reducing the relatively high weighting of the *Tangaroa* proportions-at-age had little material influence on the results (Table 14), and although the fit to the CPUE was slightly improved with a lower weight on the *Tangaroa* proportions-at-age, the fits of the two model runs to these and other data were visually indistinguishable.

Table 14: LIN 7WC base run negative log-likelihoods and quantity estimates (from MCMC), and a sensitivity model run where the multinomial effective sample size (ESS) of the *Tangaroa* trawl survey was halved (from 185, 202 to 92, 101); this halved the weight given to these data, although the weight remained relatively high compared to the other proportions-at-age data.

Likelihoods	Base ESS	Halved ESS
Trawl CPUE	-14.20	-15.36
Tangaroa survey	-1.75	1.83
Longline proportions-at-age	17.40	17.44
Trawl fishery proportions-at-age	246.91	245.56
Quantity estimates (from MCMC)		
B_0 (t)	99 200	99 700
$\%B_0$	68	72

The relatively poor fit of the base model to the first two recruited ages in the *Tangaroa* proportions-at-age for 2012 could not be resolved. It was suspected that it could even be a model artefact caused by the parameterision of CASAL, as a base model run with the ageing error reduced to zero produced a better fit (Figure 22). However the reason for the misfit, and a solution, were not fully examined because the misfit had no material influence on the model results. For example, for virgin biomass the base model MPD was 74 564 t, and the sensitivity was 75 324 t; for *M*, the base model MPD was 0.217, and the sensitivity was 0.215.

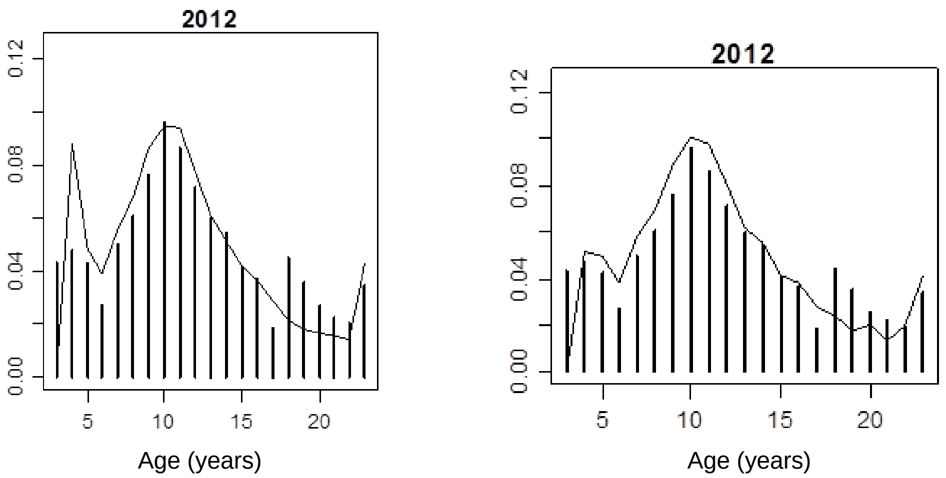


Figure 22: LIN 7WC fits to the *Tangaroa* proportions-at-age for 2012 in the base model run (left panel) and a sensitivity run where the ageing error was set to zero (right panel).

The model sensitivity run that had greatest influence on the results was that which fixed *M*. The model run with *M* fixed at 0.18 produced a marginally worse fit to the observational data, although the fits were visually indistinguishable, but made a substantial difference in biomass estimates (Table 15). The biomass estimates from the MCMC were still skewed, although credible intervals were greatly reduced compared to the base case (Figure 23).

Table 15: LIN 7WC base run negative log-likelihoods and quantity estimates (from MCMC), and the sensitivity model run where *M* was fixed at 0.18.

Likelihoods	Base	*M* = 0.18
Trawl CPUE	-14.20	-13.63
Tangaroa survey	-1.75	-1.63
Tangaroa proportions-at-age	133.40	133.81
Trawl proportions-at-age	246.91	246.81
Longline proportions-at-age	17.40	17.59
Quantity estimates (from MCMC)		
M	0.23	(0.18)
B_0	99 200	66 100
$\%B_0$	68	57

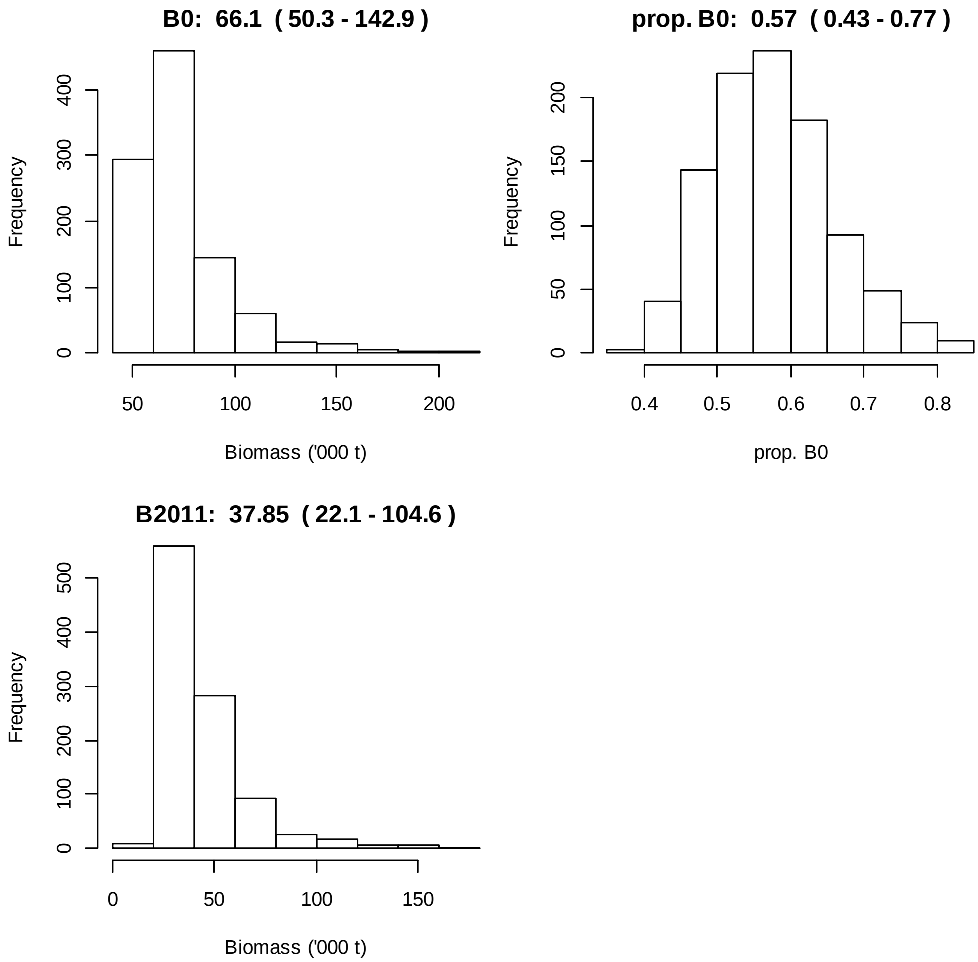


Figure 23: LIN 7WC parameter estimates from MCMC for the *M* = 0.18 model run, shown as histograms of parameter frequency. B0, virgin biomass; prop. B0, biomass in 2012 as a proportion of virgin biomass; B2012, biomass in 2012 (the last year in the estimation model). The estimates are the median of the MCMC posterior, with 95% credible intervals given in parentheses.

The parameter estimates (95% credible intervals in parentheses) for the *M* = 0.18 model run were, for the longline fishery selectivity ogive: a50 = 15.15 (9.89–16.46) and a95 = 7.13 (2.14–8.38); the parameter estimates for the trawl fishery were a1 = 12.31 (10.72–12.61), a95 LHS = 4.20 (3.28–4.26), and a95 RHS = 10.75 (5.74–14.14); and for the *Tangaroa* survey a1 = 17.00 (12.26–17.94); a95 LHS = 7.41 (5.02–7.97), a95 RHS = 172.5 (149.8–181.9). The only appreciable changes from the base run were a reduction in the a50 of the *Tangaroa* survey (from 10.99 to 9.59), although this remained older than the a50 of the trawl fishery, and a more domed selectivity for the *Tangaroa* survey (Figure 24). The reduction in the selevctivity of the right hand side of the *Tangaroa* survey ogive would be consistent with the lower *M*, which increased longevity and the relative abundance of older ling, so to fit the age frequencies the selectivity of the older ages was reduced.

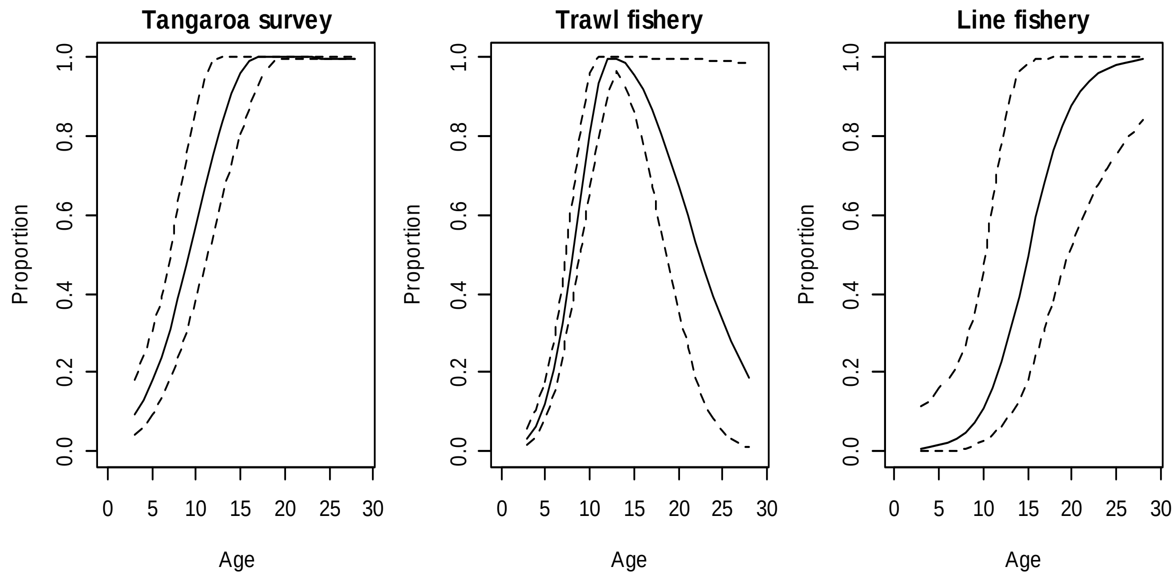


Figure 24: LIN 7WC selectivities from the MCMC of the *M* = 0.18 model run.

6.3 Biomass projections

The DFAWG considered that the assessment was not reliable enough to produce stock projections under different catch scenarios. However, they are reported here for completeness. The Ministry for Primary Industries specified four levels of catches for projections:

1) Current TAC: 2501 t. The catch should be split between trawl and longline fisheries using the ratio of the average catches for the last three years (this meant 1426 t and 1075 t respectively).
2) Current catch (approx): 2800 t. The catch increase was split as per the 3 year ratio (for trawl and longline fishery, i.e., 1596 t, 1204 t respectively).
3) Current catch (approx.) + estimate of additional bycatch from hoki fishing: 3200 t. Of this, 400 tonnes of the increase was split between fisheries as per the 3 year ratio, and the remaining 300 tonnes taken only by the trawl fleet (1954 t, 1246 t respectively).
4) High estimate of potential catches: 3400 t. Of this, 600 tonnes was split between fisheries as per the 3 year ratio, and the remaining 300 tonnes was taken by the trawl fleet (2068 t, 1332 t respectively).

The results of the projections are shown in Table 16, and biomass trajectories for the lowest and highest exploitation scenarios plotted in Figure 25.

Table 16: LIN 7WC biomass projections under deterministic recruitment and constant catch scenarios, for the base and M=0.18 model runs.

Model run	Future constant catch (t)	B_{2017}	B_{2017} / B_0 (%)	P(B_{2017}) < 0.2B0
Base	2501	63 053 (26 402–226 584)	63 (44–83)	0
	2800	61 490 (26 034–229 322)	61 (41–82)	0
	3200	60 154 (23 514–223 306)	61 (39–82)	0
	3400	59 535 (23 474–220 240)	60 (39–82)	0
M = 0.18	2501	32 955 (16 618–91 540)	50 (33–70)	0
	2800	31 636 (15 890–94 672)	47 (30–68)	0
	3200	30 494 (13 914–91 643)	46 (27–68)	0.001
	3400	29 672 (13 310–89 465)	45 (26–67)	0.001

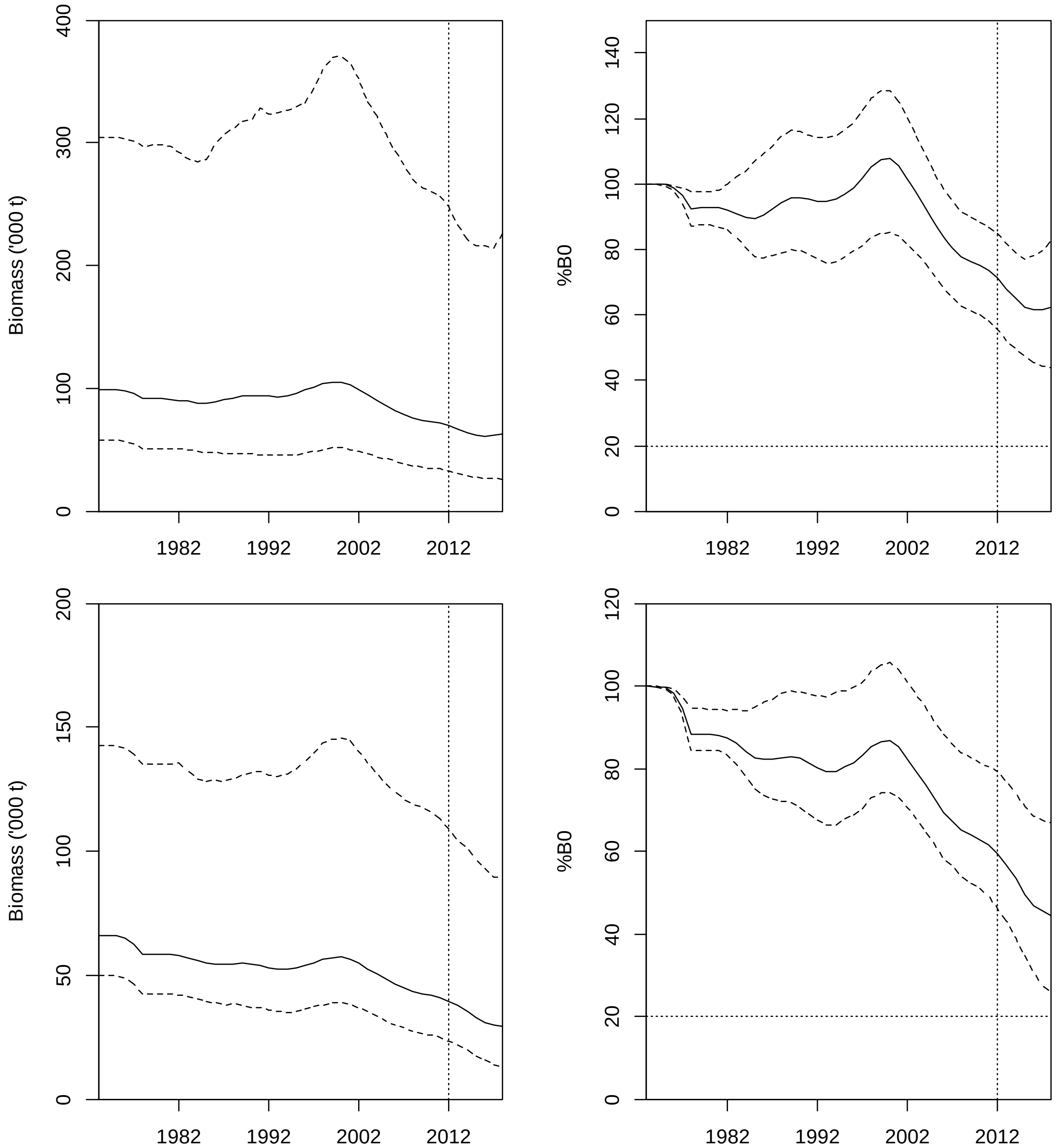


Figure 25: LIN 7WC projections (solid lines; broken lines, 95% credible intervals) of virgin biomass (left panels) and stock status (%B0, right panels) for the base model run and constant future catches of 2501 t (top panels), and *M* = 0.18 model run and constant future catches of 3400 t (bottom panels). Vertical dotted lines marks the start of the simulation period.

7. DISCUSSION

7.1 LIN 7CK (Cook Strait)

Ling in Cook Strait are believed to comprise a distinct biological stock (Horn 2005), but it does not have a separate TACC. It is a ‘trans-boundary’ stock, being partially in Fishstocks LIN 7 and LIN 2. The Cook Strait stock assessment is data poor. Model inputs are confined to a catch history, CPUE indices from trawl and longline fisheries, and series of commercial fishery catch-at-age data. No fishery-independent series of relative abundance are available.

The assessment (and clearly, the shape of the biomass trajectory) is dominated by the catch-at-age data from the trawl and line fisheries rather than the CPUE index. The CPUE index essentially moderates the estimates of biomass and year class strengths derived from the catch-at-age data. Horn & Ballara (2012) concluded that the trawl CPUE index using TCEPR data from 1994 onwards was a more reliable relative abundance series than the line CPUE because it was based on more data, and was less likely to be biased by changes in fishing practice and catch recording. Based on this recommendation, and further analyses conducted by Horn & Francis (2013), the line CPUE was omitted from the current assessment.

Much of the uncertainty in the results presented here for Cook Strait ling is attributable to the fact that M could not be estimated. However, it is difficult to ascertain the precise nature of the problem and no further investigations were conducted. Some indication of stock status could be inferred directly from the trend in trawl CPUE, which has declined steadily since 2001. Reasons for this decline are unclear, and could be due to poor recruitment and/or reduced catchability. Nevertheless, the trend is cause for concern and provides sufficient justification for monitoring of the stock into the future.

The previous base model assessment (Horn & Francis 2013), which included the trawl CPUE from 1994, indicated a B_0 in Cook Strait that was small (i.e., about 8000 t) when compared with virgin biomass estimates for stocks covering much larger geographic areas (e.g., about 113 000 t for Chatham Rise (Horn et al. 2013)). However, when geographical area is taken into account (the Chatham Rise ling grounds are about 40 times the area of the assumed Cook Strait stock distribution), the unfished density of Cook Strait ling is estimated to be about 2–3 times that of the Chatham Rise. But the actual geographic area encompassed by the ‘Cook Strait’ biological stock is unknown. For the purposes of generating data inputs for the model, the ‘stock’ is assumed to comprise the area between latitudes 41° and 42° S and longitudes 174° and 175.4° E, equating approximately to Statistical Areas 016 and 017. However, ling as far south as the Kaikoura Peninsula, and north towards Hawke Bay could easily be part of this biological stock. While this would markedly increase the area, it would increase the landings from the stock by only about a factor of 2.

7.2 LIN 7WC (WCSI)

The assessment was accepted by the DFAWG, with reservations. Given the issues in the assessment, the DFAWG did not consider that using the models for biomass projection was acceptable. All assessment runs were indicative of a B_0 greater than about 50 000 t. Only the trawl survey and trawl fishery catch-at-age data provided much information on an upper bound.

A number of other issues were raised during the assessment. The treatment of sex-specific data in ling assessment models seems to create some problems (see also Horn et al. 2013), and would warrant further investigation. The otoliths used to derive the *Tangaroa* survey proportions-at-age for 2000 were actually from the trawl fishery, and as a result the weight of these data could arguably be reduced in the model. Because of differences in application, differences between bottom and midwater trawl CPUE would be worth investigating. Finally, a prior might be considered for the left hand limb of the *Tangaroa* survey selectivity, because this survey was expected to catch younger ling than the trawl and longline fisheries.

8. MANAGEMENT IMPLICATIONS

8.1 LIN 7CK (Cook Strait)

The stock assessment presented above was considered unsuitable for the provision of management advice. The model failed to accurately represent declines in resource abundance that appear evident from CPUE values, which have declined since 2001. The last stock assessment for LIN 7CK accepted by the DFAWG was completed in 2010 (Horn & Francis 2013), and it is reported in the Fishery Assessment Plenary Document.

8.2 LIN 7WC (WCSI)

The stock assessment suggests that a TACC increase would be possible. Although biomass over the next five years was projected to decline at catch levels at or above the current TACC, the biomass was likely to remain well above the management target of 40% B_0. Whilst the models were not providing accurate information on exploitation rate, information such as the recent age-frequency data suggested that exploitation rates were low

9. ACKNOWLEDGMENTS

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10. REFERENCES

Anderson, O.F.; Bagley, N.W.; Hurst, R.J.; Francis, M.P.; Clark, M.R.; McMillan, P.J. (1998). Atlas of New Zealand fish and squid distributions from research bottom trawls. *NIWA Technical Report 42*. 303 p.

Ballara, S.L.; O'Driscoll, R.L. (2012). Catches, size, and age structure of the 2010–11 hoki fishery, and a summary of input data used for the 2012 stock assessment. *New Zealand Fisheries Assessment Report 2012/23.* 117 p.

Bentley, N.; Kendrick, T.H.; Starr, P.J.; Breen, P.A. (2012). Influence plots and metrics: tools for better understanding fisheries catch-per-unit-effort standardizations. *ICES Journal of Marine Science 69(1)*: 84–88.

Bull, B.; Dunn, A. (2002). Catch-at-age: User manual v1.06.2002/09/12. NIWA Internal Report 114. 23 p. (Unpublished report held in NIWA library, Wellington.)

Bull, B.; Francis, R.I.C.C.; Dunn, A.; McKenzie, A.; Gilbert, D.J.; Smith, M.H.; Bian, R.; Fu, D. (2012). CASAL (C++ algorithmic stock assessment laboratory): CASAL user manual v2.30-2012/03/21. *NIWA Technical Report 135*. 279 p.

Chambers, J.M.; Hastie, T.J. (1991). Statistical models in S. Wadsworth & Brooks/Cole, Pacific Grove, CA. 608 p.

Dunn, A. (2003a). Revised estimates of landings of hake (*Merluccius australis*) for the west coast South Island, Chatham Rise, and sub-Antarctic in the fishing years 1989–90 to 2000–01. *New Zealand Fisheries Assessment Report 2003/39.* 36 p.

Dunn, A. (2003b). Investigation of evidence of area misreporting of landings of ling in LIN 3, 4, 5, 6, & 7 from TCEPR records in the fishing years 1989–90 to 2000–01. Final Research Report for Ministry of Fisheries Research Project HAK2001/01, Objective 8. 21 p. (Unpublished report held by Ministry for Primary Industries, Wellington.)

Dunn, A.; Harley, S.J.; Doonan, I.J.; Bull, B. (2000). Calculation and interpretation of catch-per-unit-effort (CPUE) indices. *New Zealand Fisheries Assessment Report 2000/1*. 44 p.

Dunn, P.K.; Smyth, G.K. (1996). Randomized quantile residuals. *Journal of Computational and Graphical Statistics 5*: 1–10.

Francis, R.I.C.C. (1999). The impact of correlations in standardised CPUE indices. New Zealand Fisheries Assessment Research Document 99/42. 30 p. (Unpublished report held in NIWA library, Wellington.)

Francis, R.I.C.C. (2001). Orange roughy CPUE on the South and East Chatham Rise. *New Zealand Fisheries Assessment Report 2001/26*. 30 p.

Francis, R.I.C.C. (2011). Data weighting in statistical fisheries stock assessment models. *Canadian Journal of Fisheries and Aquatic Sciences 68*: 1124–1138.

Francis, R.I.C.C.; Haist, V.; Bull, B. (2003). Assessment of hoki (*Macruronus novaezelandiae*) in 2002 using a new model. *New Zealand Fisheries Assessment Report 2003/6*. 69 p.

Horn, P.L. (2000). Catch-at-age data, and a review of natural mortality, for ling. Final Research Report for Ministry of Fisheries Research Project MID9801, Objectives 1, 3, 4, & 5. 26 p. (Unpublished report held by Ministry for Primary Industries, Wellington.)

Horn, P.L. (2001). A descriptive analysis of commercial catch and effort data for ling from New Zealand waters. *New Zealand Fisheries Assessment Report 2001/2*. 64 p.

Horn, P.L. (2002). CPUE from commercial line fisheries for ling (*Genypterus blacodes*) around the South Island (Fishstocks LIN 3, 4, 5, 6, and 7). *New Zealand Fisheries Assessment Report 2002/17*. 32 p.

Horn, P.L. (2004a). Stock assessment of ling (*Genypterus blacodes*) on the Campbell Plateau (LIN 5 and 6) and off the west coast of the South Island (LIN 7) for the 2003–04 fishing year. *New Zealand Fisheries Assessment Report 2004/7*. 45 p.

Horn, P.L. (2004b). CPUE from commercial fisheries for ling (*Genypterus blacodes*) in Fishstocks LIN 3, 4, 5, 6, and 7 from 1990 to 2002. *New Zealand Fisheries Assessment Report 2004/12*. 41 p.

Horn, P.L. (2004c). A review of the auto-longline fishery for ling (*Genypterus blacodes*) based on data collected by observers from 1993 to 2003. *New Zealand Fisheries Assessment Report 2004/47*. 28 p.

Horn, P.L. (2005). A review of the stock structure of ling (*Genypterus blacodes*) in New Zealand waters. *New Zealand Fisheries Assessment Report 2005/59*. 41 p.

Horn, P.L. (2006a). CPUE from commercial fisheries for ling (*Genypterus blacodes*) in Fishstocks LIN 1, 2, 3, 4, 5, 6, and 7 from 1990 to 2004. *New Zealand Fisheries Assessment Report 2006/12*. 49 p.

Horn, P.L. (2006b). Stock assessment of ling (*Genypterus blacodes*) off the west coast of the South Island (LIN 7) for the 2005–06 fishing year. *New Zealand Fisheries Assessment Report 2006/24*. 47 p.

Horn, P.L. (2007a). A descriptive analysis of commercial catch and effort data for ling from New Zealand waters in Fishstocks LIN 2, 3, 4, 5, 6, and 7. *New Zealand Fisheries Assessment Report 2007/22*. 71 p.

Horn, P.L. (2007b). Stock assessment of ling (*Genypterus blacodes*) on the Bounty Plateau and in Cook Strait for the 2007–08 fishing year. Final Research Report for Ministry of Fisheries Research Project LIN2005-01, Objective 3. 51 p. (Unpublished report held by Ministry for Primary Industries, Wellington.)

Horn, P.L. (2008). Stock assessment of ling (*Genypterus blacodes*) on the Chatham Rise, Campbell Plateau, and in Cook Strait for the 2007–08 fishing year. *New Zealand Fisheries Assessment Report 2008/24*. 76 p.

Horn, P.L. (2009). Stock assessment of ling (*Genypterus blacodes*) off the west coast of South Island for the 2008–09 fishing year. *New Zealand Fisheries Assessment Report 2009/16*. 42 p.

Horn, P.L.; Ballara, S.L. (2012). A descriptive analysis and CPUE from commercial fisheries for ling (*Genypterus blacodes*) in Fishstocks LIN 2, 3, 4, 5, 6, and 7 from 1990 to 2009. *New Zealand Fisheries Assessment Report 2012/13*. 69 p.

Horn, P.L.; Dunn, M.R.; Ballara, S.L. (2013). 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*. 87 p.

Horn, P.L.; Harley, S.J.; Ballara, S.L.; Dean, H. (2000). Stock assessment of ling (*Genypterus blacodes*) around the South Island (Fishstocks LIN 3, 4, 5, 6, and 7). *New Zealand Fisheries Assessment Report 2000/37*. 70 p.

Horn, P.L.; Francis, R.I.C.C. (2013). Stock assessment of ling (*Genypterus blacodes*) in Cook Strait for the 2010–11 fishing year. *New Zealand Fisheries Assessment Report 2013/7*. 35 p.

Horn, P.L.; Sutton, C.P. (2013). Catch-at-age for hake (*Merluccius australis*) and ling (*Genypterus blacodes*) in the 2010–11 fishing year and from a trawl survey in summer 2011–12, with a summary of all available data sets. *New Zealand Fisheries Assessment Report 2013/19.* 53 p.

Horn, P.L.; Sutton, C.P. (submitted). Catch-at-age for hake (*Merluccius australis*) and ling (*Genypterus blacodes*) in the 2011–12 fishing year and from trawl surveys in 2012–13, with a summary of all available data sets. *New Zealand Fisheries Assessment Report 201x/x.* X p.

R Development Core Team (2012). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna. http://www.R-project.org.

Shertzer, K.W.; Conn, P.B. (2012). Spawner-Recruit Relationships of Demersal Marine**:** Prior distribution of steepness. *Bulletin of Marine Science 88*: 39–50.

APPENDIX A. UPDATED DESCRIPTIVE ANALYSIS OF LING FISHERIES, 1989–90 TO 2010–11

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 developed and operated. They also defined seasonal and areal patterns of fish distribution. The work presented here updates tables A2 and A3 of Horn et al. (2013), which included data to 2008–09, i.e., catch by area, by method, to indicate whether any marked changes have occurred in the fisheries in recent fishing years.

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 2010–11 had previously been extracted from the Ministry for Primary Industries 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 Plateau 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: North North Island (North NI), 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, Figure A1).

All catch data

Annual estimated catches by area, from all methods combined, are listed in Table A2, and shown in Figure A2. The estimated totals for each year amount to 85–94% of the MHR (Monthly Harvest Return) landings. Substantial catches (more than 100 t p.a.) were taken in all areas. Most catches were taken in five areas around the South Island: East SI, Chatham, Southland, Sub-Antarctic, and West SI. This pattern of catches is consistent with ling distributions derived from research trawls (Anderson et al. 1998). Catches from the Sub-Antarctic increased from 1997 to 2005 but they were much lower in the last three years, while those from Chatham have declined from 1990 levels. Deepwater bottom trawl fishery catches in East SI, Chatham, and the Sub-Antarctic decreased, and Southland and West SI increased in 2010–11 (Table A3, Figure A3). 2010–11 line-caught catches from Cook Strait and Bounty remained low, and the line catches on the Chatham Rise, in Southland and Sub-Antarctic decreased (Table A3, Figure A4), although line catches in North NI and West SI increased slightly. Total landings from the EEZ were slightly lower than in 2010, and were therefore lower than in any year since 1989–90 (Table A2).

Catch 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–g.

For the inshore bottom trawl fishery (Table A3a) the main catches have been taken on the WCSI and increasingly in Southland. Landings from the inshore midwater trawl fishery (Table A3b) were negligible in all areas except West SI.

The deepwater bottom trawl fishery (Table A3c) is still important in the Southland and Sub-Antarctic areas with annual landings generally in excess of 2000 t. Landings in the Sub-Antarctic increased from the late 1990s to peak at more than 4900 t in 2003–04, but only 1500 t was reported in 2009–10 and 750 t in 2010–11. Southland catches ranged from 1900 to 3300 t, and were 3300 t in 2010–11, i.e. at the same high level as in 1991–92. West SI catches have been more than 500 t since 1996–97, and in 2010–11 increased to 850 t. Chatham and East SI catches decreased in 2010–11. Total landings from the deepwater midwater trawl fishery (Table A3d) in 2009–10 were low in the last four years.

The line fishery (Table A3e) was substantial in all areas, but can vary markedly by area between years. The 2010–11 total catch was similar to recent years, although slightly lower, with continued low catches in Cook Strait and Bounty. Chatham, East SI, Southland, and Sub-Antarctic all had slightly lower landings than the previous year. The Chatham area was the most productive area, but its recent landings were only about a third of those taken at its peak in the mid 1990s.

Setnet fishery landings (Table A3f) were negligible in all areas except East SI and West SI. The 2010–11 landings in these two areas were slightly lower than in 2009–10. Landings from fish pots (Table A3g) were generally recorded only from East SI and Southland, and averaged about 20–50 t annually. The 2010–11 landings were 39 t.

Conclusions

In summary, the overall 2010–11 ling catch from the EEZ was slightly lower than the previous year. The distribution and size of trawl fishery landings changed little in the last year, with slight decreases in catch in East SI, Chatham, Sub-Antarctic, and slight increases in Southland and West SI, but overall trawl landings were markedly lower than those taken by this method during the early to mid 2000s.

The 2010–11 overall line fishery catch distribution was also quite similar to the previous year, but with decreases in catch for Chatham, Southland, and Sub-Antarctic, and negligible catches in Bounty and Cook Strait. This is markedly lower than in the more productive years (i.e., 1992–2002), but relatively consistent with the pattern of landings since 2003.

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

Area	Statistical areas	Approximate ling stock
North NI	041–048, 001–010, 101–110, 801	LIN 1
East NI	011–015, 201–206	LIN 2
East SI	018–024, 301	LIN 3
Chatham	049–052, 401–412	LIN 4
Southland	025–031, 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	032–036, 701–706	Part of LIN 7
Cook Strait	016, 017, 037–040	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 and by area. Fishing year 1989–90 is denoted as "1990", etc. The percentage of total estimated landings (Total) taken from each area is also presented (Percent). Total estimated landings by year (Total by year) can be compared with actual reported landings from Fishstocks LIN 1–7 (MHR total). The MHR total also includes small catches from FMA 10 and outside the EEZ.

	Area											
	North NI	East NI	East SI	Chatham	Southland	Sub-Antarctic	Bounty	West SI	Cook Strait	Total by year	MHR total	Percent of MHR
1990	83	268	1 221	512	2 116	1 216	12	2 323	414	8 167	9 026	90.5
1991	139	437	1 935	2 156	2 093	2 683	33	1 947	527	11 950	13 675	87.4
1992	185	450	1 806	4 358	3 832	2 398	908	1 859	314	16 119	17 796	90.6
1993	155	526	1 622	3 657	2 695	5 252	969	1 864	323	17 065	19 069	89.5
1994	185	508	1 573	3 756	3 249	2 282	1 149	1 765	251	14 722	15 960	92.2
1995	217	529	1 947	4 490	3 644	3 643	392	2 610	319	18 155	19 817	91.6
1996	165	553	2 395	4 147	4 502	3 622	381	2 614	366	18 749	21 472	87.3
1997	254	525	2 069	3 849	4 323	5 035	340	2 470	366	19 285	22 535	85.6
1998	220	607	2 086	4 285	4 142	5 359	395	2 755	287	20 150	23 084	87.3
1999	178	545	1 981	3 924	3 510	4 336	563	2 926	345	18 334	21 035	87.2
2000	297	485	2 150	3 969	3 185	5 072	991	2 662	331	19 146	21 595	88.7
2001	236	597	1 743	3 445	3 395	4 641	1 064	3 069	391	18 584	20 552	90.4
2002	280	583	1 583	3 217	3 255	5 406	629	2 642	289	17 885	19 566	91.4
2003	227	471	1 845	2 719	3 061	5 137	922	2 338	353	17 075	18 913	90.3
2004	207	507	1 473	2 385	3 119	5 899	853	2 402	360	17 204	18 759	91.7
2005	228	394	1 213	2 570	3 774	5 207	49	2 056	372	15 863	17 189	92.3
2006	290	415	1 207	1 663	3 656	3 195	43	2 051	297	12 819	14 183	90.4
2007	232	512	1 601	1 943	3 998	4 112	236	1 797	239	14 670	16 102	91.1
2008	361	503	1 505	2 307	4 251	3 818	503	1 909	186	15 344	16 264	94.3
2009	307	452	1 394	1 815	3 201	2 264	232	1 851	124	11 640	13 138	88.6
2010	379	451	1 373	1 844	3 240	2 272	1	1 957	75	11 593	12 609	91.9
2011	440	481	1 170	1 398	4 013	1 129	53	2 279	129	11 092	12 328	90.0
Total	5 267	10 800	36 892	64 409	76 257	83 979	10 719	50 148	6 660	345 613	384 667	–
Percent	1.0	2.6	7.2	18.9	23.9	27.3	3.7	13.9	1.2	–	–	–

Table A3: Catch of ling (t) by area, by fishing year, for various fishing methods. Fishing year 1989–90 is denoted as "1990", etc. Values were rounded to the nearest tonne, so "0" represents estimated landings of less than 0.5 t, and "–" indicates nil reported landings. Total catches also includes catches from FMA 10 and outside the EEZ.

(a) Inshore bottom trawl (method BT and BPT on CELR and TCER forms)

	Area									
	North NI	East NI	East SI	Chatham	Southland	Sub-Antarctic	Bounty	West SI	Cook Strait	Total
1990	10	25	148	4	47	–	–	148	4	386
1991	18	36	198	5	63	–	–	150	9	480
1992	30	21	145	2	53	–	0	192	4	448
1993	35	17	110	–	91	0	–	220	14	486
1994	29	22	64	1	78	–	–	111	22	326
1995	20	18	66	2	83	–	–	106	78	374
1996	9	24	50	3	50	–	–	188	82	406
1997	19	17	62	0	56	–	–	168	72	394
1998	9	7	44	0	30	–	–	104	24	219
1999	8	5	51	0	66	–	–	158	26	314
2000	57	7	80	–	48	–	–	129	20	340
2001	22	6	75	0	99	–	–	55	15	271
2002	11	4	99	1	89	–	–	55	17	275
2003	9	8	91	1	166	–	–	69	8	352
2004	3	3	88	0	137	–	–	54	4	290
2005	1	2	99	1	136	–	–	130	7	376
2006	6	2	46	10	106	–	–	127	3	299
2007	8	15	49	1	98	–	–	101	4	276
2008	52	18	72	–	109	–	–	240	6	496
2009	62	11	39	–	122	0	–	252	31	517
2010	86	14	66	–	180	0	–	277	26	649
2011	39	21	62	0	368	–	0	306	68	864

(b) Inshore midwater trawl (method MW and MPT on CELR and TCER forms)

	Area									
	North NI	East NI	East SI	Chatham	Southland	Sub-Antarctic	Bounty	West SI	Cook Strait	Total
1990	1	1	3	–	–	–	–	2	42	49
1991	–	0	9	–	–	–	–	–	125	134
1992	0	0	6	–	–	–	–	2	36	44
1993	0	0	0	–	–	–	–	1	26	30
1994	0	0	1	–	–	–	–	3	11	14
1995	1	0	0	1	–	–	–	9	6	17
1996	1	0	2	–	–	–	–	24	16	43
1997	4	–	7	–	–	–	–	21	8	45
1998	9	0	4	–	–	–	–	45	13	74
1999	1	–	20	–	–	–	–	83	9	113
2000	0	0	7	–	–	–	–	206	18	232
2001	6	0	7	–	–	–	–	175	29	218
2002	–	–	9	–	–	–	–	83	14	106
2003	–	–	30	–	0	–	–	113	36	178
2004	–	0	13	–	–	–	–	67	29	110
2005	–	0	1	–	–	–	–	70	22	93
2006	–	–	2	–	–	–	–	63	21	86
2007	0	–	0	–	–	–	–	34	18	52
2008	–	–	1	–	–	–	–	6	14	20
2009	–	–	–	–	–	–	–	33	14	48
2010	0	–	1	–	–	–	–	40	8	49
2011	0	0	0	–	–	–	–	48	4	53

Table A3a: continued.

(c) Deepwater bottom trawl (methods BT and BPT on TCEPR form)

	Area									
	North NI	East NI	East SI	Chatham	Southland	Sub-Antarctic	Bounty	West SI	Cook Strait	Total
1990	31	59	599	500	1 953	1 174	4	370	7	4 698
1991	70	117	817	1 235	1 996	2 457	7	260	13	6 972
1992	55	87	933	1 348	3 368	2 053	35	306	4	8 189
1993	30	75	807	1 028	1 985	4 308	0	491	4	8 730
1994	45	74	727	451	2 038	1 818	4	389	47	5 595
1995	44	77	828	819	2 454	2 065	0	490	57	6 833
1996	73	124	1 048	690	3 875	2 338	1	381	97	8 629
1997	140	151	1 017	760	3 254	2 772	–	512	119	8 749
1998	136	129	1 172	2 260	2 924	2 970	–	497	77	10 168
1999	102	159	971	1 835	2 609	2 382	3	875	111	9 050
2000	188	156	871	1 897	2 121	3 839	–	759	90	9 921
2001	170	205	971	1 480	1 958	3 684	–	1 019	39	9 526
2002	169	207	860	1 216	2 064	4 517	1	1 133	72	10 240
2003	121	113	1 131	1 313	1 896	4 707	1	836	35	10 153
2004	108	74	811	1 061	2 269	4 936	1	815	38	10 114
2005	73	51	589	798	2 690	4 694	8	764	29	9 696
2006	123	40	600	566	2 790	2 777	4	993	21	7 915
2007	63	71	945	854	3 108	3 920	–	701	19	9 681
2008	74	19	828	1 182	3 264	3 469	–	525	41	9 402
2009	67	37	699	498	2 674	2 042	8	556	21	6 603
2010	39	23	548	539	2 607	1 475	0	603	7	5 842
2011	52	28	390	400	3 333	749	0	854	5	5 811

(d) Deepwater midwater trawl (methods MW and MPT on TCEPR forms)

	Area									
	North NI	East NI	East SI	Chatham	Southland	Sub-Antarctic	Bounty	West SI	Cook Strait	Total
1990	–	1	72	0	116	42	8	1 261	260	1 759
1991	–	13	57	69	29	9	20	740	325	1 261
1992	–	1	61	11	121	19	38	402	201	854
1993	–	4	34	24	155	58	4	324	176	780
1994	–	1	39	33	268	14	3	348	107	812
1995	0	0	35	54	398	11	3	1 014	117	1 632
1996	0	2	88	59	271	24	2	856	117	1 419
1997	–	1	106	53	133	5	–	722	142	1 165
1998	1	12	195	44	79	5	7	984	105	1 432
1999	0	7	213	45	62	6	11	772	91	1 208
2000	–	4	222	29	114	15	7	726	109	1 226
2001	0	5	81	44	351	229	0	855	147	1 712
2002	–	1	103	38	131	233	1	651	74	1 233
2003	5	4	87	19	135	217	–	585	138	1 190
2004	–	4	80	60	130	306	2	759	119	1 460
2005	–	1	68	15	98	203	6	335	97	822
2006	0	3	24	2	80	246	1	269	65	691
2007	–	1	6	1	101	191	2	125	45	472
2008	0	2	10	0	84	3	1	87	33	220
2009	–	2	4	0	6	6	2	80	25	125
2010	–	1	18	0	36	8	0	127	22	213
2011	–	3	3	0	50	20	2	141	19	237

Table A3a: continued.

(e) Line (methods BLL,TL, and DL on CELR, LCER, and LTCER forms)

	Area									
	North NI	East NI	East SI	Chatham	Southland	Sub-Antarctic	Bounty	West SI	Cook Strait	Total
1990	39	134	185	8	0	–	–	197	66	630
1991	50	186	613	846	2	217	7	428	55	2 406
1992	98	300	478	2 997	288	326	835	691	70	6 090
1993	83	401	491	2 605	463	886	965	698	100	6 694
1994	108	406	552	3 272	863	449	1 142	761	63	7 619
1995	126	432	811	3 613	705	1 567	381	888	59	8 946
1996	81	397	1 019	3 394	301	1 259	378	992	53	7 877
1997	67	328	635	3 026	876	2 257	340	929	20	8 500
1998	60	446	416	1 971	1 095	2 381	388	996	67	7 828
1999	39	370	528	2 040	771	1 940	549	971	107	7 339
2000	50	317	779	2 043	892	1 206	984	749	94	7 115
2001	36	380	473	1 921	962	728	1 063	916	160	6 640
2002	100	370	385	1 962	955	657	627	659	111	5 826
2003	91	346	401	1 386	850	214	921	686	137	5 032
2004	95	425	356	1 264	581	656	850	679	169	5 075
2005	154	339	369	1 757	848	310	34	728	215	4 754
2006	161	365	434	1 085	676	172	38	562	187	3 680
2007	161	425	498	1 087	685	–	234	745	153	3 988
2008	235	461	521	1 125	789	345	502	1 010	93	5 081
2009	177	397	583	1 314	382	216	222	887	33	4 211
2010	252	412	638	1 303	404	789	1	864	11	4 674
2011	349	430	626	995	252	360	51	902	33	3 998

(f) Setnet (method SN on CELR and NCELR forms)

	Area									
	North NI	East NI	East SI	Chatham	Southland	Sub-Antarctic	Bounty	West SI	Cook Strait	Total
1990	2	48	210	0	0	–	–	346	36	642
1991	1	85	227	–	2	–	–	368	–	682
1992	3	40	144	0	1	–	–	264	1	453
1993	6	25	164	–	1	–	–	129	3	327
1994	3	4	179	–	0	–	–	154	1	342
1995	27	1	199	–	1	–	–	103	1	332
1996	1	5	179	–	0	0	–	170	1	357
1997	23	28	203	–	2	0	–	108	1	365
1998	4	12	200	–	2	–	–	127	–	345
1999	23	1	147	–	0	–	–	65	–	237
2000	1	1	164	–	0	–	–	94	–	261
2001	0	1	131	–	0	–	–	49	2	184
2002	1	0	123	–	1	–	–	62	–	187
2003	1	0	104	0	0	–	–	50	–	156
2004	1	1	120	–	1	–	–	24	–	148
2005	0	1	78	0	1	–	–	31	1	112
2006	0	5	51	–	1	–	–	39	–	96
2007	0	0	47	–	2	–	–	91	–	141
2008	1	2	55	–	3	–	–	43	–	104
2009	0	5	58	2	6	–	–	43	–	115
2010	0	0	62	2	5	–	–	47	–	116
2011	0	0	55	2	5	–	–	28	–	90

Table A3a: continued.

(g) Fishpots (methods RLP, CP, and FP on CELR forms)

									Area	
	North NI	East NI	East SI	Chatham	Southland	Sub-Antarctic	Bounty	West SI	Cook Strait	Total
1990	0	–	2	0	1	–	–	–	–	3
1991	0	–	15	0	1	0	–	–	0	16
1992	0	–	39	0	1	–	–	0	–	40
1993	0	–	15	0	1	–	–	–	0	16
1994	–	0	11	0	1	–	–	–	–	13
1995	–	0	8	0	2	–	–	–	–	10
1996	0	–	4	–	4	–	–	0	0	8
1997	–	0	38	–	2	–	–	0	–	40
1998	–	–	40	–	3	–	–	–	–	43
1999	–	–	41	–	0	0	–	–	–	42
2000	0	–	21	–	10	–	–	–	0	32
2001	2	–	4	–	25	–	–	1	–	31
2002	–	–	3	–	16	–	–	–	–	19
2003	0	–	1	–	13	–	–	–	–	14
2004	–	–	4	–	0	–	–	–	1	5
2005	–	–	10	–	0	–	–	–	–	10
2006	–	0	49	–	3	0	–	–	–	52
2007	–	–	56	–	3	–	–	–	–	60
2008	0	–	19	0	2	–	–	–	–	21
2009	–	–	10	0	11	–	–	0	–	21
2010	–	0	41	–	8	–	–	0	–	49
2011	0	–	33	–	5	–	–	–	0	39

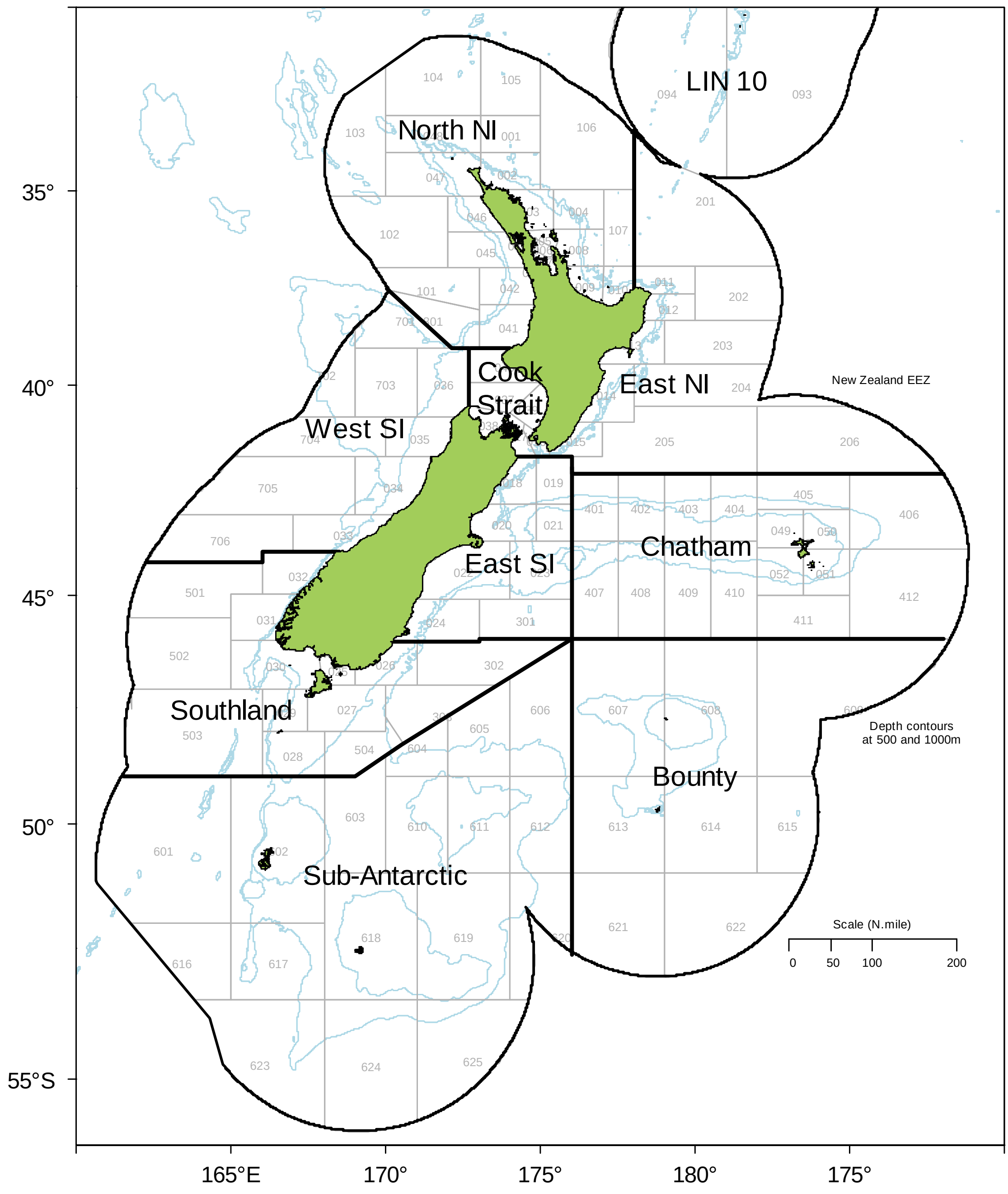


Figure A1: Definitions of geographical areas used in the analyses (based on statistical areas). See Table A1 for the administrative ling stocks they approximate.

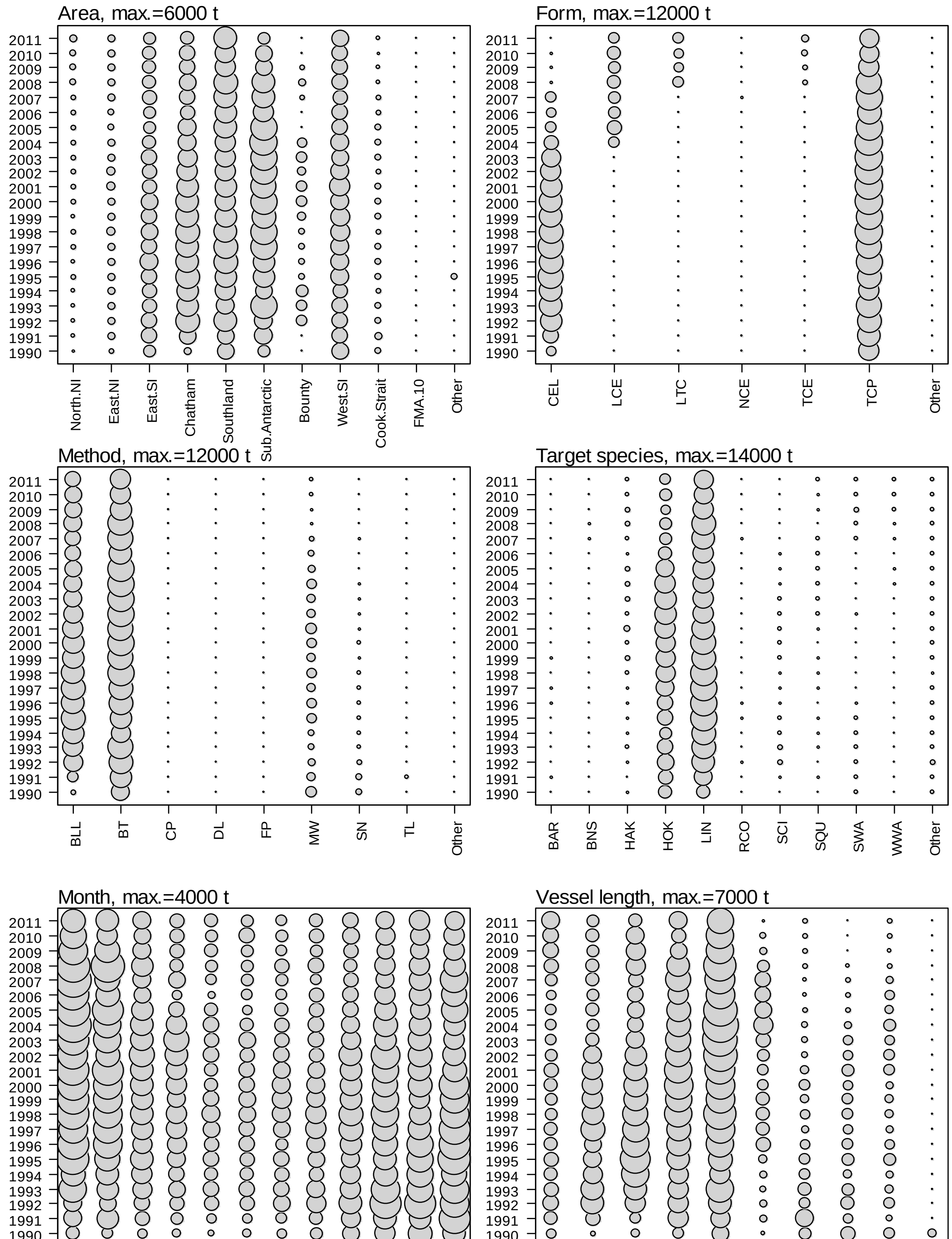


Figure A2: Distribution of annual catch by area, form type, fishing method, target species, month, and vessel length for all ling catches by all methods. Circle size is proportional to catch; maximum circle size is indicated in the heading of each plot. Form types: CEL is Catch, Effort, Landing Return; LCE is Line Catch Effort return; LTC is Lining Trip Catch, Effort return; NCE is Net Catch Effort Return; TCE is Trawl, Catch, Effort Return; TCP is Trawl, Catch, Effort, and Processing Return. Method definitions: BLL, bottom longlining; BT, bottom trawl; CP, cod potting; DL, dahn lines; FP, fish traps; MW, midwater trawl; SN, set net; TL, trot line. Species codes: BAR, Barracouta; BNS, bluenose; HAK, hake; HOK, hoki; LIN, ling; RCO, red cod; SCI, scampi; SQU, arrow squid; SWA, silver warehou; WWA, white warehou.

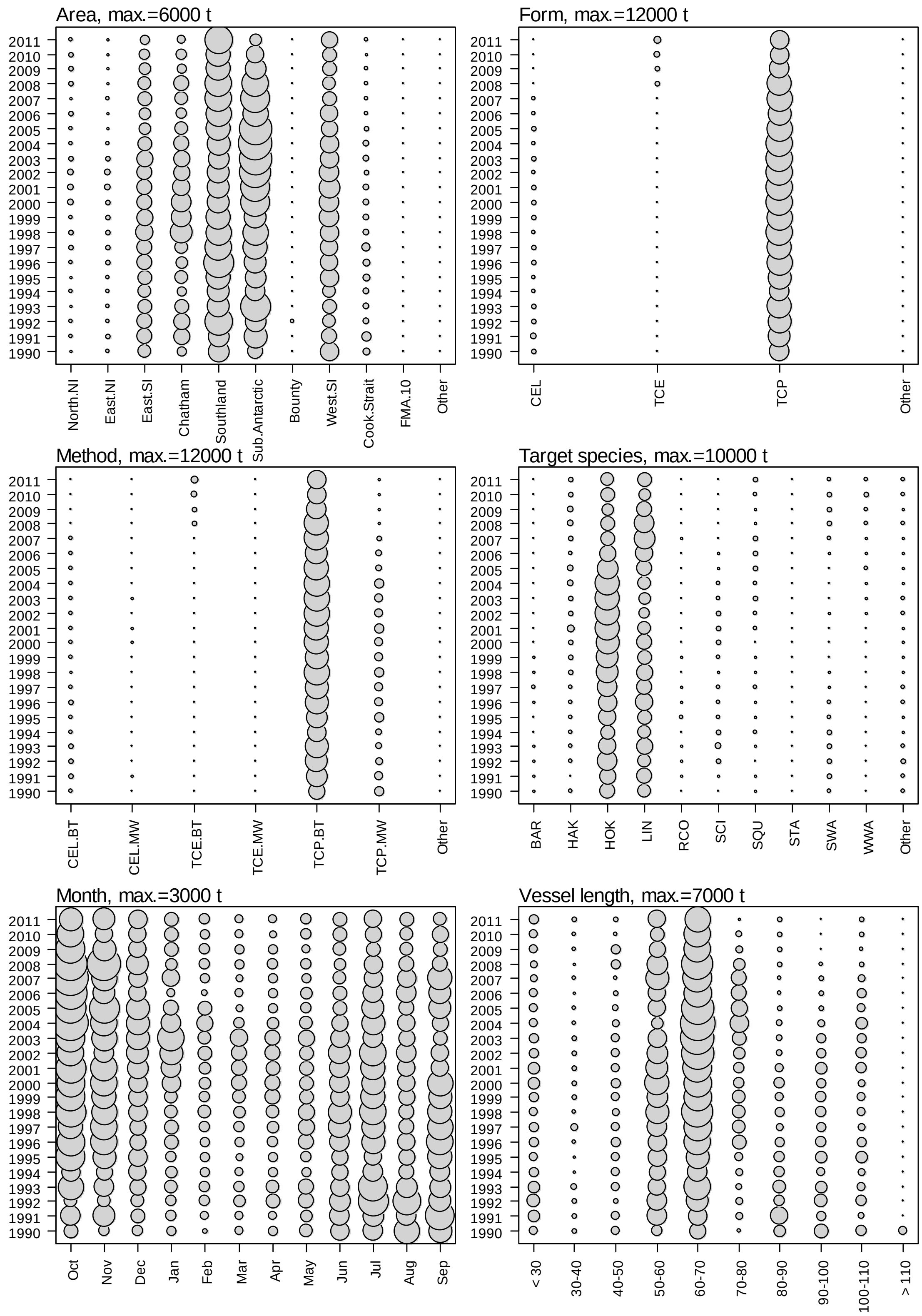


Figure A3: Distribution of annual catch by area, form type, fishing method (by form type), target species, month, and vessel length for all ling catches by trawl methods. Circle size is proportional to catch; maximum circle size is indicated in the heading of each plot. Form types and method types are defined in Figure A1. Species codes: BAR, Barracouta; HAK, hake; HOK, hoki; LIN, ling; RCO, red cod; SCI, scampi; SQU, arrow squid; STA, giant stargazer; SWA, silver warehou; WWA, white warehou.

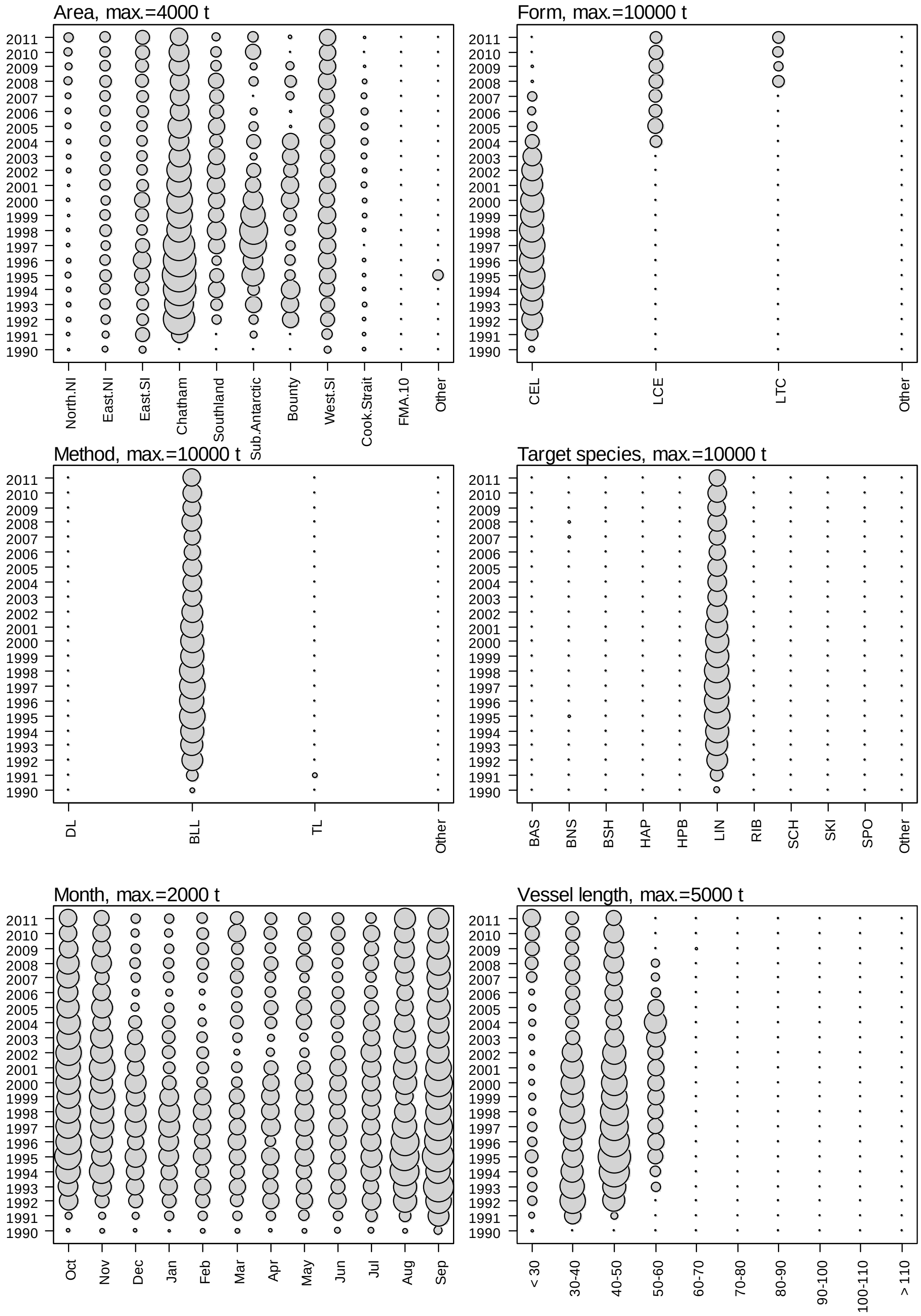


Figure A4: Distribution of annual catch by area, form type, fishing method (by form type), target species, month, and vessel length for all ling catches by line methods. Circle size is proportional to catch; maximum circle size is indicated in the heading of each plot. Form types and method types are defined in Figure A1. BAS, bass; BNS, bluenose; BSH, seal shark; HAP, hapuku; HPB, hapuku and bass; LIN, ling; RIB, ribaldo; SCH, school shark; SKI, gemfish; SPO, rig.

APPENDIX B. ESTIMATION OF CPUE FROM TRAWL AND LINE FISHERIES IN LIN 7CK AND LIN 7WC

This Appendix reports on an analysis to update the series of CPUE indices from target line and trawl fisheries for ling for LIN 7 on the WCSI and Cook Strait. 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 for Primary Industries, were used in the trawl and 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, hake or hoki 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 for Primary Industries catch-effort database "warehou" as extract 8262. 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 September 2011.

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 et al. 2013).

For the longline data, 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 as the relationship between catch per hook and the number of hooks set per day is non-linear (Horn 2002). *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.

For trawl data, CPUE was defined as catch per tow, with tow *duration* offered as an explanatory variable. *Year* was a categorical variable and defined as June–September. Season variables *month* and *day of year* were offered to the model. Hoki trawling uses both bottom and midwater gear, so method was offered as an explanatory variable in the trawl analyses, although midwater gear was further defined as midwater trawl, or midwater trawl fished on the bottom, if recorded net depth was within 5 m of recorded bottom depth. Gear width was not used as an explanatory variable as this field in the TCEPR variously contained wingspread and doorspread measurements. Consequently, headline height was the only trawl gear dimension variable offered to the trawl model.

Individual vessel details were checked for consistency each year as more than one vessel can have the same vessel identification number. Tow records with no vessel identification data were excluded from further analyses. *Vessel* was incorporated into the CPUE standardisation to allow for differences in fishing power between vessels.

Data selection

Data for the WCSI and Cook Strait were grouped by statistical area as follows: 032–036, 701–706 for West SI (LIN 7WC), and 016–017 for Cook Strait (LIN 7CK). These analyses were carried out on the basis of presumed biological stocks, rather than administrative (QMA) stocks.

Vessels not involved in the fishery for at least two years were excluded as they provided little information for the standardisations, which could result in model over-fitting (Francis 2001). The number of tows or sets for a vessel in the overall final datasets differed for different datasets, depending on quantity of data.

Trawl data

The timing of the catch on both the WCSI and Cook Strait varied slightly between years, but most ling catch was taken from May to October, often with a peak from June to September, and mainly as bycatch in the hoki target spawning fishery. For the trawl data, year was defined as June–September as this is when most of the catch was taken.

Ling trawl data on the WCSI and in Cook Strait can be recorded on TCEPR, TCER, or CELR forms. TCEPR and TCER returns contain tow-by-tow data. CELR returns often amalgamate a day's fishing into a single line of data, so some of the data on individual tows may be lost (e.g., duration, towing speed, bottom depth, gear dimensions). Only TCEPR data was used in the analysis as there was no difference in CPUE indices with the exclusion of TCER data (Horn & Ballara 2012).

For the WCSI fishery the 'accurate' TCEPR series developed by Horn (2006a) was updated, and assumes that the percentage of hoki target tows reporting a ling bycatch provides some indication of reporting accuracy. From the observer database, 90% of trips using the bottom trawl method had at least 72% of tows reporting a ling bycatch, and 90% of trips using midwater trawl had at least 50% of tows reporting a ling bycatch. These values were used as thresholds to identify vessels that were likely to have comprehensively reported their ling bycatch, e.g., if a vessel in a particular year had reported some ling bycatch in 72% or more of their bottom trawl tows, then all the data from that vessel in that year were included in the 'accurate' TCEPR data set.

To ensure that the data was in plausible ranges and related to vessels that had consistently targeted and caught significant landings of ling, data were accepted if all the following constraints were met.

WCSI	TCEPR trawl	Observer trawl
Data source	TCEPR form	Observer data
Year range	1990–2011	1990–2011
Year	June–September	June–September
Statareas	033–036, 706	034, 035
Method	MW, MB, BT	MW, MB, BT
Target	HOK, HAK, LIN	HOK, HAK
Vessel selection	Accurate vessels only, with each vessel in fishery at least 2 years, and ≥ 80 tows in 5 years	Each vessel in fishery at least 2 years, and ≥ 35 tows
Catch	< 15 t	< 10 t
Other	150–900 m 0.2–15 hours	150–900 m 0.2–15 hours

Cook Strait	TCEPR trawl	Observer trawl
Data source	TCEPR form	Observer data
Year range	1994–2011	1998–2011
Year	June–September	June–September
Statarea	016, 017	016, 017
Method	MW, BT	MW
Target	HOK	HOK
Vessel selection	Each vessel in fishery at least 2 years, and ≥ 100 tows in 5 years	Each vessel in fishery at least 2 years, and ≥ 35 tows
Catch (individual tow)	< 15 t	< 15 t
Other	150–900 m 0.2–6 hours	150–900 m 0.2–6 hours

Line data

Line 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 (Horn 2007a). This ensured that all catches in each season peak were included in a single year, rather than spread between two (fishing) years.

Some line vessels recorded 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.

Examination of the zero catch records showed 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. As in previous analyses, all zero observations for line data were removed.

To ensure that the 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:

	WCSI	Cook Strait
Data source	CEL, LCE, LTC forms	CEL, LCE, LTC forms
Year range	1990–2011	1990–2011
Year	January–December	January–December
Statareas	032, 033, 034	016, 017
Method	BLL	BLL, DL, TL
Target	LIN	LIN
Vessel selection	Vessel in fishery at least 2 years, and ≥ 50 daily records in 5 years	Vessel in fishery at least 2 years, and ≥ 50 daily records in 5 years
Catch (kg)	1–35000	1–35000
Hooks	20–10000	20–10000

The model

Annual unstandardised (raw) CPUE indices were calculated as the mean of the catch per tow (kg) for tow-by-tow data, or catch per vessel-day for line data. Estimates of relative year effects were obtained from a stepwise multiple regression method, where the data were fitted using a lognormal model using log transformed non-zero catch-effort data. A forward stepwise Generalised Linear Model (Chambers & Hastie 1991) implemented in R code (R Development Core Team 2012) 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.

For trawl analyses, model fits to the lognormal component of the combined model were investigated using standard residual diagnostics. For the binomial component, model fits were investigated visually using randomised quantile residuals (Dunn & Smyth 1996). Randomised quantile residuals are based on the idea of inverting the estimated distribution function for each observation to obtain exactly standard normal residuals. For discrete distributions, such as the binomial, some randomisation was introduced to produce continuous normal residuals.

Variables were either categorical or continuous, with model fits to continuous variables being made as third-order polynomials. Model fits to continuous variables were modelled as third-order polynomials, although a fourth-order polynomial was also offered to the models for duration. 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 CVs represent the ratio of the standard error to the index. The 95% confidence intervals are also calculated for each index.

Interaction terms with method were used for trawl fisheries with more than one method in the dataset, but were not used in the line fisheries, as in the past their inclusion resulted in some implausible *vessel* coefficients, so they were excluded (Horn & Ballara 2012).

Model predictions for all variables selected into the final model were plotted against 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). If different fixed values were chosen, the values on the *y*-axis would change but the appearance of the plots would be unchanged.

The influence of each variable that was not an interaction term that was accepted into the lognormal models was described by influence plots (Bentley et al. 2012). They show the combined effect of (a) the expected log catch for each level of the variable (model coefficients) and (b) the distribution of the levels of the variable in each year, and therefore describe the influence that the variable has on the unstandardised CPUE and which is accounted for by the standardisation.

Model fits to the model were investigated using standard residual diagnostics. For each model, a plot of residuals against fitted values and a plot of residuals against quantiles of the standard normal distribution were produced to check for departures from the regression assumptions of homoscedasticity and normality of errors in log-space (i.e., log-normal errors).

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

Results

CPUE series for the ling trawl and line fisheries for Cook Strait and WCSI are presented. For the analyses of TCEPR and observer data from both fisheries, the estimated catch of ling, number of tows, proportion of zero catches, the number of vessels involved, and unstandardised CPUE by year for the initial and final datasets used in the standardised analysis (i.e., following initial grooming and removal of seldom-fished areas) are given in Table B2. For the line data, the number of records of days fished in each statistical area, total numbers of days fished, the estimated catch of ling, and the number of vessels involved, by year are also presented in Table B2.

WCSI (LIN 7WC) trawl

The WCSI ling trawl catch is mainly bycatch in the hoki target fishery (Figure B1a), although the ling caught in hake or ling target tows has increased since 2005. The timing of the catch on the WCSI varied slightly between years, but most catch was taken from May to October, often with a peak from June to September during the hoki spawning season (Figure B1a). Most of the catch was taken in Statistical Areas 033–036. Over 88% of the catch was recorded on the TCEPR form, and 59% was taken by bottom trawling (Figure B1a).

Available TCEPR data from vessels believed to be accurately reporting ling bycatch in the trawl fishery targeting spawning hoki off WCSI is summarised in Table B2a. There were more vessels and catches targeting hoki in the 1990s than the 2000s, however more of the accurate tows and catches are from 1999–2006 (Table B2a, Figure B2a). After data grooming and selection of accurate vessels, there were 35 113 tows, with 426–3785 tows each year. Of the 71 vessels included in the accurate data, none had fished in all years, but 52 had fished in more than 5 years.

Seven variables were selected for the ling TCEPR accurate lognormal model, producing a total r^2 of 24%, with 11% attributable to *vessel*. (Table B3). Five variables were selected for the binomial model resulting in a similar total r^2 of 14%, with *depth of net in method* explaining most variance.

The standardised year effects from the lognormal model (Table B4, Figure B3) produce a series with an increasing trend to 1996, and then an overall declining trend to 2011; most indices before 2000 are greater than one, and most indices after 2000 are less than one. The unstandardised indices of non-zero catch per tow had a similar trend to the standardized indices (Figure B3). The binomial series is relatively flat, while the combined indices are similar to the lognormal indices (Figure B4). Indices from an all vessel dataset or accurate vessels targeting hoki show similar trends to the accurate indices (Figure B5a), however indices with both bottom and midwater tows in the dataset seem to be an average of datasets with either only bottom or midwater tows. For the bottom tows there seems to be no difference between whether all data, accurate vessel data or accurate vessel data targeting hoki are used (Figure B5a), however for midwater tows there is a difference between all data indices and accurate vessels, or accurate vessels targeting hoki.

Expected catches of ling for accurate vessels decreased from about 1 July to mid-August and then increased through to the end of September (Figure B6a). Higher catches tended to occur in tows close to midday. Catch rates increased with duration, and peaked at a net depth of about 400 m, and were higher for lower and higher headlines (Figure B6a). A zero ling catch is very unlikely with a *depth of net* between 300–600 m, but is more likely in August and September, and for vessels with a *headline* between 60 and 80 m (Figure B7a).

Influence plots (Figures B8a) show that there is a negative to positive trend influence on vessels for the fishing years 1994–2007, with a differing pattern before and after these years. Day of year moves from positive to negative from 1991–2006 with the years 2007–2011 positive, although these shifts are not as large as for vessel, so their overall influence is lesser. These two variables influenced CPUE with no clear trend in the first 4–5 years, or last 5 years of the series, but with a steadily changing trend throughout the middle of the series. Influence of mid time of tow on CPUE is minimal.

The diagnostics for both lognormal and binomial models were good and the quantile-quantile plots indicated very little deviation from the normal distribution of the residuals at both the lower and upper ends, i.e., very small and very large catch rates were well modelled (Figures B9 and B10).

Data collected by observers from the target trawl fishery for hoki off WCSI were also analysed to produce a CPUE series, using the combined model. Data from 71 vessels were included (Table B2b, Figure B2b). Although 30 of these vessels had been observed in only two years, 37 had been observed in 5 or more years (with the maximum being 11 years). There were 22 253 tows in the data set, of which almost 5649 (25%) reported no ling catch (Table B2b). About 35% of the midwater tows were reportedly fished on the bottom. Data from the three method categories were included in the model, and *method* was offered as an explanatory variable.

The final lognormal model explained 40% of total variance, with *vessel* and *latitude* explaining about 17%; in the binomial model, *year* explained about 1% of the variance, with the final model explaining 14% (Table B3). The standardised year effects from the lognormal model (Table B4c, Figure B3) produce a series that is spiky, but appears to increase from 1992 to about 1996, decline to 2009, and then increase to 2011. The binomial series has a flattish trend, and the combined indices are similar to the lognormal model (Figure B4). Observer combined indices show a similar trend to the previous observer analysis, and this series does seem to follow the TCEPR accurate series, although indices diverge in the last few years (Figure B5a).

Expected catches tended to be higher further east and south, tended to be lower around August, were higher for long tow *duration* especially for midwater tows, were greater in tows fishing at 400–600m, and were greater for lower *headline* heights (Figure B6b). The probability of a non-zero ling catch was highest for tows that were deeper, further west and north, and around August (Figure B7b). Bottom trawls were marginally less likely to get a zero catch of ling than midwater trawls, more likely to get a zero catch at shallower depth of net, and less likely to get zero catches with higher *headline*. *Duration* has a relatively weak effect on the probability of a zero ling catch.

Influence plots (Figures B8b) show that fleet dynamics and behaviour have changed. The vessel and day of year influence on CPUE has moved from positive to negative to positive, so these variables have a large overall influence on observed CPUE from year to year. Vessel has a large negative influence in 1993. There were shifts in longitude and latitude, including large effects in some years: for latitude, large positive shifts in 1994 and 2010, and a large negative shift in 1995, and for longitude, large positive shifts in 2004–2006, and a large negative shifts in 1993–1994 and 2009–2011.

The model assumptions were well satisfied, with very balanced residuals and no significant deviations from normality (Figures B9 and B10).

West coast South Island (LIN 7WC) line

WCSI line fisheries catch ling throughout the year, but more catch is taken from July to November (Figure B1b). Over 98% of the catch is taken by the bottom longline method and 95% of the catch is from target ling lines. Most of the line catch is taken in Statistical Areas 032–034, and by smaller inshore vessels using fewer than 5000 hooks/day.

The WCSI final analysis included 10 224 records of days fished throughout the 22 years analysed (Table B2c), and the estimated catch from this effort was 73% of the total estimated catch by line fishing in this area. Line fishing has accounted for about a third of the LIN 7 landings since 1990, although the line fishery produced 22–53% of the catch annually from 1991 to 2011 (Tables A2 and A3). The final analysis included data from 18 vessels (Figure B2c), and of these one had fished in all 22 years of the series, two had fished in 21 years, and 15 vessels had fished in six or more years.

For the lognormal model, four variables were selected with *vessel* explaining 18% (from a total of 34%) of total variance (Table B3). Other variables selected included *total hooks* and *month*. The standardised year effects (Table B4c, Figure B3) are variable, but with an overall increasing trend from 1996 to 2011, which matches the increases in the raw index. The overall trend is similar to the previous analysis (Figure B5a), although does not seem to follow the trend in either of the trawl series.

The predicted values indicated higher expected catch rates with increased total hooks, and highest catch rates from August to October (the spawning season) (Figure B6c). Vessels catching the most ling had higher expected catches (but not the highest expected catches) and had lower variability.

Influence plots (Figures B8c) suggest some change in fleet dynamics, as the vessel influence on CPUE was negative from 1990–1992, had a big positive shift in 1993, and has generally moved from positive to negative since then, except for a positive shift in 2008. Total hooks per day shows a general trend from negative to positive, although with a positive peak around 1998. Influence of month ranged between 0.9 and 1.1, so does not have much influence on the CPUE from year to year.

The model shows no marked patterns in the residuals (Figure B9c) although the diagnostics for the lognormal model were poor; the quantile-quantile plots indicated a deviation from the normal distribution of the residuals at the lower, suggesting that very small catch rates were not well modelled. The poorly estimated points (i.e., those with residuals smaller than –3) are a very small fraction of the total data set.

Cook Strait (LIN 7CK) trawl
The Cook Strait ling trawl fishery is mainly bycatch in the hoki target fishery (Figure B1c). The timing of the catch has been all year around since 1995, but most catch has been taken from May to October, often with a peak from June to September during the hoki spawning season (Figure B1c). Most of the catch was taken in statistical areas 016 and 017, but 017 (which takes in Cook Strait Canyon) provides more catch. Over 77% of the trawl catch is recorded on the TCEPR form, and 67% of the catch is taken by midwater trawling (Figure B1c), with little bottom trawling for hoki conducted in this area before 1994. In the Cook Strait target hoki trawl fishery there were 33 181 tows, ranging from 486 to 4552 per year (Table B2d). Of the 39 vessels included in the final analysis, one had fished in all years, and 20 had fished in six or more years (Figure B2d). Three vessels produced about 52% of the catch.

Five variables were selected for the ling TCEPR lognormal model, producing a total r^2 of 34%, with 18% attributable to *vessel* (Table B3). Five variables were also selected for the binomial model resulting in a total r^2 of 26%, with *vessel* explaining most variance.

The standardised year effects (Table B4d, Figure B3) indicate a slight decline from 1994 to 1999, followed by a slight increase to 2001, and a subsequent steady decline to 2011. The individual indices have narrow confidence bounds. The unstandardised indices of non-zero catch per tow had a similar trend to the standardized indices (Figure B3). The binomial series is relatively flat, while the combined indices are similar to the lognormal indices (Figure B4). Indices are similar to the previous analysis (Figure B5b).

Expected catches of ling decreased from about 1 July to mid-August and then increased through to the end of September (Figure B6d). Higher catches tended to occur in Statistical Area 017. Catch rates increased with duration up to 4 hours for bottom tows, and were higher for longer midwater tows. A zero ling catch is more likely in August, in the north of Cook Strait, for vessels with a lower overall catch of ling, and for very short or long tows (Figure B7c).

Influence plots (Figures B8d) for the lognormal model showed that for vessels there is an oscillating trend between negative and positive influence on CPUE suggesting there is a possible change in fleet dynamics. Overall influence of statistical area on CPUE is very small but moves from negative in 1994 to positive by 2011, showing there is a change in fishing area. Day of year had small shifts negative and positive, so its overall influence is minimal.

The diagnostics for both lognormal and binomial models were good and the quantile-quantile plots indicated a very little deviation from the normal distribution of the residuals at both the lower and upper ends, i.e., very small and very large catch rates were well modelled (Figures B9 and B10).

Observed tows from the target trawl fishery for hoki in Cook Strait from June to September were analysed to produce a CPUE series. From 1998 to 2011 there were 2284 observed tows ranging from 86 to 244 per year (Table B2e). Because of the relatively low number of tows, these results should be treated with caution. The final lognormal model explained 37% of total variance, with *vessel* alone explaining 24%. In the binomial model, *vessel* explained about 14% of the variance, and the final model explained 20% (Table B3). The binomial index showed an increasing trend, however it did not affect the combined model as standardised year effects from the lognormal and combined model show a declining trend from 2000 to 2011 (Table B4e, Figure B3), with the overall trend similar to the previous analysis. The combined model shows a steeper but similar declining trend to the TCEPR series (Figure B5b).

Expected catches of ling from observed tows show higher expected catch rates in June, for longer tows, and for tows further west and south (Figure B6e). A zero ling catch is more likely for vessels with a lower overall catch of ling, for short or long tows, and for shallow or deep tows (Figure B7d). Influence plots for the lognormal model showed positive extremes for vessel in 1999 and 2001, and a negative extreme in 2003; a positive influence on years with June data; and a trend from positive to negative for distance towed (Figure B8e).

The diagnostics for both lognormal and binomial models were good and the quantile-quantile plots indicated little deviation from the normal distribution of the residuals at both the lower and upper ends, i.e., very small and very large catch rates were well modelled (Figures B9 and B10).

Cook Strait (LIN 7CK) line

The Cook Strait line fishery has taken about 30% of the ling landings from this area since 1990, although it took about 17% of landings during the 1990s, and about 35% of the landings since 2000 (Tables A2 and A3). Cook Strait line fisheries catch ling throughout the year, but more catch is taken from April to July (Figure B1d). Over 82% of the catch is taken by the bottom longline method, although bottom longline and dahn line are both used, and 92% of the catch is from target ling lines. Most of the line catch is taken in Statistical Area 016, although smaller amounts are taken in Statistical Area 017. Most catch is taken by larger inshore vessels using less than 5000 hooks/day. Three large auto-longline vessels have fished since 1998, so since then more catch has been taken by vessels setting 10 000–35 000 hooks/day. The ling target line fishery had relatively few records in 1997–2001, 2006, and 2008–2011 (Table B2f), but data from all years were included in the analysis. Data from 14 vessels were incorporated in the final analysis, and one of these had fished in all but the six most recent years of the series (Figure B2f). Nine vessels had fished in six or more years. Only one auto-longline vessel met the data selection threshold (see Section 1.3).

For the lognormal model, variables *vessel* and *total hooks* were selected and explained 68% of total variance (Table B3). The standardised year effects (Table B4f, Figure B3) are quite variable showing a slight decline to 1995, followed by an increase to 2002, and then a steady decline to 2011. This trend does not match the trend in the raw index, although is similar to the previous analysis, and matches the TCEPR and observer series (Figure B5b). An analysis of a subset of the data with 50–5000 hooks (i.e., removing the auto-longline vessel) produced similar indices (Figure B5b).

The predicted values indicated higher expected catch rates with increased total hooks (Figure B6f). Vessels catching the most ling had higher expected catches (but not the highest expected catches) but not lower variability. Influence plots (Figures B8f) show that fleet dynamics may have changed as the overall vessel influence on CPUE moved from negative to positive. Total hooks per day also shows a general trend from negative to positive, with some large positive shifts in 1999, 2001, and 2006–2009 when the auto-longline vessel fished the area.

The model shows no marked patterns in the residuals (Figure B9f) although the diagnostics for the lognormal model were poor; the quantile-quantile plots indicated a deviation from the normal distribution of the residuals at the lower and upper ends, suggesting that very small and large catch rates were not well modelled.

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 2009, Horn & Francis 2013, Horn et al. 2013). CPUE has been the only relative abundance series available for LIN 7CK, and LIN 7WC before the current assessment.

Trawl fishery ling bycatch series

The CPUE series for ling bycatch in the target hoki trawl fisheries in Cook Strait and off WCSI have been updated using TCEPR data and observer data.

For the WCSI trawl fishery, there has been active avoidance of ling since 2000 (Horn 2006b), and there are still incentives to dump or under-report ling (believed to have occurred especially regularly before 1994) (Horn 2006b). Hence the 'accurate' TCEPR series was developed by using observer data to identify years when particular vessels were likely to have comprehensively reported their ling bycatch (Horn 2006b). Overall 'accurate' TCEPR data is 47% of total estimated catch (see Table B2a), and this data set selection strongly indicated that ling bycatch had been frequently not reported on the 'estimated catch' section of the TCEPRs especially from 1990 until at least 2001. The 'accurate' TCEPR combined model was updated and the incorporation of the reported zero tows in the combined model has little effect on the lognormal series (see Figure B4), with the series showing a slight increasing trend to 1996, and then an overall declining trend to 2011. The TCEPR combined model for all TCEPR data or TCEPR accurate vessels targeting hoki showed a similar trend (see Figure B5).

There may be changes in fleet dynamics as influence plots show a steadily changing trend throughout the middle of the series (Figure B8). In the previous assessment of WCSI ling (Horn 2009), the Middle Depth Species Working Group chose the accurate trawl CPUE series for 1999 onwards, as there was a large proportion of vessels before 1999 not reporting ling accurately on a tow-by-tow basis. This may still be the sensible choice, although given the fleet changes in recent years it is possible that the last few years of the CPUE series may not be representative of abundance.

A combined model using observer data from the WCSI hoki and hake target trawl fishery was updated. There is a large volume of data used in the analysis, but many of the vessels (30 out of 71) contributed to the series in only two years. The resulting series was spiky, but appears to increase from 1992 to about 1996, decline to 2009, and then increase to 2011. Most of the explanatory variables selected into the observer model were the same as those selected into the TCEPR model (see Table B2). The overall year effects were similar between series (see Figure B5), although indices diverged in the last few years: the TCEPR series increased from 2007 to 2009 and then decreased, while the observer series decreased to 2009 and then increased. There is no way of establishing which of the two data sources is likely to produce the more reliable index series. Consequently, we can still not be confident that a reliable index of ling abundance is available from the trawl fishery.

Horn (2004a) discussed the reliability of the TCEPR data from the Cook Strait trawl fishery and concluded that ling in Cook Strait hoki target catches would be sufficiently abundant to be consistently reported on the TCEPR forms and any changes in fishing practice would probably have been accounted for by the variables accepted into the CPUE models. As there were marked changes in fleet structure that occurred around 1994 (Horn & Ballara 2012), it was considered desirable to place lower weighting on the CPUE series before then, and rely on the series starting in 1994. Either ling were more abundant in the early 1990s, or some as yet unidentified change in reporting or fishing behaviour by fishers has biased the series (Horn & Ballara 2012). The TCEPR model was updated for the years 1994 to 2011, and the combined series showed a decline from 1994 to 1999, a slight increase to 2001, and a subsequent decline to 2011. The combined model using observer data from the Cook Strait hoki target trawl fishery was updated for 1998 to 2011, was relatively data poor, and was indicative of a steady decline in abundance since about 2000 (see Figure B4). Both Cook Strait trawl series are indicative of an increase in biomass to 2000 or 2001 followed by a decline in biomass, with the 2011 indices being the lowest in both series (see Figure B5).

Longline target ling fisheries series

Horn (2002) concluded that most ling line CPUE series performed well in relation to 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) with the exception of the Cook Strait longline series.

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. In both longline analyses, *total hooks* and *vessel* were selected into the model, and *month* was accepted into the WCSI model. Skill levels and/or gear efficiency will vary between vessels so the selection of a *vessel* variable in each model would be expected, although vessel catch rates seldom differed by more than a factor of 4 in each stock. With the CPUE unit being ‘kg per day’, it would be expected that the number of hooks set per day would be influential. Clearly, catch rates vary throughout the year, probably in relation to the spawning season for ling. Hence, *month* was an important explanatory variable on the WCSI.

It is apparent from influence plots that the fleet dynamics in the line fisheries have changed, with periods when several vessels ceased to operate and new ones entered the fishery (Figure B8). 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).

The CPUE from the Cook Strait ling line fishery is considered to be the least reliable line series. This series may be biased owing to the existence of target line fisheries for bluenose and hapuku (Horn & Ballara 2012). Ling is often taken as a bycatch in these fisheries, and the distributions of the three species overlap in depth and area. The CPUE analysis uses only data where ling was the stated target species. If it is general practice to define the reported target species as the most abundant species once the catch is onboard, then any real decline in ling abundance would be underestimated in the CPUE series (because only sets where ling was the most abundant species would be included in the analysis). However, fishing practices and areas can differ when targeting each of the three species, so the reported target is often likely to be the true target. The approximate doubling of biomass between 1998 and 2002 indicated by the CPUE series could have been achieved through growth and recruitment, but if so, it does represent an exceptional increase for a fished population. The possibility of population enhancement by migration from other areas cannot be ruled out. Hence, although the reliability of this CPUE series is questionable, there are no factors that have obviously biased this series.

The WCSI line series may be biased to some extent. The fishery generally targets ling on clearly defined geological features using relatively short longlines that can be accurately placed. The accurate placement of fishing gear in optimal ling habitat could enable a degree of hyperstability in the CPUE indices. Also, some interactions with the trawl fishery in the same area could also lead to biases.

The line fishery CPUE analyses presented here may not provide sets of indices that are valid as relative abundance series (for that section of the population exploited by the fisheries) in stock assessment models for ling.

Summary
CPUE series from both the trawl and line fisheries are available for the Cook Strait and WCSI stocks; in both areas there are some differences in the trends from the two fishing methods. However, indices from a different data source in an individual stock would not necessarily be expected to exhibit similar trends, owing to different fishing selectivities in the trawl and longline fisheries.

The WCSI trawl TCEPR and observer series exhibit similar overall trends but diverge from 2007. There has always been, and still is, some incentive for the trawl bycatch of ling to be actively avoided or under-reported; the use of the 'accurate' TCEPR data hopefully removed much of the bias that misreporting would introduce. The observer data series should be relatively free of biases, and is also indicative of an overall decline in ling biomass during the 2000s. The WCSI line CPUE series is spiky with an overall flat trend (Figure B5), but shows increases when the trawl series show a decrease in 1996 to 2001, and shows indices greater than one since 2007 whereas trawl indices are below one. The two trawl CPUE series are also spiky, and show more variation that the line series. For the line fishery, it is suggested that the hoki trawlers sometimes direct the line vessels to areas with apparently high ling abundance, as indicated by the trawl bycatch, thereby increasing fishing pressure on a species the trawlers are trying to avoid (Horn & Ballara 2012). This behaviour would enable line fishers to reduce their search time and/or fish in areas that are likely to produce relatively high ling catch rates, hence biasing the recent line CPUE upwards. There are also reports of trawlers directly transferring some of their ling catch (presumably for which they have no quota) to line or setnet boats; this behaviour would bias both trawl and line CPUE. However, catch-at-age data from the trawl fishery are not consistent with a fishing down of the larger older fish; fish aged 15 and over are still as abundant in the catch now as they were in the early 1990s (Horn 2009) and also indicate some relatively strong recent recruitment (Horn & Sutton 2013). Also, there is no perception by the line fishers that WCSI ling are more difficult to catch now than they were in the early 1990s, a view supported by the generally flat line series. However, there are no fishery-independent data available to validate any of the WCSI CPUE series, and while it seems likely that the biomass has declined in recent years there is still no relative abundance index series that can confidently be used in stock assessments of LIN 7WC.

All three Cook Strait CPUE series exhibit similar trends, i.e., a decline followed by a recovery, and then another decline from 2000–2002 to 2011 (see Figure B5). The TCEPR trawl series is based on extensive data, but relies on consistent and relatively accurate estimation of ling bycatch per tow. The observer trawl series is based on a small proportion of the catch. The line series is disadvantaged by having few vessels and low data volumes in most years, and the potential for some bias as a result of being able to determine the target species after the catch is landed. There are no fishery-independent data available to validate either of the Cook Strait CPUE series.

Table B1: Summary of the variables offered in the CPUE models for the trawl and line fisheries. All continuous variables were third order polynomials except for duration which was offered as both third and fourth order polynomials.

Variable	Type	Description
Line fisheries		
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
Method	Categorical	Fishing method (bottom longline, trot line, dahn line)
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
Trawl fisheries		
Year	Categorical	Fishing year, or June–September
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
Method	Categorical	Trawl method (bottom trawl, midwater trawl on bottom, midwater trawl)
Twin trawl	Categorical	Vessel did or did not use a twin trawl
Headline height	Continuous	Distance between trawl headline and groundrope (m)
Duration	Continuous	Tow duration, in hours
Start time	Continuous	Start time of tow, 24-hour clock
Mid time	Continuous	Time at the midpoint of the tow, 24-hour clock
Depth bottom	Continuous	Bottom depth (m)
Depth net	Continuous	Depth of groundrope (m)
Speed	Continuous	Towing speed (kts)
Latitude	Continuous	Start latitude of tow
Longitude	Continuous	Start longitude of tow
CPUE	Continuous	Ling catch (kg) per tow

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 tow records for non-zero and zero ling catches for trawl data (Tows), number of vessel-days overall for non-zero and zero ling catches for line data (Days), proportion of tows (trawl data) or vessel-days (line data) that caught zero catch (Zeros), estimated catch, and unstandardised CPUE from non-zero catches from the tow-by-tow data.

(a) WCSI TCEPR tow-by-tow data

	All data					Final CPUE data (Accurate vessels)				
Year	Vessels	Tows	Zeros	Catch (t)	CPUE	Vessels	Tows	Zeros	Catch (t)	CPUE
1990	76	8 243	0.57	1563.6	0.44	14	1 459	0.25	478.3	0.44
1991	73	8 416	0.75	972.6	0.46	14	821	0.29	379.2	0.65
1992	67	6 470	0.75	657.3	0.41	14	682	0.35	216.3	0.49
1993	62	7 524	0.80	725.9	0.48	12	502	0.20	219.6	0.54
1994	67	9 312	0.80	718.3	0.39	11	474	0.28	162.1	0.47
1995	63	8 830	0.74	1 391.1	0.59	9	459	0.21	233.0	0.64
1996	61	7 318	0.64	1 215.4	0.46	11	681	0.34	268.3	0.60
1997	78	8 621	0.70	1 199.9	0.46	13	631	0.38	202.6	0.52
1998	68	8 155	0.64	1 428.3	0.48	23	1 925	0.34	596.5	0.47
1999	58	7 285	0.54	1 544.0	0.46	27	2 453	0.26	973.9	0.54
2000	51	7 365	0.54	1 452.7	0.43	24	2 441	0.26	768.2	0.43
2001	63	8 513	0.46	1 830.2	0.40	34	3 785	0.27	1 226.1	0.44
2002	56	7 774	0.45	1 766.8	0.41	25	3 521	0.25	1 015.8	0.38
2003	51	7 590	0.48	1 391.8	0.35	23	3 254	0.21	901.5	0.35
2004	51	6 631	0.41	1 549.1	0.39	28	3 583	0.23	1 120.8	0.40
2005	38	4 286	0.47	1 021.2	0.45	19	1 719	0.22	616.6	0.46
2006	36	4 260	0.42	1 228.9	0.50	20	1 961	0.23	733.7	0.49
2007	33	2 947	0.57	690.0	0.55	6	426	0.27	154.4	0.50
2008	25	2 326	0.42	537.3	0.40	13	1 198	0.25	331.5	0.37
2009	24	1 975	0.51	492.3	0.51	6	452	0.16	187.2	0.49
2010	28	2 336	0.42	645.3	0.48	14	987	0.14	390.3	0.46
2011	27	3 065	0.37	900.3	0.47	20	1 699	0.21	642.9	0.48
Total	245	139 242		24 922.1		71	35 113		11 819.0	

Table B2: continued.

(b) WCSI observer data

	All data					Final CPUE data				
Year	Vessels	Tows	Zeros	Catch (t)	CPUE	Vessels	Tows	Zeros	Catch (t)	CPUE
1987	25	2 414	0.44	241.5	0.18	13	1 368	0.43	151.7	0.19
1988	22	2 490	0.30	690.4	0.40	16	2 099	0.28	587.8	0.39
1989	14	1 472	0.33	473.1	0.48	10	1 047	0.30	302.2	0.41
1990	14	1 544	0.15	646.2	0.50	8	992	0.11	368.4	0.42
1991	14	1 257	0.32	240.6	0.28	7	600	0.29	137.5	0.32
1992	12	859	0.36	147.5	0.27	9	385	0.20	107.7	0.35
1993	15	1 248	0.48	168.0	0.26	14	993	0.50	117.4	0.24
1994	15	1 640	0.50	169.9	0.21	11	959	0.46	100.3	0.19
1995	9	845	0.15	223.5	0.31	8	612	0.15	168.4	0.32
1996	15	1 070	0.21	282.0	0.33	10	813	0.19	220.6	0.33
1997	12	698	0.34	129.6	0.28	12	667	0.34	121.4	0.28
1998	16	908	0.22	325.7	0.46	12	797	0.23	275.4	0.45
1999	14	1 114	0.22	288.6	0.33	14	1 094	0.21	274.7	0.32
2000	17	1 158	0.28	286.7	0.34	16	1 139	0.28	277.0	0.34
2001	21	1 019	0.20	246.7	0.30	19	951	0.20	226.5	0.30
2002	16	1 320	0.16	508.5	0.46	15	1 223	0.16	439.0	0.43
2003	13	958	0.24	192.7	0.27	13	803	0.23	149.2	0.24
2004	16	1 382	0.12	509.3	0.42	14	1 175	0.12	382.1	0.37
2005	13	1 067	0.11	289.6	0.31	12	1 016	0.11	263.9	0.29
2006	15	1 124	0.17	290.4	0.31	15	1 017	0.16	242.6	0.28
2007	16	672	0.35	81.5	0.19	16	517	0.36	66.4	0.20
2008	14	739	0.31	96.0	0.19	14	586	0.30	80.6	0.20
2009	16	562	0.29	73.2	0.18	15	460	0.29	57.0	0.17
2010	14	569	0.17	137.7	0.29	13	398	0.15	88.3	0.26
2011	11	635	0.19	225.6	0.44	11	542	0.20	168.7	0.39
Total	245	28 764		6 964.5		71	22 253		5 374.5	

Table B2: continued.

(c) WCSI line data

	All data					Final CPUE data (Accurate vessels)				
Year	Vessels	Days	Zeros	Catch (t)	CPUE	Vessels	Days	Zeros	Catch (t)	CPUE
1990	16	347	0.01	247.7	0.72	6	208	0.00	181.5	0.87
1991	17	535	0.01	500.1	0.94	8	307	0.00	331.4	1.08
1992	22	746	0.00	820.8	1.10	9	502	0.00	669.6	1.33
1993	18	595	0.00	683.6	1.15	9	412	0.00	579.5	1.41
1994	22	657	0.00	847.2	1.29	10	453	0.00	679.6	1.50
1995	23	685	0.00	857.8	1.26	11	532	0.00	752.4	1.41
1996	25	717	0.04	781.1	1.13	12	589	0.00	729.0	1.24
1997	23	696	0.03	824.1	1.22	11	540	0.00	763.6	1.41
1998	18	711	0.07	933.5	1.42	8	537	0.00	853.0	1.59
1999	20	723	0.08	803.3	1.21	9	495	0.00	686.8	1.39
2000	22	710	0.00	866.7	1.22	10	515	0.00	692.5	1.34
2001	20	673	0.00	845.6	1.26	10	498	0.00	743.4	1.49
2002	18	544	0.00	615.4	1.13	9	445	0.00	605.6	1.36
2003	20	637	0.00	753.3	1.18	9	519	0.00	686.4	1.32
2004	21	551	0.00	641.6	1.17	10	394	0.00	528.8	1.34
2005	20	787	0.00	666.8	0.85	9	589	0.00	631.1	1.07
2006	13	567	0.00	566.7	1.00	7	423	0.00	498.6	1.18
2007	15	712	0.00	928.9	1.31	9	536	0.00	861.6	1.61
2008	18	646	0.00	850.6	1.32	9	430	0.00	718.8	1.67
2009	18	653	0.00	825.0	1.27	9	464	0.00	702.1	1.51
2010	16	678	0.00	947.3	1.40	9	497	0.00	846.4	1.70
2011	13	471	0.00	638.9	1.36	6	339	0.00	558.7	1.65
Total	95	14 041		16 446.1		18	10 224		14 300.5	

(d) Cook Strait TCEPR tow-by-tow data

	All data					Final CPUE data				
Year	Vessels	Tows	Zeros	Catch (t)	CPUE	Vessels	Tows	Zeros	Catch (t)	CPUE
1994	30	1 990	0.69	113.6	0.18	20	1 302	0.62	80.4	0.16
1995	24	2 248	0.68	109.1	0.15	22	1 819	0.65	98.9	0.16
1996	41	4 424	0.80	115.7	0.13	31	2 889	0.77	89.7	0.14
1997	39	4 552	0.74	158.9	0.14	30	3 237	0.71	118.6	0.13
1998	29	2 812	0.62	112.6	0.11	24	2 059	0.58	96.4	0.11
1999	21	2 459	0.51	118.7	0.10	19	1 858	0.48	102.6	0.11
2000	22	2 173	0.53	110.9	0.11	21	1 652	0.49	98.2	0.12
2001	25	1 899	0.48	127.6	0.13	20	1 429	0.48	109.5	0.15
2002	16	1 042	0.46	71.9	0.13	14	824	0.39	66.3	0.13
2003	20	1 855	0.51	120.4	0.13	13	1 160	0.44	82.8	0.13
2004	19	1 788	0.54	108.0	0.13	16	1 354	0.47	100.2	0.14
2005	14	1 357	0.50	94.8	0.14	13	1 064	0.44	89.4	0.15
2006	11	1 011	0.49	61.2	0.12	11	809	0.45	57.2	0.13
2007	7	898	0.59	37.6	0.10	6	745	0.56	35.0	0.11
2008	5	568	0.48	42.0	0.14	4	459	0.41	40.6	0.15
2009	7	813	0.65	17.3	0.06	5	587	0.64	14.1	0.07
2010	8	806	0.69	16.9	0.07	6	687	0.68	15.6	0.07
2011	6	486	0.70	5.3	0.04	6	410	0.69	4.7	0.04
Total	66	33 181		1 542.5		39	24 344		1 300.1	

Table B2: continued.

(e) Cook Strait observer data

	All data					Final CPUE data				
Year	Vessels	Tows	Zeros	Catch (t)	CPUE	Vessels	Tows	Zeros	Catch (t)	CPUE
1998	11	213	0.31	6.8	0.05	9	160	0.28	5.2	0.04
1999	10	216	0.31	15.6	0.11	8	157	0.25	13.2	0.11
2000	7	153	0.21	9.2	0.08	6	109	0.13	8.5	0.09
2001	9	235	0.29	14.8	0.09	6	146	0.21	12.5	0.11
2002	9	141	0.38	6.0	0.07	4	71	0.18	4.3	0.07
2003	5	133	0.36	5.1	0.06	4	91	0.34	3.6	0.06
2004	7	130	0.29	4.0	0.04	5	76	0.24	2.5	0.04
2005	9	124	0.39	3.8	0.05	4	67	0.31	2.1	0.05
2006	5	65	0.49	1.9	0.06	4	49	0.45	1.6	0.06
2007	7	169	0.39	9.7	0.09	5	113	0.35	7.8	0.11
2008	6	203	0.60	7.2	0.09	5	155	0.57	6.5	0.10
2009	6	172	0.45	2.6	0.03	4	107	0.40	1.7	0.03
2010	9	244	0.54	4.0	0.04	6	185	0.50	3.7	0.04
2011	5	86	0.69	0.3	0.01	4	64	0.64	0.3	0.01
Total	31	2 284		91.0		14	1 550		73.4	

(f) Cook Strait line data

	All data					Final CPUE data				
Year	Vessels	Days	Zeros	Catch (t)	CPUE	Vessels	Days	Zeros	Catch (t)	CPUE
1990	21	204	0.02	58.5	0.29	6	79	0.00	36.2	0.46
1991	23	203	0.02	53.0	0.27	8	78	0.00	33.3	0.43
1992	16	189	0.01	78.3	0.42	8	117	0.00	51.2	0.44
1993	16	251	0.02	84.1	0.34	9	163	0.00	69.4	0.43
1994	24	321	0.02	65.4	0.21	8	159	0.00	31.5	0.20
1995	21	255	0.02	40.7	0.16	6	82	0.00	25.6	0.31
1996	14	141	0.01	34.5	0.25	4	69	0.00	27.6	0.40
1997	10	99	0.01	15.9	0.16	4	32	0.00	11.5	0.36
1998	10	117	0.00	65.3	0.56	2	55	0.00	20.0	0.36
1999	11	120	0.00	98.9	0.82	3	32	0.00	88.6	2.77
2000	14	115	0.00	82.1	0.71	3	29	0.00	56.3	1.94
2001	17	128	0.00	153.7	1.20	3	31	0.00	89.6	2.89
2002	20	189	0.00	113.1	0.60	4	92	0.00	106.6	1.16
2003	24	335	0.00	138.8	0.41	6	153	0.00	126.5	0.83
2004	19	293	0.00	196.1	0.67	8	179	0.00	186.7	1.04
2005	18	245	0.00	169.7	0.69	6	132	0.00	156.2	1.18
2006	13	117	0.00	185.5	1.59	4	60	0.00	179.9	3.00
2007	15	168	0.01	166.4	1.00	5	92	0.00	139.6	1.52
2008	15	98	0.01	80.5	0.83	2	22	0.00	63.9	2.90
2009	15	107	0.03	26.6	0.26	3	13	0.00	21.6	1.66
2010	18	103	0.01	22.9	0.22	4	12	0.00	5.3	0.44
2011	20	94	0.00	15.6	0.17	3	13	0.00	6.0	0.46
Total	107	3892		1945.6		14	1694		1533.1	

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

	Lognormal		Binomial
Variable	r^2	Variable	r^2
WCSI TCEPR tow-by-tow accurate vessel data			
Year	1.7	Year	1.1
Vessel	13.0	Vessel	4.6
Day of year	14.7	Day of year	6.2
Time mid	15.8	Method: Depth net	12.9
Method: Depth net	19.0	Method: headline	14.0
Method: Duration	22.0		
Method: Headline	23.8		
WCSI observer data			
Year	5.2	Year	6.4
Vessel	12.0	Depth of bottom	12.5
Latitude	16.7	Vessel	16.0
Longitude	20.8	Latitude	18.5
Day of year	25.1	Longitude	19.8
Method: Headline	32.5	Day of year	21.4
Method: Depth net	36.3	Method: Headline	25.1
Method: Duration	39.6	Method: Duration	27.9
		Method: Depth net	28.4
WCSI line			
Year	3.4		
Vessel	17.7		
Month	28.5		
Total hooks	34.1		
Cook Strait TCEPR tow-by-tow			
Year	5.8	Year	5.2
Vessel	15.9	Vessel	15.5
Day of year	20.1	Day of year	21.3
Latitude	21.4	Statistical area	22.9
Method:Distance2	23.3	Method:Duration	26.3
Cook Strait observer data			
Year	11.9	Year	8.9
Vessel	24.0	Vessel	14.4
Month	29.0	Duration	17.9
Distance	32.7	Depth of bottom	20.0
Longitude	35.4		
Latitude	36.9		
Cook Strait line			
Year	30.8		
Vessel	64.9		
Total hooks	67.5		

Table B4: Lognormal CPUE standardised indices for trawl and line fisheries, and binomial, and combined CPUE indices for trawl indices (with 95% confidence intervals and CVs).

(a) WCSI TCEPR tow-by-tow accurate vessel data

	Lognormal			Binomial			Combined
Year	Index	95% CI	CV	Index	95% CI	CV	Index
1990	0.97	0.88–1.08	0.05	0.95	0.87–1.03	0.04	0.97
1991	1.06	0.95–1.17	0.05	1.00	0.91–1.08	0.04	1.04
1992	0.98	0.88–1.10	0.06	1.04	0.95–1.14	0.05	0.96
1993	0.98	0.86–1.13	0.07	1.00	0.89–1.13	0.06	0.96
1994	1.37	1.21–1.55	0.06	1.02	0.92–1.14	0.05	1.34
1995	1.19	1.05–1.34	0.06	1.04	0.93–1.15	0.05	1.16
1996	1.48	1.33–1.65	0.05	1.02	0.94–1.12	0.04	1.45
1997	1.28	1.15–1.43	0.05	1.10	1.01–1.20	0.04	1.23
1998	1.11	1.04–1.19	0.03	1.09	1.03–1.16	0.03	1.07
1999	1.19	1.12–1.26	0.03	0.98	0.93–1.03	0.03	1.18
2000	1.00	0.95–1.06	0.03	1.00	0.95–1.05	0.02	0.98
2001	1.05	1.00–1.10	0.02	0.99	0.95–1.03	0.02	1.04
2002	0.93	0.89–0.98	0.02	0.96	0.92–1.00	0.02	0.92
2003	0.77	0.73–0.81	0.02	0.96	0.92–1.01	0.02	0.77
2004	1.06	1.01–1.11	0.03	0.92	0.88–0.96	0.02	1.06
2005	0.83	0.78–0.89	0.03	0.97	0.92–1.02	0.03	0.82
2006	0.77	0.72–0.82	0.03	0.98	0.93–1.04	0.03	0.76
2007	0.76	0.68–0.86	0.06	1.02	0.92–1.13	0.05	0.74
2008	0.79	0.73–0.85	0.04	1.02	0.96–1.09	0.03	0.77
2009	1.05	0.94–1.17	0.05	0.95	0.86–1.05	0.05	1.05
2010	0.89	0.82–0.96	0.04	0.99	0.92–1.05	0.03	0.88
2011	0.86	0.81–0.91	0.03	1.03	0.97–1.09	0.03	0.84

(b) WCSI observer data

	Lognormal			Binomial			Combined
Year	Index	95% CI	CV	Index	95% CI	CV	Index
1987	0.57	0.50–0.65	0.07	1.32	1.19–1.47	0.05	0.49
1988	1.01	0.90–1.12	0.06	1.11	1.01–1.21	0.05	0.92
1989	1.45	1.28–1.64	0.06	1.09	0.98–1.21	0.05	1.33
1990	1.34	1.19–1.50	0.06	0.96	0.87–1.06	0.05	1.27
1991	0.89	0.78–1.01	0.06	1.10	0.99–1.23	0.05	0.81
1992	0.82	0.71–0.95	0.07	1.07	0.94–1.22	0.06	0.76
1993	1.13	1.00–1.29	0.06	1.09	1.00–1.20	0.05	1.04
1994	0.96	0.87–1.07	0.05	0.98	0.91–1.06	0.04	0.91
1995	1.36	1.20–1.54	0.06	0.90	0.81–1.00	0.05	1.31
1996	1.81	1.64–1.99	0.05	0.92	0.85–1.01	0.04	1.73
1997	1.50	1.34–1.68	0.06	1.01	0.92–1.10	0.05	1.40
1998	1.43	1.30–1.57	0.05	0.94	0.87–1.02	0.04	1.36
1999	1.68	1.53–1.83	0.05	0.96	0.88–1.04	0.04	1.59
2000	1.30	1.19–1.41	0.04	0.96	0.90–1.04	0.04	1.23
2001	0.99	0.90–1.08	0.04	0.94	0.87–1.02	0.04	0.94
2002	1.33	1.23–1.45	0.04	0.94	0.87–1.01	0.04	1.27
2003	0.76	0.69–0.83	0.05	1.00	0.92–1.08	0.04	0.71
2004	1.17	1.07–1.27	0.04	0.92	0.85–0.99	0.04	1.12
2005	0.83	0.76–0.90	0.04	0.93	0.86–1.00	0.04	0.79
2006	0.77	0.71–0.84	0.04	0.96	0.89–1.04	0.04	0.73
2007	0.59	0.53–0.67	0.06	1.00	0.91–1.10	0.05	0.55
2008	0.58	0.52–0.65	0.06	1.06	0.97–1.16	0.05	0.54
2009	0.51	0.45–0.58	0.06	1.01	0.91–1.12	0.05	0.48
2010	0.67	0.59–0.76	0.06	0.97	0.87–1.09	0.06	0.63
2011	1.12	1.00–1.25	0.06	0.95	0.86–1.04	0.05	1.06

Table B4: continued.

(c) WCSI line data

	Lognormal		
Year	Index	95% CI	CV
1990	0.90	0.78–1.03	0.07
1991	1.07	0.95–1.21	0.06
1992	1.25	1.14–1.38	0.05
1993	0.90	0.81–0.99	0.05
1994	0.88	0.80–0.97	0.05
1995	0.90	0.82–0.98	0.04
1996	0.68	0.62–0.74	0.04
1997	0.80	0.73–0.88	0.05
1998	0.92	0.84–1.00	0.05
1999	0.95	0.87–1.04	0.05
2000	0.96	0.88–1.05	0.04
2001	1.12	1.02–1.23	0.05
2002	1.06	0.96–1.17	0.05
2003	1.10	1.01–1.20	0.04
2004	1.10	1.00–1.22	0.05
2005	0.84	0.77–0.91	0.04
2006	0.84	0.76–0.93	0.05
2007	1.11	1.02–1.21	0.04
2008	1.13	1.02–1.25	0.05
2009	1.14	1.04–1.25	0.05
2010	1.39	1.26–1.52	0.05
2011	1.28	1.12–1.46	0.07

(d) Cook Strait TCEPR tow-by-tow

	Lognormal			Binomial			Combined
Year	Index	95% CI	CV	Index	95% CI	CV	Index
1994	1.36	1.23–1.50	0.05	1.00	0.94–1.06	0.03	1.25
1995	1.33	1.22–1.46	0.04	1.09	1.03–1.14	0.03	1.16
1996	1.33	1.22–1.45	0.04	1.16	1.11–1.21	0.02	1.12
1997	1.14	1.06–1.23	0.04	1.09	1.05–1.14	0.02	1.00
1998	1.13	1.05–1.21	0.04	1.05	1.00–1.10	0.02	1.01
1999	1.08	1.01–1.15	0.03	0.95	0.91–1.00	0.02	1.02
2000	1.33	1.23–1.42	0.04	0.94	0.89–0.99	0.03	1.27
2001	1.54	1.42–1.66	0.04	0.95	0.90–1.00	0.03	1.46
2002	1.32	1.20–1.44	0.05	0.92	0.86–0.99	0.03	1.27
2003	1.34	1.24–1.46	0.04	0.95	0.90–1.01	0.03	1.27
2004	1.19	1.10–1.29	0.04	0.95	0.90–1.00	0.03	1.13
2005	1.24	1.14–1.34	0.04	0.95	0.89–1.01	0.03	1.18
2006	1.14	1.03–1.25	0.05	0.92	0.86–0.99	0.03	1.10
2007	0.83	0.74–0.92	0.06	1.07	0.99–1.15	0.04	0.73
2008	0.93	0.82–1.05	0.06	0.91	0.83–1.00	0.05	0.90
2009	0.48	0.42–0.55	0.07	1.00	0.92–1.08	0.04	0.44
2010	0.49	0.43–0.57	0.07	1.05	0.97–1.14	0.04	0.44
2011	0.27	0.23–0.32	0.09	1.10	1.00–1.21	0.05	0.23

Table B4: continued.

(e) Cook Strait observer data

	Lognormal			Binomial			Combined
Year	Index	95% CI	CV	Index	95% CI	CV	Index
1998	1.43	1.14–1.80	0.11	0.89	0.74–1.07	0.09	1.29
1999	1.26	0.99–1.60	0.12	0.97	0.80–1.18	0.10	1.10
2000	2.06	1.61–2.63	0.12	0.87	0.71–1.08	0.11	1.87
2001	1.56	1.21–2.00	0.13	0.98	0.81–1.19	0.10	1.36
2002	1.44	1.07–1.95	0.15	0.90	0.70–1.16	0.13	1.29
2003	1.52	1.10–2.10	0.16	0.94	0.72–1.22	0.13	1.35
2004	1.56	1.17–2.09	0.15	0.88	0.69–1.13	0.12	1.41
2005	1.01	0.72–1.42	0.17	0.95	0.72–1.23	0.13	0.89
2006	1.44	0.97–2.13	0.20	1.05	0.78–1.41	0.15	1.23
2007	0.57	0.43–0.75	0.14	1.04	0.85–1.26	0.10	0.49
2008	0.58	0.44–0.76	0.14	1.21	1.00–1.45	0.09	0.47
2009	0.70	0.51–0.96	0.16	1.01	0.81–1.26	0.11	0.60
2010	0.45	0.34–0.59	0.14	1.13	0.95–1.35	0.09	0.37
2011	0.34	0.22–0.52	0.21	1.27	0.98–1.65	0.13	0.27

(f) Cook Strait line data

	Lognormal		
Year	Index	95% CI	CV
1990	1.29	0.95–1.74	0.15
1991	1.44	1.11–1.87	0.13
1992	1.43	1.14–1.80	0.11
1993	1.11	0.89–1.38	0.11
1994	0.90	0.73–1.12	0.11
1995	0.83	0.65–1.06	0.12
1996	0.97	0.75–1.26	0.13
1997	1.32	0.92–1.89	0.18
1998	0.83	0.62–1.11	0.15
1999	1.54	1.08–2.22	0.18
2000	1.45	1.00–2.10	0.19
2001	1.27	0.88–1.82	0.18
2002	2.04	1.63–2.55	0.11
2003	1.66	1.35–2.03	0.10
2004	1.45	1.20–1.75	0.09
2005	1.16	0.96–1.41	0.10
2006	0.97	0.72–1.30	0.15
2007	0.70	0.55–0.88	0.12
2008	0.82	0.53–1.28	0.22
2009	0.60	0.35–1.04	0.28
2010	0.35	0.20–0.63	0.30
2011	0.22	0.12–0.40	0.30

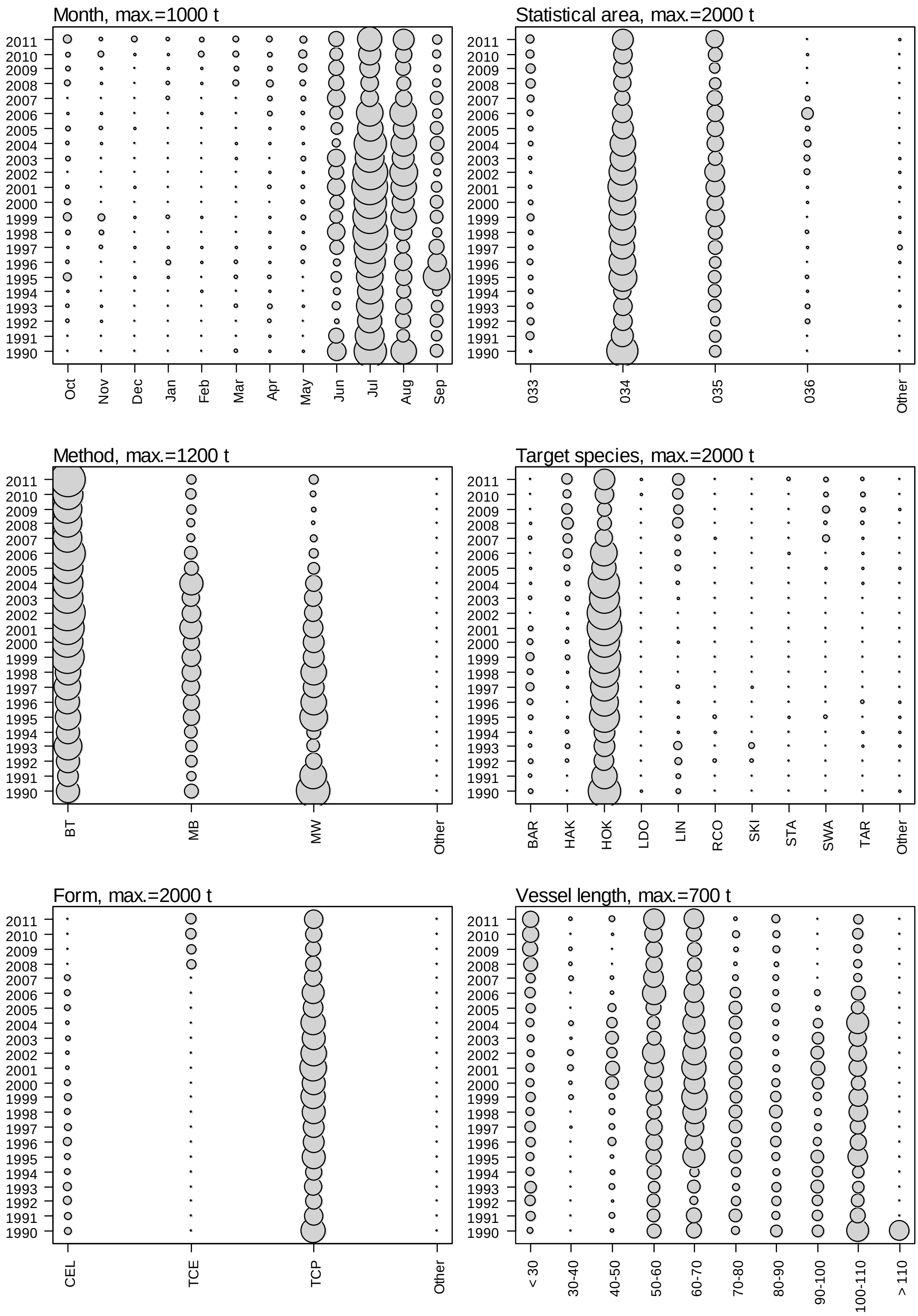


Figure B1a: Distribution of WCSI TCEPR tow-by-tow ling trawl catch by month, statistical area, method, target species, and vessel length for 1990 to 2011 calendar years. Circle size is proportional to catch; maximum circle size is indicated on the top left hand corner of each plot. Statistical areas are defined in Figure A1. Form and method definitions defined in Figure A2, although MB is midwater trawl within 5 m of the bottom. Species codes: BAR, barracouta; HAK, hake; HOK, hoki; LDO, lookdown dory; RCO, red cod; SKI, gemfish; STA, stargazers; SWA, silver warehou; TAR, tarakihi.

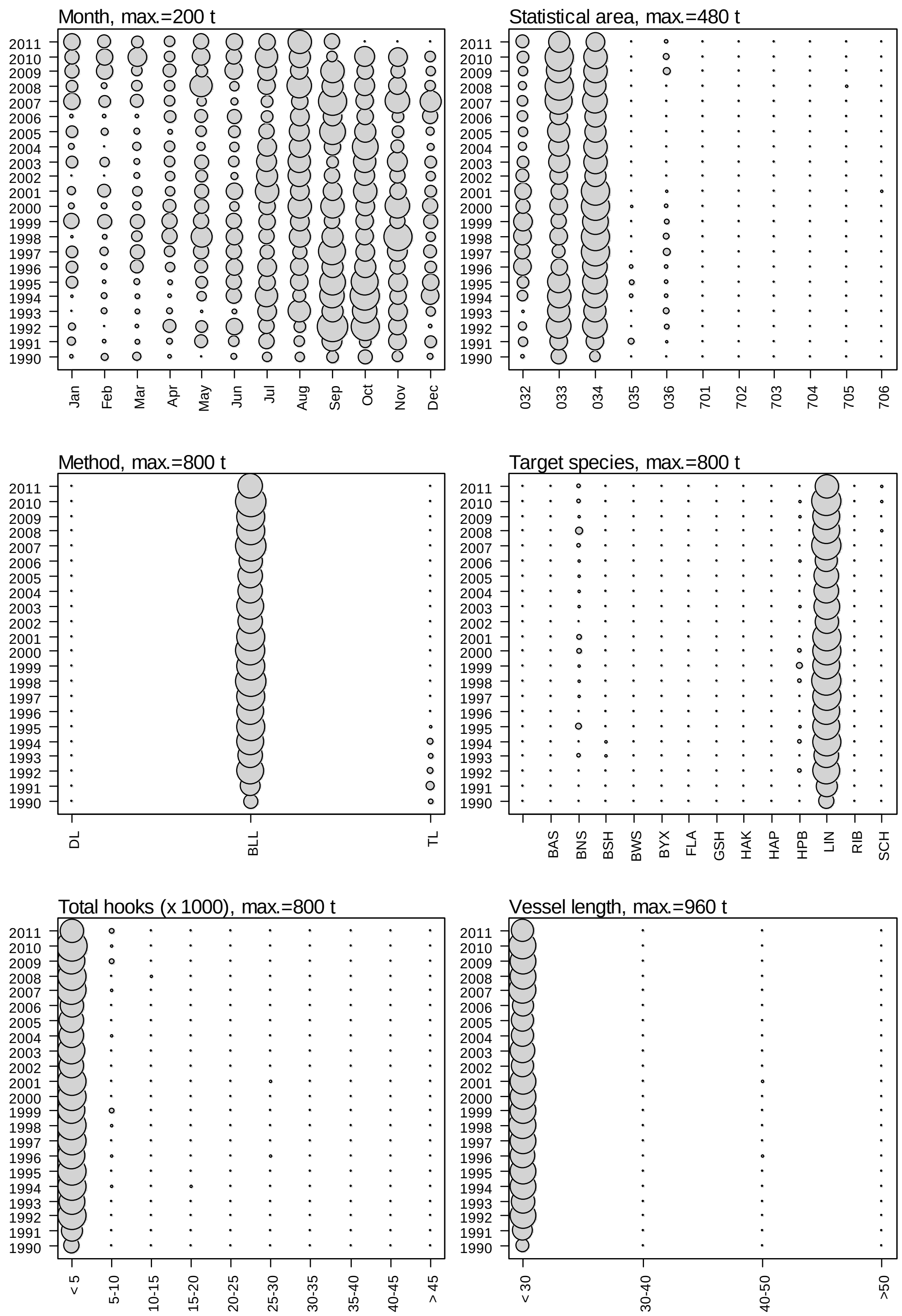


Figure B1b: Distribution of WCSI line ling catch by month, statistical area, method, and target species for 1990 to 2011 calendar years. Circle size is proportional to catch; maximum circle size is indicated on the top left hand corner of each plot. Statistical areas are defined in Figure A1. Method definitions defined in Figure A2. Species codes: BAS, bass; BNS, bluenose; BSH, seal shark; BWS, blue shark, BYX, alfonsino; FLA, flatfish; GSH, ghost shark; HAK, hake; HAP, hapuku; HPB, hapuku and bass; LIN, ling; RIB, ribaldo; SCH, school shark.

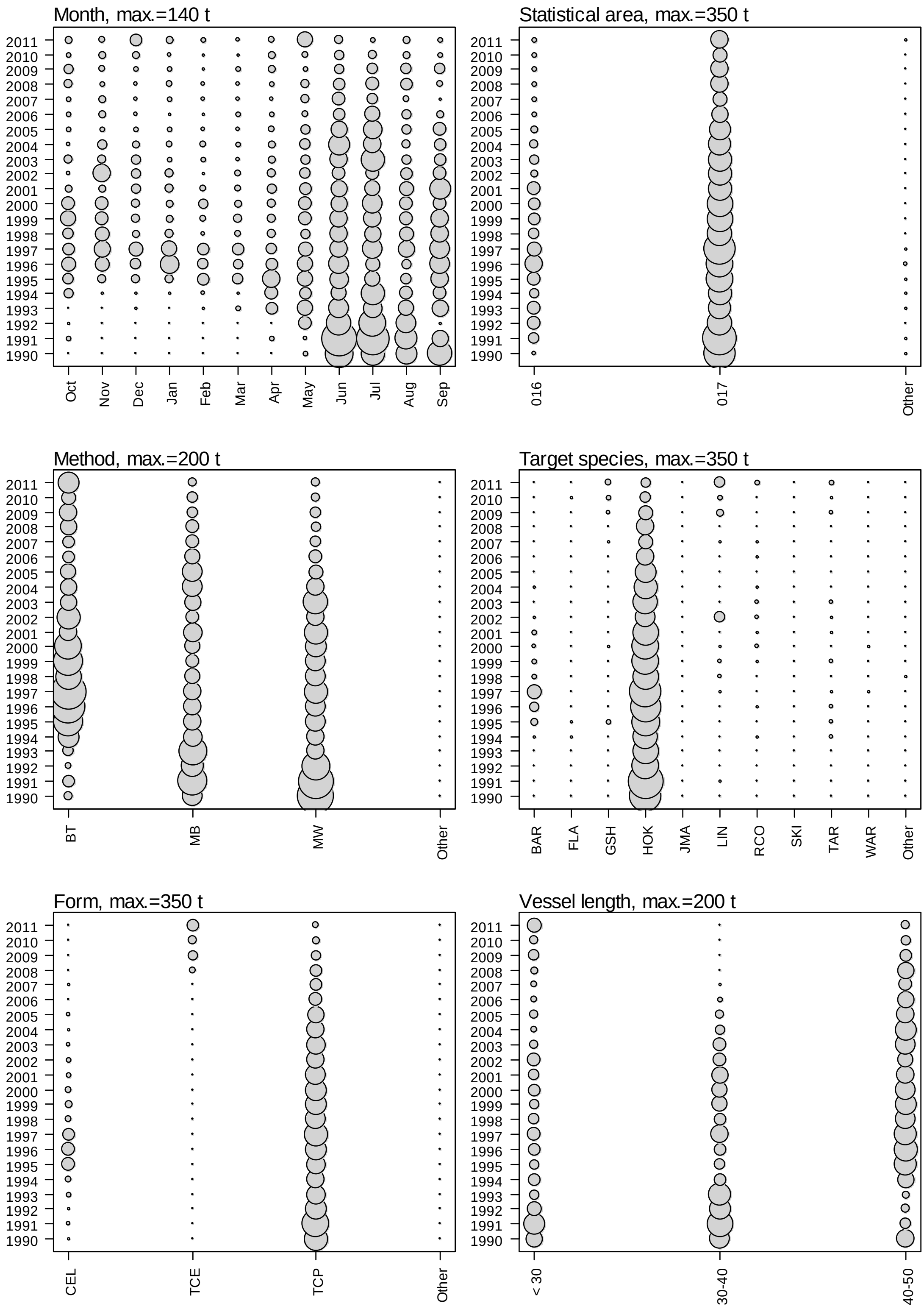


Figure B1c: Distribution of Cook Strait TCEPR tow-by-tow ling trawl catch by month, statistical area, method, target species, and vessel length for 1990 to 2011 calendar years. Circle size is proportional to catch; maximum circle size is indicated on the top left hand corner of each plot. Statistical areas are defined in Figure A1. Methods defined in Figure A2, although MB is midwater trawl within 5 m of the bottom. Species codes: BAR, barracouta ; FLA, flatfish; GSH, ghost shark; HOK, hoki; JMA, jack mackerel; LIN, ling; RCO, red cod; SKI, gemfish; TAR, tarakihi; WWA, white warehou.

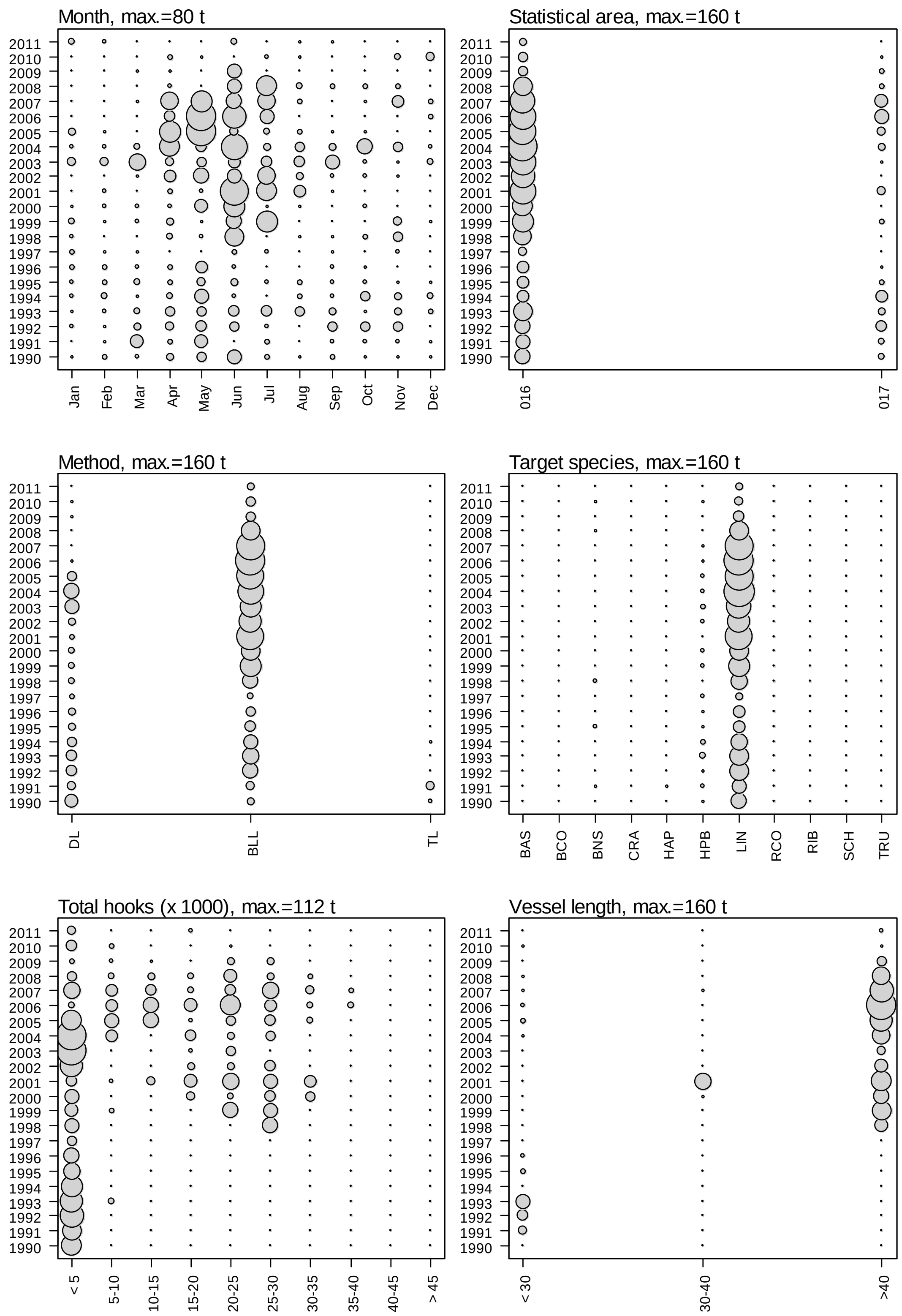
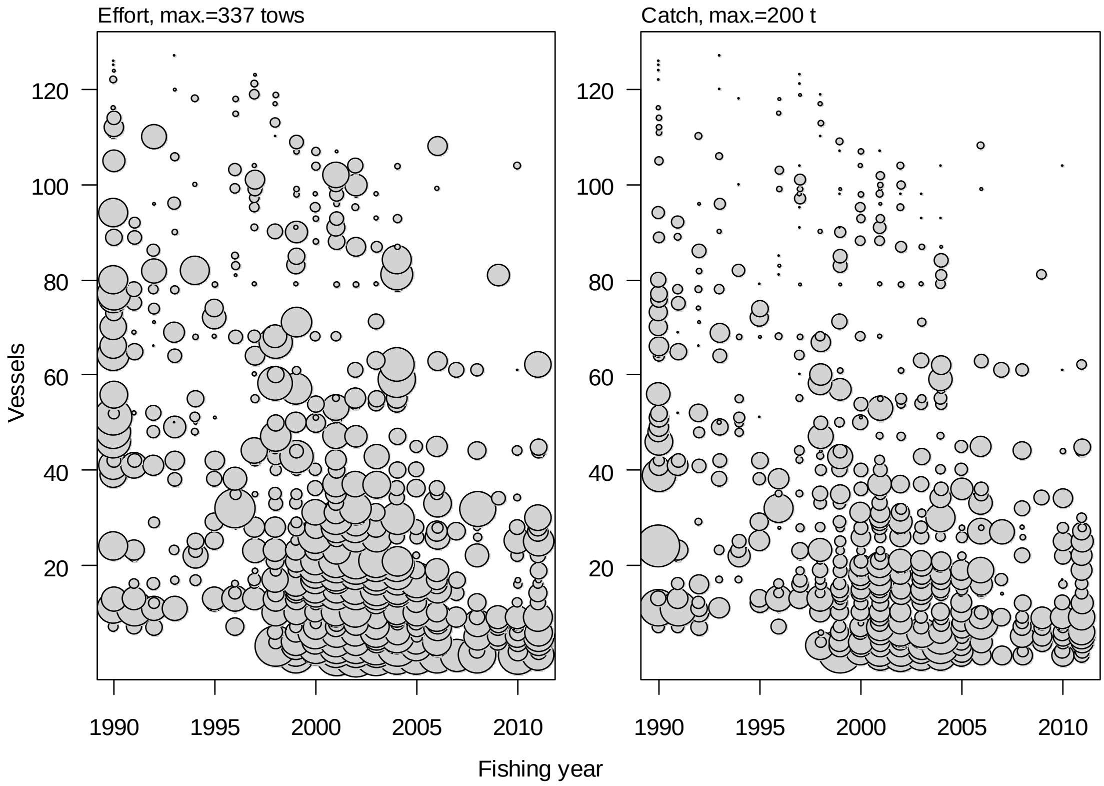


Figure B1d: Distribution of Cook Strait TCEPR tow-by-tow ling trawl catch by month, statistical area, method, target species, and vessel length for 1990 to 2011 calendar years. Circle size is proportional to catch; maximum circle size is indicated on the top left hand corner of each plot. Statistical areas are defined in Figure A1. Methods defined in Figure A2. Species codes: BAS, bass; BCO, blue cod; BNS, bluenose; CRA, rock lobster; HAP, hapuku; LIN, ling; RCO, red cod; RIB, ribaldo; SCH, school shark; TRU, trumpeter.

(a) WCSI TCEPR tow-by-tow accurate vessel data



(b) WCSI tow-by-tow observer data

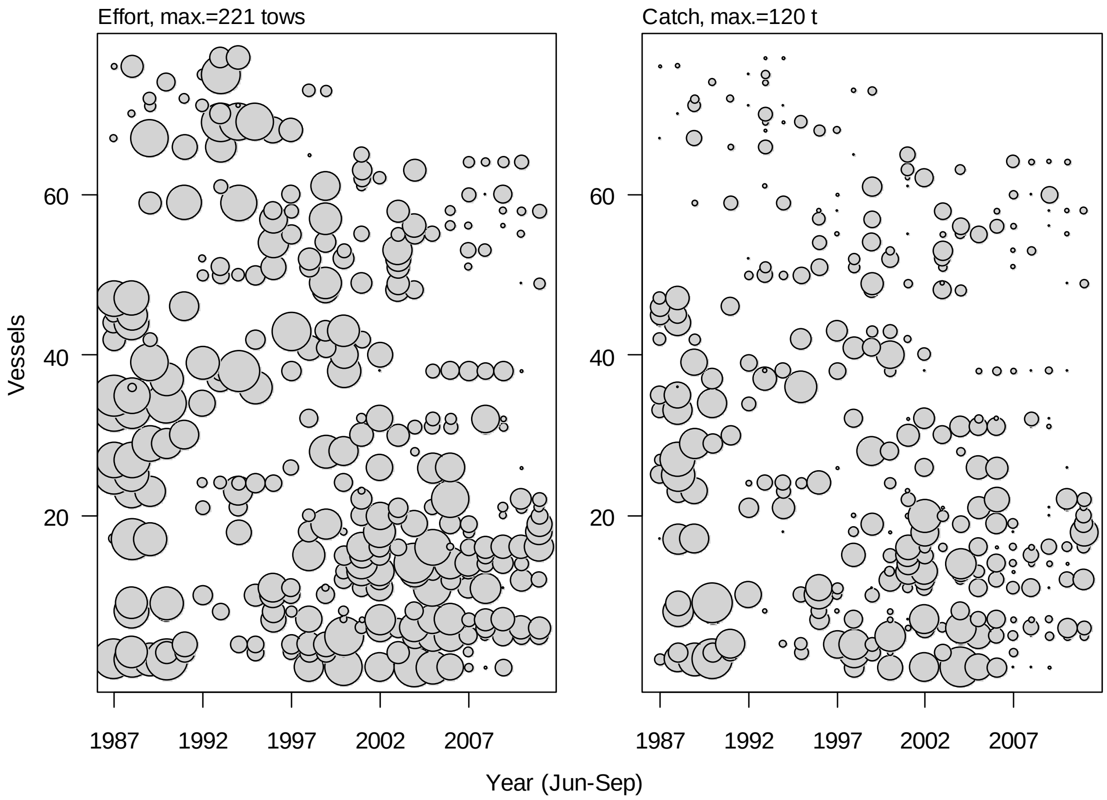
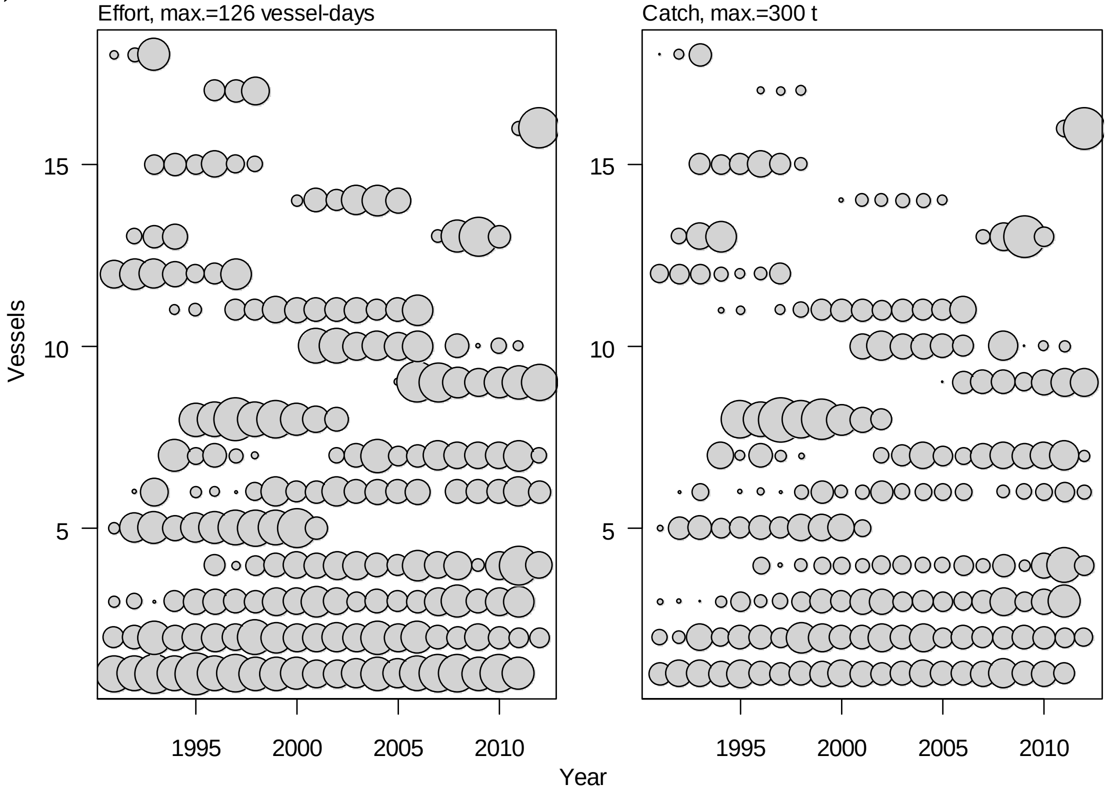


Figure B2a: Trawl or line fishing effort and catches (where circle area is proportional to the effort or catch) by year for individual vessels (denoted anonymously by number on the *y*-axis) in final CPUE analyses for WCSI and Cook Strait.

(c) WCSI line



(d) Cook Strait TCEPR tow-by-tow vessel data

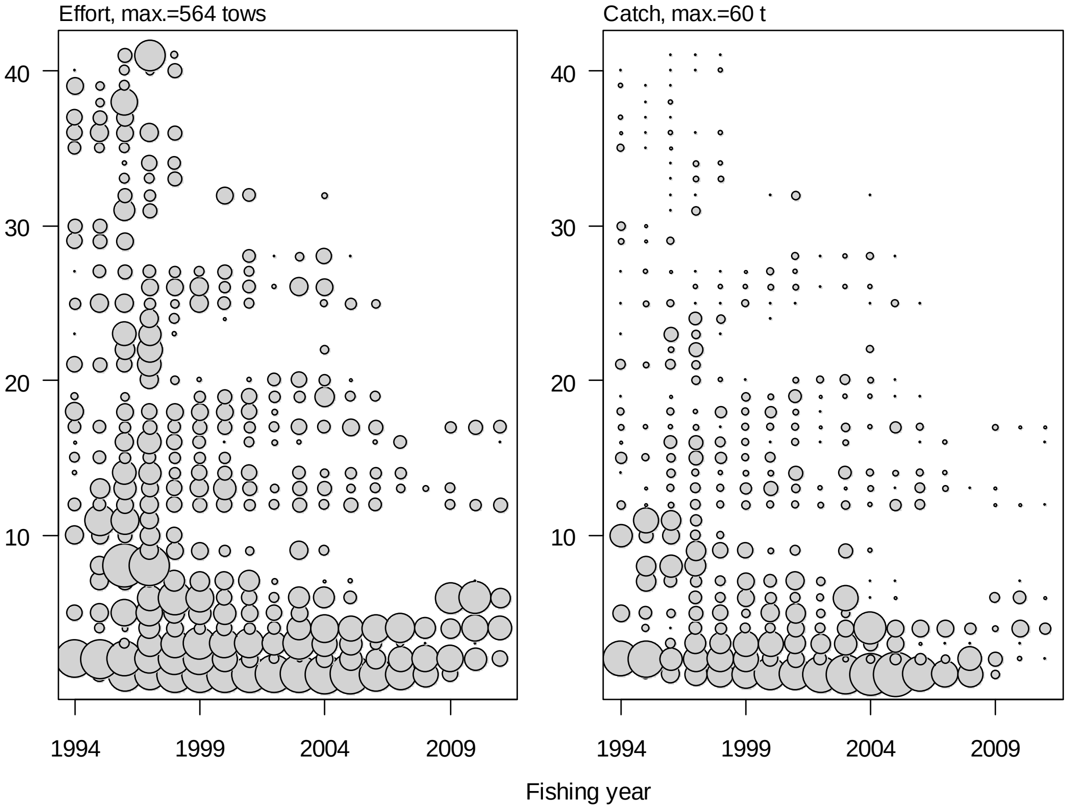
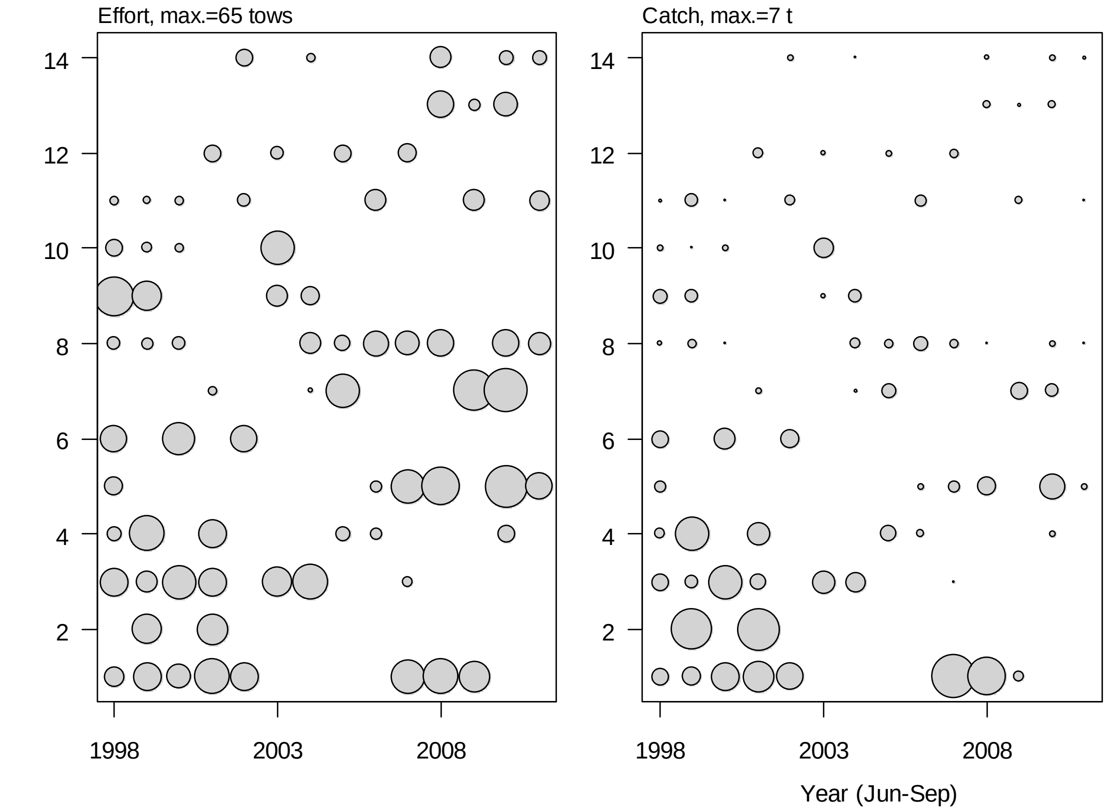


Figure B2a: continued.

(e) Cook Strait tow-by-tow observer data



(f) Cook Strait line

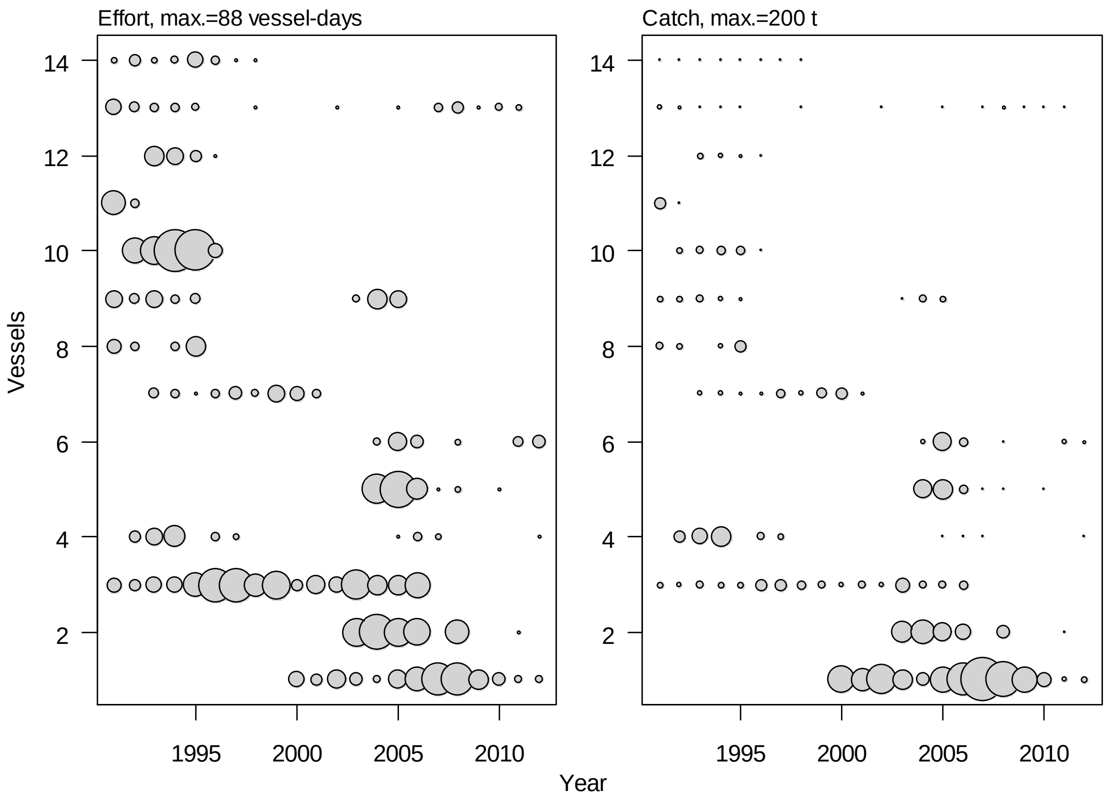


Figure B2a: continued.

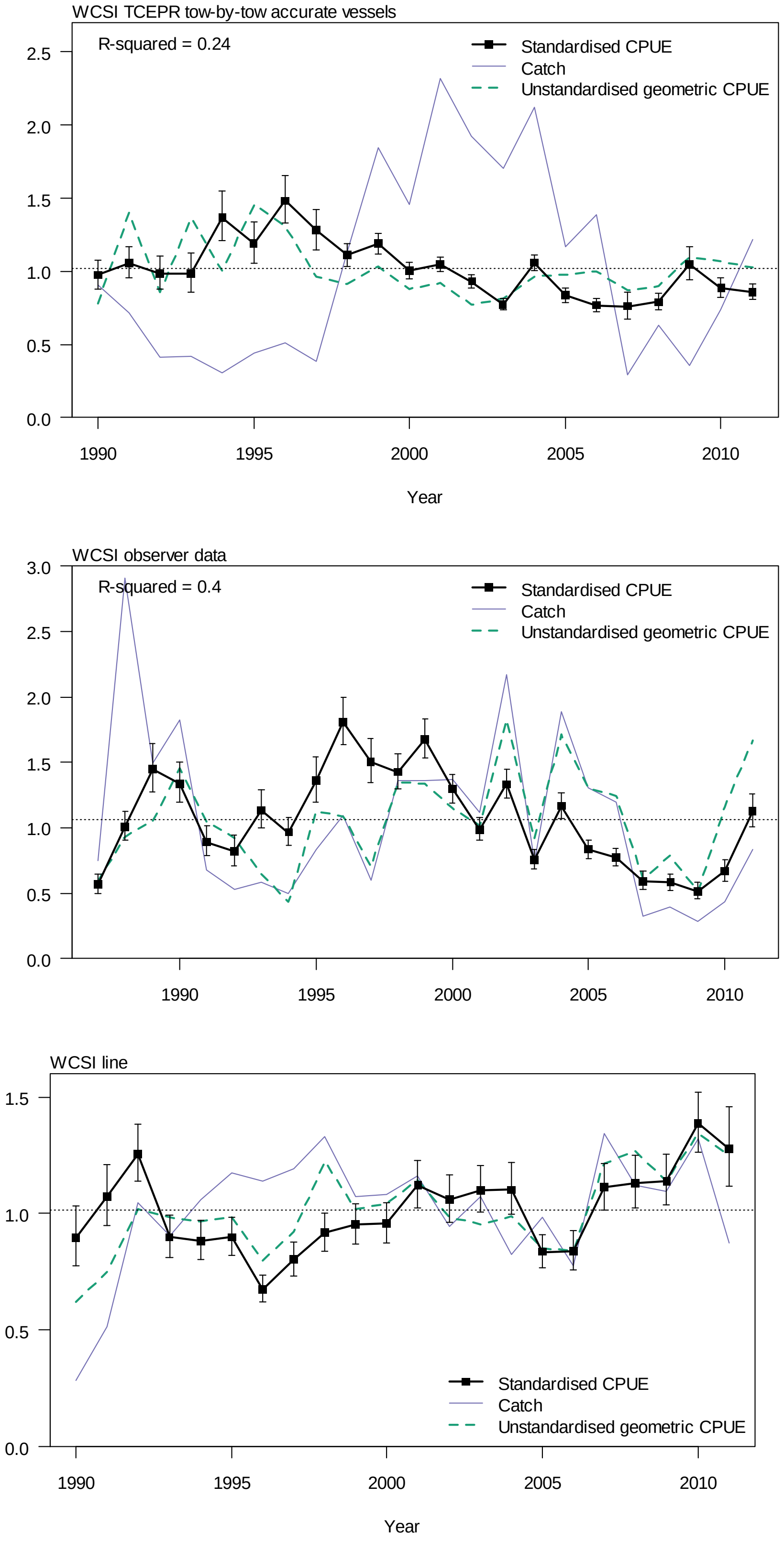


Figure B3: CPUE index from the lognormal model for each fishery, 1990–2011. Bars indicate 95% confidence intervals.

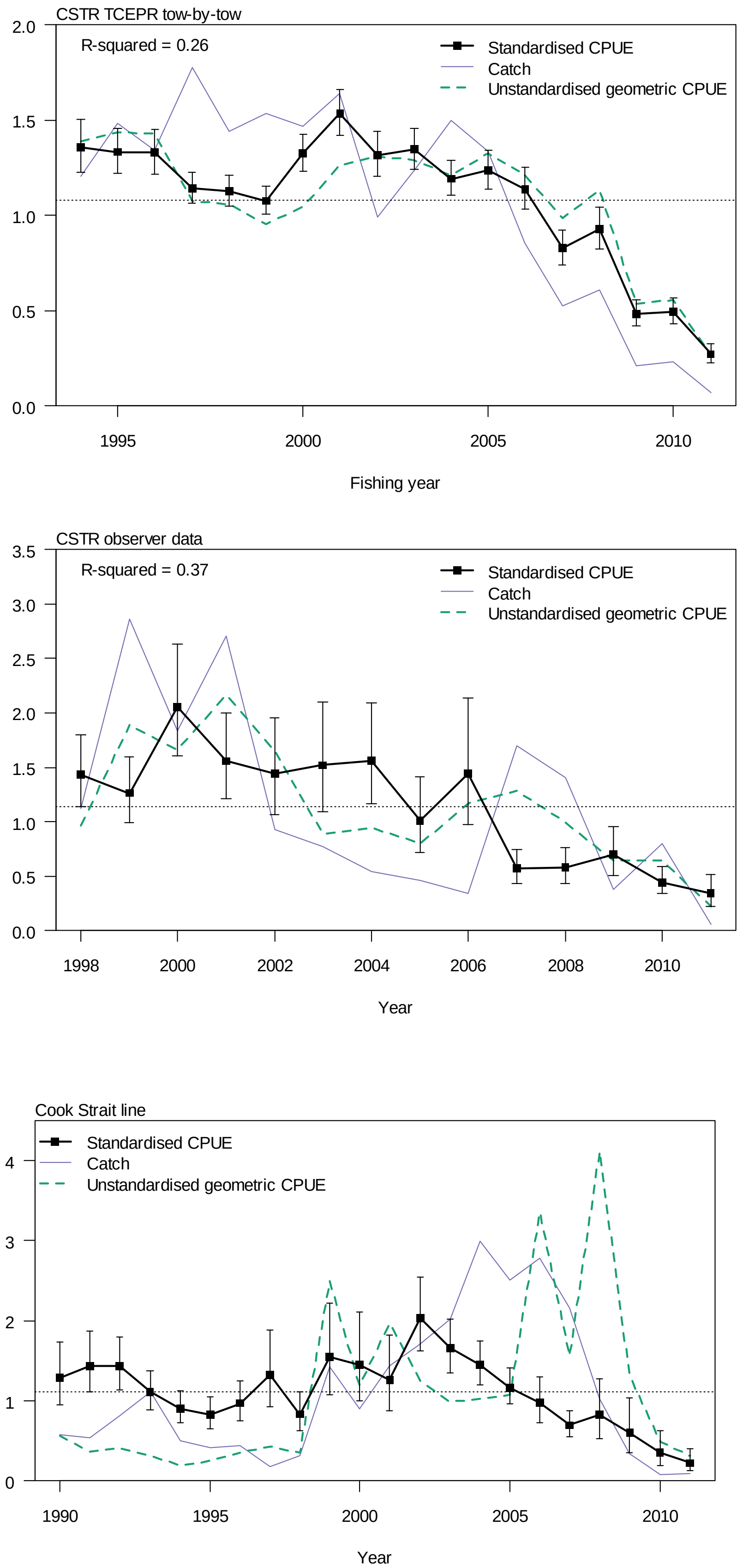


Figure B3: continued.

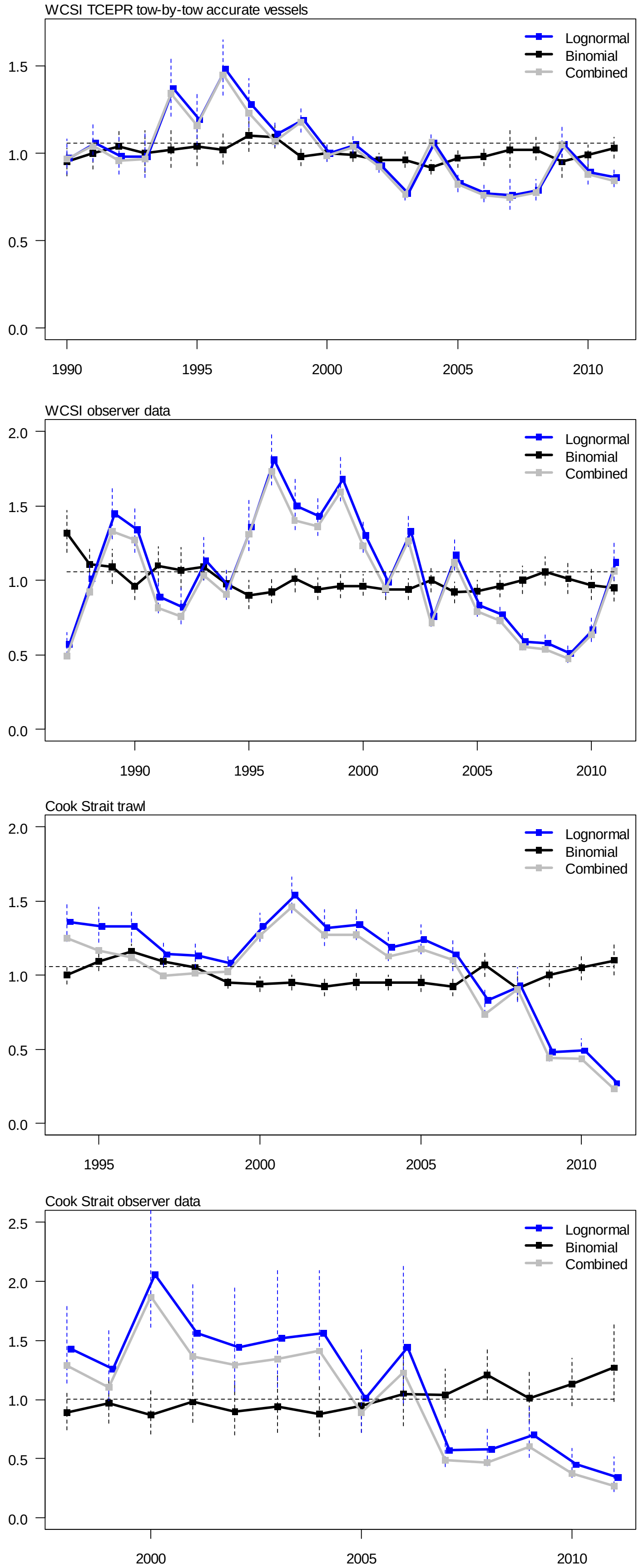


Figure B4: CPUE index from the lognormal, binomial and combined model for the WCSI and Cook Strait trawl fisheries, 1990–2011. Bars indicate 95% confidence intervals.

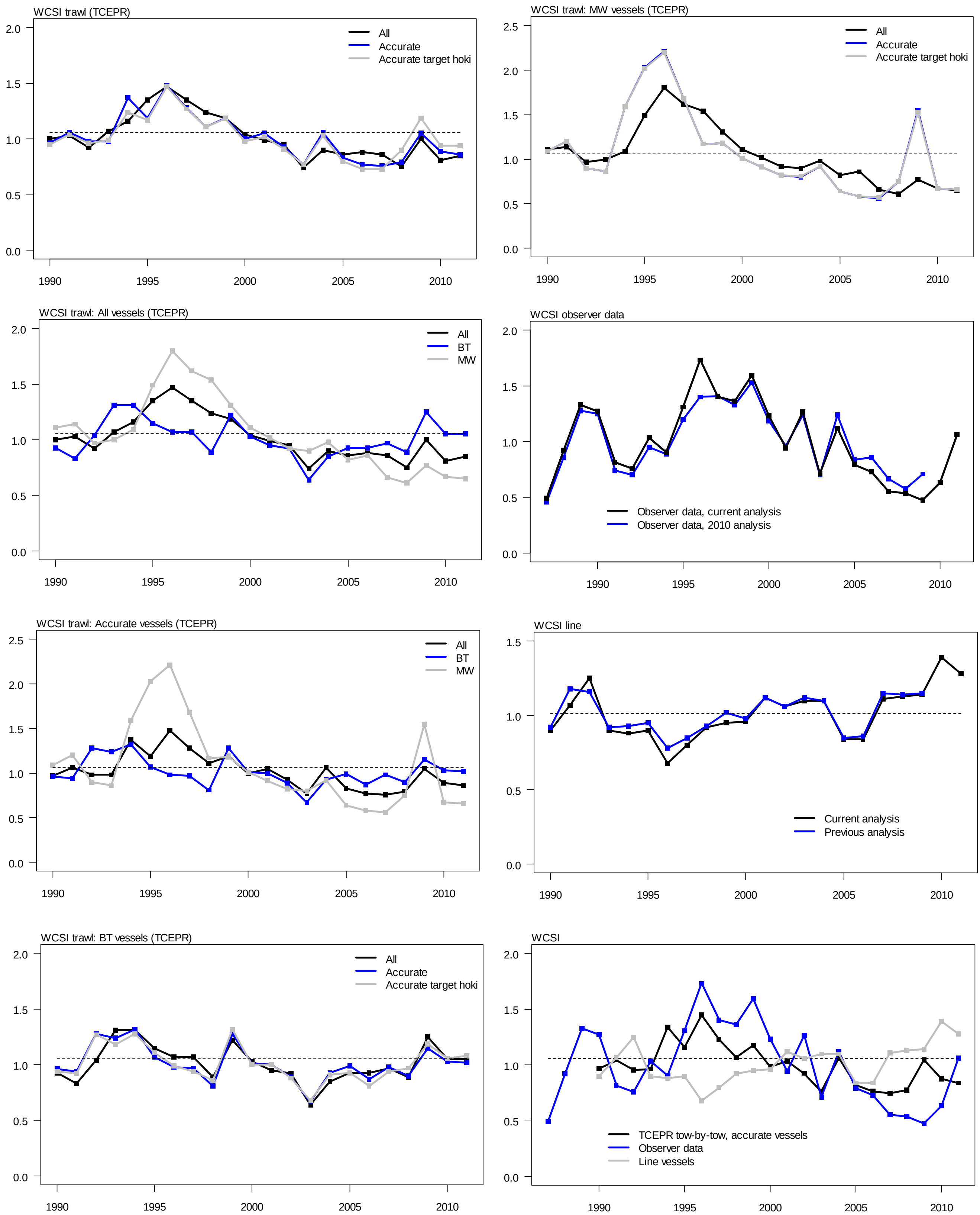


Figure B5a: Comparison of CPUE indices for the lognormal model for WCSI fishery models, by year (June–September for TCEPR and observer data, and calendar year for the line data).

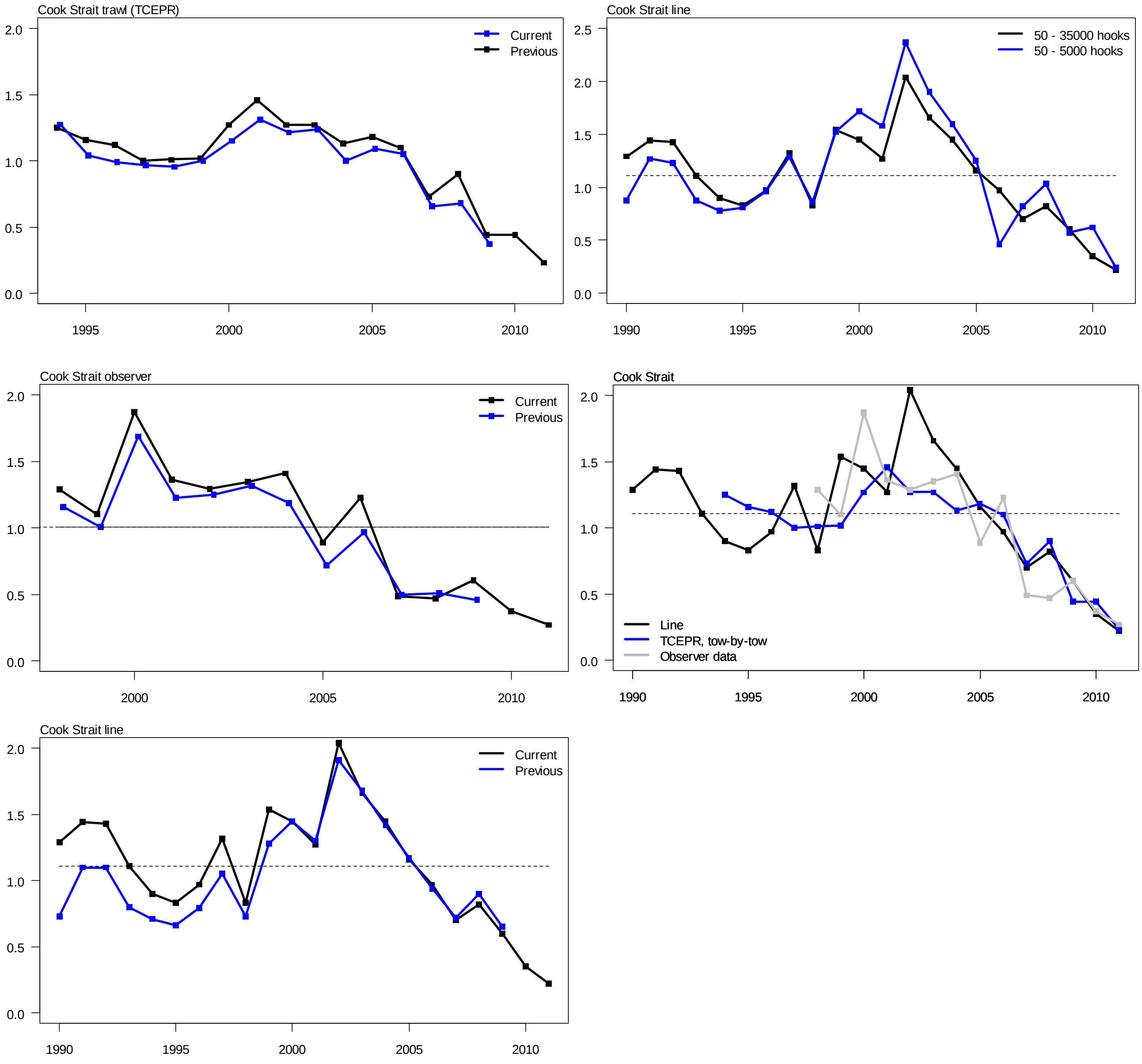


Figure B5b: Comparison of CPUE indices for the lognormal model for the Cook Strait fishery models, by year (June–September for TCEPR and observer data, and calendar year for the line data).

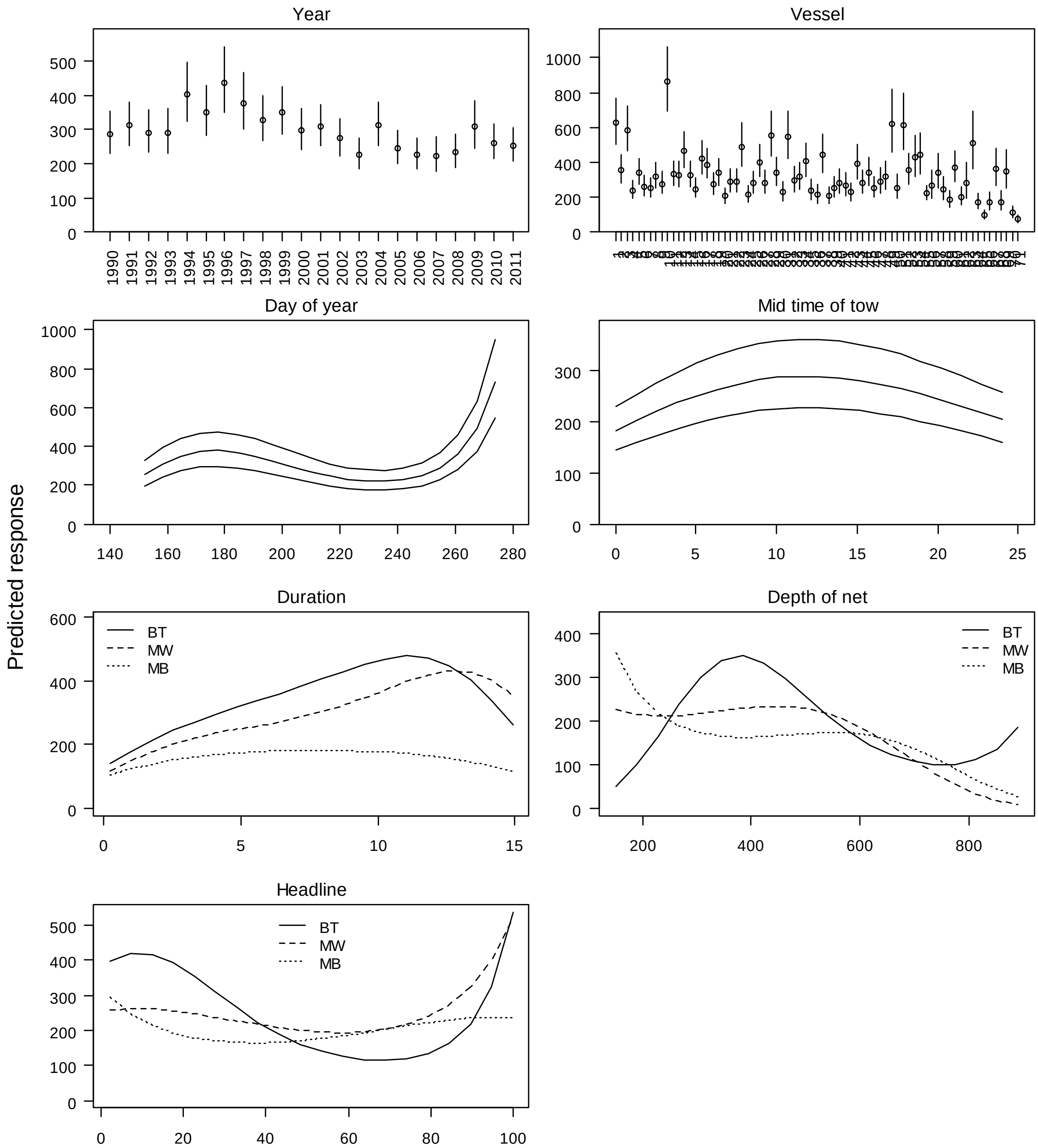


Figure B6a: Expected variable effects for variables selected into the CPUE lognormal model for the WCSI trawl accurate vessel fishery, 1990–2011. The 95% confidence intervals are shown as bars for categorical variables and as upper and lower lines for continuous variables.

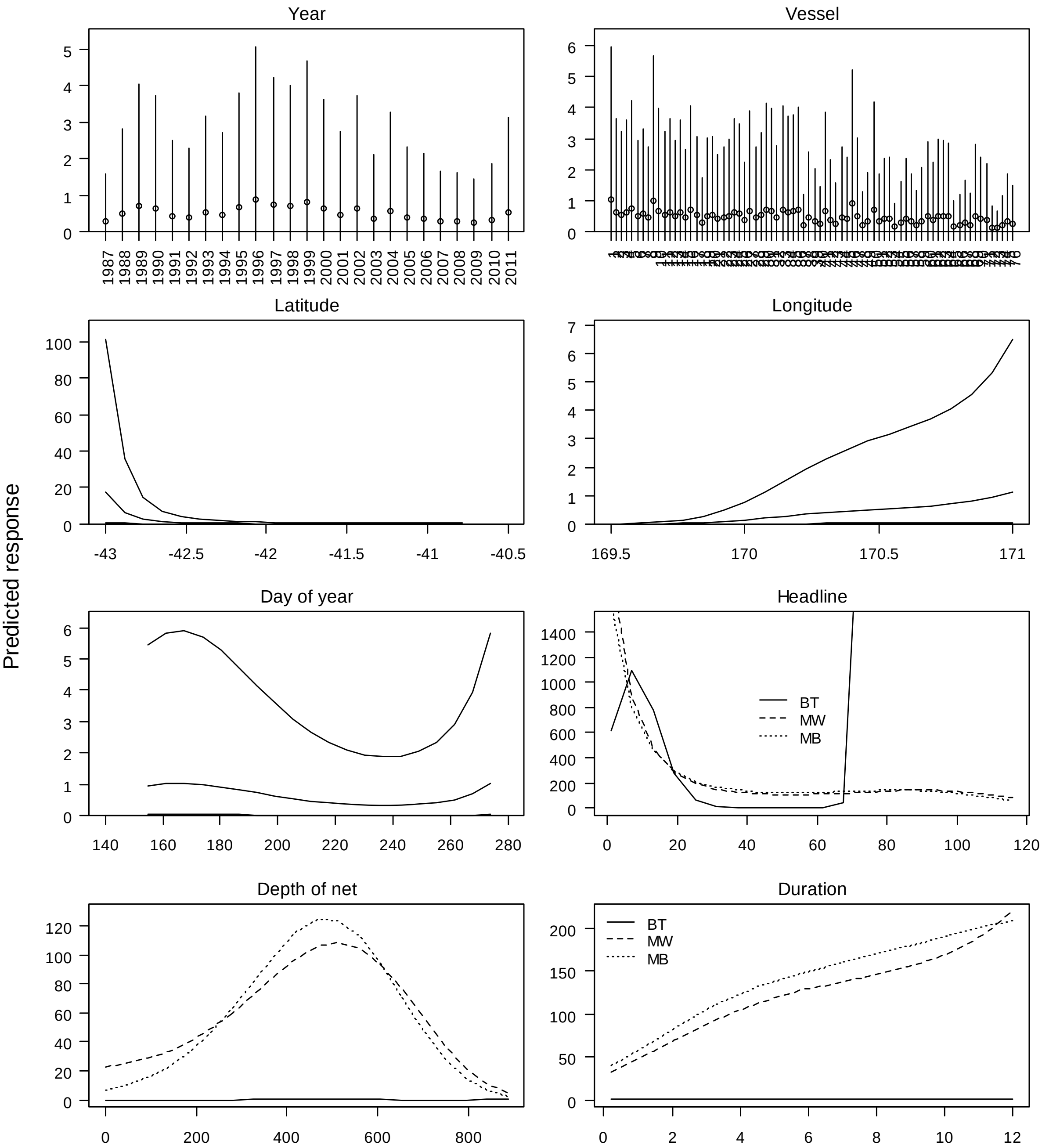


Figure B6b: Expected variable effects for variables selected into the CPUE lognormal model for the WCSI observer data, 1987–2011. The 95% confidence intervals are shown as bars for categorical variables and as upper and lower lines for continuous variables.

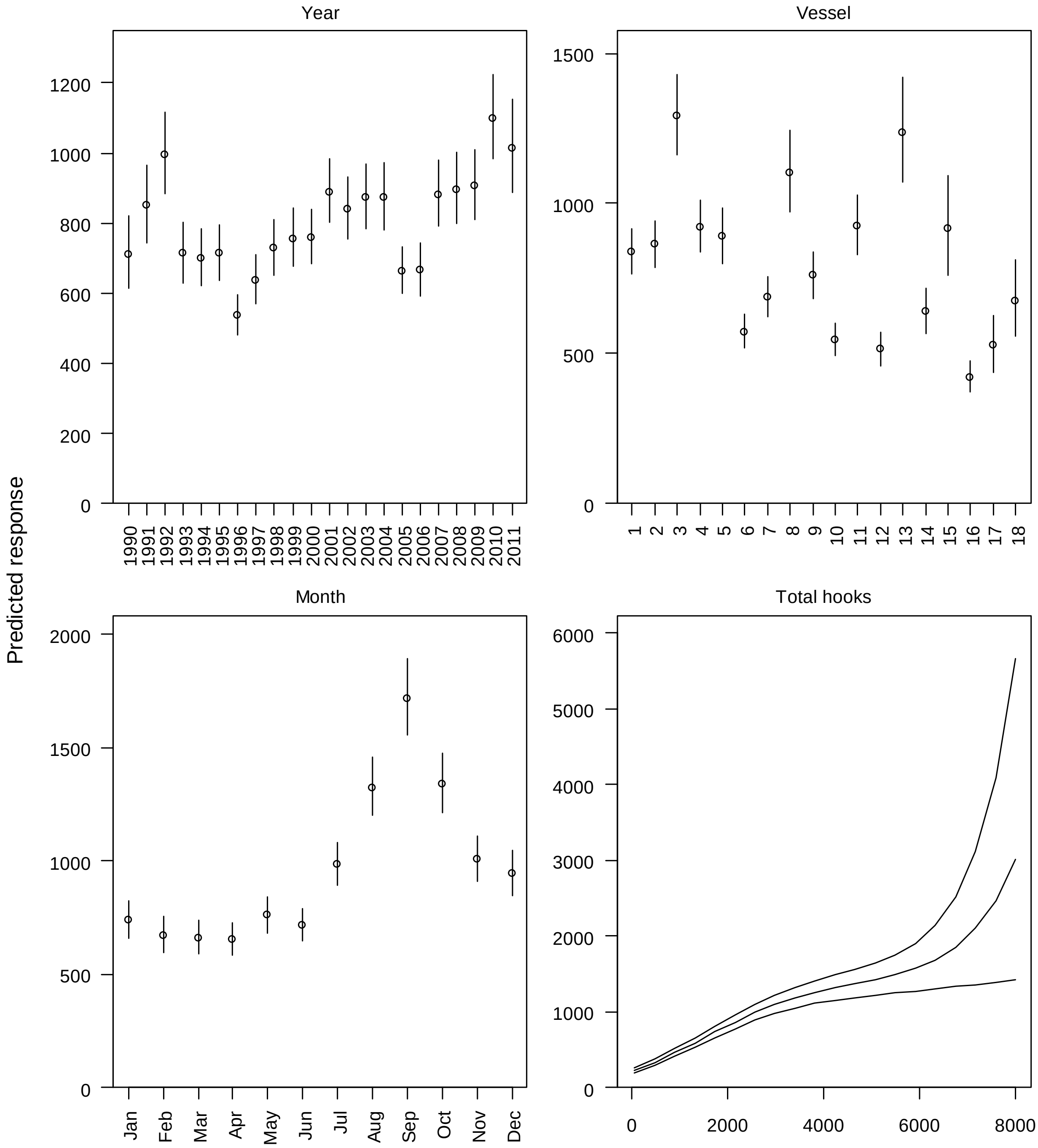


Figure B6c: Expected variable effects for variables selected into the CPUE lognormal model for the WCSI line data, 1990–2011. The 95% confidence intervals are shown as bars for categorical variables and as upper and lower lines for continuous variables.

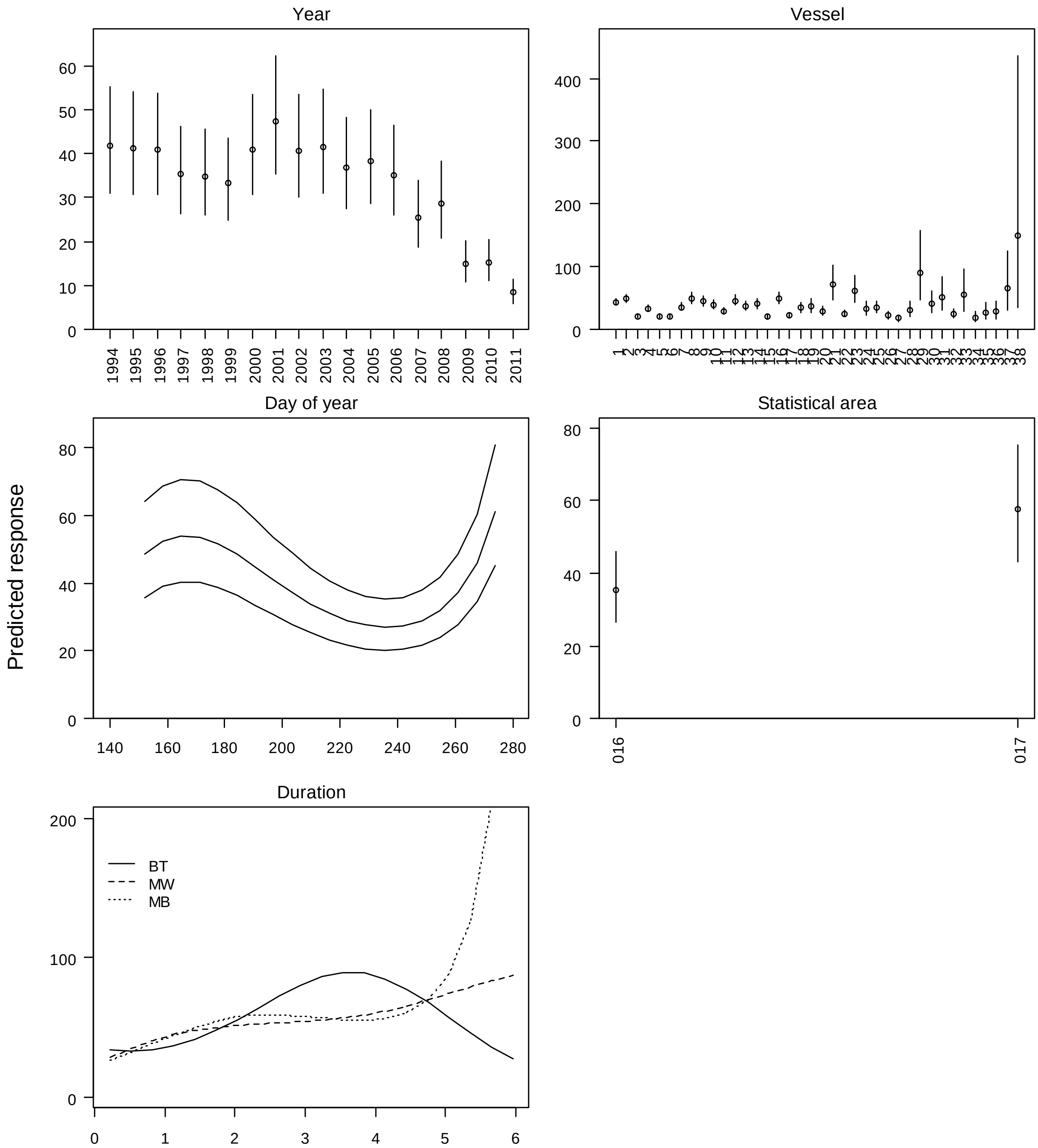


Figure B6d: Expected variable effects for variables selected into the CPUE lognormal model for the Cook Strait TCEPR tow-by-tow data, 1987–2011. The 95% confidence intervals are shown as bars for categorical variables and as upper and lower lines for continuous variables.

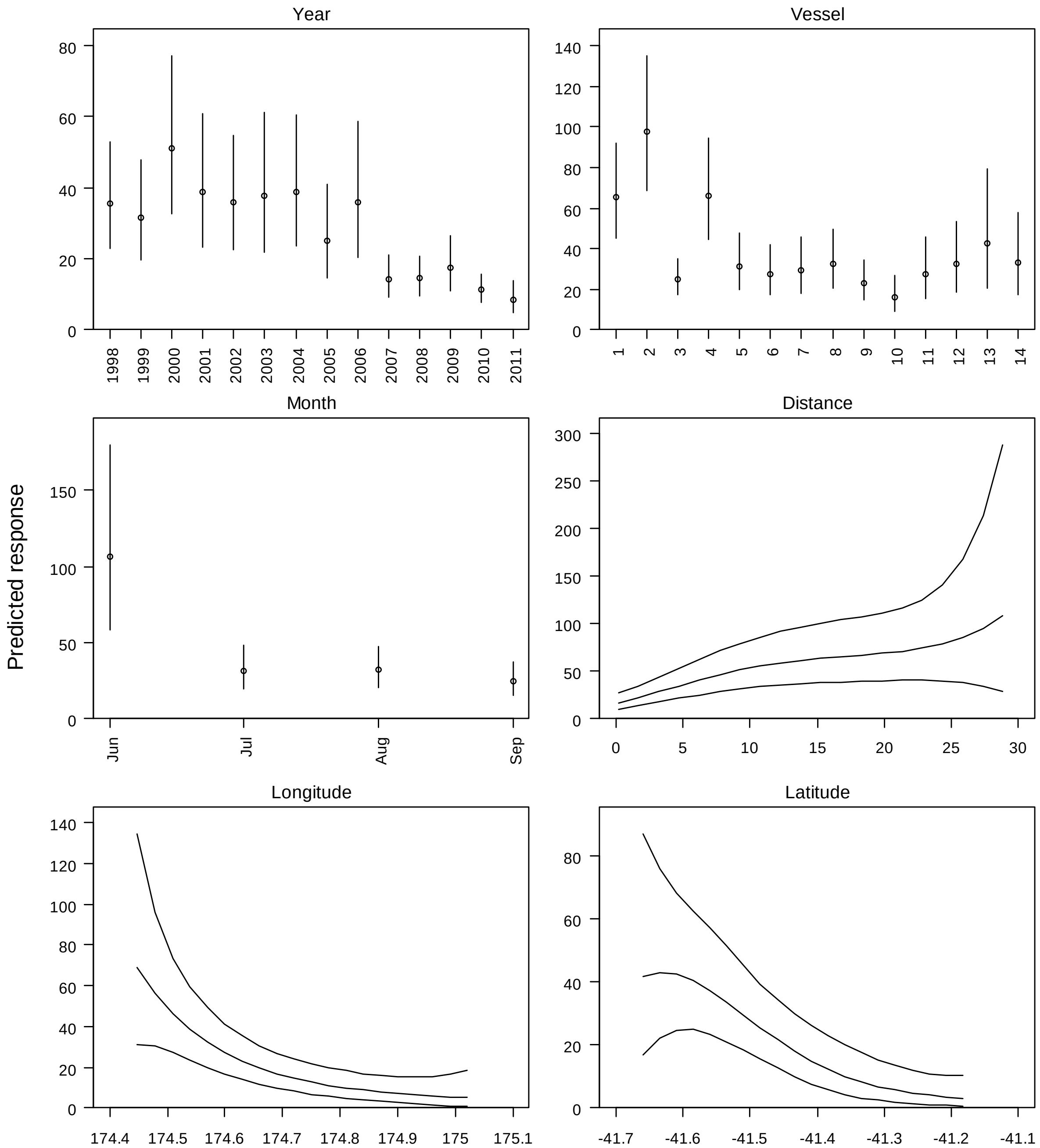


Figure B6e: Expected variable effects for variables selected into the CPUE lognormal model for the Cook Strait observer data, 1998–2011. The 95% confidence intervals are shown as bars for categorical variables and as upper and lower lines for continuous variables.

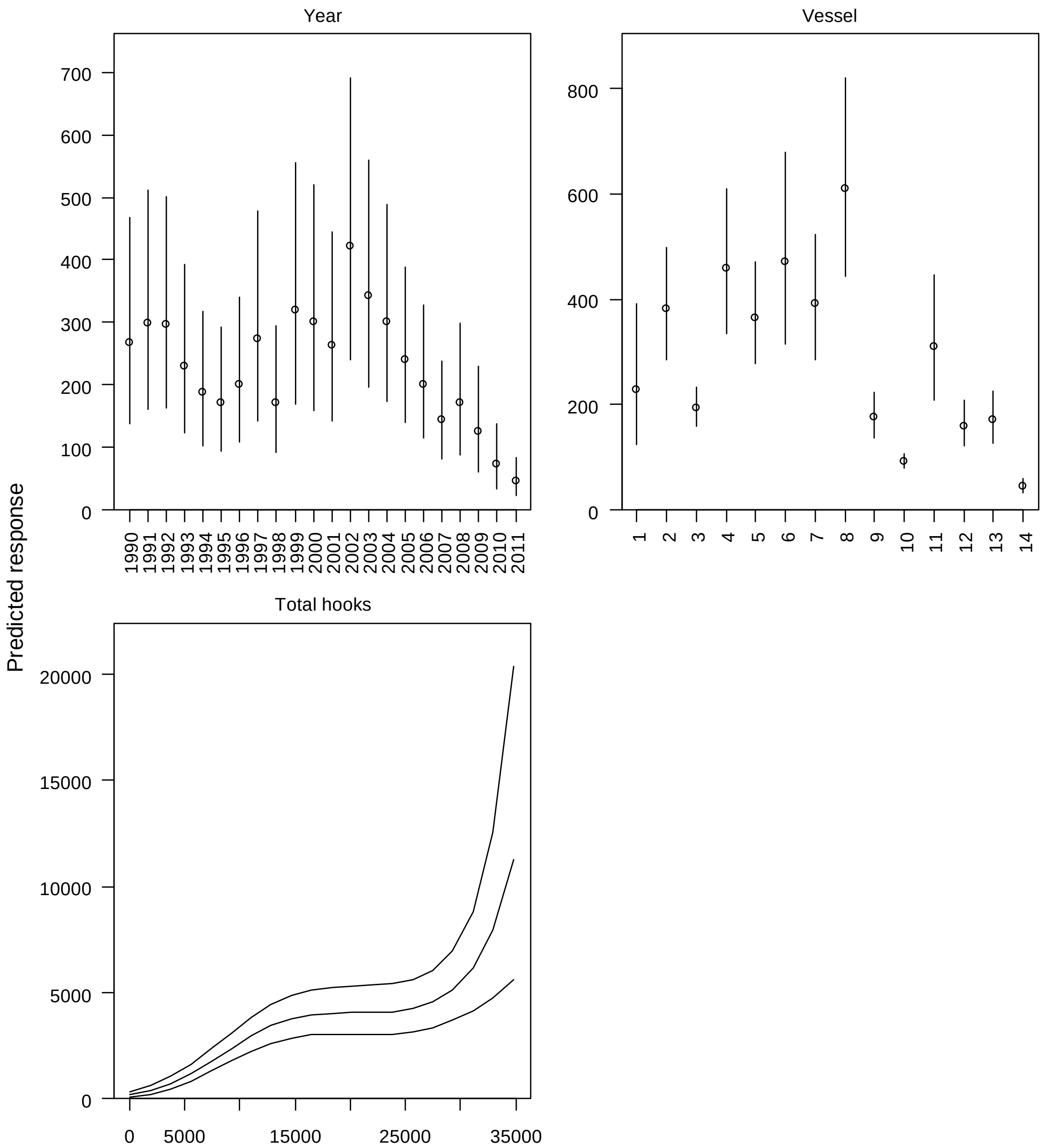


Figure B6f: Expected variable effects for variables selected into the CPUE lognormal model for the Cook Strait line data, 1990–2011. The 95% confidence intervals are shown as bars for categorical variables and as upper and lower lines for continuous variables.

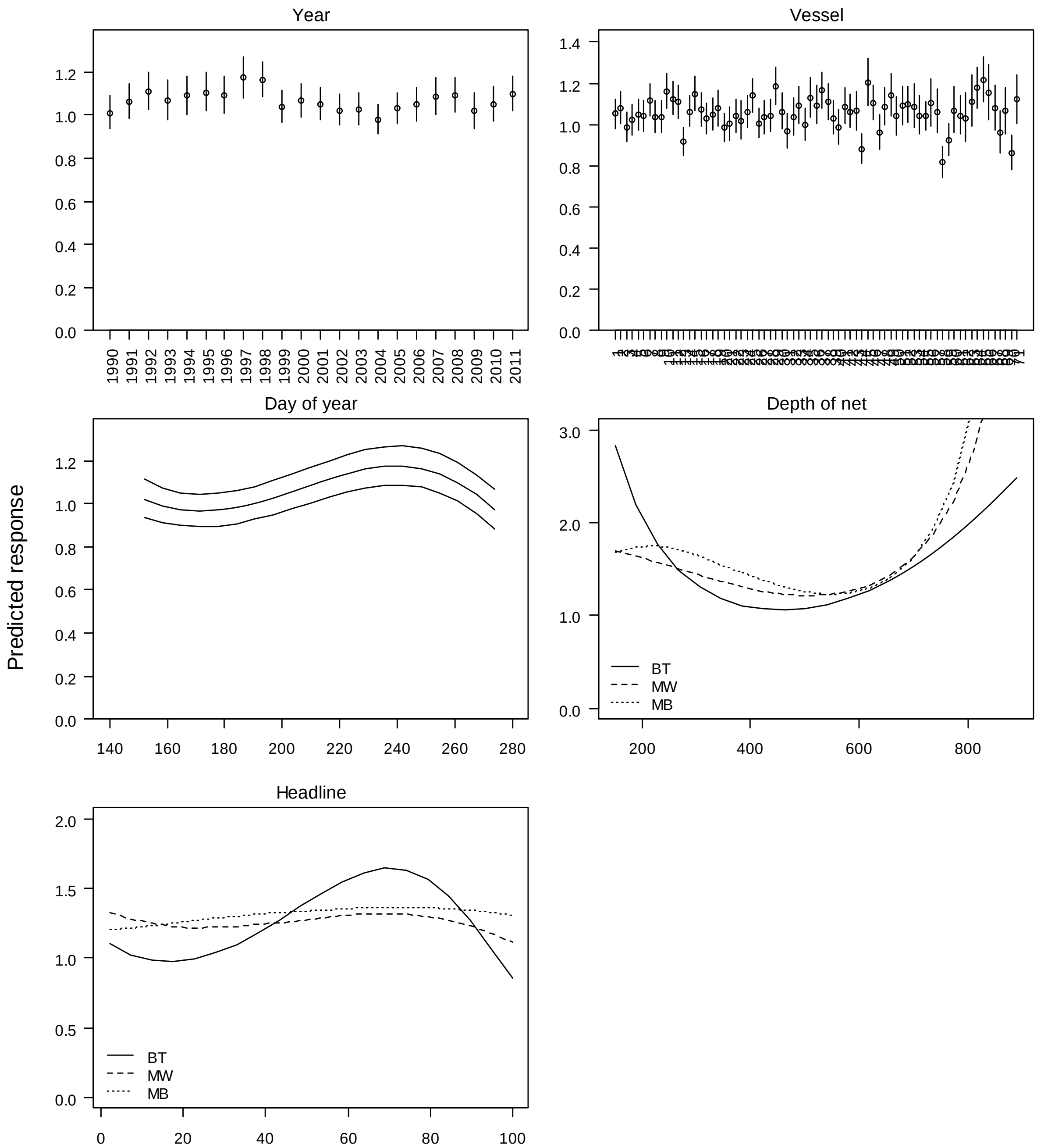


Figure B7a: Expected variable effects for variables selected into the CPUE binomial model for the WCSI trawl accurate vessel fishery, 1990–2011. The 95% confidence intervals are shown as bars for categorical variables and as upper and lower lines for continuous variables.

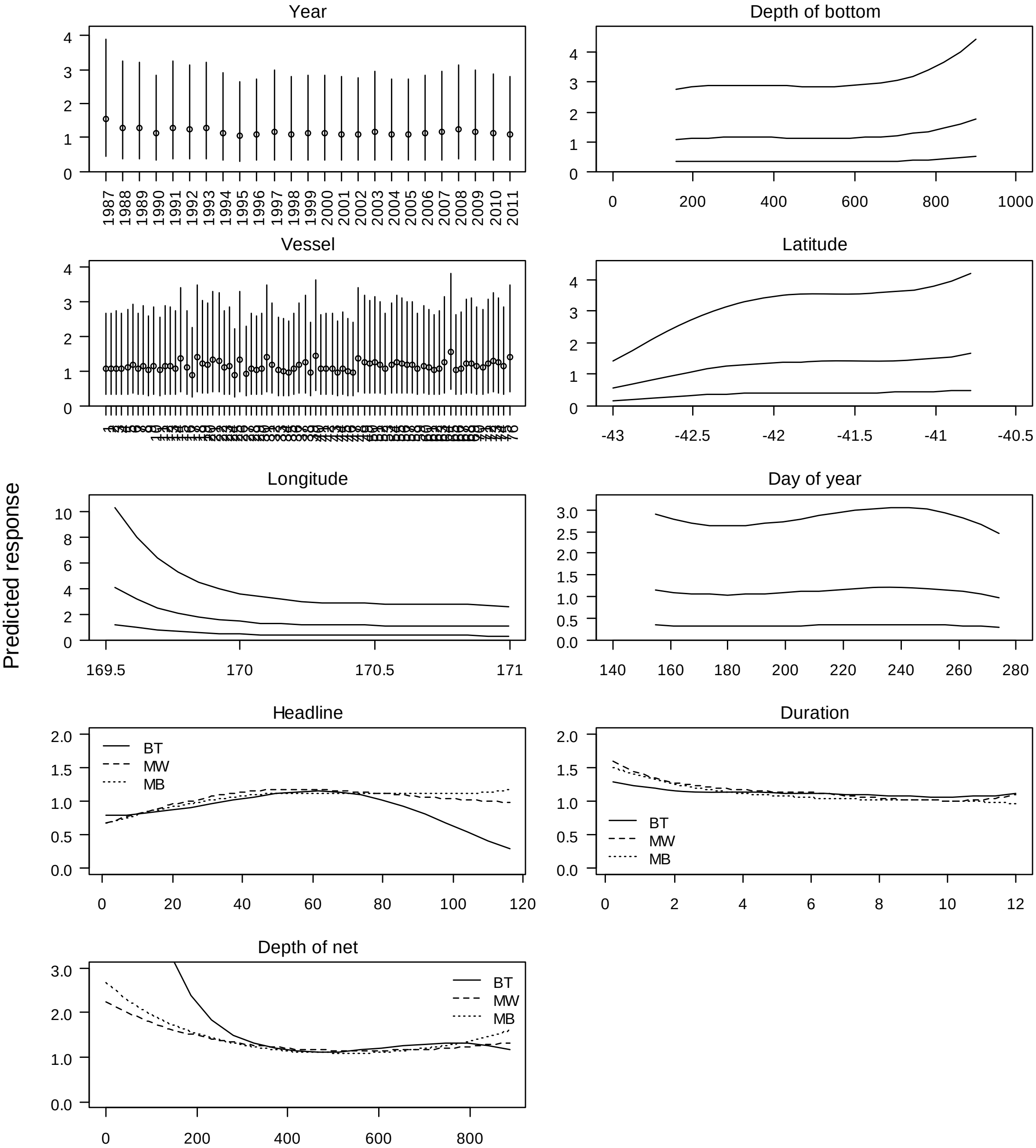


Figure B7b: Expected variable effects for variables selected into the CPUE binomial model for the WCSI trawl observer data, 1987–2011. The 95% confidence intervals are shown as bars for categorical variables and as upper and lower lines for continuous variables.

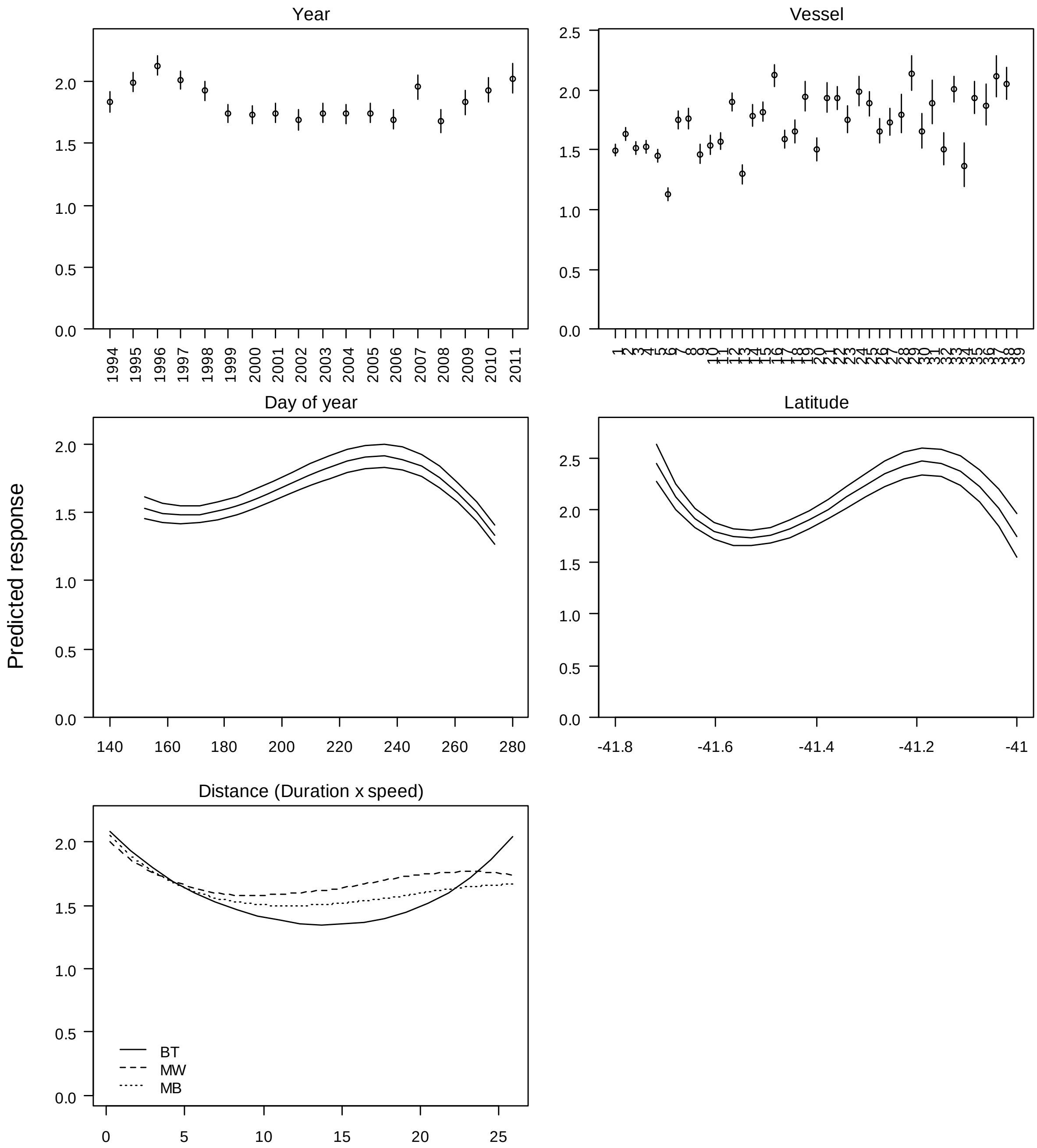


Figure B7c: Expected variable effects for variables selected into the CPUE binomial model for the Cook Strait TCEPR tow-by-tow trawl data, 1990–2011. The 95% confidence intervals are shown as bars for categorical variables and as upper and lower lines for continuous variables.

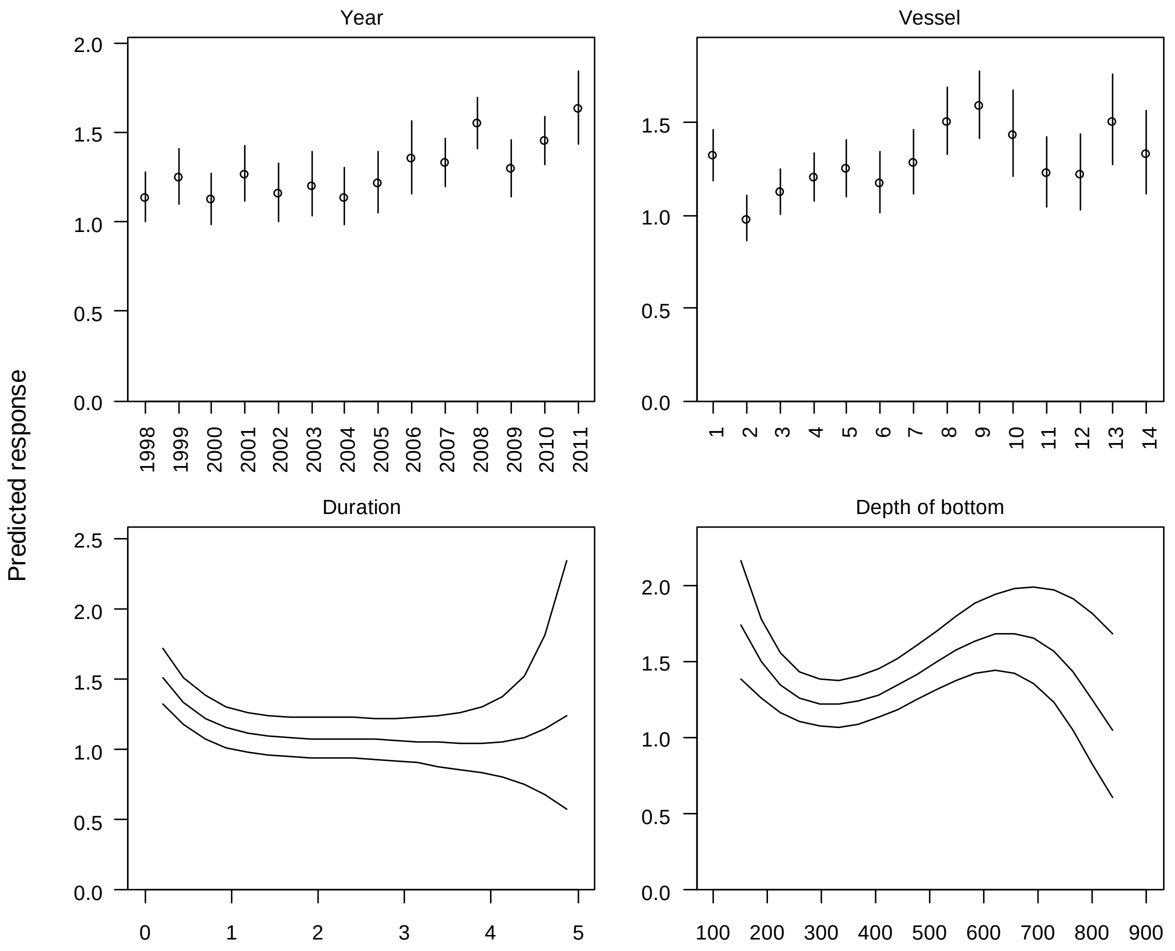


Figure B7d: Expected variable effects for variables selected into the CPUE binomial model for the Cook Strait trawl observer data, 1987–2011. The 95% confidence intervals are shown as bars for categorical variables and as upper and lower lines for continuous variables.

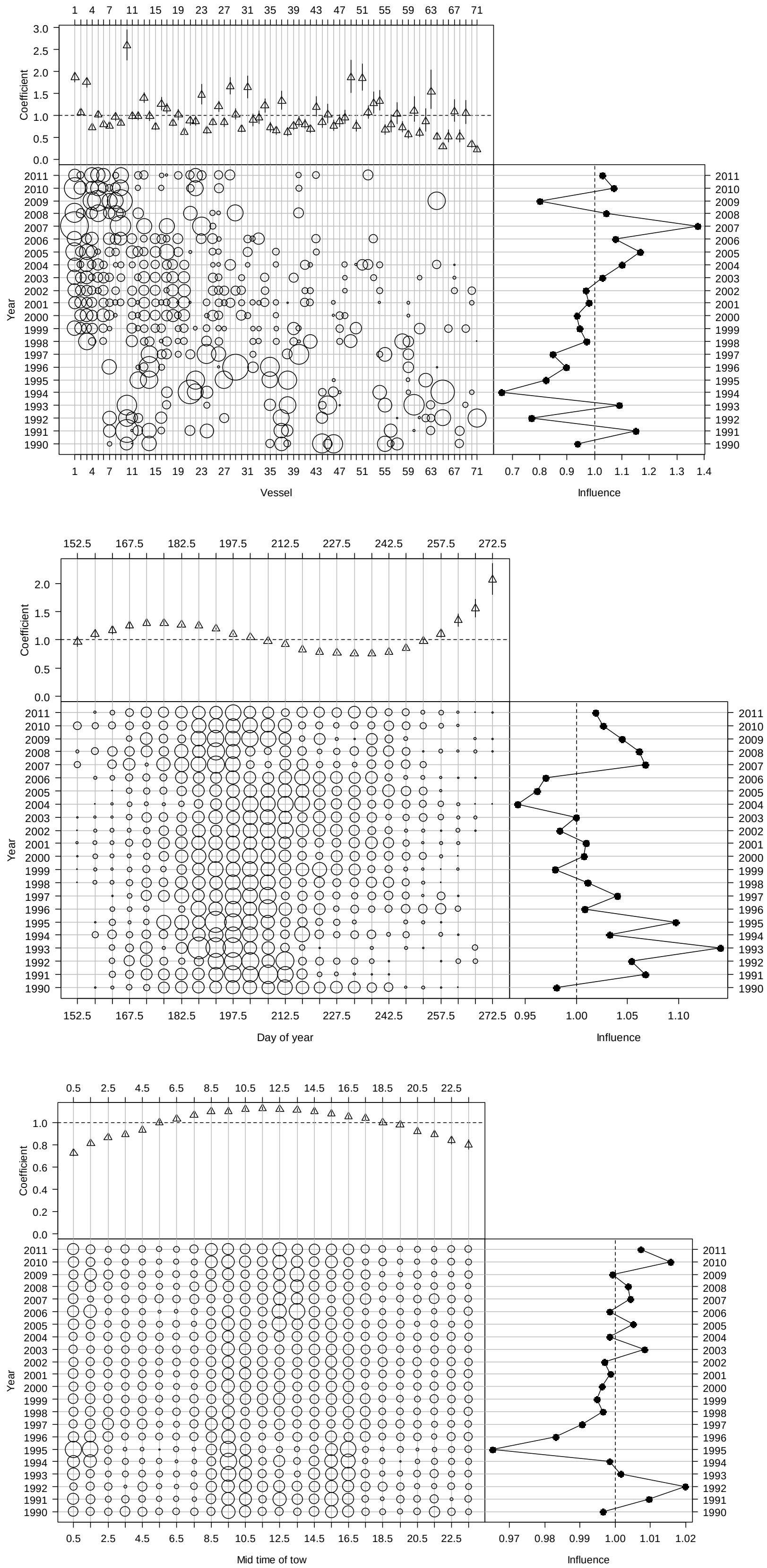


Figure B8a: Effect and influence of non-interaction term variables in the WCSI estimated accurate vessel lognormal model. Top: relative effect by level of each variable. Bottom left: relative distribution of each variable by fishing year. Bottom right: influence of variable on unstandardised CPUE by fishing year.

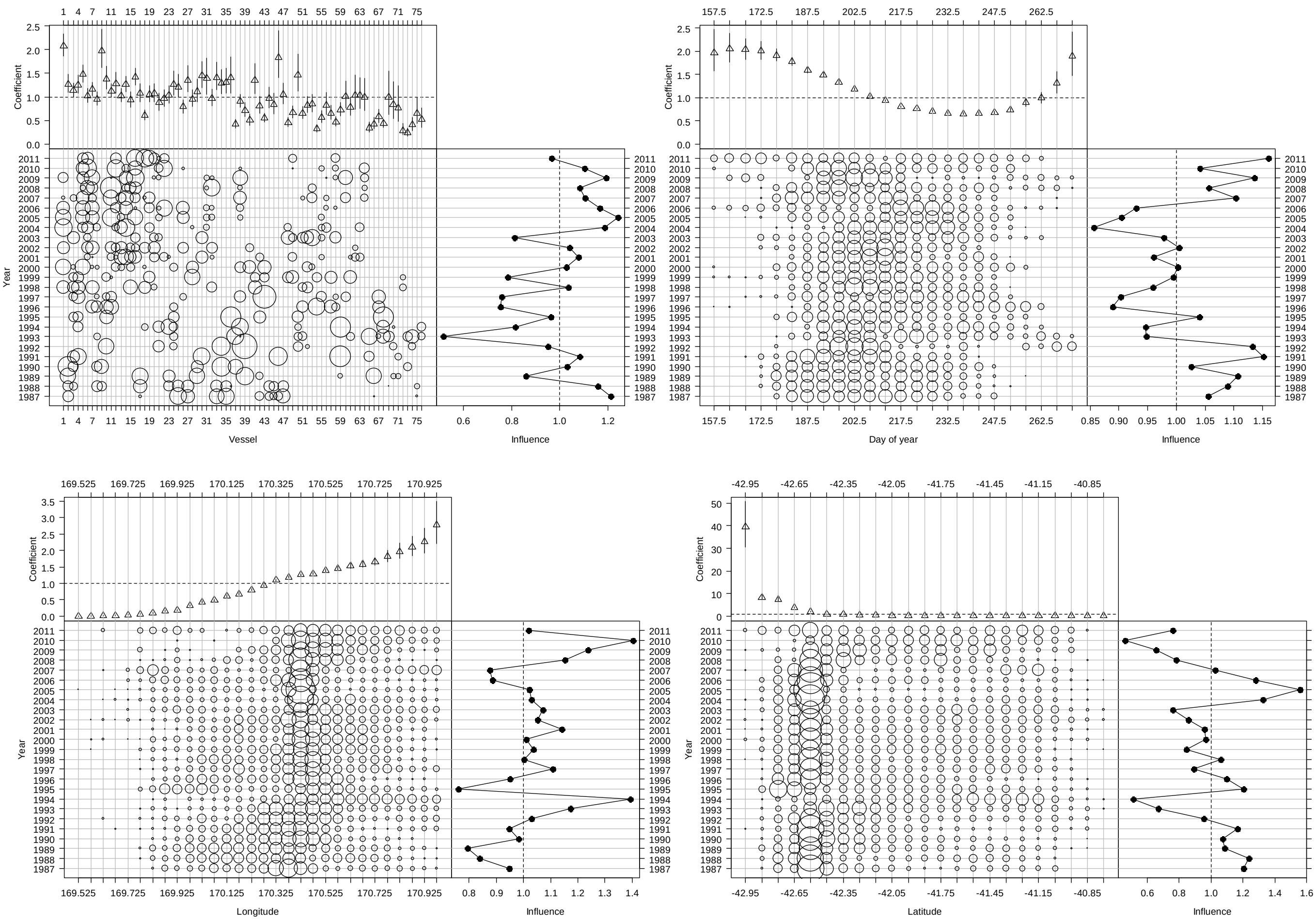


Figure B8b: Effect and influence of non-interaction term variables in the WCSI observer data lognormal model. Top: relative effect by level of each variable. Bottom left: relative distribution of each variable by fishing year. Bottom right: influence of variable on unstandardised CPUE by fishing year.

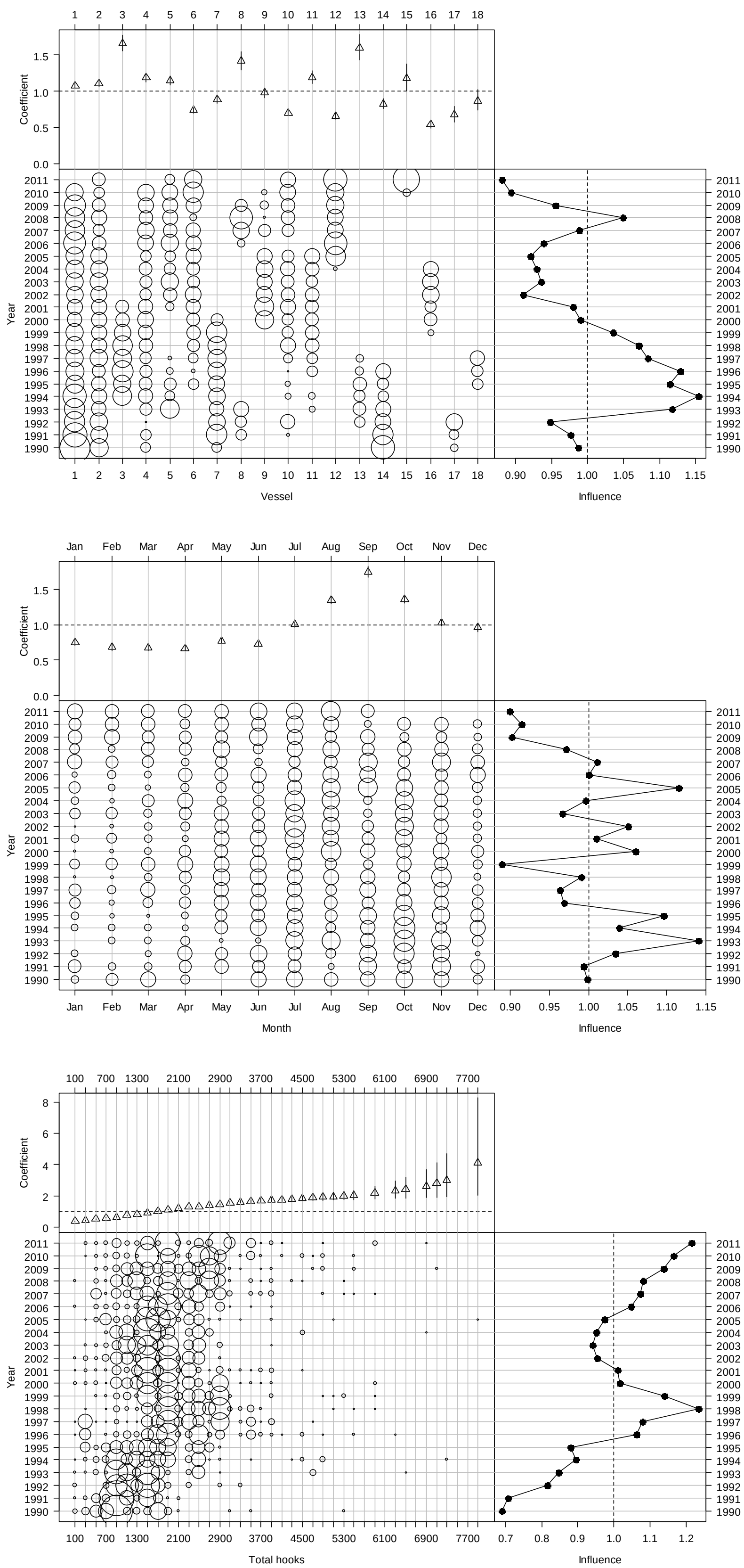


Figure B8c: Effect and influence of variables in the WCSI line data lognormal model. Top: relative effect by level of each variable. Bottom left: relative distribution of each variable by fishing year. Bottom right: influence of variable on unstandardised CPUE by fishing year.

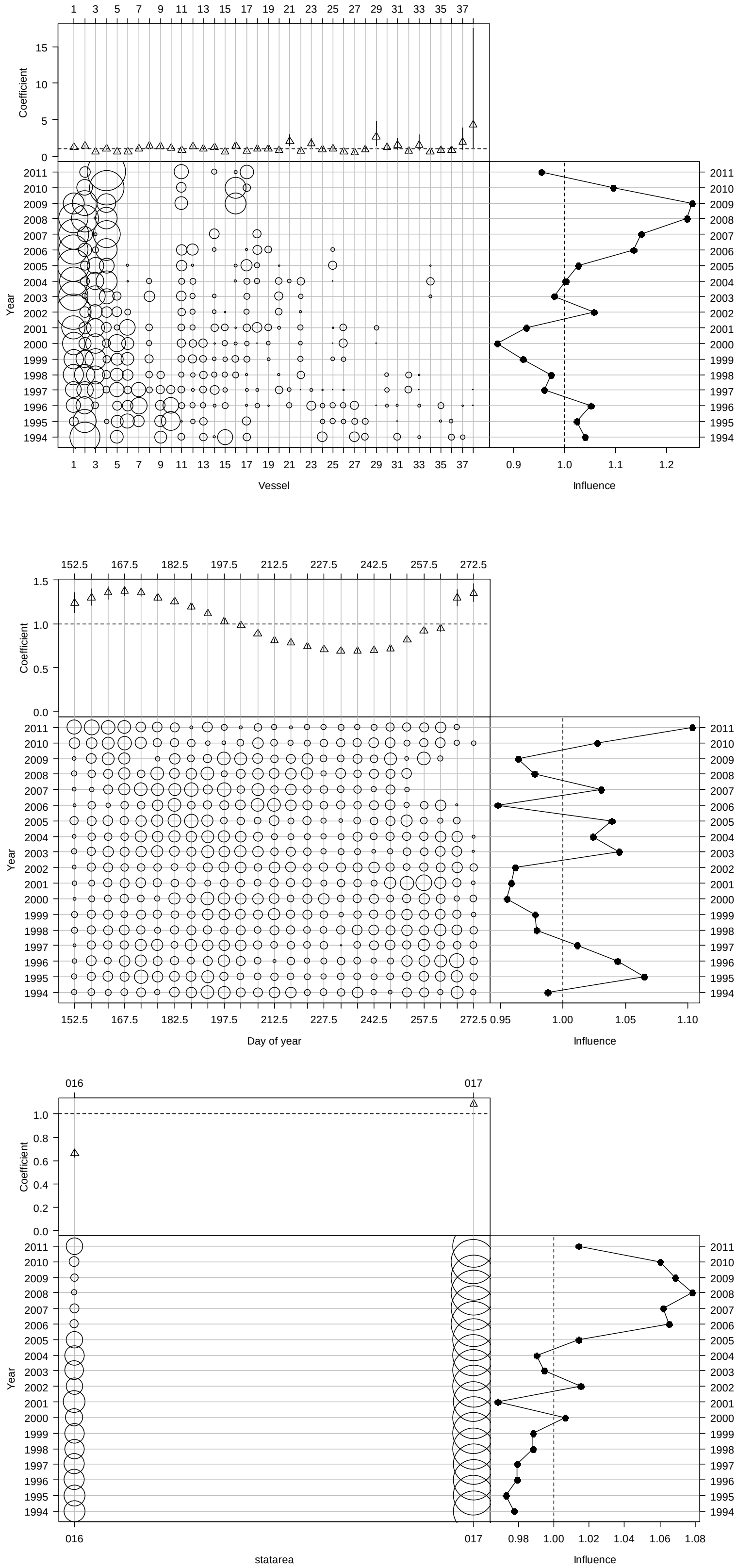


Figure B8d: Effect and influence of non-interaction term variables in the Cook Strait TCEPR tow-by-tow lognormal model. Top: relative effect by level of each variable. Bottom left: relative distribution of each variable by fishing year. Bottom right: influence of variable on unstandardised CPUE by fishing year.

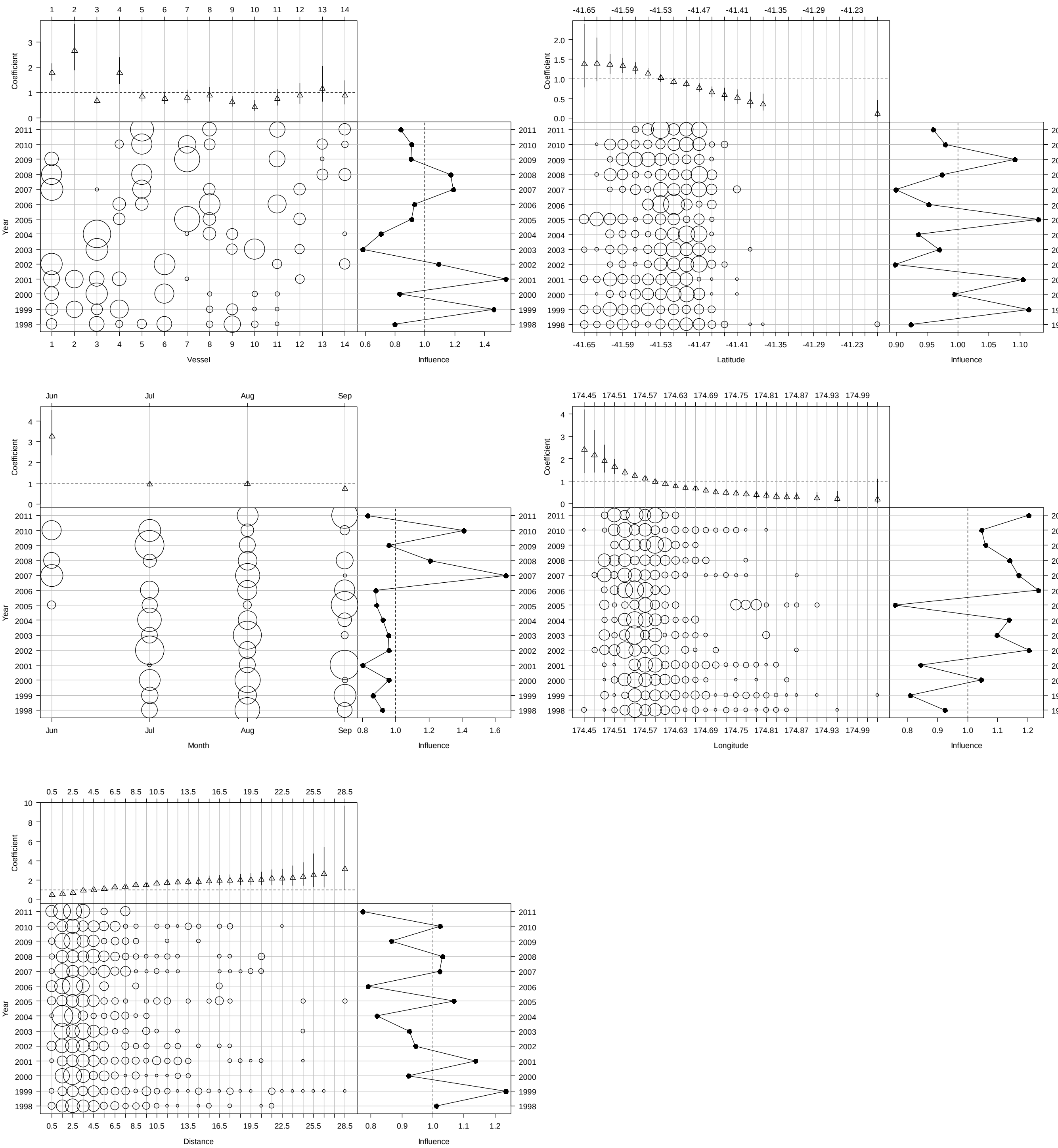


Figure B8e: Effect and influence of the variables in the Cook Strait observer data lognormal model. Top: relative effect by level of each variable. Bottom left: relative distribution of each variable by fishing year. Bottom right: influence of variable on unstandardised CPUE by fishing year.

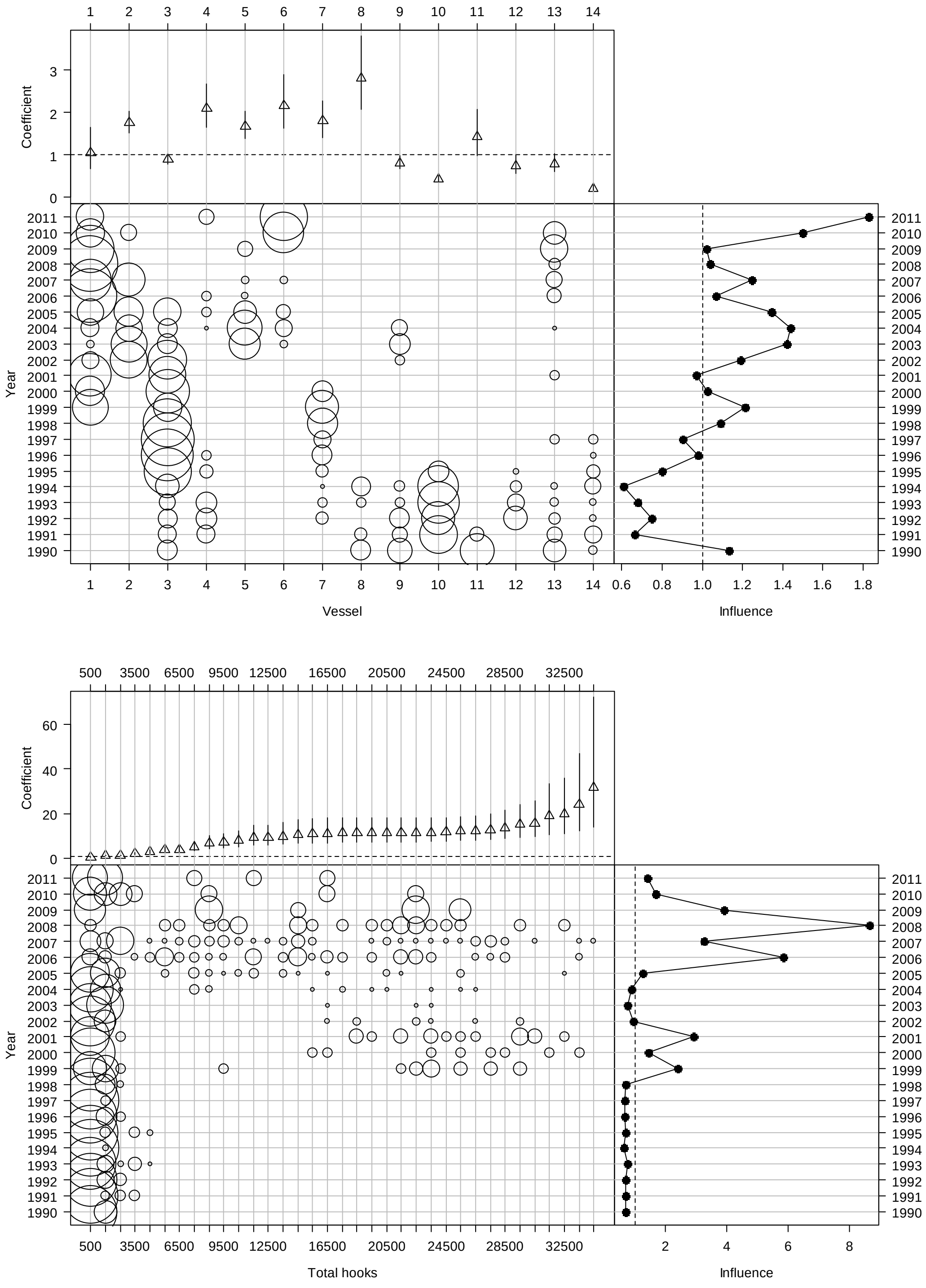
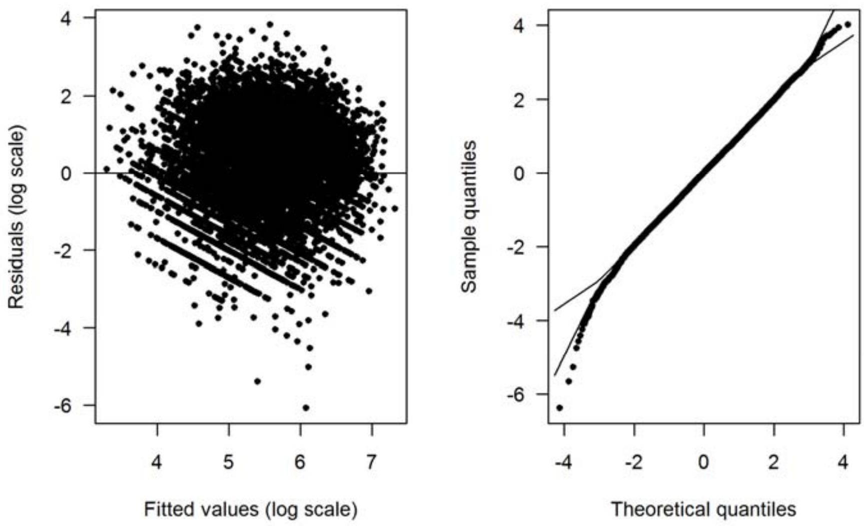
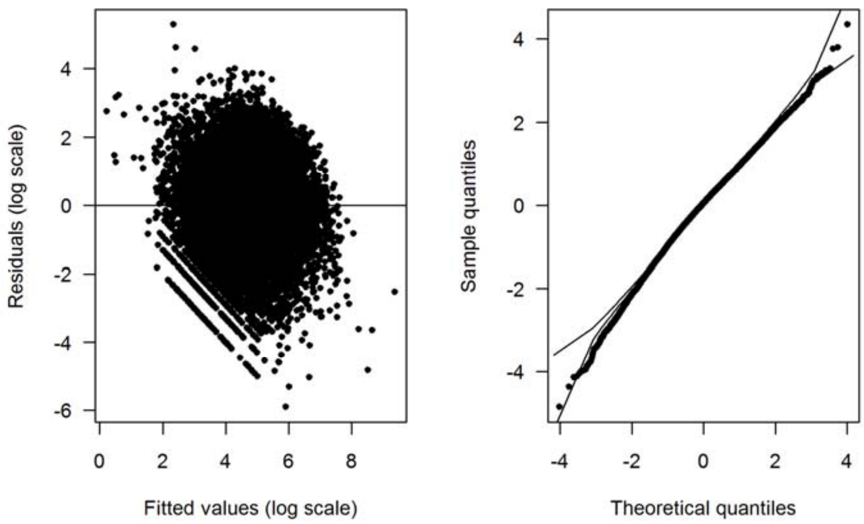


Figure B8f: Effect and influence of variables in the Cook Strait line lognormal model. Top: relative effect by level of each variable. Bottom left: relative distribution of each variable by fishing year. Bottom right: influence of variable on unstandardised CPUE by fishing year.

(a) WCSI TCEPR tow-by-tow accurate vessels



(b) WCSI observer data



(c) WCSI line

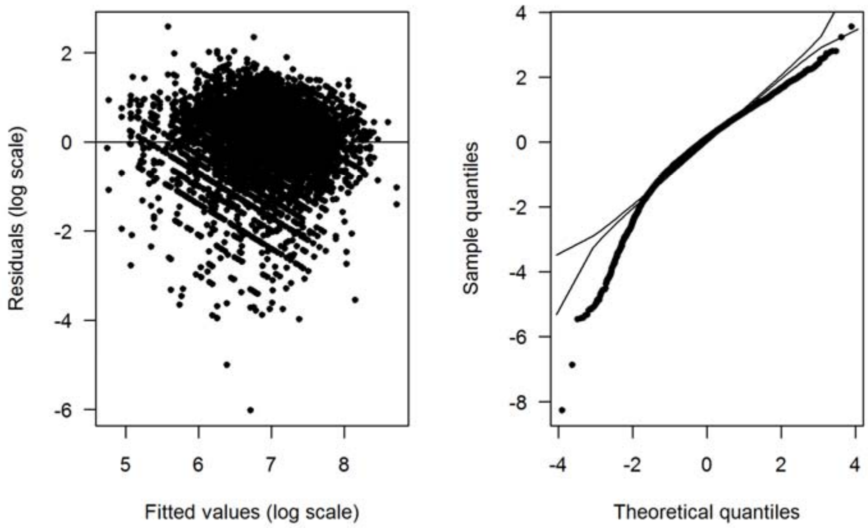
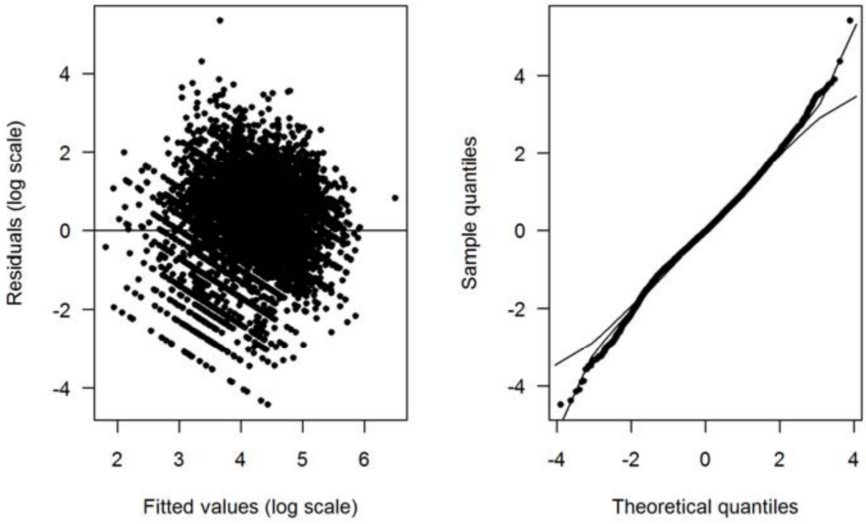
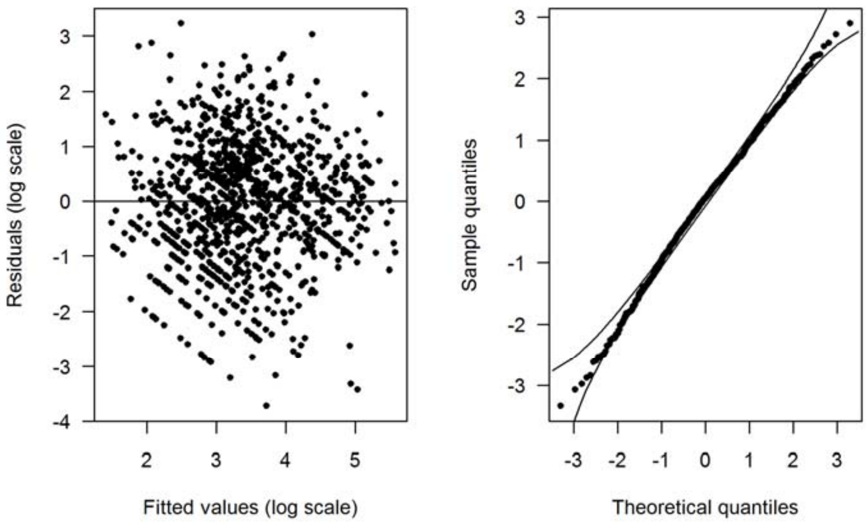


Figure B9: Diagnostic plots for the lognormal CPUE models.

(d) Cook Strait trawl



(e) Cook Strait observer data



(f) Cook Strait line

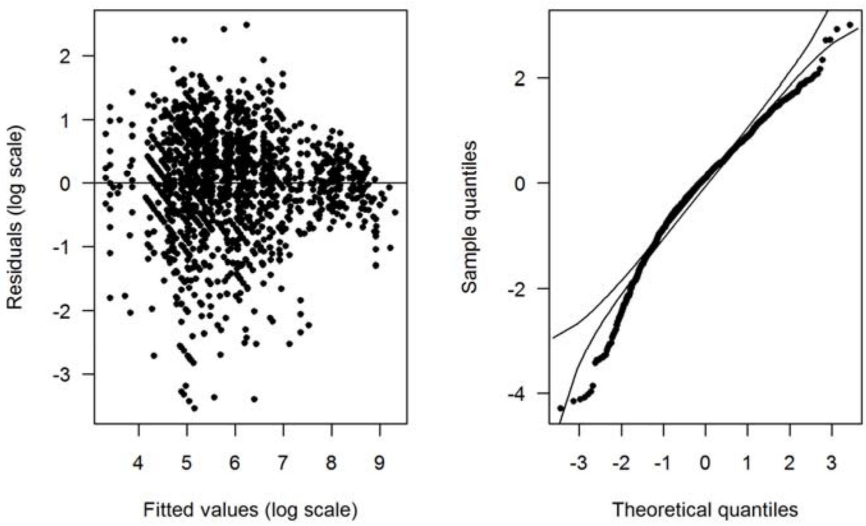
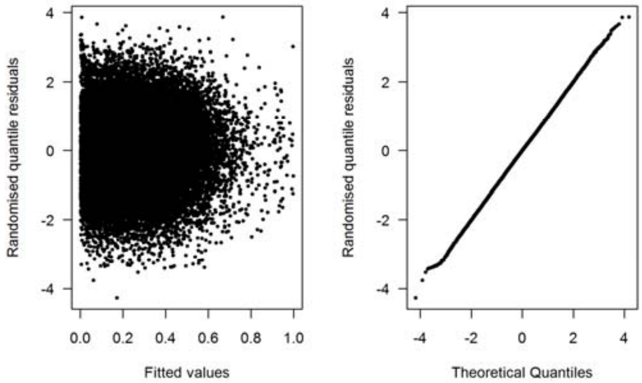
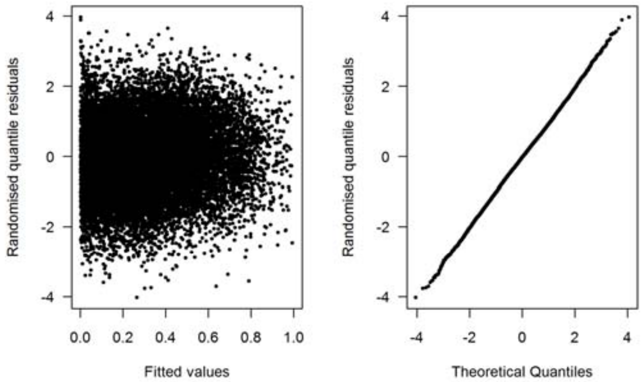


Figure B9: continued.

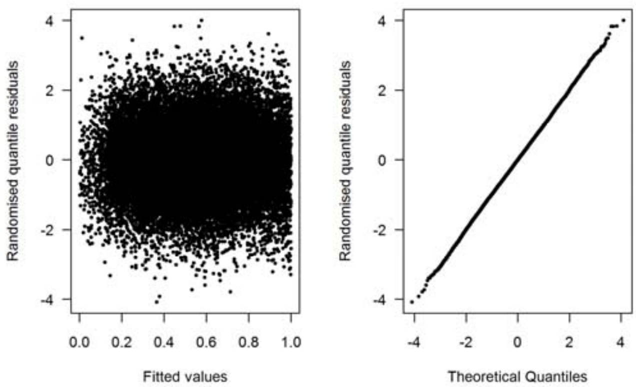
(a) WCSI TCEPR tow-by-tow accurate vessels



(b) WCSI observer data



(c) Cook Strait trawl



(d) Cook Strait observer

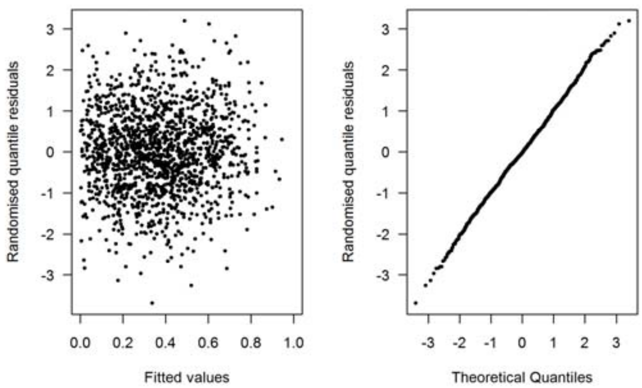


Figure B10: Diagnostic plots for the binomial CPUE models.