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Fishery description and stock assessment for ling off the West Coast South Island (LIN 7) to the 2015–16 fishing year

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EXECUTIVE SUMMARY

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Updated descriptive analyses for all New Zealand ling fisheries are presented incorporating data up to the 2015–16 fishing year. The overall 2015–16 ling catch remained at similar levels to the three previous years, but catches had increased from low levels in 2008–09 to 2011–12. Recent catches remained lower than the landings from the 1991–92 to 2007–08 fishing years. The Southland fishery had the largest overall catches of any fishery in 2015–16. The distribution and size of trawl fishery landings showed little change. Overall trawl landings were lower than those taken in 2014–15, and lower than those taken during the early to mid-2000s. The line fishery catch distribution was also quite similar to previous years, although catches from the east South Island, Chatham Rise, and Bounty Plateau increased in 2015–16, and were again low for the Sub-Antarctic. The line fishery catch was markedly lower than in the most productive years (1992–2002), but relatively consistent with the pattern of landings since 2003.

An updated Bayesian assessment is presented for the ling stock on the west coast of the South Island (LIN 7WC). The assessment incorporated all relevant biological parameters, commercial catch histories, updated Catch-Per-Unit-Effort (CPUE) and research trawl surveys as biomass indices, and catch-at-age composition data from research surveys and the commercial trawl and line fisheries. The sensitivity of the model fit to assumptions and data sets was investigated; these included changes to assumed growth rate, natural mortality rate, CPUE index, the research survey biomass survey catchability (q) prior, inclusion of an inshore research trawl survey, assumed shape of selectivity ogives for the trawl survey and fishery, weights assigned to different observational data sets, priors on year class strength estimates, and choice of stock-recruitment model. Model sensitivity to assumptions concerning sex ratio (and related issues) was investigated in detail in the previous assessment.

The Ministry for Primary Industries Deepwater Fisheries Assessment Working Group (DWFAWG) chose three model runs for the provision of fishery management advice; these used either a combined or lognormal-only standardised CPUE index with an estimated natural mortality rate (M) ("Combined CPUE" and "Lognormal CPUE" runs), or a lognormal CPUE index with a fixed M of 0.18 yr^{-1} ("M = 0.18" run) There was no accepted 'base' case, rather the three model runs were chosen to represent the key alternative assumptions, and the range of model outcomes.

All model runs were indicative of an unfished biomass (B_0) greater than about 60 000 t, and suggested that the stock in 2015–06 had not been depleted to more than about half of this size. The upper bound on B_0 was highly uncertain, and was influenced by the weight assigned to the trawl survey catch-at-age, and the priors on M and the research trawl survey q. The "Combined CPUE" model run indicated a biomass decline until 1992, followed by fluctuating but stable biomass until 2016, whereas the "Lognormal CPUE" and "M = 0.18" model runs indicated slow overall biomass decline from 2000–2012. The model fit to the trawl survey biomass series was good, but to the CPUE series (both lognormal and combined indices) was poor. All model runs estimated recent trawl fishing pressure to be stable, and recent longline fishing pressure to have been relatively high in 2013–14 and 2014–15. All model runs estimated a period of higher recruitment around 1990, and in several years since 2001. Although the status of the stock in 2015–16 was highly uncertain, and influenced by model assumptions, the stock was very likely to be above the biomass target (40% B0), and virtually certain to be above the limit reference point (20% B_0). Constant catch projections out to 2022 indicated that biomass was likely to remain about the same with future catches equal to recent previous catch levels, or even if catches were to increase modestly (by around 10%).

1. INTRODUCTION

New Zealand ling are managed as eight administrative Quota Management Areas (QMAs), although five of these (LIN 3, 4, 5, 6, and 7) (Figure 1) currently produce about 95% of the New Zealand landings of ling. Research has supported the assumption of 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.

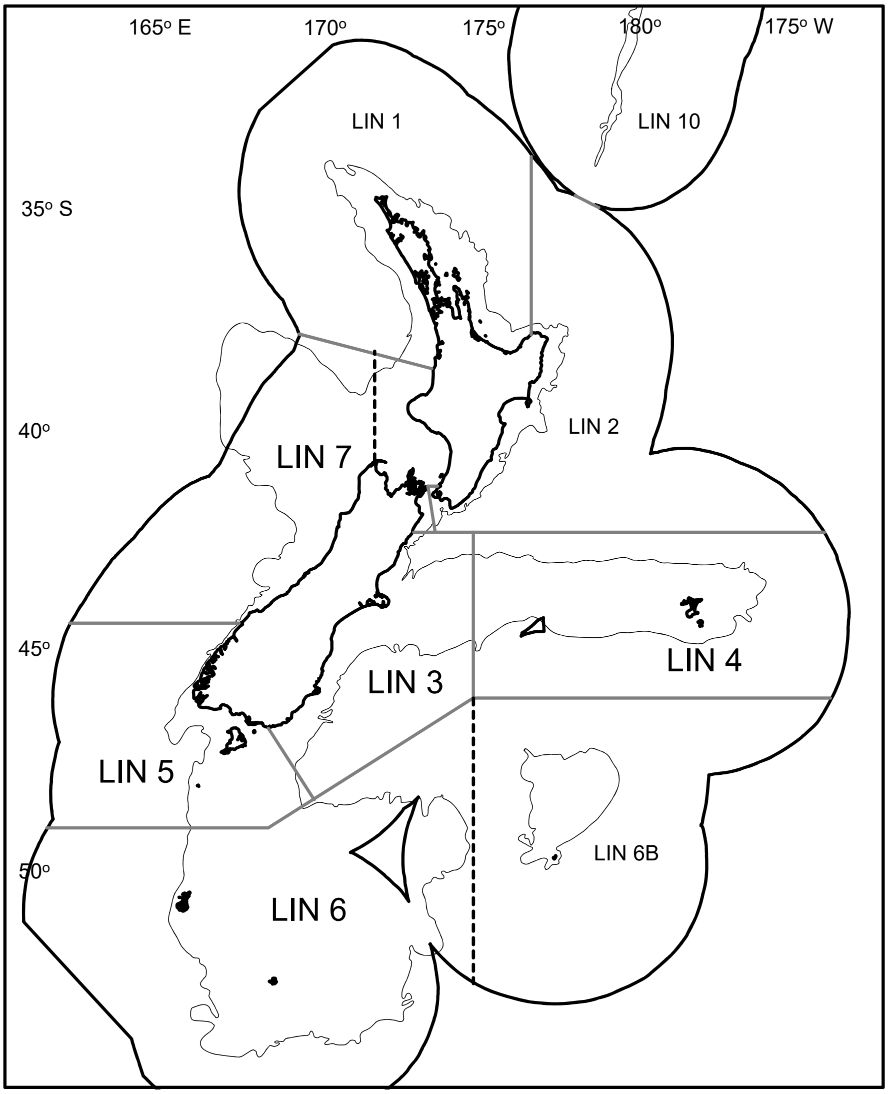


Figure 1: Ling fishstocks, and the 1000 m isobath. The boundaries used to separate biological stock LIN 6B from the rest of LIN 6, and the west coast South Island section of LIN 7 from the rest of LIN 7, are shown as broken lines.

In the stock assessment process, these five biological stocks of ling are assumed, 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 in 2015 (McGregor

2015), LIN 5&6 in 2015 (Roberts 2016), LIN 6B (Horn 2007a), LIN 7CK in 2013 (Dunn et al. 2013), and (prior to this report) LIN 7WC in 2013 (Dunn et al. 2013).

This document describes the stock assessmet of LIN 7WC that took place in 2017. We have attempted to document the process of model development and sensitivity runs for future reference; this process was not (is not) linear, however, so the assessment modelling section of this report (Section 4.2.2) suffers from some cross-referencing.

This report describes the research conducted under all objectives of Ministry for Primary Industries (MPI) Project DEE2016-10. The specific project objectives were: *to carry out a descriptive analysis of the commercial catch and effort data; to update the standardised catch and effort analyses from the LIN 7WC fisheries*; and *to conduct a stock assessment, including estimating biomass and sustainable yields, for LIN 7WC.*

2. REVIEW OF THE FISHERY

2.1 Data set

Earlier 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 2007b). These reports showed how the ling fisheries in the New Zealand EEZ had developed and operated, and defined seasonal and areal patterns of fish distribution. The work presented here updates an analysis by Ballara & Horn (2015) which included data to the fishing year 2012–13 (fishing years run 1 October – 30 September).

Horn (2007b) provided a detailed description of the methods used to extract and summarise MPI landings data. Catch-effort, daily processed, and landed data were extracted from the MPI catch-effort database "warehou" (extract 10800) and consisted of all fishing and landing events associated with a set of fishing trips that reported a positive catch or landing of hoki, hake, or ling during fishing years 1989–90 to 2015–16. The extract included all fishing recorded on Trawl Catch, Effort and Processing Returns (TCEPRs); Trawl Catch Effort returns (TCERs); Catch, Effort and Landing Returns (CELRs); Lining Catch Effort Returns (LCERs); Lining Trip Catch Effort Returns (LTCERs); and Netting Catch Effort Landing Returns (NCELRs); and included high seas versions of these forms.

Data were groomed to identify and remove errors using simple checking and imputation algorithms developed in the statistical software package 'R' (R Development Core Team 2016), similar to those used by Ballara & O'Driscoll (2016). Individual tows or sets were investigated, and missing values or incorrect values (e.g., typing 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. The identification of errors also used range checks, and outliers were corrected if possible with median imputation for data such as vessel, target species and fishing method for a year or month. If the error could not be resolved the record was removed from the data set. Missing fields for statistical area were calculated from positions where these were available. Transposition of some data fields was carried out where the errors were clear (e.g., bottom depth and depth of net, or number of hooks and number of sets).

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 was not based on depth or position, but rather on the form type that the catch was reported on. TCEPR records were classified as deepwater; CELR and TCER records were 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 fishery areas are labelled in this section as 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 1, Figure 2).

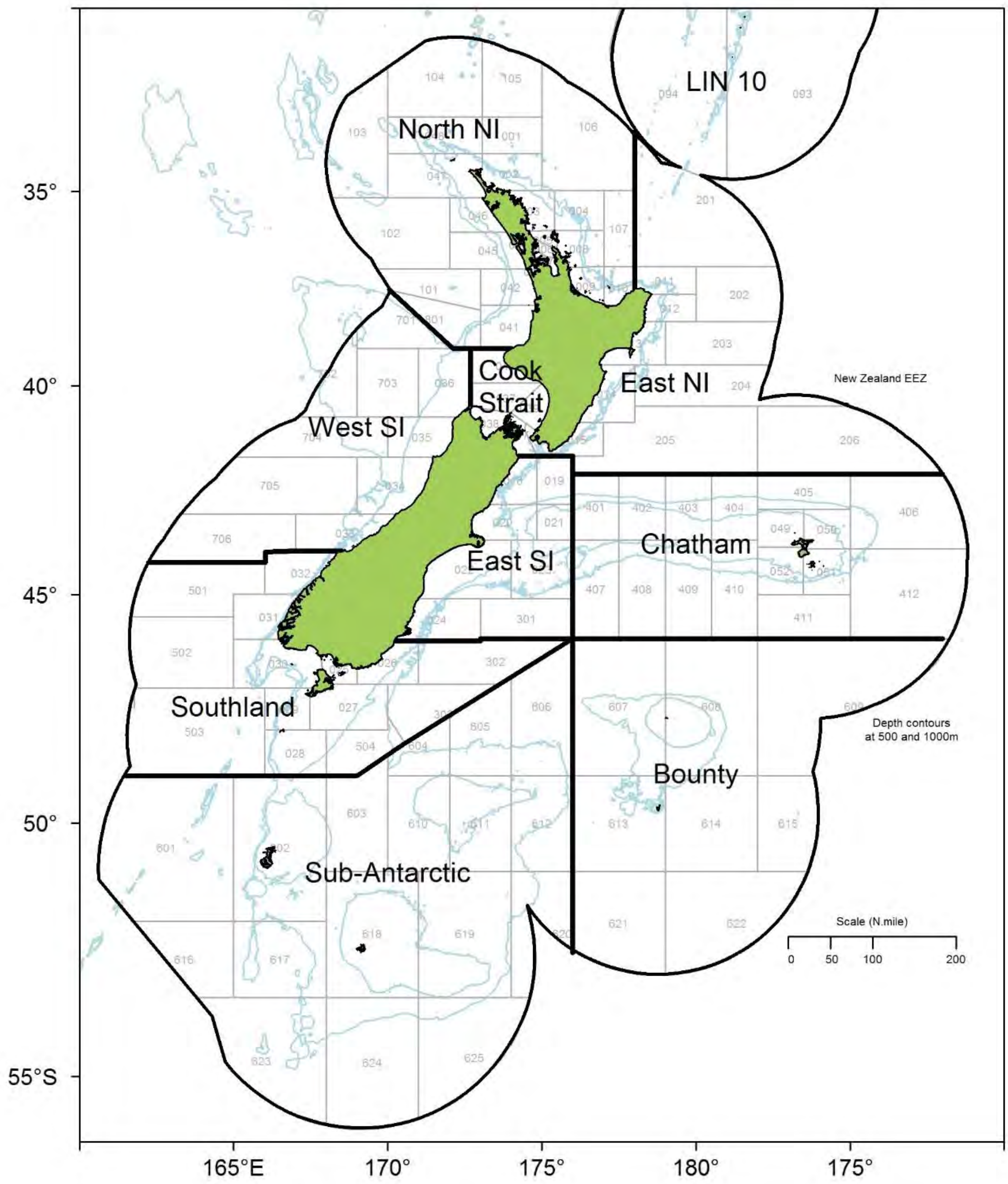


Figure 2: Definitions of geographical areas used in the analyses (based on statistical areas). See Table 1 for the administrative ling stocks they approximate.

Table 1: Definitions of geographical areas used in the fisheries descriptive analyses (based on statistical areas), and the administrative ling stocks they approximate. For a plot of statistical areas, see Figure 2.

Area	Statistical Areas	Administrative stock	Assessment 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	LIN 3 & 4
Chatham	049–052, 401–412	LIN 4	LIN 3 & 4
Southland	025–031, 302, 303, 501–504	LIN 5	LIN 5 & 6
Sub-Antarctic	601–606, 610–612, 616–620, 623–625	Part of LIN 6	LIN 5 & 6
Bounty	607–609, 613–615, 621, 622	Part of LIN 6	LIN 6B
West SI	032–036, 701–706	Part of LIN 7	LIN 7WC
Cook Strait	016, 017, 037–040	Parts of LIN 2 & 7	LIN 7CK

2.2 Estimated catch summary

Annual estimated catches by area, from all methods combined, are listed in Table 2, and shown in Figure 3. The estimated catch totals for each year ranged between 85 and 101% of the Monthly Harvest Return (MHR) landings. Substantial catches were taken in all areas, but most catches were taken in five areas around the South Island: East SI, Chatham, Southland, Sub-Antarctic, and West SI. This pattern of catches was consistent with ling distributions derived from research trawls (Anderson et al. 1998).

Table 2: Total estimated ling catches (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											
Fishing year	North NI	East NI	East SI	Chatham	Southland	Sub-Antarctic	Bounty	West SI	Cook Strait	Total by year	MHR total	Percent of MHR
1989–90	83	268	1 221	512	2 116	1 216	12	2 323	414	8 167	9 026	90.5
1990–91	139	437	1 935	2 156	2 093	2 683	33	1 947	527	11 950	13 675	87.4
1991–92	185	450	1 806	4 358	3 832	2 398	908	1 859	314	16 119	17 796	90.6
1992–93	155	526	1 622	3 657	2 685	5 252	969	1 874	323	17 065	19 069	89.5
1993–94	185	508	1 573	3 756	3 248	2 282	1 149	1 766	251	14 722	15 959	92.3
1994–95	219	530	2 139	5 737	3 765	3 683	396	2 875	321	20 027	19 817	101.1
1995–96	165	553	2 430	4 174	4 764	4 112	381	2 625	366	19 575	21 471	91.2
1996–97	254	525	2 069	3 849	4 294	5 035	340	2 498	366	19 285	22 535	85.6
1997–98	220	607	2 086	4 285	4 132	5 359	395	2 766	287	20 150	23 083	87.3
1998–99	178	545	1 981	3 924	3 510	4 336	563	2 927	345	18 334	21 019	87.2
1999–00	297	485	2 150	3 969	3 150	5 072	991	2 697	331	19 146	21 594	88.7
2000–01	236	597	1 743	3 445	3 394	4 641	1 064	3 070	391	18 584	20 551	90.4
2001–02	280	583	1 583	3 217	3 255	5 406	629	2 642	289	17 885	19 563	91.4
2002–03	227	471	1 845	2 719	3 061	5 137	922	2 338	353	17 075	18 908	90.3
2003–04	207	507	1 473	2 385	3 119	5 899	853	2 402	360	17 204	18 758	91.7
2004–05	241	399	1 267	2 927	4 126	5 389	49	2 057	372	16 827	17 186	97.9
2005–06	291	415	1 218	1 729	3 917	3 737	43	2 053	297	13 700	14 178	96.6
2006–07	232	512	1 601	1 943	3 998	4 112	236	1 797	239	14 670	16 099	91.1
2007–08	361	503	1 505	2 307	4 251	3 818	503	1 909	186	15 344	16 263	94.3
2008–09	307	452	1 394	1 815	3 201	2 264	232	1 851	124	11 640	13 137	88.6
2009–10	379	451	1 373	1 844	3 240	2 272	1	1 957	75	11 593	12 609	91.9
2010–11	440	482	1 173	1 398	4 013	1 129	53	2 288	129	11 105	12 337	90.0
2011–12	377	346	815	2 017	3 828	1 885	2	2 142	110	11 523	12 955	88.9
2012–13	386	369	1 032	1 918	3 691	3 396	3	2 460	176	13 431	14 339	93.7
2013–14	395	425	1 046	2 041	3 889	2 832	277	2 661	147	13 713	15 225	90.1
2014–15	400	453	876	1 876	3 817	2 993	23	2 745	146	13 329	15 002	88.9
2015–16	390	467	1 071	2 258	3 632	1 931	220	2 890	170	13 030	14 651	88.9
Total	7 230	12 867	42 025	76 214	96 024	98 270	11 247	63 421	7 411	415 194	456 804	-
Percent	1.7	3.1	10.1	18.4	23.1	23.7	2.7	15.3	1.8	-	-	-

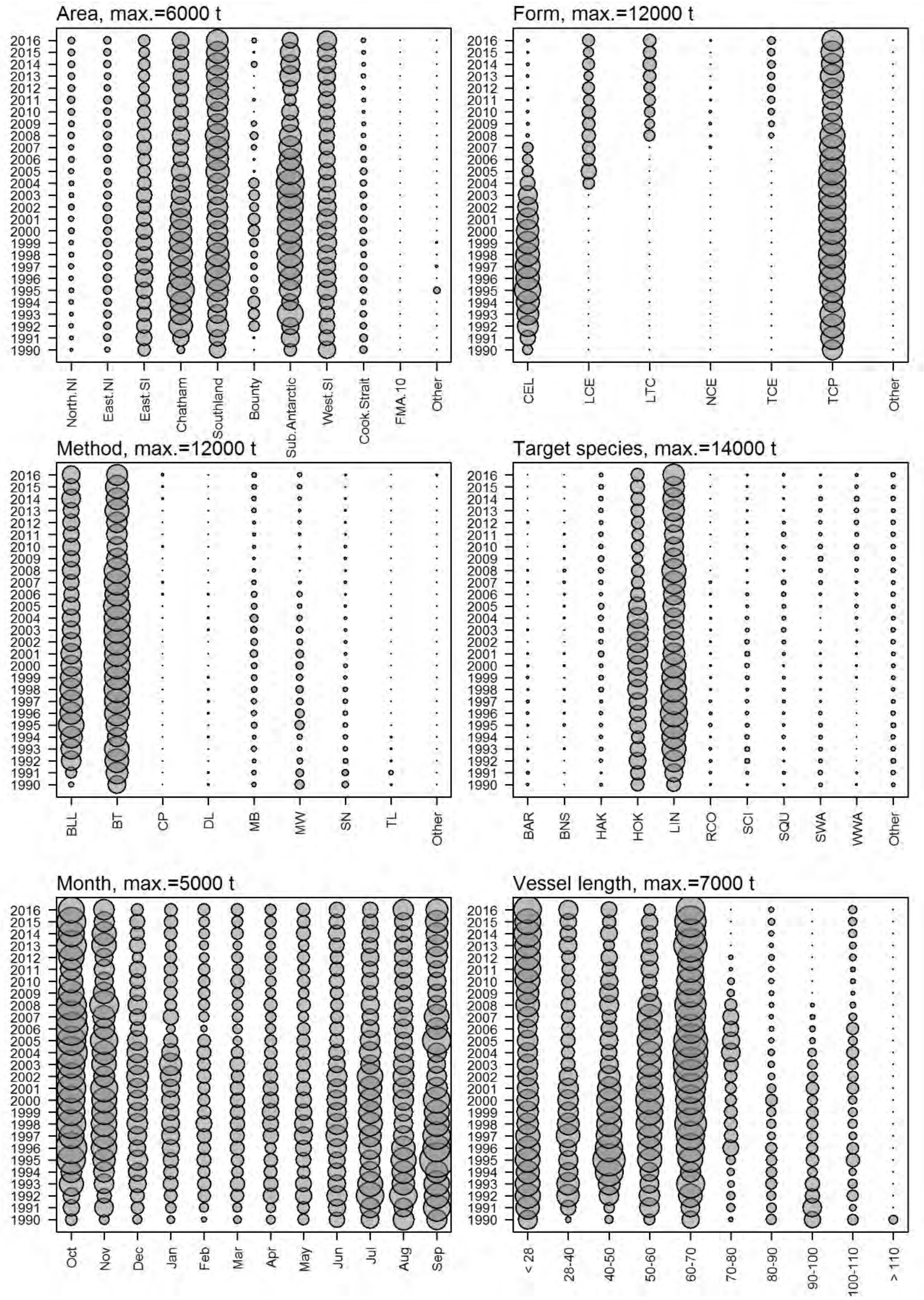


Figure 3: Distribution of annual catch by area, form type, fishing method, target species, month, and vessel length for all ling catches by all methods. Circle size is proportional to catch; maximum circle size is indicated in the heading of each plot. Form types: CEL is Catch, Effort, Landing Return; 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; MB, midwater trawl on the bottom; 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.

There were some changes to the proportions of catch contributed by some areas before and after 2000. Catches from the Sub-Antarctic increased in the latter period (although have been lower from 2008–09 to 2015–16), while those from Chatham declined. By catch weight, the largest overall fishery in 2015–16 was the Southland fishery.

The catch history is described in Tables 3 and 4. Compared to the previous fishing year, the 2015–16 trawl fishery catches in North NI, East NI, East SI, Southland, West SI, and Cook Strait were similar, and Chatham trawl and Sub-Antarctic trawl catches decreased (Table 4, Figure 4). The line catches in 2015–16 increased overall, with most of the increase taking place for Chatham Rise and Bounty, with a notable decrease for the Sub-Antarctic (Table 3, Figure 5). Total catches from the EEZ remained at similar levels, of over 13 000 t, from 2012–13 to 2015–16, which was an increase from the lowest levels in 2008–09 to 2011–12. Catches from the last eight years were all below those from the historically high catch period of 1991–92 to 2007–08 (Table 3).

For the inshore bottom trawl fishery, there were low levels of catches (i.e., generally less than 100 t annually) in all areas except for Sub-Antarctic, and Bounty, where catches were negligible or zero (Table 4). There were increased catches in Southland and West SI by inshore trawl from about 2008–09. Catches from the inshore midwater trawl fishery were negligible in all areas except West SI and Cook Strait; catches in 2015–16 in both those areas were low (Table 3).

The deepwater bottom trawl fishery was still important in the Southland and Sub-Antarctic areas with annual catches generally greater than 2000 t (Table 3). Catches from the Sub-Antarctic increased from the late 1990s to peak at more than 4900 t in 2003–04. Only 750–1500 t was reported from 2009–10 to 2011–12, but there was a large increase to 3390 t taken in 2012–13, with a decrease to just over 1500 t in 2015–16. Southland catches ranged from 1900 to 3300 t, with 2900 t taken in 2015–16. West SI catches have been greater than 500 t since 1996–97, and in 2015–16 decreased slightly to 799 t. Chatham and East SI catches increased in 2015–16. Total landings from the deepwater midwater trawl fishery have been relatively low since 2006–07, ranging between 125 and 630 t (Table 3).

The line fishery catches by area varied markedly between years (Table 3). The total catch in 2015–16 was higher than in 2014–15, primarily due to East SI, Chatham and Bounty catches increasing. The Chatham area was still the most productive, but recent catches were only about a third of those taken at its peak in the mid-1990s.

The setnet fishery catches have been negligible in all areas except East SI and West SI (Table 3). The 2015–16 catches in East SI and West SI remained low.

Catches from fish pots were generally recorded only from East SI and Southland, and averaged about 20–50 t annually, and were moderately low in 2015–16 (Table 3).

Table 3: 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									
Fishing year	North NI	East NI	East SI	Chatham	Southland	Sub-Antarctic	Bounty	West SI	Cook Strait	Total
1989–90	10	25	148	4	47	–	–	148	4	386
1990–91	18	36	198	5	63	–	–	150	9	480
1991–92	30	21	145	2	53	–	0	192	4	448
1992–93	35	17	110	0	91	0	–	220	14	486
1993–94	29	22	64	1	78	–	–	111	22	326
1994–95	20	18	66	2	83	0	–	106	78	374
1995–96	9	24	50	3	50	0	0	188	82	406
1996–97	19	17	62	0	56	–	–	168	72	394
1997–98	9	7	45	0	30	–	–	104	24	220
1998–99	8	5	51	0	66	0	–	158	26	314
1999–00	57	7	80	0	48	–	–	129	20	340
2000–01	22	6	75	0	99	–	–	55	15	271
2001–02	11	4	99	1	89	–	–	55	17	275
2002–03	9	8	91	1	166	–	–	69	8	352
2003–04	3	3	88	0	137	–	–	54	4	290
2004–05	1	2	99	1	136	–	–	130	7	376
2005–06	6	2	46	10	106	–	–	127	3	299
2006–07	8	15	49	1	98	–	–	101	4	276
2007–08	52	18	72	0	109	–	–	240	6	496
2008–09	62	11	39	–	122	0	–	252	31	517
2009–10	86	14	66	0	180	0	–	277	26	649
2010–11	39	21	62	0	368	–	0	315	68	873
2011–12	25	51	64	13	288	0	0	275	36	753
2012–13	86	36	45	39	249	–	–	270	39	764
2013–14	78	71	53	25	399	0	–	254	19	899
2014–15	52	58	36	42	395	–	–	177	15	774
2015–16	51	65	53	25	459	–	0	234	13	900

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

	Area									
Fishing year	North NI	East NI	East SI	Chatham	Southland	Sub-Antarctic	Bounty	West SI	Cook Strait	Total
1989–90	1	1	3	–	–	–	–	2	42	49
1990–91	0	0	9	–	–	–	–	–	125	134
1991–92	0	1	6	–	–	–	–	2	36	44
1992–93	0	2	0	–	–	–	–	1	26	30
1993–94	0	0	1	–	–	–	–	3	11	14
1994–95	1	0	0	1	–	–	–	9	6	17
1995–96	1	0	2	–	–	–	–	24	16	43
1996–97	4	0	7	–	–	–	–	21	8	45
1997–98	9	0	4	–	–	–	–	45	13	74
1998–99	1	0	20	–	–	–	–	83	9	113
1999–00	0	0	7	–	–	–	–	206	18	232
2000–01	6	1	7	–	–	–	–	175	29	218
2001–02	0	0	9	–	–	–	–	83	14	106
2002–03	0	0	30	–	0	–	–	113	36	178
2003–04	0	0	13	0	–	–	–	67	29	110
2004–05	0	0	1	0	0	–	–	70	22	93
2005–06	0	0	2	–	–	–	–	63	21	86
2006–07	0	0	0	–	–	–	–	34	18	52
2007–08	–	–	0	–	0	–	–	2	4	6
2008–09	–	–	0	–	–	–	–	20	4	24
2009–10	–	0	0	–	–	–	–	19	2	21
2010–11	–	–	0	0	0	–	–	33	2	35
2011–12	–	–	0	–	0	–	–	43	1	45
2012–13	–	–	0	–	–	–	–	39	1	40
2013–14	–	0	0	–	–	–	–	48	2	49
2014–15	–	0	0	–	–	–	–	58	3	62
2015–16	0	–	0	–	–	–	–	89	4	93

Table 3: continued.

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

Fishing year	North NI	East NI	East SI	Chatham	Southland	Sub-Antarctic	Bounty	West SI	Area Cook Strait	Total
1989–90	31	59	599	500	1 953	1 174	4	370	7	4 698
1990–91	70	117	817	1 235	1 996	2 457	7	260	13	6 972
1991–92	55	87	933	1 348	3 368	2 053	35	306	4	8 189
1992–93	30	75	807	1 028	1 985	4 308	0	491	4	8 730
1993–94	45	74	727	451	2 038	1 818	4	389	47	5 595
1994–95	44	77	1 016	968	2 557	2 102	0	505	57	7 327
1995–96	73	125	1 081	697	3 945	2 807	1	385	97	9 213
1996–97	141	151	1 017	764	3 254	2 772	0	516	119	8 757
1997–98	136	130	1 174	2 262	2 933	2 970	0	498	78	10 182
1998–99	104	159	973	1 836	2 609	2 389	3	875	111	9 063
1999–00	188	156	871	1 897	2 121	3 850	0	759	90	9 932
2000–01	170	205	971	1 480	1 958	3 684	0	1 019	39	9 527
2001–02	169	207	860	1 216	2 064	4 517	1	1 133	72	10 240
2002–03	121	113	1 131	1 313	1 896	4 707	1	836	35	10 153
2003–04	108	74	811	1 061	2 269	4 936	1	815	38	10 114
2004–05	75	55	641	814	3 042	4 875	8	764	29	10 302
2005–06	124	40	610	595	2 982	3 095	4	994	21	8 465
2006–07	63	71	945	854	3 108	3 920	0	701	19	9 681
2007–08	74	19	828	1 182	3 264	3 469	0	525	41	9 402
2008–09	67	37	699	498	2 674	2 042	8	556	21	6 603
2009–10	39	23	548	539	2 607	1 475	0	603	7	5 842
2010–11	52	28	390	400	3 333	749	0	854	5	5 811
2011–12	86	6	256	731	2 914	1 158	0	761	4	5 916
2012–13	83	7	260	486	3 063	3 390	–	811	9	8 109
2013–14	39	16	242	427	3 156	2 135	3	665	21	6 705
2014–15	72	9	286	687	3 090	2 387	–	859	15	7 405
2015–16	75	4	307	541	2 919	1 541	0	779	2	6 168

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

Fishing year	North NI	East NI	East SI	Chatham	Southland	Sub-Antarctic	Bounty	West SI	Area Cook Strait	Total
1989–90	0	1	72	0	116	42	8	1 261	260	1 759
1990–91	0	13	57	69	29	9	20	740	325	1 261
1991–92	0	1	61	11	121	19	38	402	201	854
1992–93	0	4	34	24	155	58	4	324	172	775
1993–94	0	1	35	33	268	14	3	348	107	809
1994–95	0	0	38	58	417	14	3	1 260	119	1 909
1995–96	0	2	92	60	463	46	2	863	117	1 645
1996–97	0	1	106	59	133	5	0	722	145	1 174
1997–98	1	13	195	44	79	8	7	985	102	1 435
1998–99	3	11	218	47	62	6	11	772	90	1 221
1999–00	0	4	227	29	114	16	7	726	109	1 231
2000–01	0	5	81	44	351	229	0	855	147	1 712
2001–02	0	1	103	38	131	233	1	651	74	1 233
2002–03	5	4	87	19	135	217	0	585	138	1 190
2003–04	0	4	80	60	130	306	2	759	119	1 460
2004–05	0	1	70	15	98	204	6	335	97	826
2005–06	0	3	25	2	149	470	1	269	65	985
2006–07	0	1	6	1	101	191	2	125	45	472
2007–08	0	2	10	0	84	3	1	87	33	220
2008–09	0	2	4	0	6	6	2	80	25	125
2009–10	0	1	18	0	36	8	0	127	22	213
2010–11	0	3	3	0	50	20	2	141	19	237
2011–12	0	0	6	1	138	3	0	165	31	344
2012–13	0	1	16	2	5	6	3	317	34	384
2013–14	0	0	9	1	1	16	8	455	29	520
2014–15	0	1	13	0	75	39	0	467	35	630
2015–16	0	0	10	0	28	11	0	567	33	650

Table 3: continued.

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

Fishing year	North NI	East NI	East SI	Chatham	Southland	Sub-Antarctic	Bounty	West SI	Area Cook Strait	Total
1989–90	39	134	185	8	0	–	–	197	66	630
1990–91	50	186	613	846	2	217	7	428	55	2 406
1991–92	98	300	478	2 997	288	326	835	691	70	6 090
1992–93	83	401	491	2 605	453	886	965	708	100	6 694
1993–94	108	406	552	3 272	863	449	1 142	761	63	7 619
1994–95	128	432	811	4 707	704	1 567	385	891	59	10 047
1995–96	81	397	1 021	3 414	301	1 259	378	994	53	7 900
1996–97	67	328	635	3 026	847	2 258	340	963	20	8 506
1997–98	60	446	427	1 979	1 084	2 381	388	1 008	67	7 848
1998–99	39	370	528	2 040	770	1 940	549	972	107	7 339
1999–00	50	317	779	2 043	857	1 206	984	784	94	7 115
2000–01	36	380	473	1 921	961	728	1 063	917	160	6 640
2001–02	100	370	385	1 962	955	657	627	659	111	5 826
2002–03	91	346	401	1 386	850	214	921	686	137	5 032
2003–04	95	425	356	1 264	581	656	850	682	169	5 078
2004–05	166	340	369	2 097	848	310	34	728	215	5 107
2005–06	161	365	434	1 123	676	172	38	562	187	3 718
2006–07	161	425	498	1 087	685	–	234	745	153	3 988
2007–08	235	461	521	1 125	789	345	502	1 010	93	5 081
2008–09	177	397	583	1 314	382	216	222	887	33	4 211
2009–10	252	412	638	1 303	404	789	1	864	11	4 674
2010–11	349	431	629	995	252	360	51	902	33	4 002
2011–12	266	289	446	1 272	483	723	1	848	34	4 362
2012–13	217	325	655	1 391	367	0	–	957	88	4 000
2013–14	275	337	659	1 587	328	681	265	1 190	71	5 394
2014–15	275	385	461	1 147	249	566	23	1 157	63	4 327
2015–16	254	386	519	1 670	220	378	220	1 149	81	4 877

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

Fishing year	North NI	East NI	East SI	Chatham	Southland	Sub-Antarctic	Bounty	West SI	Area Cook Strait	Total
1989–90	2	48	210	0	0	–	–	346	36	642
1990–91	1	85	227	–	2	–	–	368	0	682
1991–92	3	40	144	0	1	–	–	264	1	453
1992–93	6	25	164	–	1	–	–	129	3	327
1993–94	3	4	179	0	0	–	–	154	1	342
1994–95	27	1	199	–	1	–	–	103	1	332
1995–96	1	5	179	–	0	0	–	170	1	357
1996–97	23	28	203	0	2	0	–	108	1	365
1997–98	4	12	201	–	2	–	–	127	0	346
1998–99	23	1	147	–	0	0	–	65	0	237
1999–00	1	1	165	–	0	–	–	94	0	262
2000–01	0	1	131	–	0	–	–	49	2	184
2001–02	1	0	123	–	1	0	–	62	0	187
2002–03	1	0	104	0	0	–	–	50	0	156
2003–04	1	1	120	–	1	–	–	24	0	148
2004–05	0	1	78	0	1	–	–	31	1	112
2005–06	0	5	51	–	1	–	–	39	0	96
2006–07	0	0	47	–	2	0	–	91	0	141
2007–08	1	2	55	0	3	0	0	43	0	104
2008–09	0	5	58	2	6	0	–	43	0	115
2009–10	0	0	62	2	5	0	–	47	0	116
2010–11	0	0	55	2	5	0	–	28	0	90
2011–12	0	0	34	–	4	0	–	22	1	62
2012–13	0	0	27	0	4	0	–	34	0	66
2013–14	1	0	26	0	2	0	–	18	0	48
2014–15	1	1	32	–	2	0	–	0	0	36
2015–16	1	1	46	0	4	0	–	40	0	92

Table 3: continued.

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

Fishing year	North NI	East NI	East SI	Chatham	Southland	Sub-Antarctic	Bounty	West SI	Area Cook Strait	Total
1989–90	0	0	2	0	1	–	–	0	0	3
1990–91	0	0	15	0	1	0	–	–	0	16
1991–92	0	–	39	0	1	–	–	0	0	40
1992–93	0	0	15	0	1	–	–	–	0	16
1993–94	0	0	11	0	1	–	–	0	0	13
1994–95	0	0	8	0	2	–	–	–	0	10
1995–96	0	0	4	0	4	–	–	0	0	8
1996–97	0	0	38	0	2	–	–	0	0	40
1997–98	0	0	40	0	3	–	–	–	0	43
1998–99	–	0	41	0	0	0	–	–	0	42
1999–00	0	0	21	–	10	–	–	–	0	32
2000–01	2	0	4	0	25	–	–	1	0	31
2001–02	0	0	3	–	16	–	–	–	0	19
2002–03	0	–	1	0	13	–	–	0	0	14
2003–04	0	0	4	0	0	–	–	0	1	5
2004–05	0	0	10	0	0	–	–	0	0	10
2005–06	0	0	49	–	3	0	–	0	0	52
2006–07	0	0	56	0	3	–	–	0	0	60
2007–08	0	0	19	0	2	–	–	–	0	21
2008–09	0	0	10	0	11	–	–	0	0	21
2009–10	0	0	41	–	8	–	–	0	0	49
2010–11	0	0	33	–	5	–	–	–	0	39
2011–12	0	0	8	0	1	–	–	0	0	10
2012–13	0	0	26	–	3	–	–	0	0	29
2013–14	0	0	56	1	3	–	–	0	0	60
2014–15	0	0	45	–	7	0	–	0	–	52
2015–16	1	9	106	0	2	–	–	16	0	134

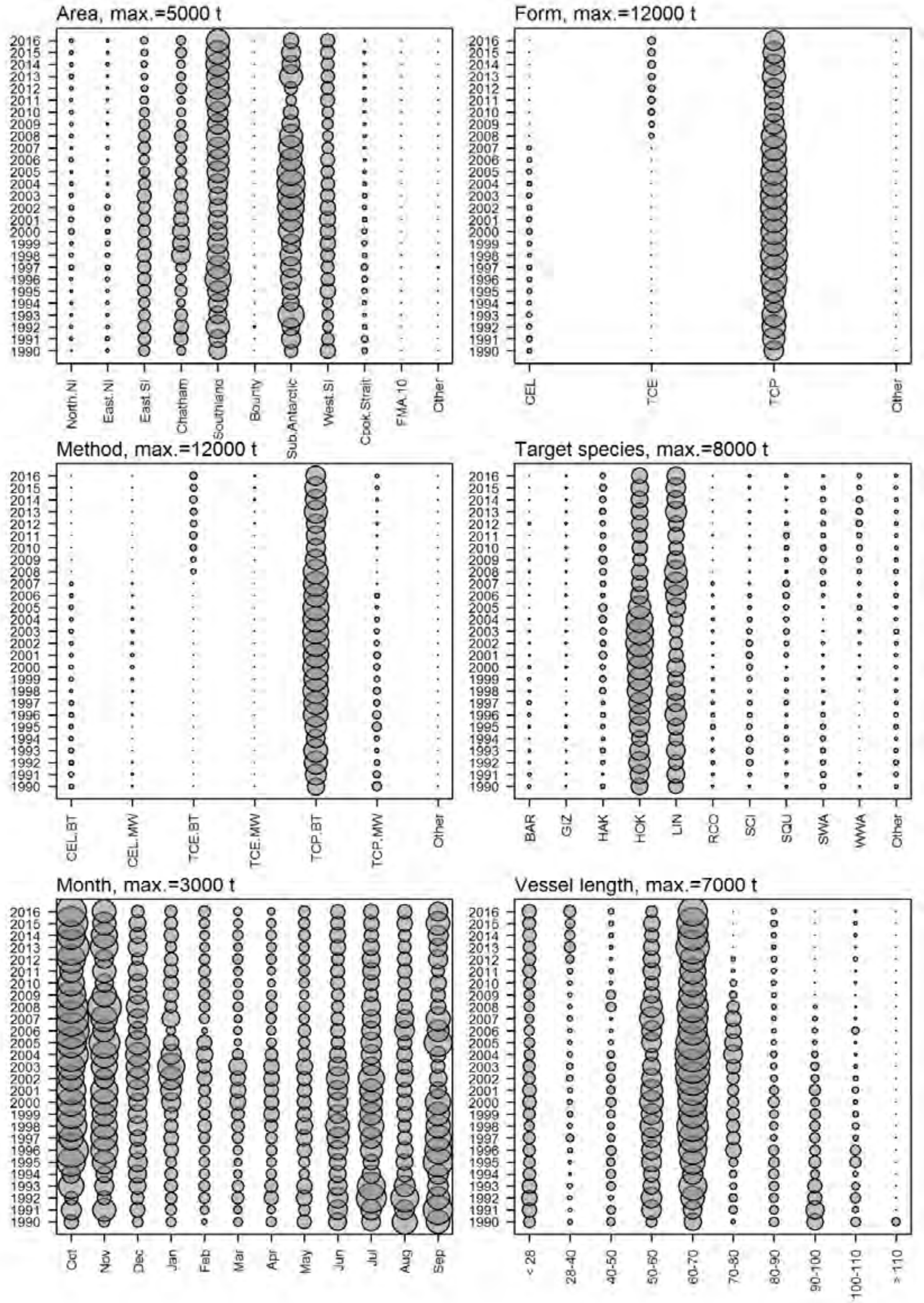


Figure 4: Distribution of annual catch by area, form type, fishing method (by form type), target species, month, and vessel length for all ling catches by trawl methods. Circle size is proportional to catch; maximum circle size is indicated in the heading of each plot. Form types and method types are defined in Figure 3. Species codes: BAR, barracouta; GIZ, giant stargazer; HAK, hake; HOK, hoki; LIN, ling; RCO, red cod; SCI, scampi; SQU, arrow squid; SWA, silver warehou; WWA, white warehou.

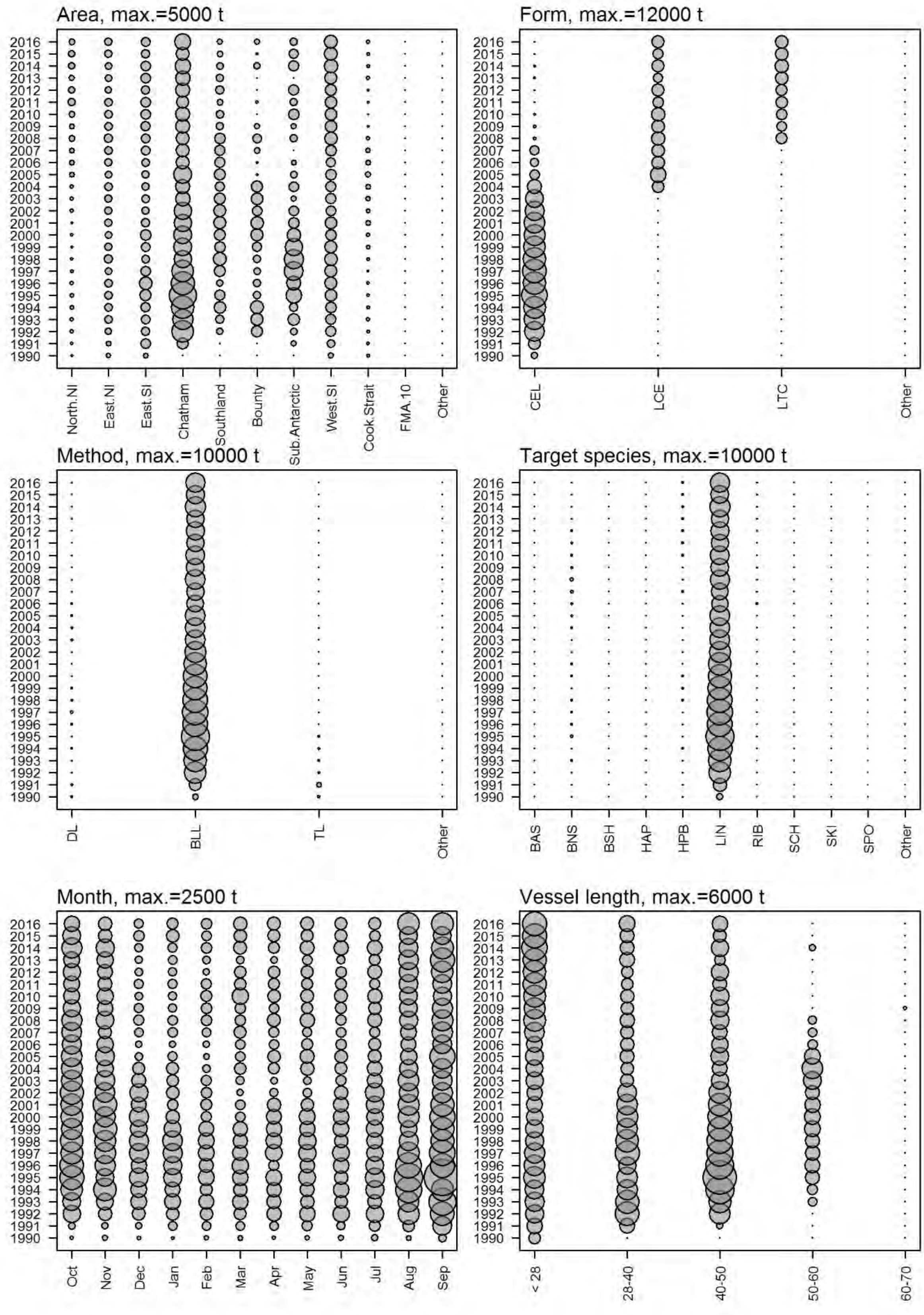


Figure 5: Distribution of annual catch by area, form type, fishing method (by form type), target species, month, and vessel length for all ling catches by line methods. Circle size is proportional to catch; maximum circle size is indicated in the heading of each plot. Form types and method types are defined in Figure 3. BAS, bass; BNS, bluenose; BSH, seal shark; HAP, hapuku; HPB, hapuku and bass; LIN, ling; RIB, ribaldo; SCH, school shark; SKI, gemfish; SPO, rig.

3. ASSESSMENT INPUT DATA

3.1 Catch history

The estimated commercial catch history for the LIN 7WC stock is shown in Table 4. Catches up to 1973 were assumed to be zero, although it is very likely that small quantities of ling were taken in various areas before then. The TACC for LIN 7 was consistently exceeded throughout the 1990s, sometimes by as much as 50%. It is strongly believed that catches of ling by trawlers off the west coast of the South Island (WCSI) were under-reported in fishing years 1989–90 to 1992–93; this has been incorporated into the catch estimates used in the assessment (Dunn et al. 2013) (Table 4). The catch estimates for the last years in the previous assessment (2011–12 and 2012–13) were updated (and modified) for the current assessment.

Table 4: Estimated catch histories (t) for LIN 7WC (West Coast South Island section of LIN 7) by fishing gear, as used in the previous assessment (Dunn et al. 2013), and in the 2017 assessment (this report). *, catch for current year assumed the same as previous year. Fishing years labelled as year ending, i.e., 2017 is 2016–17.

	Trawl		Line			Trawl		Line	
Fishing year	Dunn et al. (2013)	This report	Dunn et al. (2013)	This report	Fishing year	Dunn et al. (2013)	This report	Dunn et al. (2013)	This report
1972	0	0	0	0	1995	1 750	1 750	1 032	1 032
1973	85	85	20	20	1996	1 838	1 838	1 121	1 121
1974	144	144	40	40	1997	1 749	1 749	1 077	1 077
1975	401	401	800	800	1998	1 887	1 887	1 021	1 021
1976	565	565	2 100	2 100	1999	2 146	2 146	1 069	1 069
1977	715	715	4 300	4 300	2000	2 247	2 247	923	923
1978	300	300	323	323	2001	2 304	2 304	977	977
1979	539	539	360	360	2002	2 250	2 250	810	810
1980	540	540	305	305	2003	1 980	1 980	807	807
1981	492	492	300	300	2004	2 013	2 013	814	814
1982	675	675	400	400	2005	1 558	1 558	871	871
1983	1 040	1 040	710	710	2006	1 753	1 753	666	666
1984	924	924	595	595	2007	1 306	1 306	933	933
1985	1 156	1 156	302	302	2008	1 067	1 067	1 170	1 170
1986	1 082	1 082	362	362	2009	1 089	1 089	1 009	1 009
1987	1 105	1 105	370	370	2010	1 346	1 346	1 063	1 063
1988	1 428	1 428	291	291	2011	1 597	1 733	1 046	1 011
1989	1 959	1 959	370	370	2012	1 300	1 744	1 050	976
1990	2 205	2 205	399	399	2013	–	1 915	–	1 045
1991	2 163	2 163	364	364	2014	–	1 721	–	1 411
1992	1 631	1 631	661	661	2015	–	1 786	–	1 358
1993	1 609	1 609	716	716	2016	–	1 780	–	1 160
1994	1 136	1 136	860	860	2017*	–	1 780	–	1 160

3.2 Commercial Catch-Per-Unit-Effort biomass indices

Catch-per-unit-effort (CPUE) from the commercial trawl and longline fisheries were previously reported by Dunn et al. (2013). The analysis for 2017 followed a similar methodology, where CPUE was corrected (“standardised”) for covariates using a Generalised Linear Model (GLM).

3.2.1 CPUE data selection

LIN 7WC was defined as catches and effort from Statistical Areas 032–036, and 701–706. Data from vessels that fished infrequently were excluded, by including data only from "core" vessels, which were those that together reported at least 80% of ling estimated catches, and were all involved in the fishery for two or more years, and for a substantial number of tows or vessel-days in a year (criteria varied by gear, see below).

For trawls, the timing of the ling catch in LIN 7WC varied slightly between years, but most ling catches were taken between May and October, often with a peak from June to September, and mainly as bycatch in the hoki spawning target fishery. For the trawl data, data for each year were restricted to records between June and September inclusive, as this was when most of the catch was taken. The trawl data for CPUE analyses were MPI observer tow-by-tow records of catch and effort, from core vessels that targeted hoki or hake. Core vessels had completed at least 20 tows a year for two or more years. Data were accepted for midwater and bottom trawling for the calendar years 1987–2016, June–September, and Statistical Areas 034–036. Records were excluded if catch weight was greater than 10 t (assumed to be an error), bottom depths were not within 150–900 m (known depth range of ling), or duration of trawling was not within 0.2–15 hours (assumed to be an error).

For lines, data were available from 1 October 1989 and analysed by calendar year rather than fishing year (1 October to 30 September), because of a seasonal trend of higher catch rates in most ling line fisheries running across the fishing year boundary, from about June to December (see Horn 2007a). This produced a more accurate CPUE index, because all catches in a fishing season were included in a single year, rather than being spread (and mixed) across two fishing years. Although this could create a problem for stock assessment models, where the year definition for trawl and line CPUE was different, the line CPUE have ultimately not been used in previous assessments (Dunn et al. 2013), and were similarly not used in this one (see below). Some line vessels recorded individual set data on CELR forms, but most vessels reported a single CELR record for a days fishing. If uncorrected, this would bias CPUE analyses, as those vessels recording individual events would contribute about four times as many records per day. Consequently, all line data for CELR, LTCER and LCER forms were condensed (catches, hooks, and sets summed for each vessel, day, and statistical area) to ensure that each record represented total catch and effort per statistical area per day. The estimated catch of the top five species per day can be reported on the CELR form, whereas the estimated catch of the top eight species per set can be reported on the LCER and LTCER forms. If there was more than one set recorded in a day, the estimated catch of numerous (up to 20–30) species may be reported for a single day of fishing on LCER and LTCER forms, compared to five species on CELR forms. This can result in small catches being reported in LCER and LTCER frecords that would not have appeared had CELR forms been used. Therefore the daily aggregate estimated catch of ling was only included with the LCER or LTCER daily aggregate effort record if the catch of that species was ranked amongst the five largest species catches (by weight) for the vessel fishing day and statistical area. As a result of this correction, there were 425 vessel-day-statistical area aggregate records removed from the dataset. Data were accepted from the CEL, LCE, and LTC forms for target ling and line method BLL (bottom longline) for calendar years 1990–2016, for Statistical Areas 032–034. Core vessels had completed at least 50 daily records over five years. Records were excluded if catches were outside of the range 1–35 000 kg, and the total number of hooks was outside of the range 20–10 000. Examination of records reporting zero catch indicated that most represented either duplicate records (two records for a particular day, one with and one without catches) or obvious mistakes (two or three days fishing with no catch). Because of the relatively high number of hooks fished in any set, a zero catch of ling in any set that was targeting ling was likely to result either from a reporting error or, if real, some gear malfunction or unsuccessful exploratory fishing. As a result, zero catch records were removed from the data set. There were 190 records having zero ling catch, making up 1.4 % of the records.

3.2.2 CPUE standardisation

Standardised catch-per-unit-effort (CPUE) analyses were carried out by fitting generalised linear models (GLMs) to CPUE, using the stepwise multiple regression technique described by Francis (2001). For trawls there were zero catch tows in the data set, therefore the models for the CPUE were split into two parts (1) a normal model for the natural log of the non-zero catch tows, with a normal error distribution and identity link function, and (2) a binomial model which estimated the probability of a non-zero catch, with a binomial response and logit link function. A (3) combined model estimated catch rates from all tows (including those with zero catch) by combining results from the normal and binomial models. The coefficient of variation (CV) of the estimates was estimated analytically for (1) and (2), and for (3) was calculated using a bootstrap procedure (Francis 2001). For lines, only model (1) was used.

The predictor variable fishing year was forced into the model (as it is mandatory for a biomass index), and other variables tested for inclusion. A stepwise forward procedure was used to select additional predictor variables, and they were entered into the model in the order which gave the maximum decrease in the AIC. Predictor variables were accepted into the final model if they explained at least 1% of the deviance and their predicted effects were sensible. Predictors were either categorical or continuous, with continuous variables offered as third- or fourth-order polynomials (Table 5). The year indices were standardised to the mean and presented in canonical form (Francis 1999). Interaction terms (with method) were offered for trawl fisheries, but were not used in the line fisheries, because in the past their inclusion resulted in some implausible vessel coefficients (Dunn et al. 2013). Model fits were investigated using standard residual diagnostics.

Table 5: Summary of predictors offered in the CPUE models for the trawl and line fisheries.

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 sets 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
Number of nets	Categorial	Number of nets used in a 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

The influence of each variable accepted into the lognormal models was described by coefficient–distribution–influence (CDI) plots (Bentley et al. 2012). These plots 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 that is accounted for by the standardisation.

For trawls, the response variable was catch per tow, with tow duration offered as an explanatory variable. Midwater trawl was specified 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. For lines, the response variable was catch per day per statistical area, with number of hooks set per day offered as an explanatory variable. Catch per day (rather than catch per hook) was used as the unit of CPUE because the relationship between catch per hook and the number of hooks set per day has been shown to be non-linear (Horn 2002). Total hooks per day and number of sets per day were offered untransformed and log-transformed. Annual unstandardised (raw) CPUE indices were calculated as the mean of the catch per tow (kg) for trawl data, or catch per vessel-day for line data.

The LIN 7 WC trawl catch was mainly bycatch in the hoki target fishery, although the ling caught in hake or ling target tows increased from 2005 (Table 6, Figure 6). In general, most catch was taken between May and October, often with a peak from June to September (Table 7, Figure 6). Most of the trawl catch was taken in Statistical Areas 033–036 (Figure 7).

Table 6: LIN 7 WC trawl and line catch by target species and fishing method, 1989–90 to 2015–16. Values have been rounded to the nearest tonne, so '0' denotes catches from 1 to 499 kg and '–' denotes zero catch.

	Trawl fishery				Line fishery	
Fishing	**Hake**	**Hoki**	**Ling**	**Other**	**Ling**	**Other**
1989–90	1	1 627	59	92	195	2
1990–91	0	1 030	58	62	422	6
1991–92	24	659	94	126	666	26
1992–93	43	729	123	142	662	46
1993–94	35	714	16	86	721	40
1994–95	22	1 683	21	155	824	68
1995–96	11	1 305	16	129	981	13
1996–97	16	1 210	31	169	935	28
1997–98	23	1 517	7	85	973	35
1998–99	41	1 684	4	160	910	62
1999–00	26	1 681	13	100	716	68
2000–01	13	2 034	–	56	869	48
2001–02	22	1 847	8	45	649	10
2002–03	41	1 496	21	45	655	31
2003–04	52	1 566	31	46	662	21
2004–05	69	1 058	79	92	702	26
2005–06	159	1 147	70	76	547	15
2006–07	153	544	76	187	711	34
2007–08	226	322	197	112	940	70
2008–09	204	347	164	205	850	37
2009–10	125	554	213	154	838	27
2010–11	209	742	251	155	846	56
2011–12	124	847	173	127	809	39
2012–13	154	1 073	110	132	922	35
2013–14	145	1 085	107	116	1 146	44
2014–15	205	1 225	86	72	1 133	25
2015–16	99	1 335	105	146	1 114	35

Table 7: LIN 7WC estimated ling catch (t) by gear and month from 1989–90 to 2015–16. Values have been rounded to the nearest tonne, so '0' denotes catches from 1 to 499 kg.

Trawl

	Month												
Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
1989–90	1	0	0	3	3	13	11	12	269	810	527	131	1 780
1990–91	4	2	0	2	1	1	9	5	190	684	150	103	1 151
1991–92	12	11	1	1	0	2	13	3	29	490	193	148	903
1992–93	17	11	2	1	5	13	21	7	64	546	231	119	1 037
1993–94	10	4	1	3	12	5	8	4	45	509	165	85	851
1994–95	66	2	9	11	4	13	15	5	103	617	245	792	1 881
1995–96	28	2	0	26	10	15	11	17	53	754	261	282	1 461
1996–97	8	15	7	9	7	8	7	29	173	809	159	196	1 426
1997–98	25	32	6	6	0	0	9	11	264	944	263	72	1 631
1998–99	56	43	8	12	10	4	10	21	136	900	539	150	1 889
1999–00	33	2	6	2	1	3	6	17	165	999	446	140	1 820
2000–01	19	4	11	2	2	3	12	18	248	1 098	578	109	2 104
2001–02	1	3	0	2	1	1	8	6	204	1 004	640	53	1 922
2002–03	20	4	5	6	3	7	6	25	251	717	426	133	1 603
2003–04	16	11	0	3	5	8	11	8	72	846	556	161	1 695
2004–05	26	20	7	1	1	4	9	18	108	539	405	161	1 298
2005–06	12	8	4	5	9	3	21	17	139	584	576	75	1 453
2006–07	4	4	6	14	2	1	25	22	243	254	246	140	960
2007–08	31	9	1	14	8	41	48	38	193	245	171	58	857
2008–09	22	7	5	9	8	22	28	70	185	314	202	48	921
2009–10	24	30	7	10	39	41	20	62	138	395	217	61	1 046
2010–11	59	15	35	14	28	31	40	43	188	466	349	92	1 358
2011–12	10	24	24	10	10	12	31	60	156	574	259	101	1 272
2012–13	15	16	21	7	14	12	26	77	381	406	362	133	1 469
2013–14	7	21	7	9	4	7	26	106	287	600	214	165	1 453
2014–15	3	4	2	14	13	8	16	95	348	451	435	199	1 588
2015–16	5	6	3	6	26	24	21	85	311	444	565	187	1 685

Line

	Month												
Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
1989–90	5	22	20	4	16	20	4	0	12	25	28	41	197
1990–91	54	32	11	22	6	8	12	48	35	63	34	102	428
1991–92	40	89	41	18	0	7	48	44	74	61	37	234	691
1992–93	207	87	6	0	11	10	13	4	7	98	137	128	708
1993–94	161	106	29	3	11	8	6	26	64	133	50	165	761
1994–95	218	79	85	41	6	14	11	41	63	72	89	172	891
1995–96	183	99	72	40	11	47	27	45	81	137	122	128	994
1996–97	140	61	53	37	34	57	34	70	76	59	96	247	963
1997–98	144	110	55	3	8	36	62	125	76	95	136	157	1 008
1998–99	129	213	28	64	58	56	65	66	61	71	93	68	972
1999–00	114	68	55	11	13	19	48	59	28	72	144	151	784
2000–01	92	163	67	23	46	24	25	58	72	151	94	101	917
2001–02	144	70	38	0	1	11	26	37	18	123	128	62	659
2002–03	112	69	28	37	28	12	31	54	34	110	130	40	686
2003–04	130	109	37	15	1	22	31	21	26	98	113	78	682
2004–05	172	50	17	41	14	10	10	31	41	65	102	173	728
2005–06	118	39	23	4	4	6	38	44	52	39	93	101	562
2006–07	74	43	67	78	40	47	33	30	14	38	72	208	745
2007–08	84	165	120	45	11	36	36	132	28	82	158	113	1 010
2008–09	102	81	34	55	75	35	51	43	83	100	89	139	887
2009–10	79	54	25	52	75	93	36	88	67	133	126	35	864
2010–11	113	96	36	74	52	42	35	69	82	82	152	68	902
2011–12	79	72	46	56	50	69	63	90	44	108	128	43	848
2012–13	62	122	44	100	98	89	63	128	58	47	92	57	957
2013–14	45	124	29	120	109	143	88	131	110	96	89	105	1 190
2014–15	66	87	92	182	96	102	105	119	38	91	92	86	1 157
2015–16	26	73	64	99	85	120	139	125	62	68	130	157	1 149

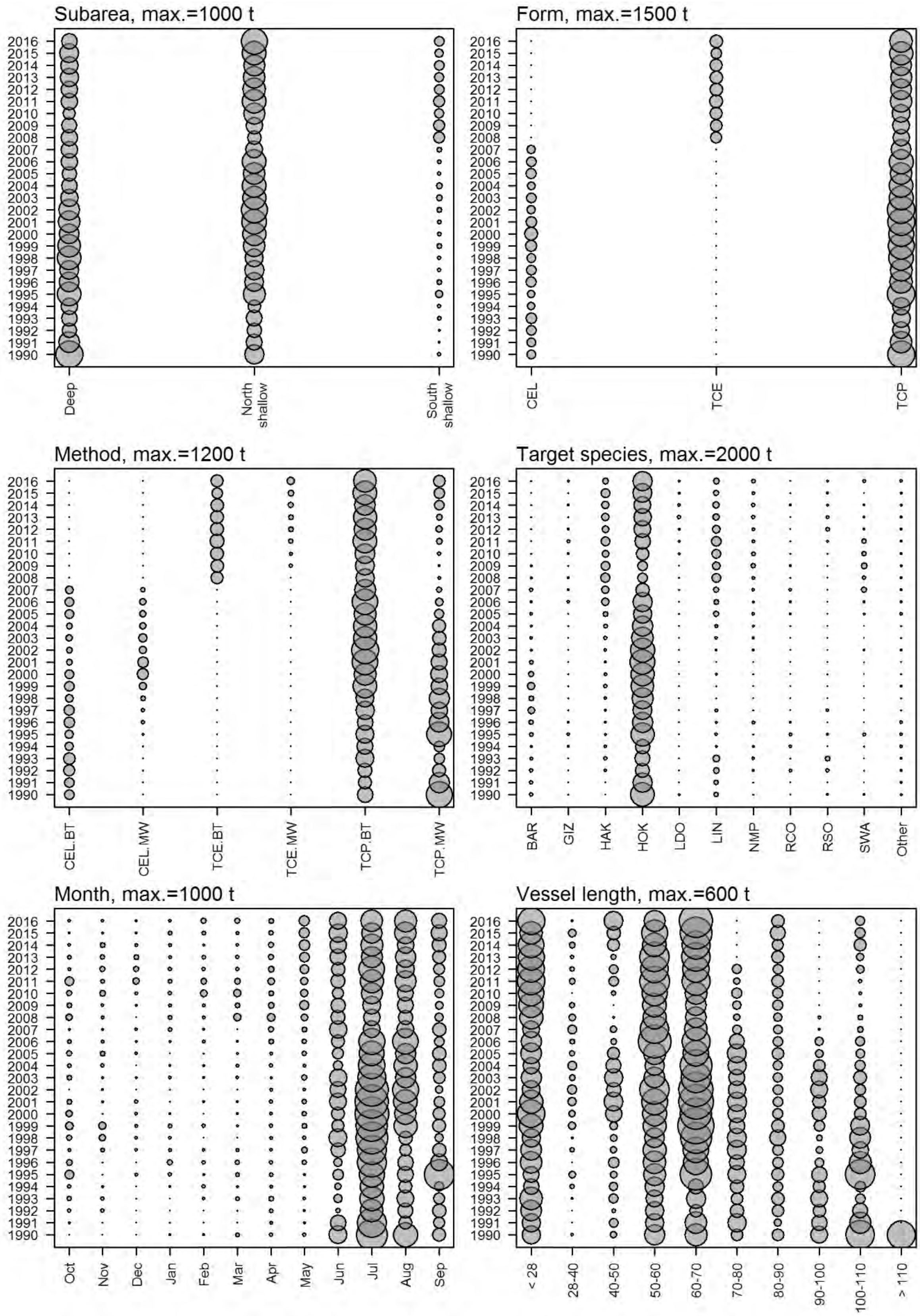


Figure 6: LIN 7WC Trawl; distribution of annual catch by statistical area, form type, fishing method (by form type), target species, month, and vessel length. Circle size is proportional to catch; maximum circle size is indicated in the heading of each plot. Species codes: BAR, barracouta; GIZ, giant stargazer; HAK, hake; HOK, hoki; LDO, lookdown dory; LIN, ling; NMP, tarakihi; RCO, red cod; RSO, gemfish; SWA, silver warehou.

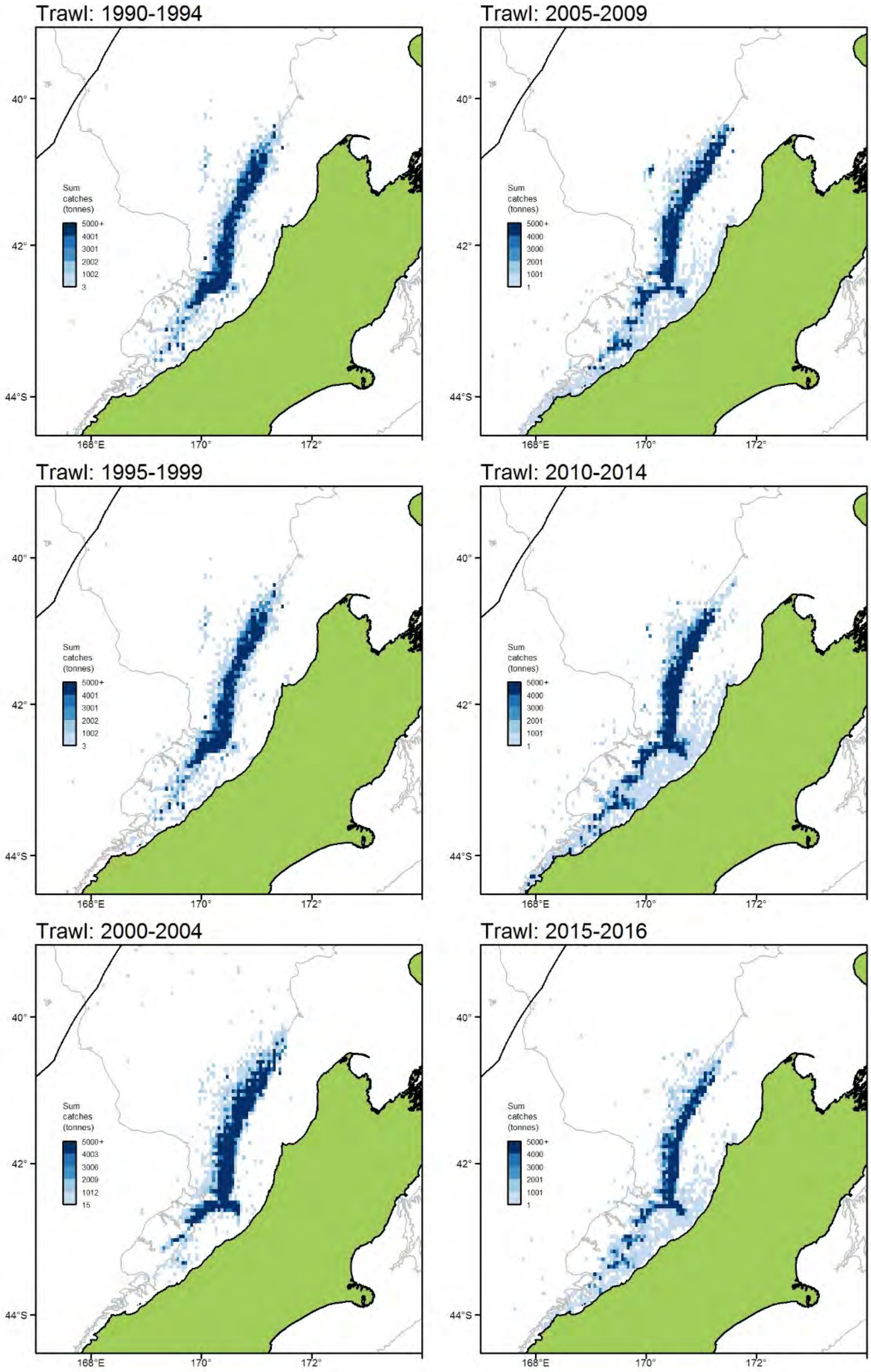


Figure 7: Density plots of LIN 7WC commercial ling catches by trawls for fishing years or combined fishing years groups (labelled by year-ending).

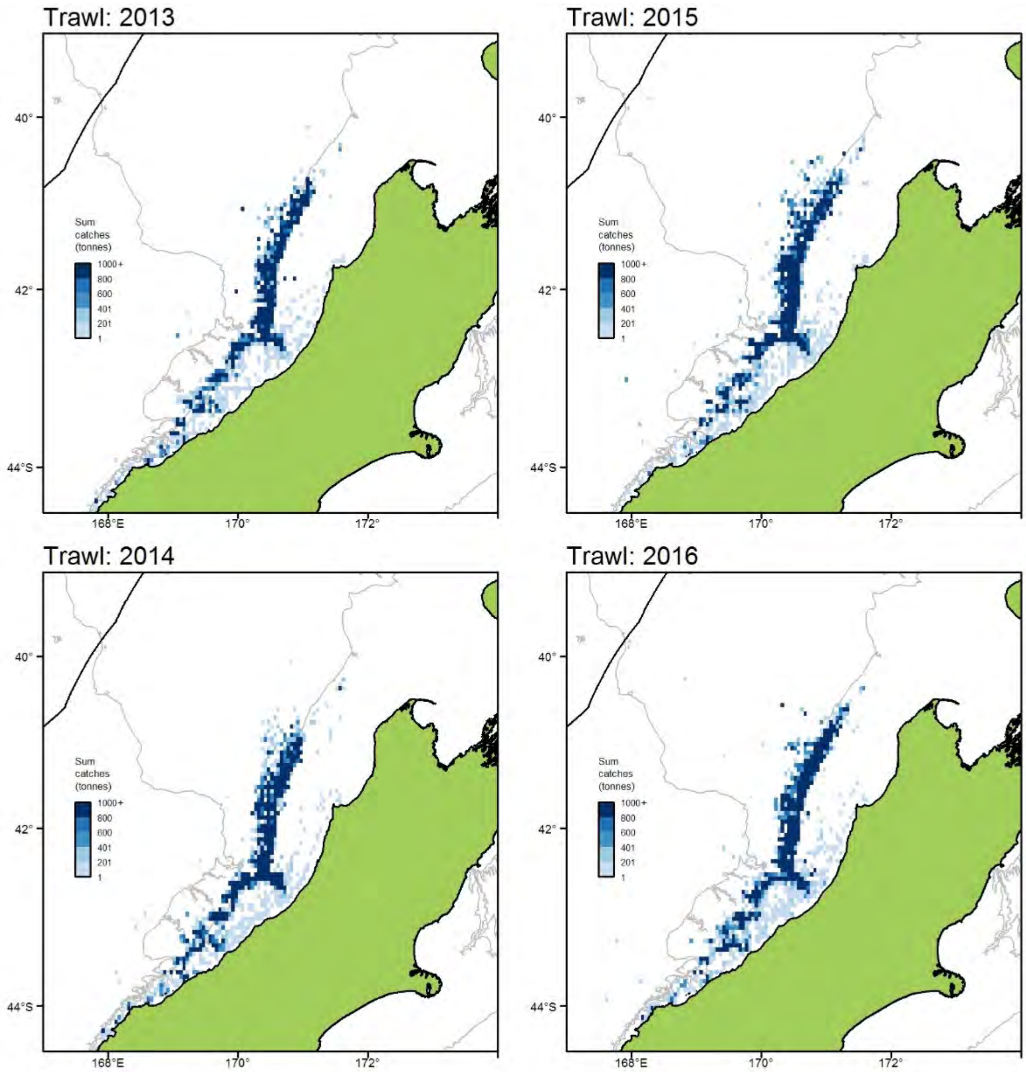


Figure 7 (cont.): Density plots of LIN 7WC commercial ling catches by trawls for fishing years or combined fishing years groups (labelled by year-ending).

About 81% of the catch was recorded on TCEPR forms, and 70% taken by bottom trawling (Figure 6). Mean duration, distance, speed, and depth per tow decreased after about 2003–04 (Figure 8), which can be attributed in part to the increased bottom tow catches since 2002 by smaller Korean vessels targeting hake, and changes in midwater and bottom tow vessels.

For trawls, the data set included 68 vessels (Table 8, Figure 9). Although 28 of these vessels had been observed in only two years, 25 had been observed in 5 or more years (with the maximum being 13 years). There were 28 002 tows in the data set, of which almost 5623 (16%) reported no ling catch (Table 8). About 36% of the midwater tows were reportedly fished on the bottom. Most of the trawl effort involved vessels greater than 28 m in length (Table 9). The MPI observer samples were a good representation of the majority of the catches of the fleet but coverage was relatively poor of small vessels (under 28 m) and to a lesser extent intermediate sized vessels (around 70–90 m), poor outside of the peak June to September fishery, and poor in Statistical Area 033 (Figure 10).

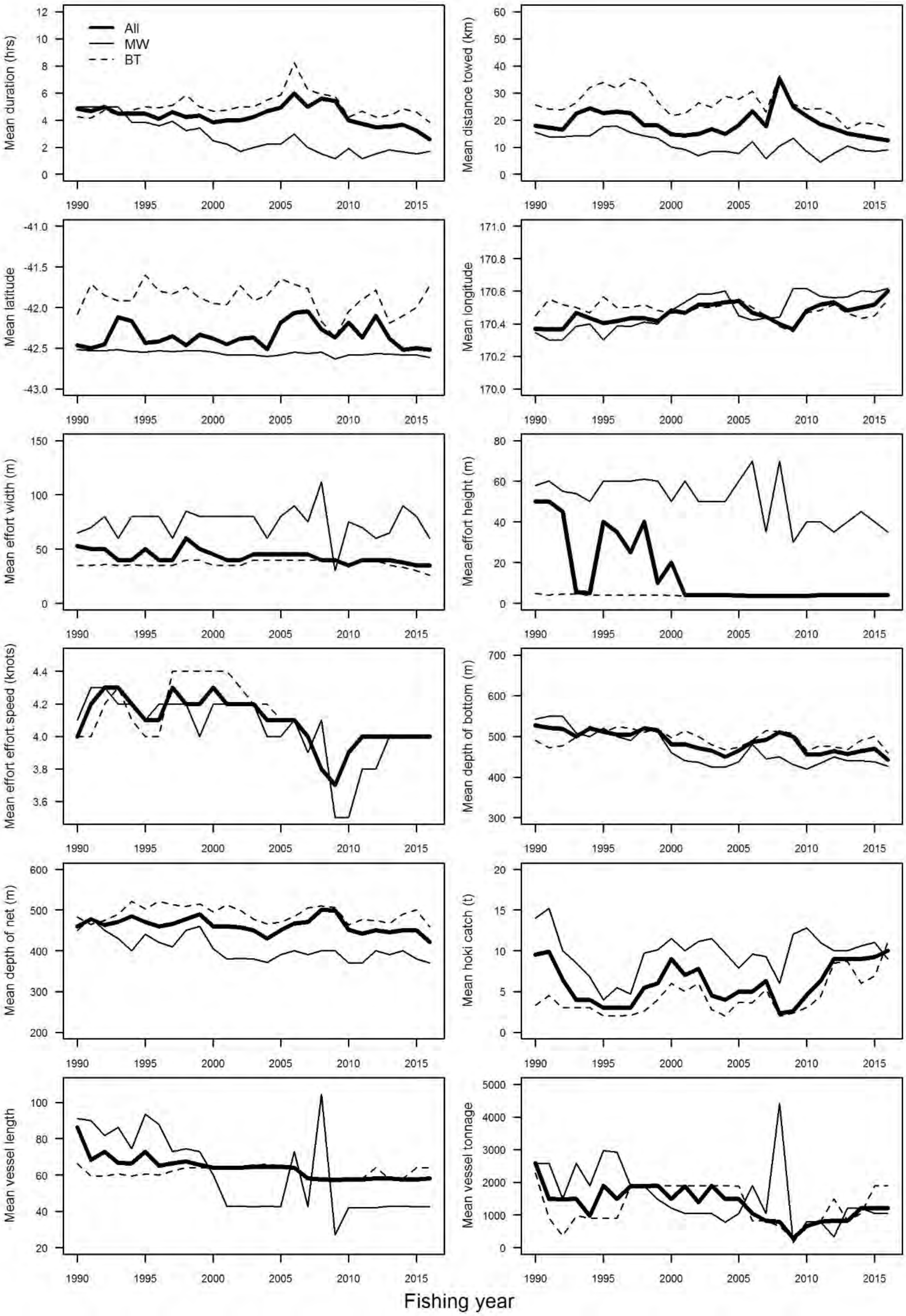


Figure 8: LIN 7WC Trawl; means of effort variables by fishing year tows targeting hake, hoki, or ling , for all tows (All), bottom tows (BT), and midwater tows (MW).

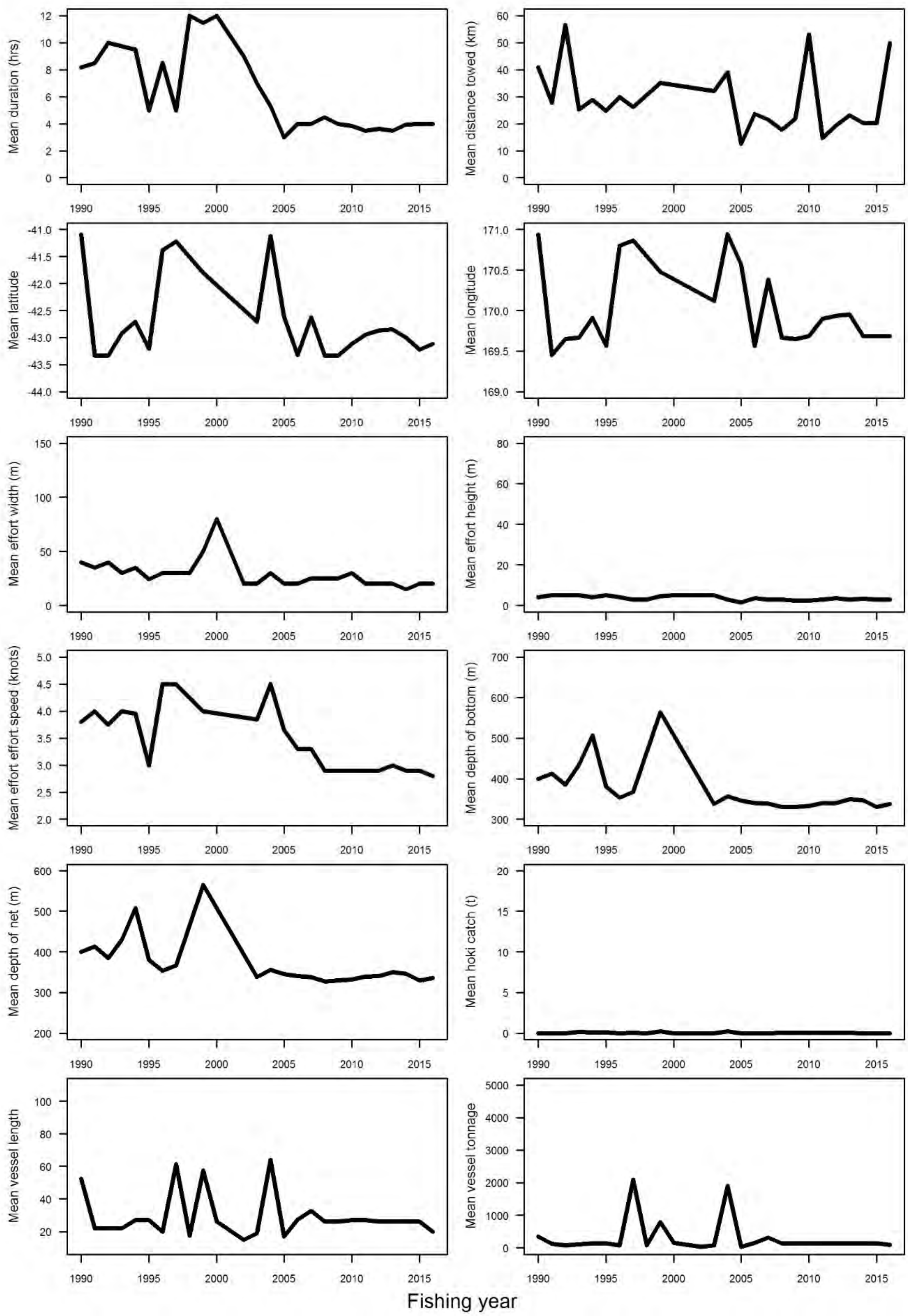


Figure 8 (cont.): LIN 7WC Trawl; means of effort variables by fishing year tows targeting hake, hoki, or ling , for all tows (All), bottom tows (BT), and midwater tows (MW).

Table 8: Summary of data for all vessels and for vessels included in the final LIN 7WC CPUE standardisation datasets. 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: Observer catch for target hoki and hake

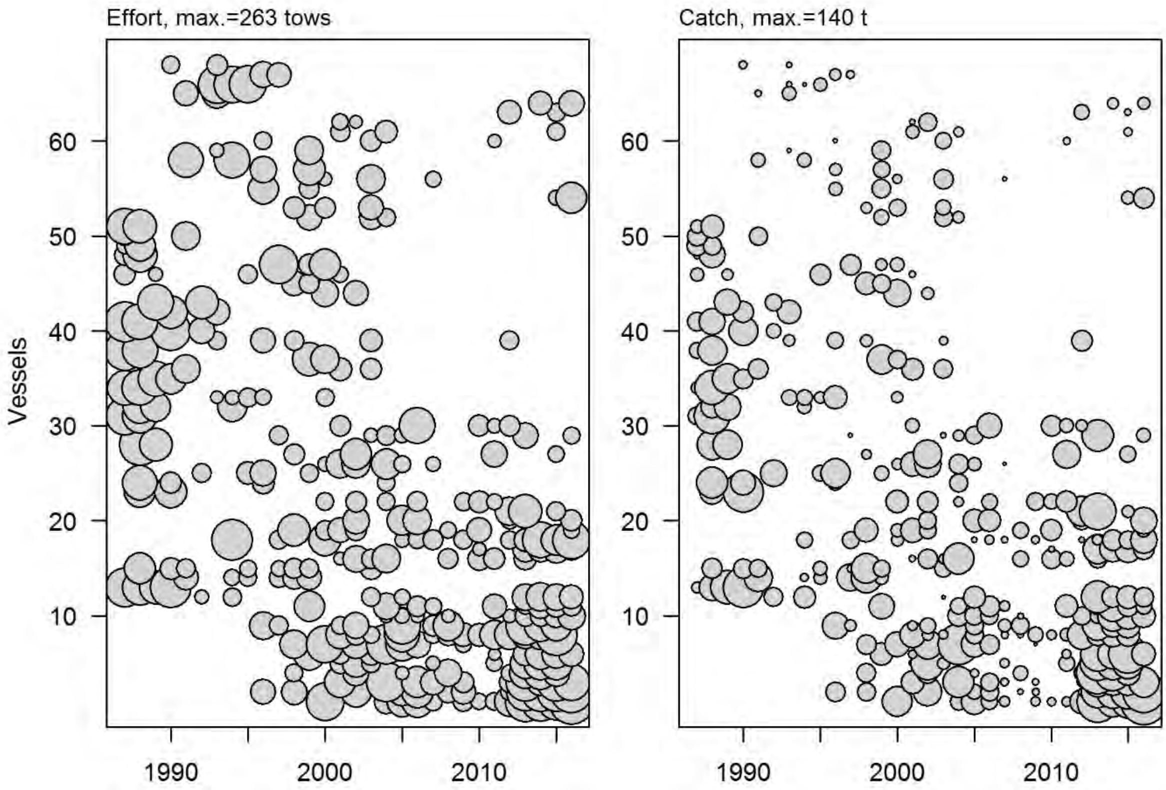
	All vessels					Core vessels				
Fishing year	No. vessels	Catch	Tows	Prop. zeros	CPUE	No. vessels	Catch	Tows	Prop. zeros	CPUE
1987	25	238.7	1 326	0.44	0.18	10	150.8	771	0.42	0.20
1988	22	684.8	1 721	0.30	0.40	13	597.2	1 462	0.27	0.41
1989	14	458.0	964	0.30	0.48	6	268.4	581	0.24	0.46
1990	14	558.6	1 234	0.16	0.45	8	368.4	885	0.11	0.42
1991	14	204.6	764	0.30	0.27	6	133.5	413	0.29	0.32
1992	12	123.2	474	0.31	0.26	4	99.5	252	0.17	0.39
1993	15	157.0	576	0.47	0.27	7	77.7	333	0.39	0.23
1994	15	130.2	708	0.51	0.18	7	93.1	455	0.42	0.20
1995	9	188.3	655	0.15	0.29	6	88.1	350	0.17	0.25
1996	15	262.9	831	0.21	0.32	10	220.6	662	0.19	0.33
1997	12	122.3	440	0.34	0.28	7	111.1	366	0.27	0.30
1998	16	284.0	670	0.22	0.42	10	272.0	580	0.23	0.47
1999	14	284.7	862	0.21	0.33	12	279.2	838	0.21	0.33
2000	17	281.8	824	0.28	0.34	12	267.7	783	0.29	0.34
2001	21	243.5	795	0.19	0.31	13	222.5	706	0.17	0.32
2002	16	441.6	1 040	0.16	0.42	14	439.0	1 024	0.16	0.43
2003	13	149.2	621	0.23	0.24	13	149.2	621	0.23	0.24
2004	16	429.0	1 126	0.12	0.38	12	359.9	960	0.12	0.37
2005	13	265.7	911	0.11	0.29	12	263.9	903	0.11	0.29
2006	15	242.6	858	0.16	0.28	10	222.9	803	0.15	0.28
2007	16	66.4	332	0.36	0.20	9	44.0	277	0.33	0.16
2008	14	82.5	425	0.27	0.19	7	72.4	366	0.21	0.20
2009	16	62.3	342	0.28	0.18	7	52.5	285	0.27	0.18
2010	14	116.1	402	0.16	0.29	7	107.3	350	0.15	0.31
2011	11	180.4	433	0.20	0.42	10	176.3	427	0.19	0.41
2012	16	297.9	693	0.19	0.43	12	265.8	650	0.16	0.41
2013	17	875.5	1 680	0.10	0.52	16	874.4	1 671	0.10	0.52
2014	17	666.1	1 574	0.13	0.42	14	657.0	1 529	0.13	0.43
2015	20	662.0	1 713	0.12	0.39	18	659.6	1 689	0.12	0.39
2016	17	589.3	1 455	0.12	0.41	14	579.1	1 391	0.12	0.42

Table 8 (cont.): Summary of data for all vessels and for vessels included in the final LIN 7WC CPUE standardisation datasets. 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.

(b) WCSI: Line catch

	All vessels					Final vessels				
Fishing year	No. vessels	Catch	Days	Prop. zeros	CPUE	No. vessels	Catch	Days	Prop. zeros	CPUE
1990	16	247.7	342	0.01	0.72	6	181.5	208	-	0.87
1991	17	500.1	530	0.01	0.94	8	331.4	307	-	1.08
1992	22	820.8	744	-	1.10	9	669.6	502	-	1.33
1993	18	683.6	595	-	1.15	9	579.5	412	-	1.41
1994	22	847.2	655	-	1.29	10	677.8	452	-	1.50
1995	23	859.6	683	-	1.26	11	753.5	532	-	1.42
1996	25	781.1	691	0.04	1.13	12	729.0	589	-	1.24
1997	23	824.0	674	0.03	1.22	11	763.6	540	-	1.41
1998	18	933.5	658	0.07	1.42	8	853.0	537	-	1.59
1999	20	803.3	663	0.08	1.21	9	686.8	495	-	1.39
2000	22	866.7	708	-	1.22	10	692.5	515	-	1.34
2001	20	845.6	673	-	1.26	11	744.8	501	-	1.49
2002	18	615.4	543	-	1.13	10	605.9	449	-	1.35
2003	20	753.3	636	-	1.18	9	686.4	519	-	1.32
2004	21	641.6	550	-	1.17	11	531.7	401	-	1.33
2005	20	666.8	786	-	0.85	10	633.3	596	-	1.06
2006	13	566.7	566	-	1	8	498.7	424	-	1.18
2007	15	928.9	711	-	1.31	10	874.9	556	-	1.57
2008	18	850.6	643	-	1.32	11	745.4	451	-	1.65
2009	18	825.0	652	-	1.27	10	709.2	477	-	1.49
2010	16	947.3	678	-	1.40	10	863.9	520	-	1.66
2011	13	836.0	621	-	1.35	8	766.4	484	-	1.58
2012	15	870.0	698	-	1.25	8	788.0	516	-	1.53
2013	13	925.1	587	-	1.58	8	830.6	413	-	2.01
2014	17	1 237.1	689	-	1.80	9	1 126.7	509	-	2.21
2015	16	1 074.9	650	-	1.65	10	964.1	501	-	1.92
2016	14	981.6	564	-	1.74	7	805.3	393	-	2.05

(a) WCSI tow-by-tow observer data



(b) WCSI line

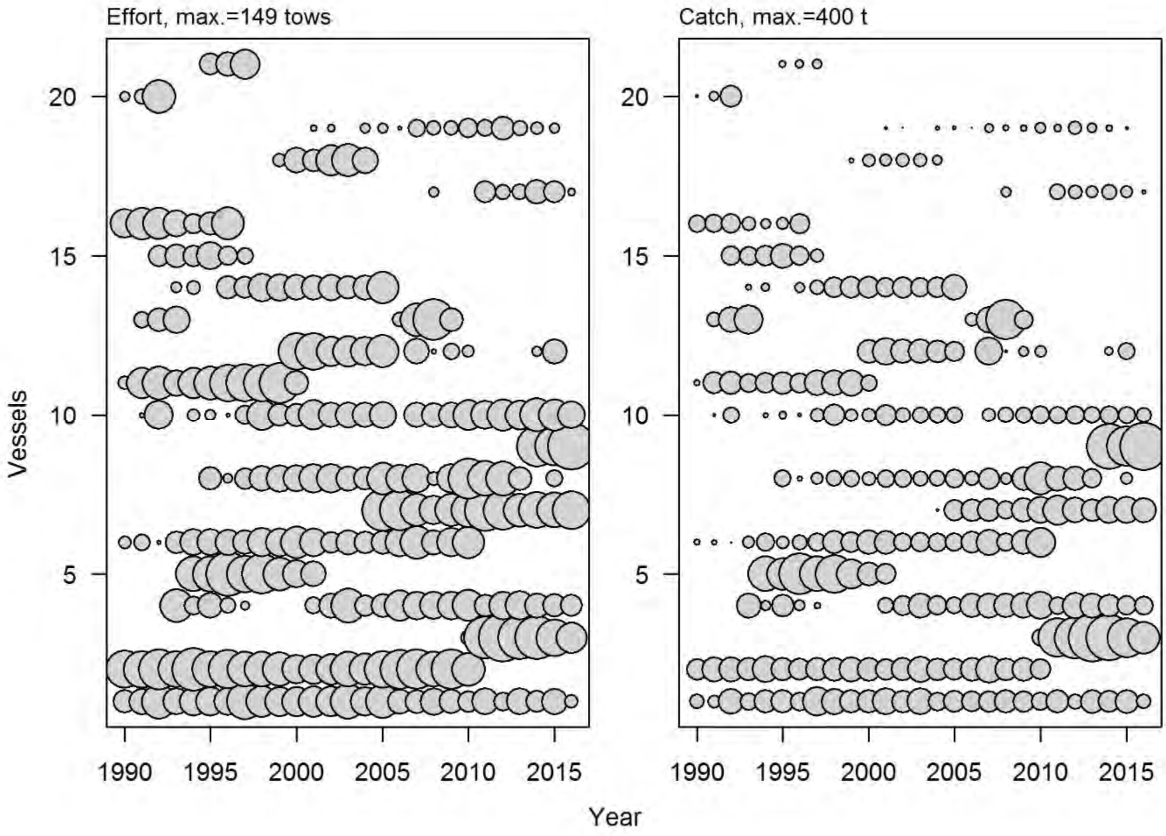


Figure 9: LIN 7WC trawl and line fishing effort and catches by year for individual vessels (denoted anonymously by number on the y-axis) in core CPUE analyses. Circle area is proportional to the effort or catch.

Table 9: LIN 7WC catches and effort for vessels < 28 m and ≥28 m overall length, by year.

Trawls

	Catches (t)		Total number of tows		Total duration (hrs)	
Fishing year	**< 28 m**	**≥ 28 m**	**< 28 m**	**≥ 28 m**	**< 28 m**	**≥ 28 m**
1989–90	154	1 625	1 072	9 834	10 310	43 067
1990–91	151	999	1 237	9 788	10 453	41 315
1991–92	195	708	1 901	7 991	19 178	31 673
1992–93	237	800	3 234	9 105	31 653	33 364
1993–94	114	737	2 228	11 494	20 657	41 242
1994–95	118	1 763	1 961	12 078	19 091	48 477
1995–96	216	1 244	2 131	8 916	20 663	37 362
1996–97	201	1 225	2 770	10 517	27 163	46 422
1997–98	157	1 474	1 740	10 142	16 012	44 013
1998–99	253	1 636	2 436	9 739	24 382	39 580
1999–00	348	1 471	2 161	8 929	21 432	33 650
2000–01	250	1 854	2 296	9 780	22 679	37 127
2001–02	155	1 767	1 738	8 617	15 388	32 893
2002–03	185	1 418	1 920	8 460	19 086	38 605
2003–04	123	1 572	2 032	7 000	19 998	33 350
2004–05	200	1 098	2 105	5 432	22 376	26 917
2005–06	190	1 263	2 249	4 977	23 559	28 329
2006–07	135	825	2 360	3 975	25 756	23 410
2007–08	246	610	5 979	3 218	27 125	18 351
2008–09	286	636	6 318	2 757	28 097	17 682
2009–10	317	730	6 823	2 754	27 707	12 801
2010–11	364	994	5 602	3 594	22 170	15 990
2011–12	346	925	5 815	3 726	24 204	15 489
2012–13	341	1 128	5 773	3 768	24 088	15 550
2013–14	333	1 120	6 231	4 553	26 421	19 346
2014–15	262	1 325	6 122	5 585	25 522	23 247
2015–16	351	1 334	6 416	5 204	26 045	17 852

Lines

	Catches (t)		Total number of days		Total number of sets	
Fishing year	**< 28 m**	**≥ 28 m**	**< 28 m**	**≥ 28 m**	**< 28 m**	**≥ 28 m**
1989–90	197	–	317	–	452	–
1990–91	428	–	509	–	598	–
1991–92	690	2	742	2	845	2
1992–93	708	0	656	1	826	1
1993–94	760	1	709	1	962	1
1994–95	887	4	751	3	921	6
1995–96	974	20	917	7	1 063	25
1996–97	953	9	987	8	1 207	8
1997–98	924	84	792	62	984	173
1998–99	921	51	930	20	1 225	57
1999–00	784	0	826	2	1 172	2
2000–01	916	1	868	1	1 107	1
2001–02	641	17	629	3	860	5
2002–03	686	–	718	–	977	–
2003–04	680	2	735	2	950	2
2004–05	728	–	867	–	1 272	–
2005–06	559	2	744	1	917	1
2006–07	745	–	732	–	1 005	–
2007–08	1 010	–	820	–	1 221	–
2008–09	887	–	763	–	1 176	–
2009–10	864	–	663	–	838	–
2010–11	902	–	768	–	1 494	–
2011–12	848	–	737	–	1 301	–
2012–13	954	2	673	37	1 029	149
2013–14	1 190	1	788	17	1 231	48
2014–15	1 157	0	729	19	990	61
2015–16	1 147	2	759	11	1 020	31

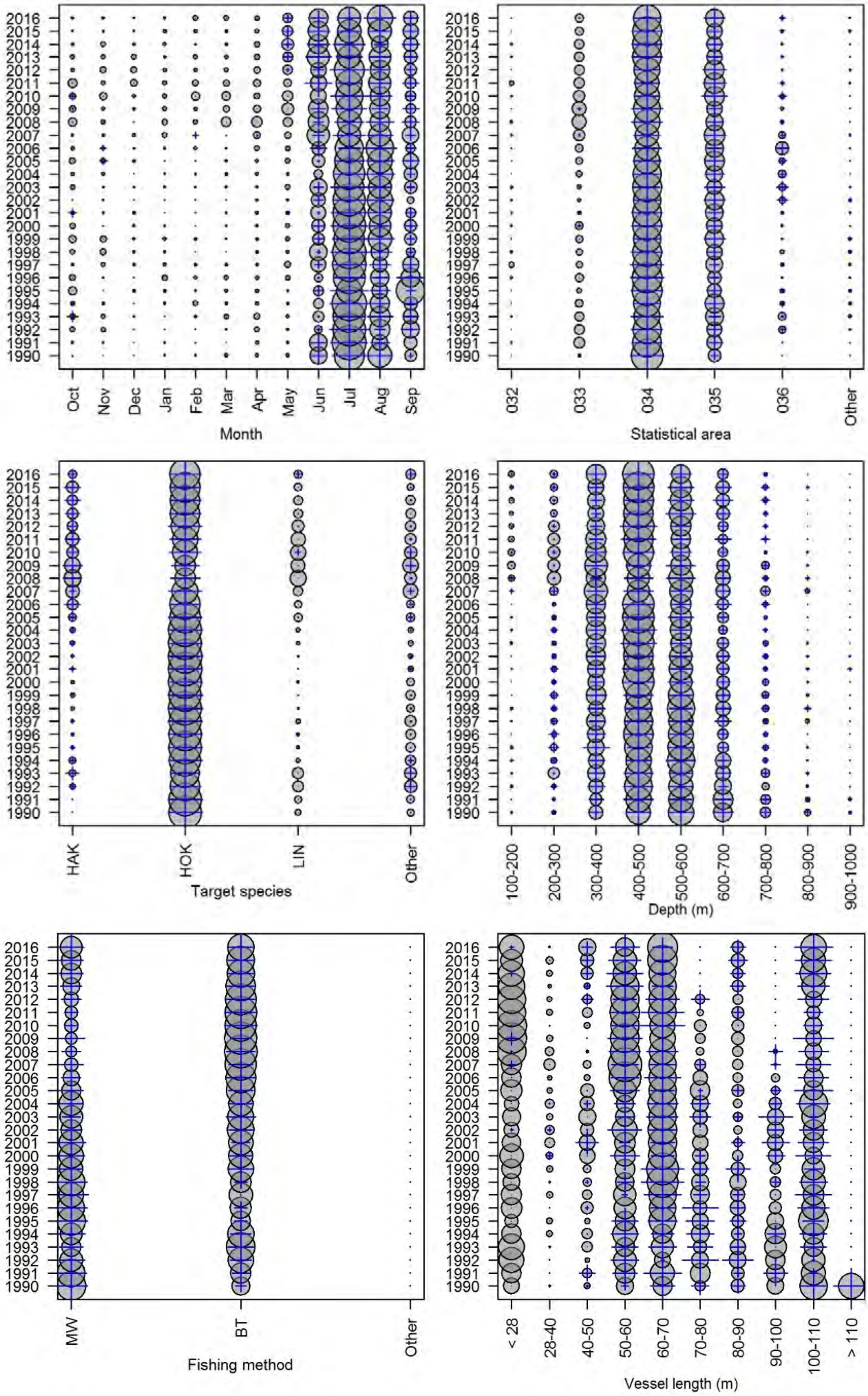


Figure 10: Representativeness of observer sampling of ling catch for LIN 7WC. Circles show the proportion of target catch by month within a year, crosses show the proportion of observed target catch for the same cells. Representation is demonstrated by how closely the cross dimensions match the circle diameter.

LIN 7WC line fisheries caught ling throughout the year, but most catch was taken from July to November (Figure 11). Over 98% of the catch was taken by the bottom longline method, and 95% of the catch was from lines targeting ling (Figure 11). Most of the line catch was taken in Statistical Areas 032–034 (Figures 11 and 12), and by smaller inshore vessels using fewer than 5000 hooks/day (Table 9).

The WCSI final analysis included 12 799 records of days fished throughout the 27 years analysed, with the fishery dominated by small vessels (Table 9). The estimated catch from this CPUE data set was 88% 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 1989–90, although the line fishery produced 20–53% of the catch annually from 1989–90 to 2015–16 (Table 6). The final analysis included data from 21 vessels, and of these one had fished in all 27 years of the series, 6 in over 20 years, and 18 vessels had fished in six or more years (Figure 9). There was no strong trend in effort variables over time Figure 13).

For trawl CPUE, the lognormal model explained 38% of the deviance, with vessel and latitude explaining about 15%; the binomial model explained 25% of the deviance (Table 10). The CPUE index increased from 1991–92 to about 1995–96, declined to 2008–09, and then increased to 2010–11, and then leveled off to 2014–15 with an increase in 2015–16 (Table 10: Figures 14 and 15). The binomial model had higher values in later years, and the combined index showed a similar trend to the lognormal model, although the 2016 value was the highest along with 1995 (Figure 16). The trawl index had a similar trend to the previous analysis (Figure 17). Influence plots (Figure 18) showed that the vessel and day of year had a large and variable influence on CPUE. In particular, vessel had a large negative influence on CPUE in 1993. There were temporal shifts in longitude and latitude, which influenced the CPUE index: for latitude, a large positive shift in 2004–2006 and large negative shift in 1994; for longitude, large positive shifts in 1994, 2010, and 2012, and large negative shifts in 1988–1989 and 2006–2007. Expected catches tended to be higher further east and south. The probability of a zero ling catch was highest for tows that were deeper, further west and south (Figure 19). Bottom trawls were marginally less likely to get a zero catch of ling than midwater trawls, and less likely to get zero catches with higher headline. Tow duration had a relatively weak effect on the probability of a zero ling catch. The diagnostics for both lognormal and binomial models were considered acceptable, with substantial deviation from model assumptions only occurring outside 2 standard deviations (Figures 20 and 21).

For line CPUE, four variables were selected for the lognormal model (Table 10; Figure 14). The index had an overall increasing trend from 1995–96 to 2010–11, which matched the raw CPUE (Table 11; Figure 15). The overall trend was similar to the previous analysis, although different to the trend shown by the trawl CPUE (Figure 17). Influence plots (Figure 22) showed that total hooks per day had a trend from a negative to a positive influence, with a positive peak around 1998, and with higher expected catch rates with increased total hooks. Higher influence was estimated for August to October (the probable peak spawning season). The vessel influence on CPUE was negative from 1990–1992, became positive in 1993–1996, and then reverted to negative since then (except for a positive shift in 2008 and 2014–2016). The diagnostics for the line model showed greater departure from model assumptions, and the extremes of the catch rate were not captured by the model (Figure 20).

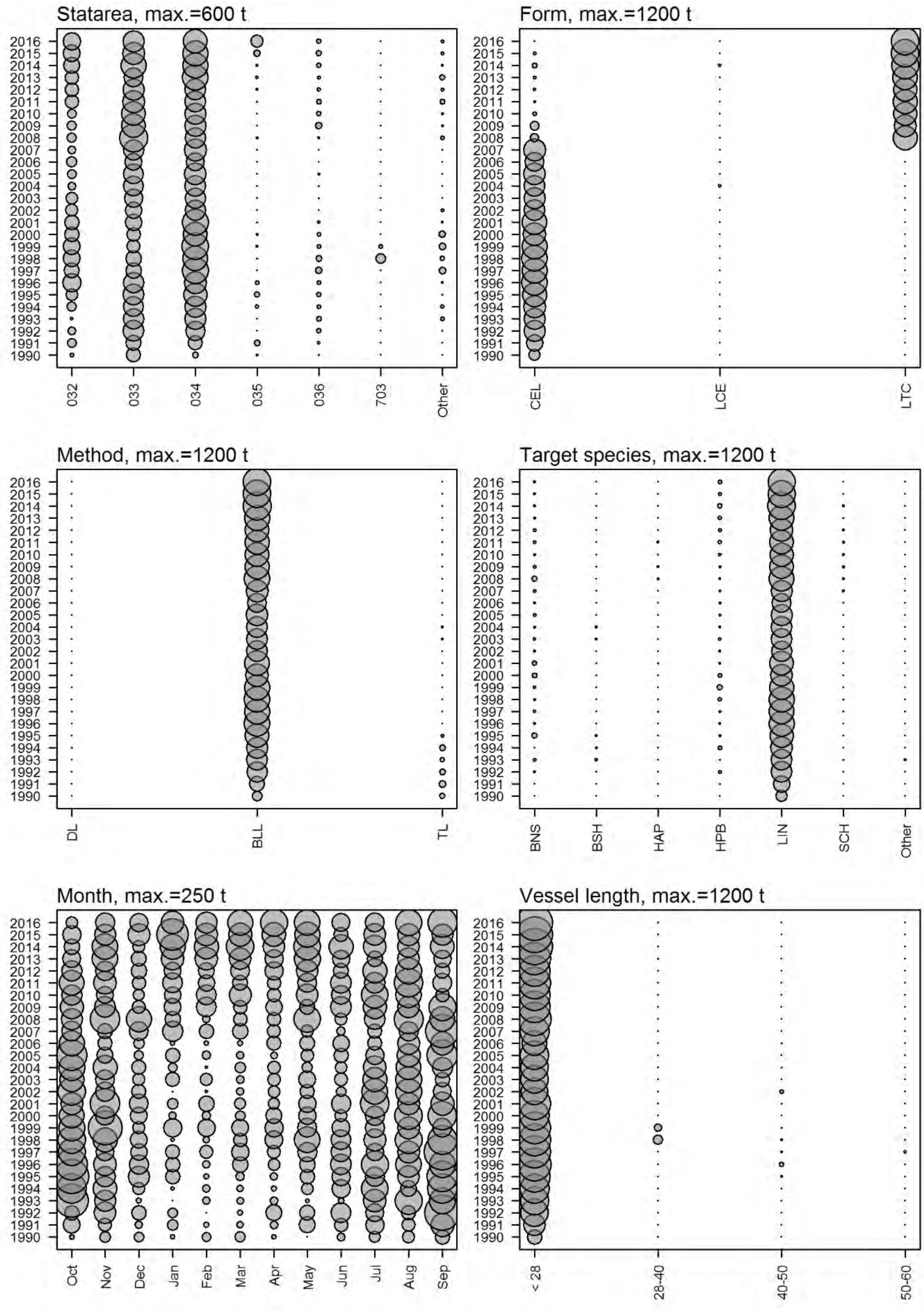


Figure 11: LIN 7WC line; distribution of ling catch by fishing year, area, form type, fishing method (by form type), target species, month, and vessel length. Circle size is proportional to catch; maximum circle size is indicated in the heading of each plot. Form types and method types are defined in Figure 3. BNS, bluenose; BSH, seal shark; HAP, hapuku; HPB, hapuku and bass; LIN, ling; SCH, school shark.

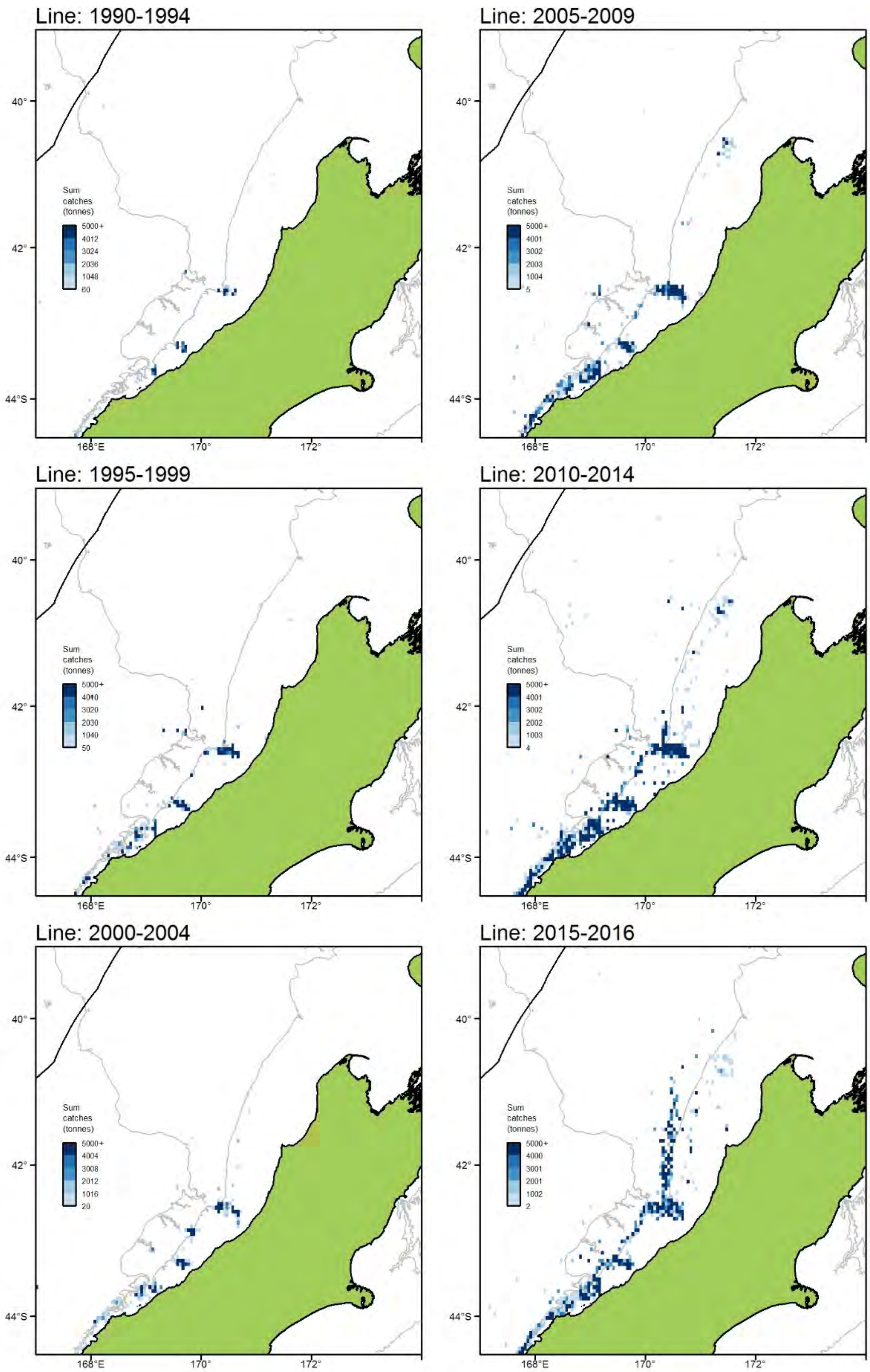


Figure 12: LIN 7WC line; density plots of ling catches by fishing years (labelled as year-ending).

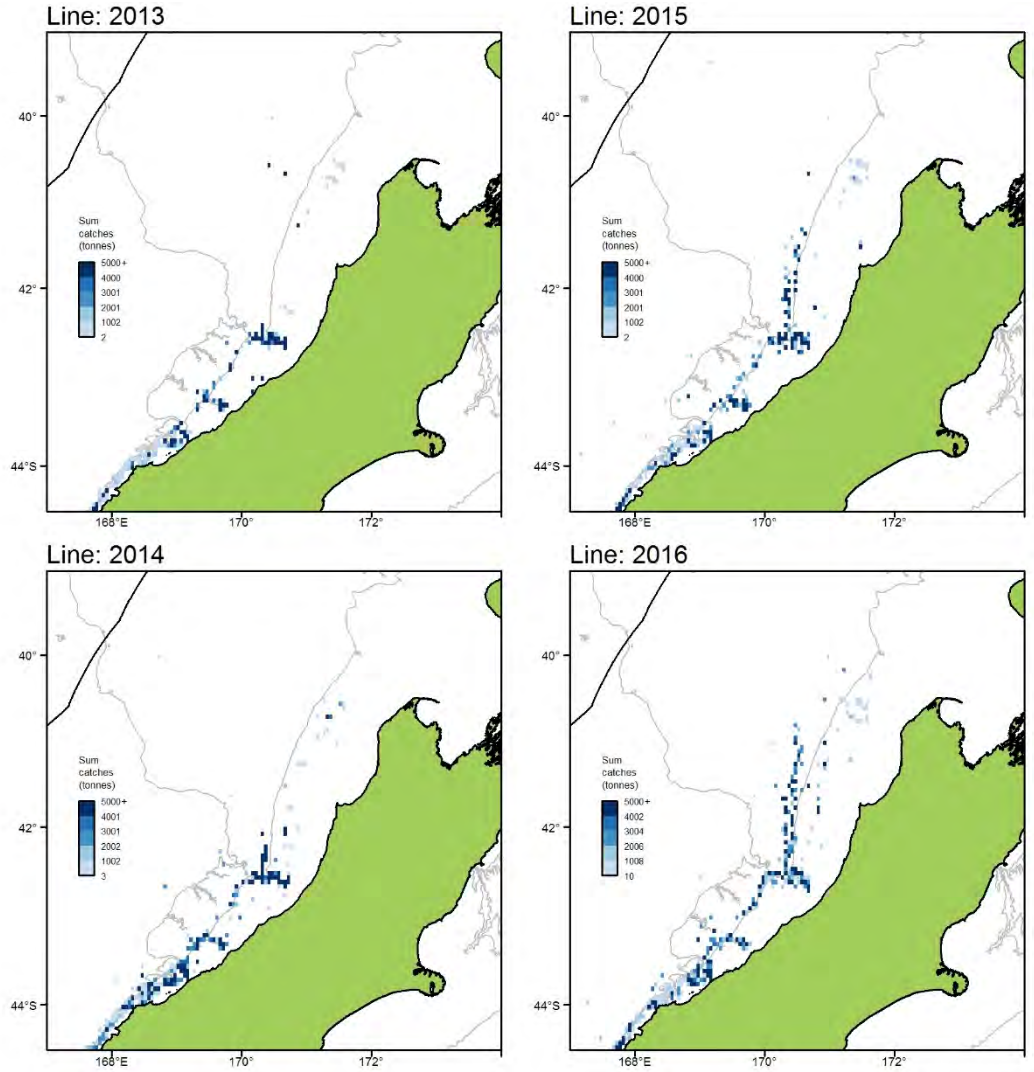


Figure 12 (cont.): LIN 7WC line; density plots of ling catches by fishing years (labelled as year-ending)

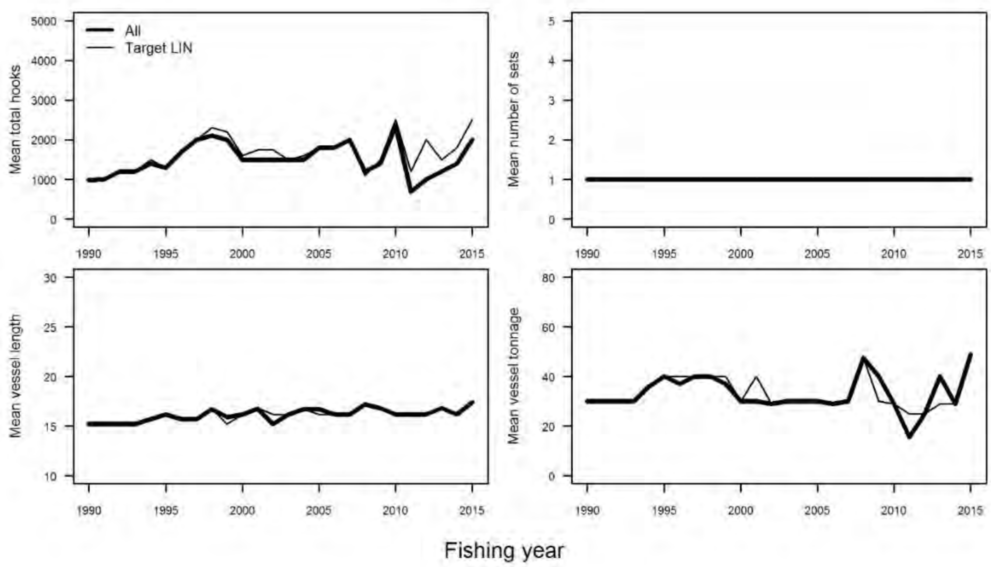


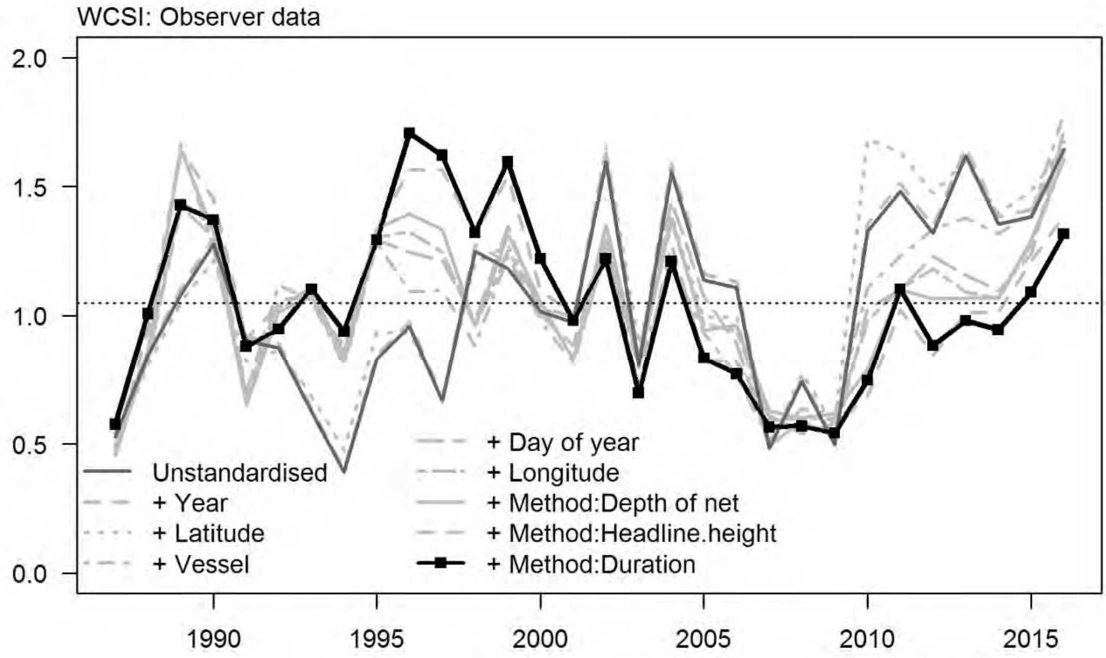
Figure 13: LIN 7WC line; means of effort variables by fishing year for vessels targeting all species or ling by line methods.

Table 10: Variables retained in the GLMs in order of decreasing explanatory value, for each model (lognormal, binomial) and fishery, with the corresponding deviance explained (%).

	Lognormal		Binomial
Variable	Deviance explained (%)	Variable	Deviance explained (%)
IN 7WC observer trawl			
Year	5.27	Year	5.16
Latitude	8.70	Depth of bottom	10.76
Vessel	14.92	Vessel	14.06
Day of year	18.30	Latitude	16.21
Longitude	22.47	Longitude	17.44
Method : Depth of net	27.29	Method: Headline height	22.14
Method: Headline height	34.78	Method: Duration	24.61
Method: Duration	37.83		
LIN 7WC line			
Year	5.19		
Total hooks	22.65		
Month	31.04		
Vessel	38.52		

Table 11: CPUE standardised year indices for trawl and line fisheries, and binomial, and combined CPUE indices for trawl indices (with CVs). Fishing year labelled as year-ending.

	Trawl						Line	
	Lognormal		Binomial		Combined		Lognormal	
Fishing year	Index	CV	Index	CV	Index	CV	Index	CV
1987	0.58	0.07	0.10	0.06	0.08	0.09		
1988	1.01	0.06	0.25	0.05	0.37	0.08		
1989	1.43	0.07	0.54	0.05	1.13	0.09		
1990	1.37	0.06	0.87	0.04	1.74	0.07	0.87	0.07
1991	0.88	0.07	0.25	0.05	0.32	0.09	1.04	0.06
1992	0.95	0.08	0.35	0.05	0.49	0.10	1.23	0.05
1993	1.10	0.07	0.48	0.05	0.76	0.09	0.88	0.05
1994	0.94	0.06	0.52	0.05	0.72	0.08	0.86	0.05
1995	1.29	0.07	1.00	0.04	1.88	0.08	0.87	0.05
1996	1.71	0.05	0.67	0.05	1.66	0.07	0.65	0.04
1997	1.62	0.06	0.60	0.05	1.41	0.08	0.77	0.05
1998	1.32	0.05	0.62	0.05	1.18	0.07	0.89	0.04
1999	1.60	0.04	0.63	0.05	1.46	0.06	0.92	0.05
2000	1.22	0.04	0.51	0.05	0.91	0.06	0.94	0.05
2001	0.98	0.04	0.75	0.05	1.08	0.06	1.09	0.05
2002	1.22	0.04	0.73	0.05	1.30	0.06	1.02	0.05
2003	0.70	0.05	0.49	0.05	0.50	0.07	1.08	0.04
2004	1.21	0.04	0.80	0.05	1.40	0.06	1.08	0.05
2005	0.83	0.04	0.78	0.05	0.94	0.06	0.81	0.04
2006	0.77	0.04	0.52	0.05	0.58	0.06	0.81	0.05
2007	0.57	0.06	0.72	0.05	0.60	0.08	1.08	0.04
2008	0.57	0.06	0.57	0.05	0.47	0.08	1.10	0.05
2009	0.54	0.06	0.56	0.05	0.44	0.08	1.09	0.05
2010	0.75	0.06	0.80	0.05	0.87	0.08	1.33	0.04
2011	1.10	0.05	0.66	0.05	1.06	0.07	1.15	0.05
2012	0.88	0.05	0.77	0.05	0.99	0.07	1.18	0.05
2013	0.98	0.03	0.87	0.04	1.24	0.05	1.32	0.05
2014	0.94	0.03	0.83	0.05	1.14	0.05	1.23	0.05
2015	1.09	0.03	0.87	0.04	1.39	0.05	1.06	0.05
2016	1.32	0.03	0.98	0.04	1.88	0.05	1.03	0.06



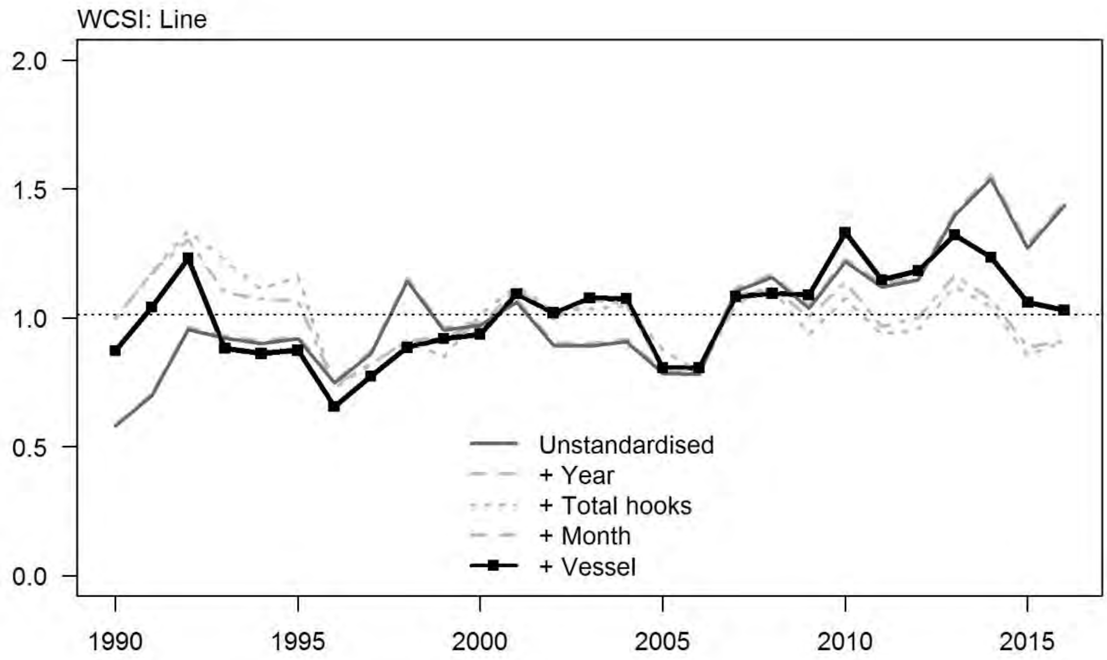
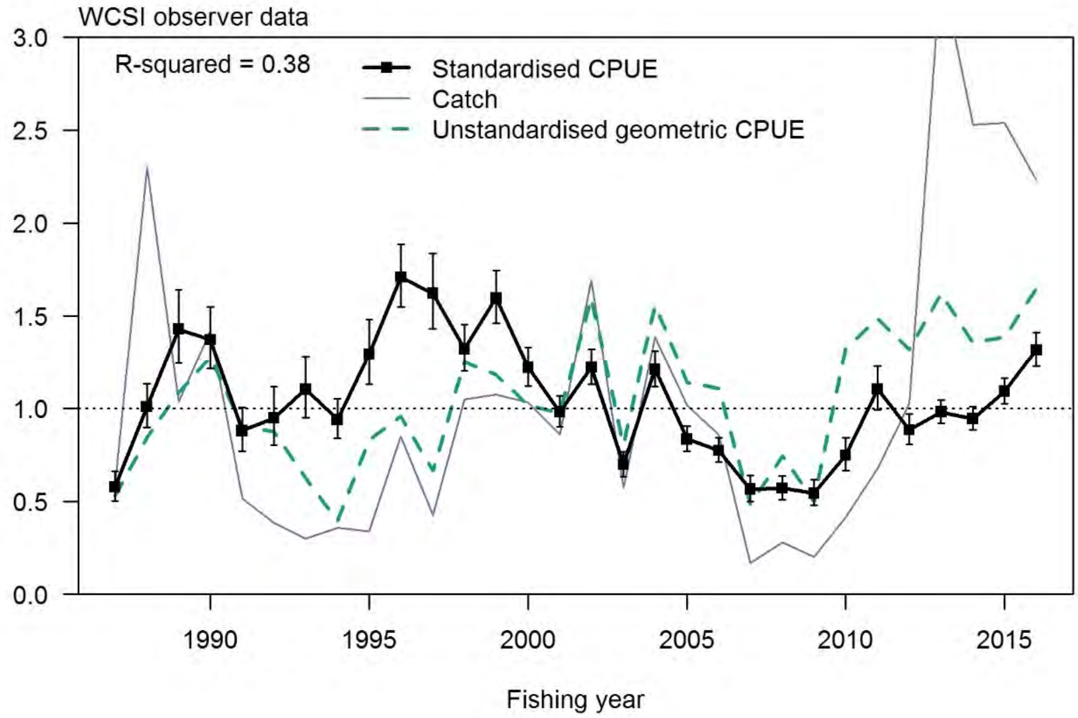


Figure 14: LIN 7WC; addition of variables into the lognormal CPUE model for each fishery (WCSI Observer data, trawl fishery; WCSI Line, line fishery).



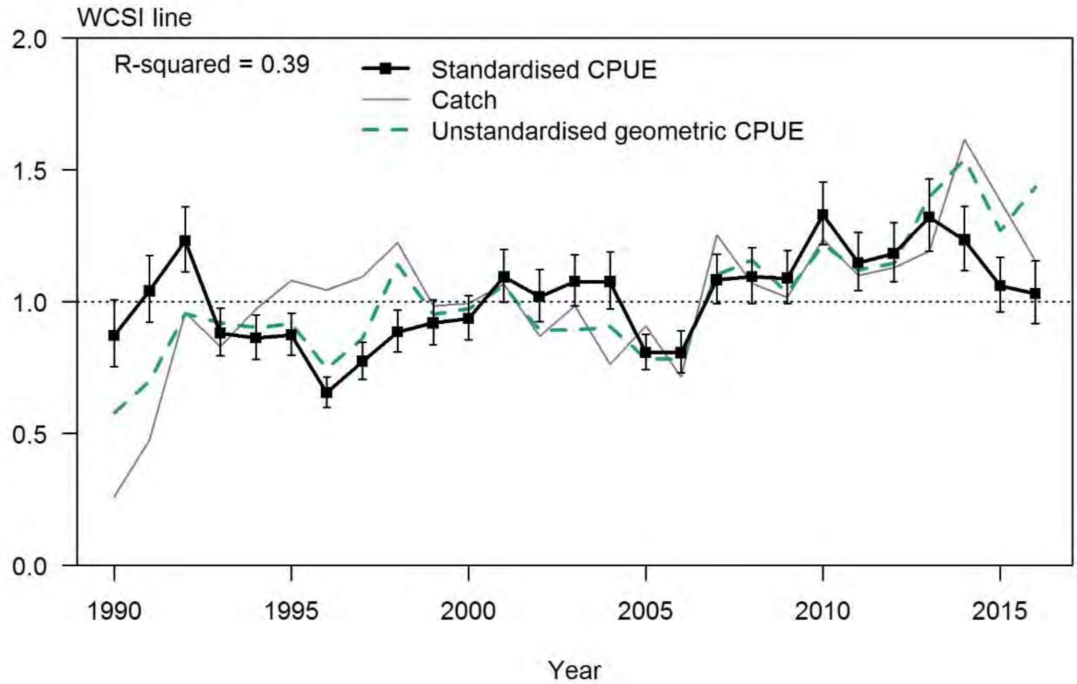


Figure 15: Year index from the lognormal model for each fishery (WCSI observer data, trawl fishery; WCSI line, line fishery). Bars indicate 95% confidence intervals.

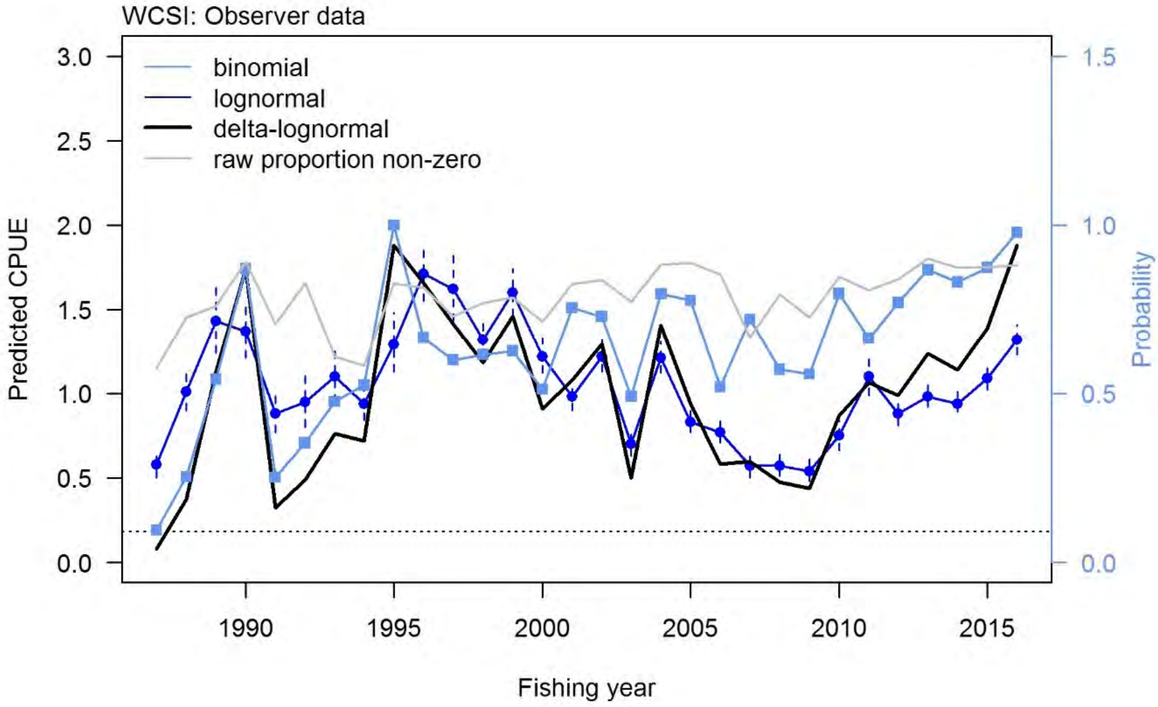


Figure 16: LIN 7WC Trawl CPUE index from the lognormal, binomial and combined model, and proportion of non-zero tows, 1987–2016. Bars indicate 95% confidence intervals.

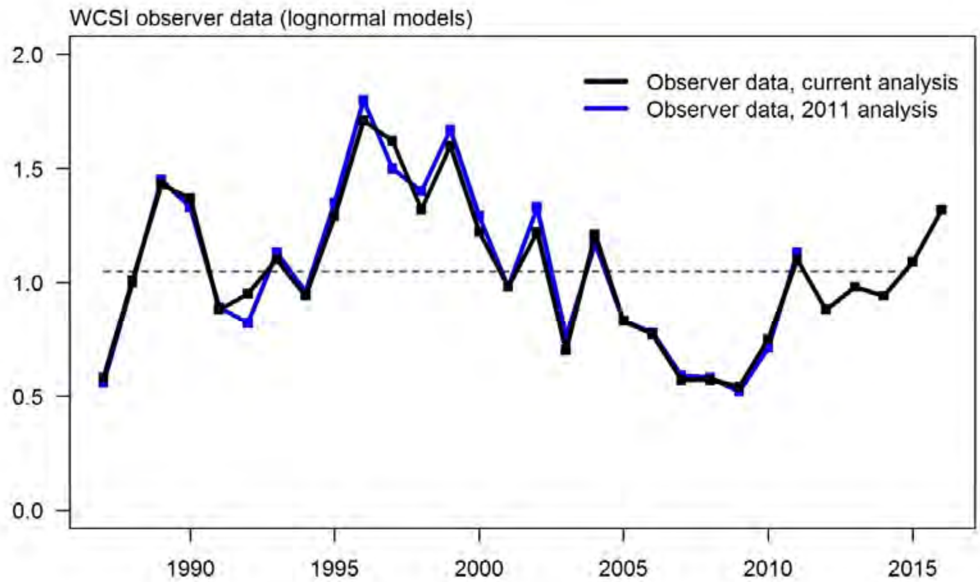


Figure 17: LIN 7WC; comparison of CPUE indices for the combined models for trawl, lognormal model for lines, and all models (June–September for observer data, and calendar year for the line data).

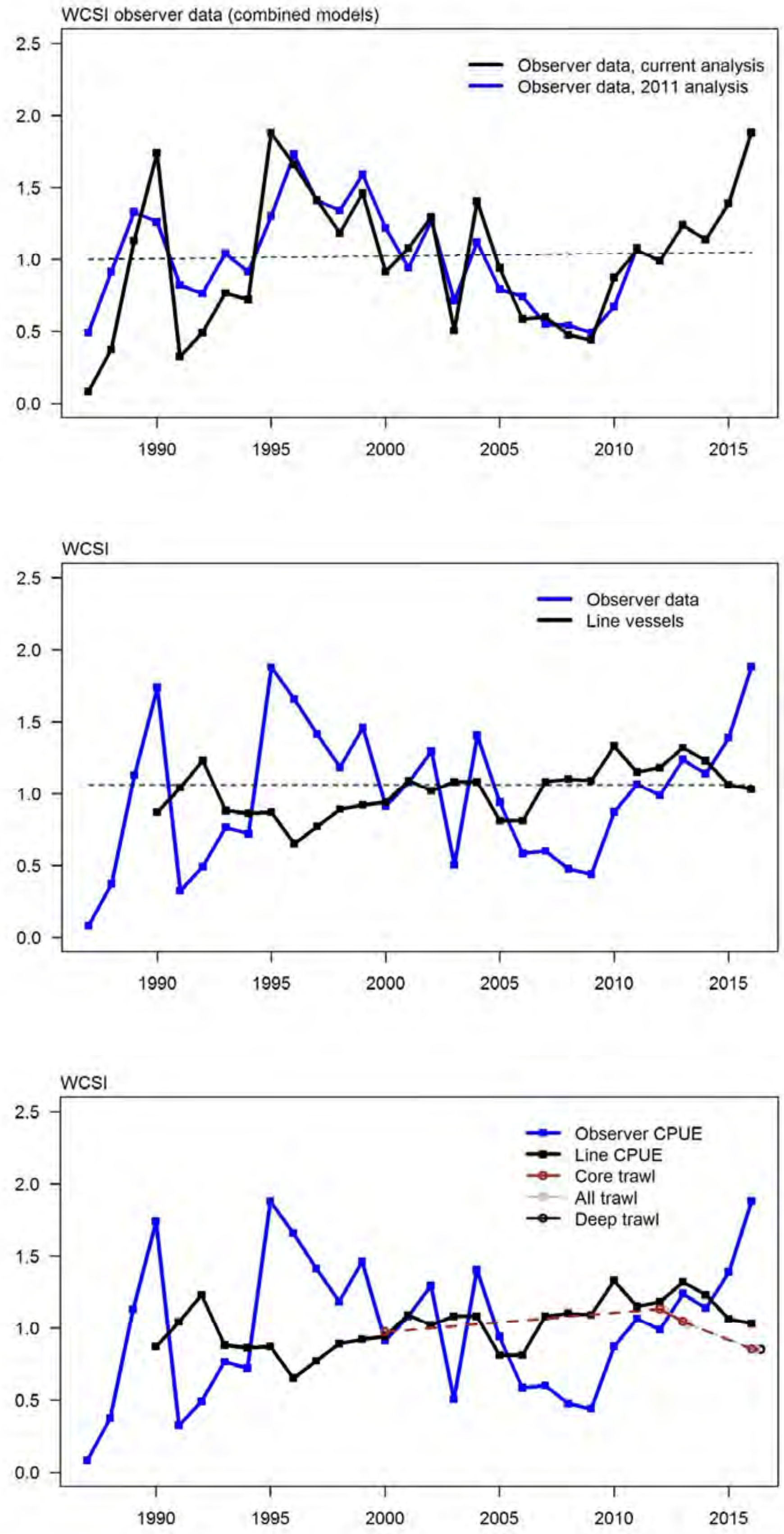


Figure 17 (cont.): LIN 7WC; comparison of CPUE indices for the combined models for trawl, lognormal model for lines, and all models (June–September for observer data, and calendar year for the line data).

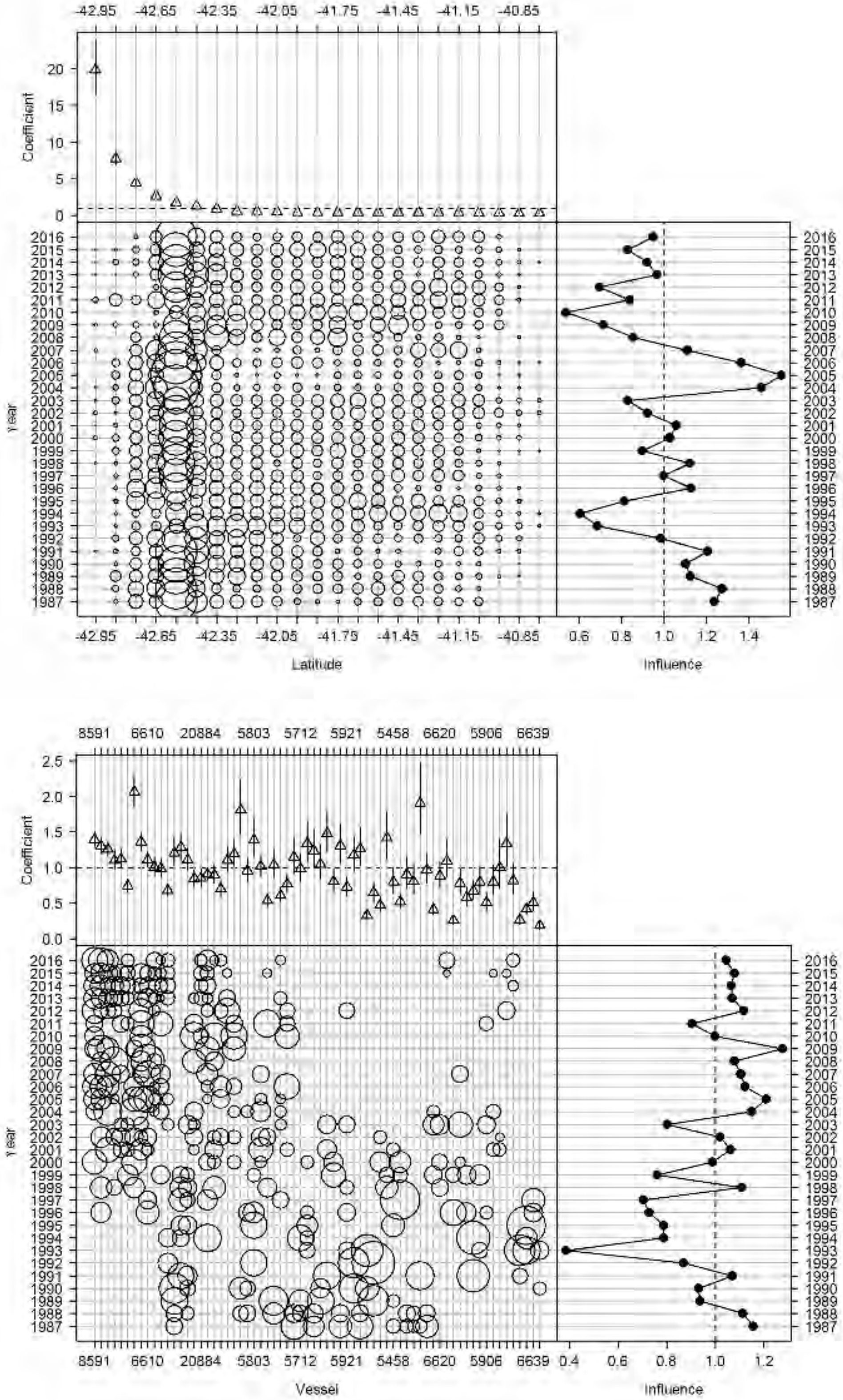
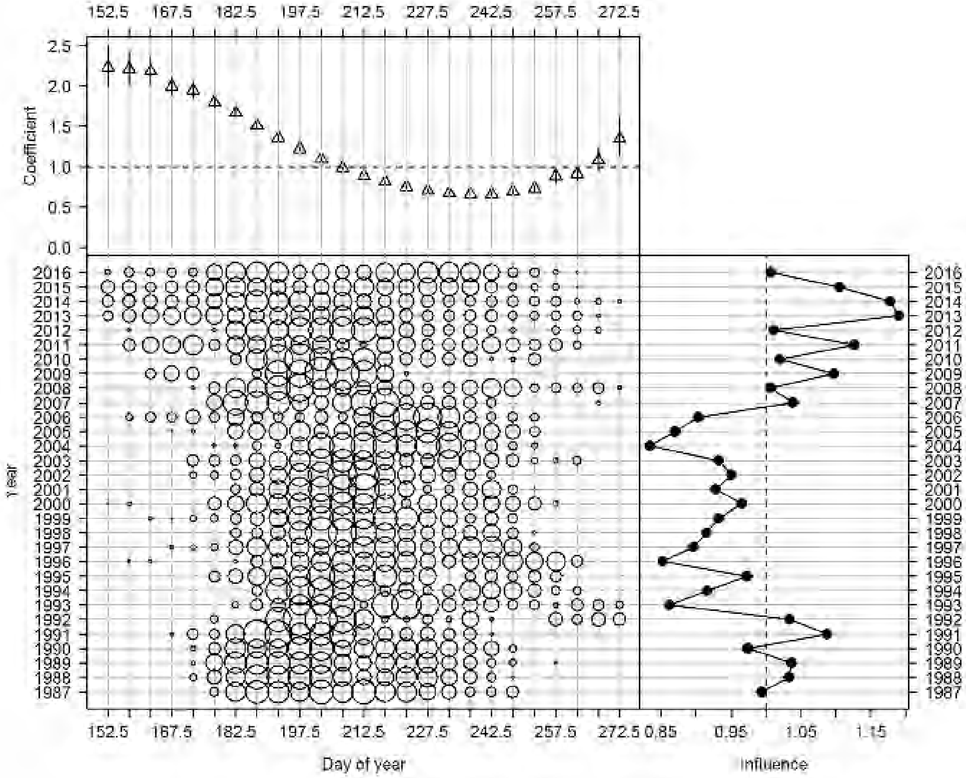


Figure 18: LIN 7WC Trawl; effect and influence of variables (influence plot).



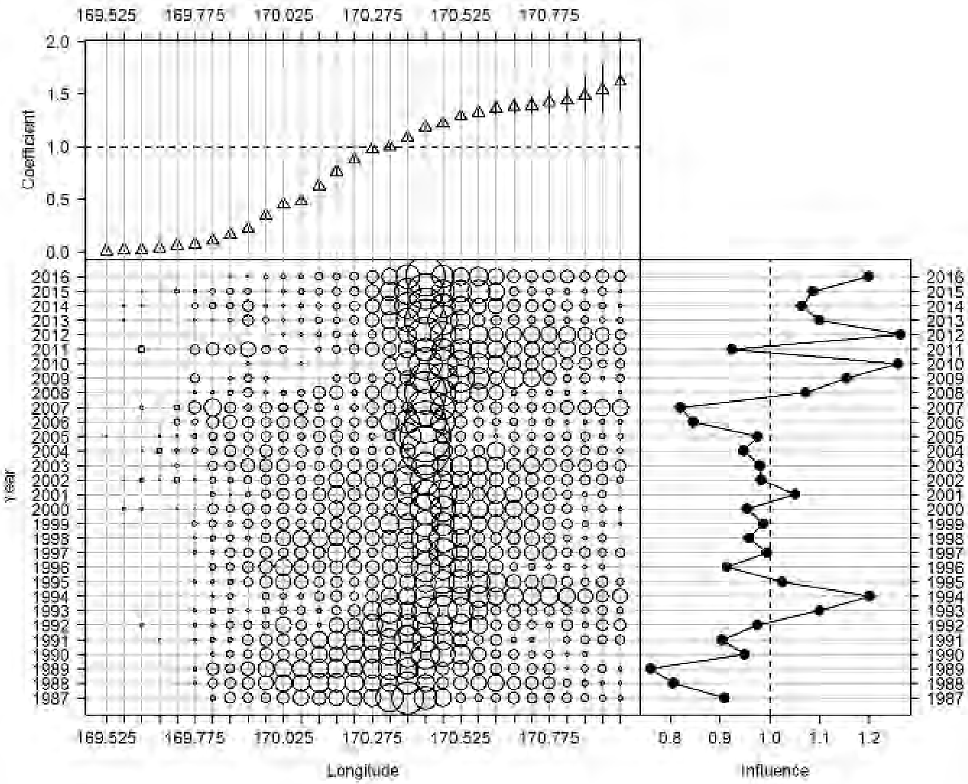


Figure 18 (cont.): LIN 7WC Trawl; effect and influence of variables (influence plot).

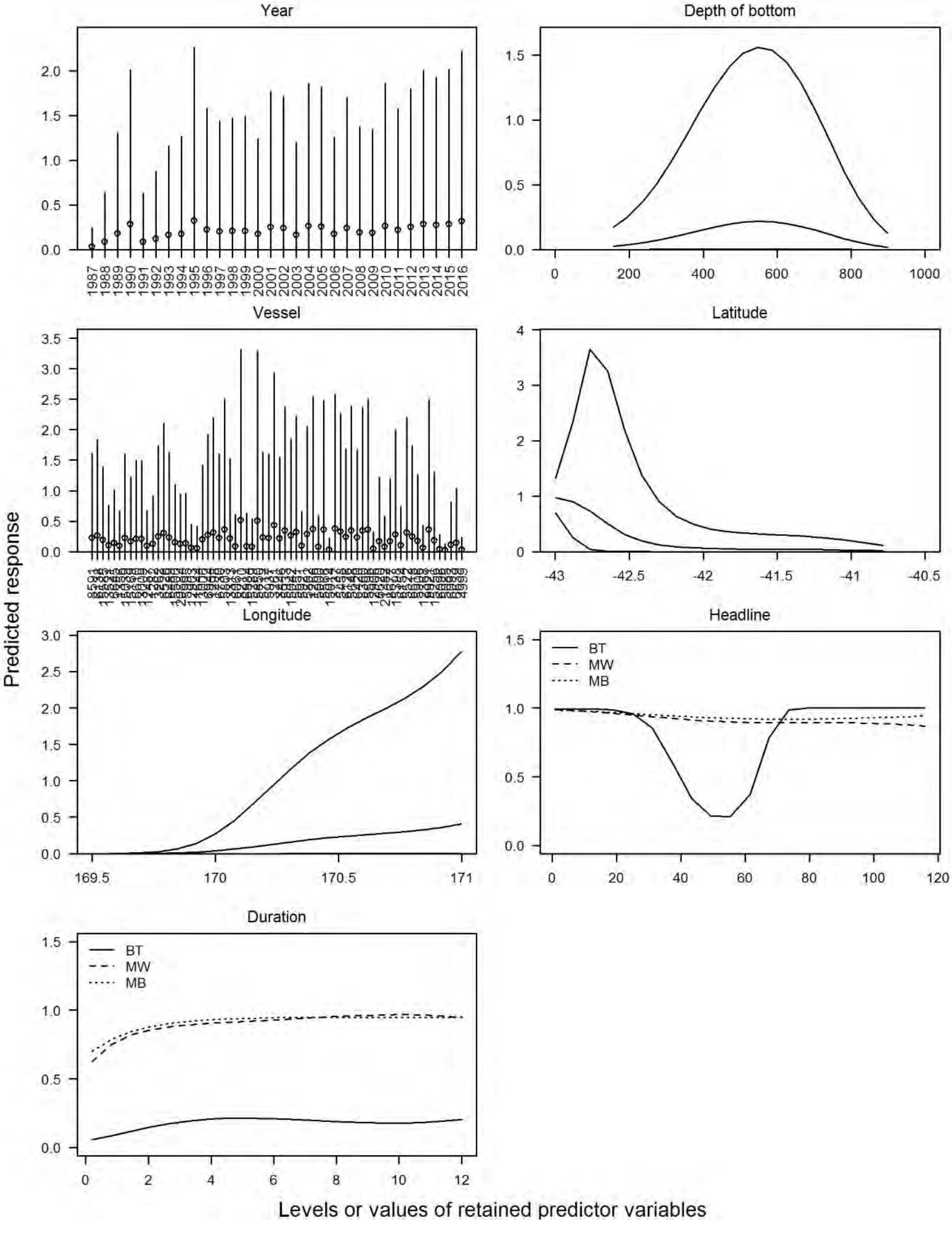
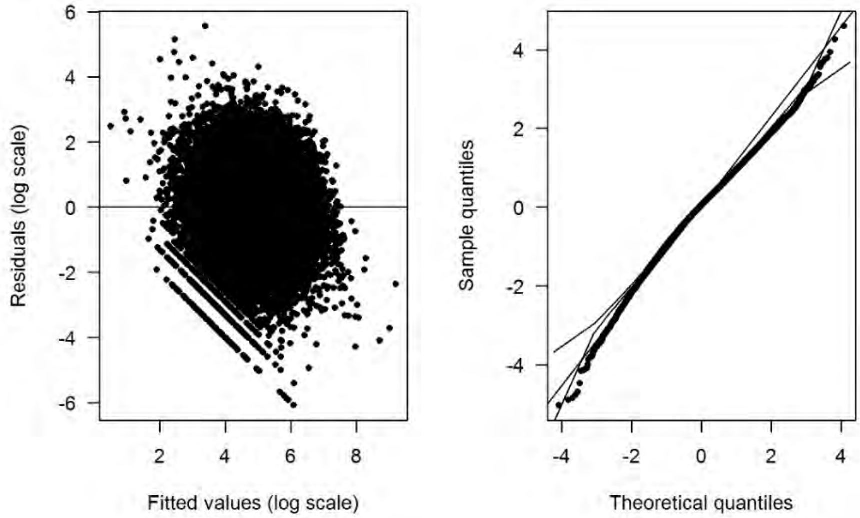


Figure 19: LIN 7WC Trawl; expected variable effects for predictors in the binomial model. The 95% confidence intervals are shown as bars for categorical variables and as upper and lower lines for continuous variables. Effects for individual predictors are made with all other predictors set to their median values.

(a) LIN 7WC Trawl



(b) LIN 7WC Line

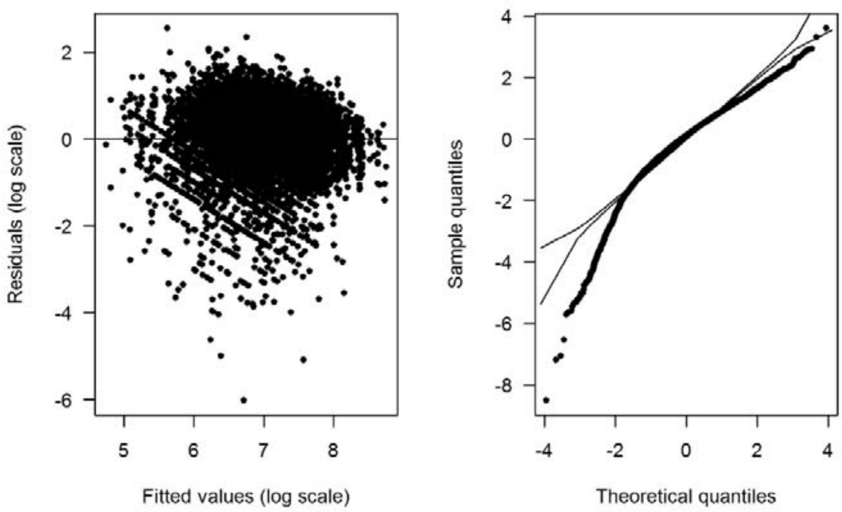


Figure 20: Diagnostic (residual and q-q) plots for the lognormal CPUE models.

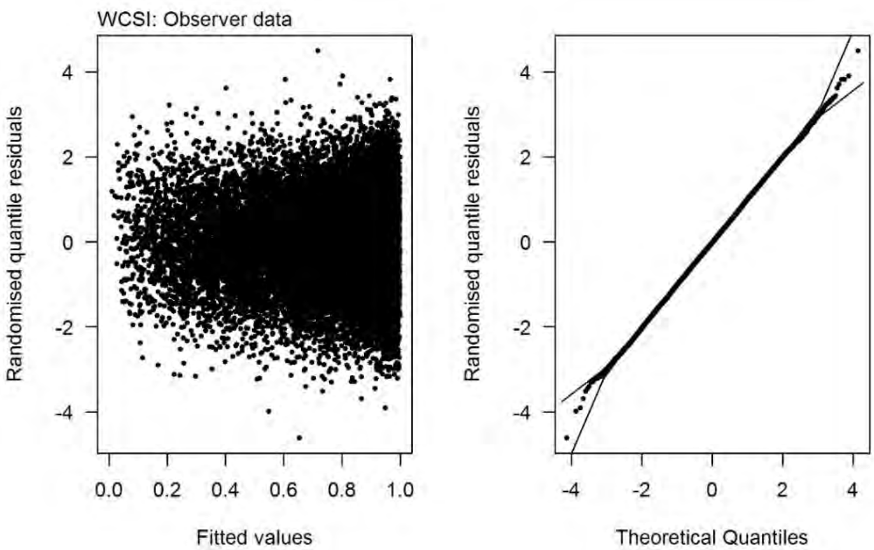


Figure 21: Diagnostic (residual and q-q) plots for the binomial LIN 7WC Trawl model.

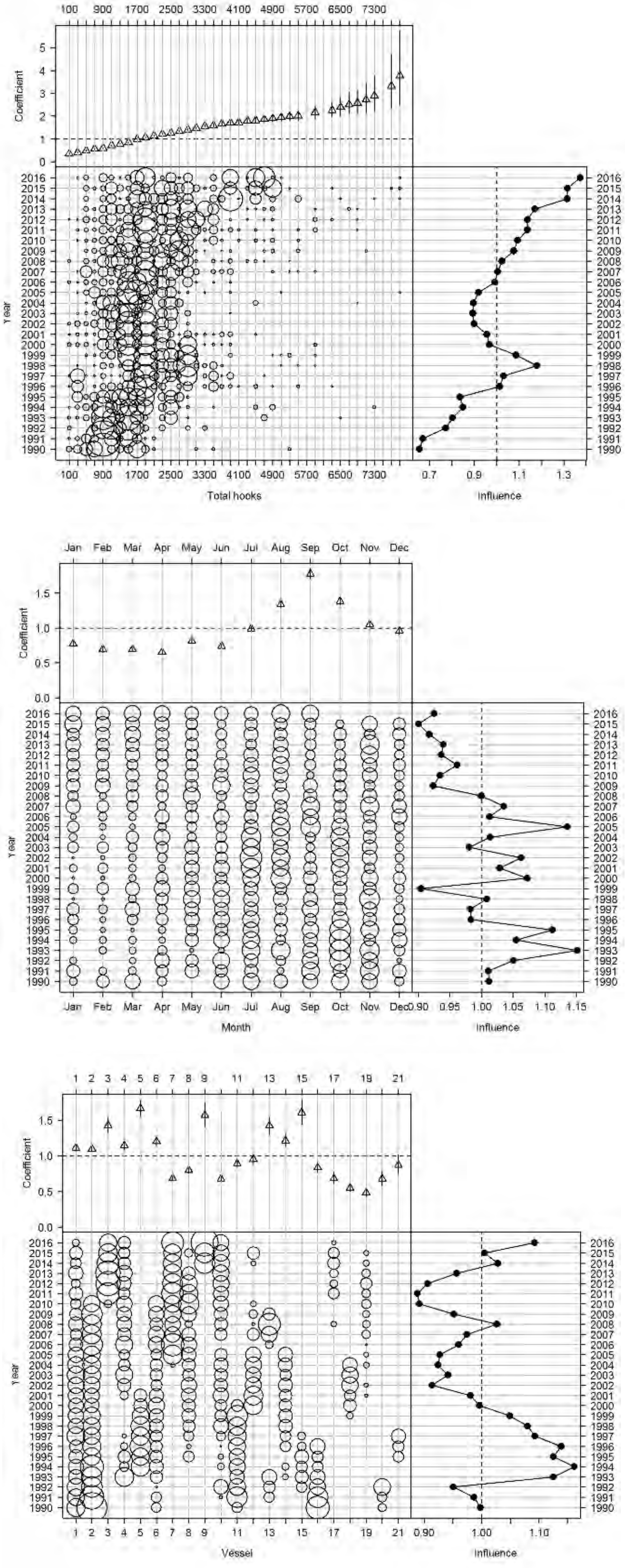


Figure 22: LIN 7WC Line; effect and influence of variables (influence plot).

The trends in the indices, and the variables selected into the models, did not change markedly from previous analyses (Dunn et al. 2013), as expected given that most of the data set was the same.

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 fishery). Although the fleet composition has changed over time, Horn (2004a) completed parallel analyses for shorter time series of data and compared the results with the "all years" indices to show that the change in fleet dynamics did not bias the line CPUE. It is considered unlikely that line CPUE series have been seriously biased by any changes in fishing practice over the duration of the fisheries (Horn 2004b), 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 trawl CPUE, using MPI observer data rather than vessel-supplied data, was expected to provide a relatively unbiased CPUE index. However, biases in CPUE caused by changes in fishing pattern not accounted for by the available predictors were still present. Biases in both CPUE series are likely. For example, the line 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 bring about hyperstability in the CPUE index. Also, some interactions with the trawl fishery in the same area could also lead to biases, and it has been suggested that the hoki trawlers may direct the line vessels to areas with apparently high ling abundance, as indicated by the trawl bycatch (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, and consistently high, ling catch rates. If the extent of this behavior changed over time, it would bias the line CPUE. There are also anecdotal reports of trawlers directly transferring some of their ling catch (presumably for which they have no quota) to line or setnet boats.

3.2 Biological parameters

The estimates of biological parameters used in previous assessments are given in Table 12 (repeated from Ministry for Primary Industries 2017). Growth and length-weight relationships were revised most recently by Horn (2006). Natural mortality rate (*M*) was initially set at 0.18 yr^{-1} for all stocks (Horn 2000), but was revised on a stock by stock basis by Horn (2008). The maturity ogive represented the proportion of fish (in the virgin stock) that were estimated to be mature at each age; ogives by sex are from Horn (2005). The proportion spawning was assumed to be 1.0 (in the absence of data to estimate this parameter). Variability in size-at-age around the von Bertalanffy age-length model was assumed to be normal with a constant CV of 0.15. A stock-recruitment relationship (Beverton-Holt) was used with assumed steepness parameter (*h*).

Table 12: 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 7WC	0.20	0.20	0.18

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

	Female		Male		Combined	
	a	*b*	*a*	*b*	*a*	*b*
LIN 7WC	0.000934	3.368	0.001146	3.318	0.001040	3.318

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

	Male				Female			
	n	*k*	t_0	L_∞	*n*	*k*	t_0	L_∞
LIN 7WC	2 366	0.067	-2.37	159.9	2 320	0.078	-0.87	169.3

	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
LIN 7WC										
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

The growth parameters for separate and combined sexes reported by Ministry for Primary Industries (2017) appeared to be inconsistent (Table 12), with the L_∞ for combined sexes being lower than for either males or females. The current growth estimates (Ministry for Primar Industries 2017) originate in Dunn et al. (2013) for the combined sex estimates, and seemed to originate in Horn & Dunn (2003) for the separate sex estimates. Because of the inconsistency of the L_∞ in Ministry for Primary Industries (2017), an attempt was made to re-estimate them using all LIN 7WC age data to the end of 1991, using a simple least-squares fitting method (Table 13). The results suggested that the combined estimates from Dunn et al. (2013) were incorrect. However, the parameters were also found to be potentially sensitive to assumptions made about selectivity; in particular, a t_0 of zero would be consistent with the ageing protocol and assumed birthdate (P. Horn, pers.comm.), but fixing this parameter made a notable difference to the estimated L_∞ and *K* (Table 13; Figure 23). Edwards (2017) also estimated growth, but exact details of the selection of age and length samples were not reported (although they must be similar). Although there are differences in the parameter estimates, which might lead to different biological interpretations (e.g., the L_∞), the divergence of the curves tends to be at the older and younger ages (Figure 23), and for the older ages at least this should have little impact in the stock assessment (which assumes a plus group at age 28).

Table 13: Estimates of von Bertalanffy Growth curve parameters for LIN 7WC, from different sources and samples. *n*, sample size; *, fixed parameter.

Source	Sex	*n*	L_∞	*K*	t_0
Horn (1993)	M	168	146.1	0.087	-0.13
	F	203	165.9	0.090	0.22
Ministry for Primary	M	2 366	159.9	0.067	-2.37
Industries (2017)	F	2 320	169.3	0.078	-0.87
	Combined	4 686	150.8	0.077	-1.37
LIN 7WC 1989–2001	M	2 380	159.6	0.067	-2.32
	F	2 326	167.4	0.080	-0.78
	Combined	4 706	168.5	0.070	-1.50
	Combined	4 706	153.7	0.095	0*
LIN 7WC 1989–2016	M	4 897	149.4	0.079	-1.91
	F	5 421	166.3	0.082	-0.92
	Combined	10 318	164.6	0.075	-1.44
Edwards (2017)	M	1 353	141.0	0.090	-1.18
	F	2 358	164.2	0.080	-0.75
	Combined	3 711	160.2	0.080	-1.16

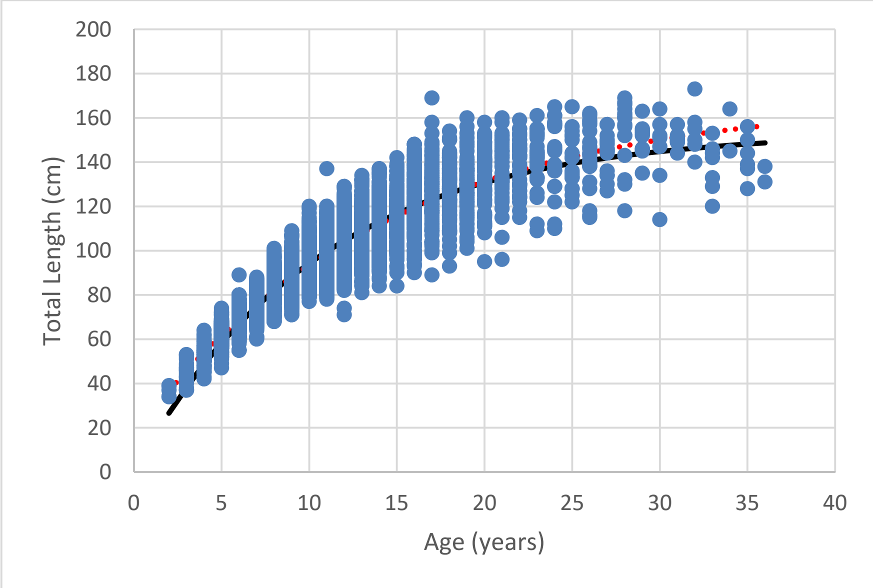


Figure 23: LIN 7WC combined sex length at age samples 1989–2001, showing the fit of two von Bertalanffy Growth curves with t_0 fixed at zero (solid line), or estimated (dotted line) (Table 5).

3.4 Research biomass surveys

A series of deepwater research trawl surveys by R.V. *Tangaroa* covering the known ling depth range were available for LIN 7WC (O'Driscoll et al. 2015) (Table 14). Biomass estimates from the trawl surveys were used as relative biomass indices, with associated CVs estimated from the survey analysis. Ling were caught predominantly in the Core survey strata, and including deeper strata made negligible difference to the biomass estimate or trend (Table 14). As a result, only the Core strata biomass index was used for stock assessment.

Table 14: Series of relative biomass indices (t) from *Tangaroa* (TAN) trawl surveys of the LIN 7WC fish stock. with coefficients of variation (CV) available for the assessment modelling.

			Core (300–650 m)		200–800 m		200–1000 m	
Area	Trip code	Year	Biomass (t)	CV (%)	Biomass (t)	CV (%)	Biomass (t)	CV (%)
WCSI	TAN0007	2000	1 861	17.3	–	–	–	–
	TAN1210	2012	2 169	14.8	2 194	14.7	–	–
	TAN1308	2013	2 000	18.4	2 009	18.3	–	–
	TAN1609	2016	1 635	12.7	1 661	12.5	1 661	12.5

Ling catch composition at age was obtained from otolith samples taken during each survey (Horn & Sutton 2017). The number of otoliths used to derive the age frequency distributions for 2000, 2012, 2013, and 2016 were respectively 560, 603, 519, and 453.

3.5 Stock composition

Data describing stock composition were catch-at-age only (no length frequencies were used). The catch-at-age data were fitted to the model as proportions-at-age, and available for the trawl fishery, line fishery, and research trawl surveys (Tables 15, 16, and 17 respectively). For the trawl fishery, the mean age of selectivity (A_{50}) appeared to increase around 1998 to 1999, but this might equally be the result of a relatively large cohort (or group of cohorts) originating around 1990 dominating the age composition at the time. The potential large year class from 1990 (age 5 in 1995), and also perhaps around 2001 (age 5 in 2006) did not appear to track particularly clearly across the catch-at-age composition, which may reflect ageing error. The estimation of the 1991 year class (following the potentially large 1990 year class) seemed relatively erratic, again suggestive of ageing error. Ageing error for the observed proportions-at-age data was previously assumed to have a discrete normal distribution with a CV of 5% (Dunn et al. 2013); examination of the catch-at-age data suggested a CV any lower than this would not be plausible. For the line fishery, the age composition of adjacent years (2006, 2007) was so different that it would not seem plausible that the samples were drawn from the same population. Such variability would not be down to ageing error alone, and suggested unrepresentative sampling. A decision was made to down-weight these data in the assessment model so that they had would have little influence other than in estimating the selectivity for the fishery (i.e., relatively little influence on year class strength or mortality rate estimates). The age composition from the research trawl survey appeared to be persistently bimodal, with a "gap" in abundance at around age 6 or 7, which was close to the mean age at first maturity (Table 12). This was not concluded in the previous assessment, where only data from relatively distant years 2000 and 2012 were available, and the bimodal pattern was instead interpreted as indicative of year class strength (not selectivity) (Dunn et al. 2013).

4. ASSESSMENT MODELLING

4.1 Research since the last assessment

The previous assessment included data from two research trawl surveys (2000, 2012), an abundance index from trawl CPUE (the ling target line fishery CPUE was considered to be low quality and excluded), and proportions at age from the commercial fisheries and trawl survey (Dunn et al. 2013). Relative biomass data from the R.V. *Kaharoa* inshore survey were not used because it was considered to have inadequate spatial coverage of the stock. The model estimated that initial stock size (B_0) was around 100 000 t, and stock status in 2012 was about 70% B_0. Biomass was estimated to have been declining, but the stock age composition was broad, indicating a low exploitation rate. There was a lack of contrast in the biomass indices to inform the estimate of B_0, and whilst the assessment was very uncertain, it was highly probable that B_{2012} was greater than 40% B_0 and could be much higher. As a result, it was concluded that in B_{2012} the stock was Exceptionally Unlikely (< 1%) to be below the Soft Limit and Exceptionally Unlikely (< 1%) to be below the Hard Limit. Model sensitivity runs investigated whether sex was included or not (i.e., male and female, or combined sex models), and the weighting of biomass and composition data. *M* was estimated in the base model; the model sensitivity run that had greatest influence on the results was that which fixed *M*. Because of model uncertainties, no projections under different catch scenarios were conducted.

The Dunn et al. (2013) assessment model did not fit all of the observational data well. The composition data showed inconsistencies that were hard to fit, or explain (e.g., line fishery data, as above). Information on the upper limit to estimated stock biomass came as much from priors (on survey *q*, and *M*) as from observational data. Selectivity was estimated to take place first in the trawl fishery (*a50* at 8.5 years), then the *Tangaroa* research trawl survey (*a50* = 11.0 years), and finally in the longline fishery (*a50* = 15.0 years). The veracity of these estimates was questioned, because the *Tangaroa* survey was expected to catch ling earlier than the trawl fishery. All observational data sets other than the trawl fish proportions-at-age indicated a relatively high *M*, greater than 0.21 yr^{-1}, and overall greater than 0.23 yr^{-1}. 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. YCS estimation for recent year classes was highly uncertain because it was based on only one survey. The 2013 assessment was accepted by the MPI Deepwater Fisheries Assessment Working Group (DWFAWG), but with reservations (Dunn et al. 2013). Problems were noted with the treatment of sex-specific data in ling, and further investigation of this was recommended. It was noted that 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. Finally, it was suggested that a prior could 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.

Table 15: Proportions of ling at age by fishing year (labelled as year-ending) in the commercial trawl fishery. Higher values have darker shading. Line across the table tracks the 1990 year class across the years 1993–94 to 2007–08.

Age	1991	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2012	2013	2014	2015
4	0.002	0.008	0.017	0.002	0.002	0.002	0.014	0.010	0.014	0.017	0.032	0.030	0.067	0.048	0.024	0.038	0.021	0.078	0.034	0.072
5	0.008	0.018	0.063	0.023	0.012	0.024	0.029	0.018	0.054	0.037	0.090	0.054	0.074	0.115	0.054	0.118	0.022	0.057	0.054	0.106
6	0.012	0.034	0.061	0.082	0.047	0.033	0.034	0.028	0.053	0.057	0.066	0.078	0.054	0.078	0.058	0.053	0.029	0.034	0.058	0.044
7	0.018	0.067	0.108	0.072	0.063	0.037	0.046	0.048	0.044	0.040	0.060	0.074	0.053	0.058	0.119	0.087	0.055	0.044	0.062	0.045
8	0.052	0.100	0.148	0.108	0.072	0.099	0.123	0.147	0.069	0.115	0.085	0.093	0.071	0.064	0.065	0.089	0.093	0.105	0.066	0.061
9	0.046	0.105	0.135	0.144	0.104	0.196	0.153	0.058	0.105	0.095	0.076	0.078	0.077	0.068	0.094	0.063	0.125	0.137	0.124	0.098
10	0.084	0.110	0.079	0.101	0.112	0.140	0.150	0.216	0.123	0.104	0.095	0.069	0.089	0.086	0.059	0.069	0.134	0.135	0.154	0.100
11	0.077	0.118	0.084	0.097	0.108	0.126	0.136	0.101	0.136	0.131	0.103	0.098	0.089	0.088	0.079	0.075	0.129	0.097	0.102	0.079
12	0.139	0.077	0.066	0.087	0.132	0.122	0.101	0.098	0.110	0.122	0.118	0.128	0.079	0.084	0.076	0.076	0.083	0.096	0.106	0.103
13	0.172	0.084	0.055	0.100	0.112	0.068	0.059	0.108	0.075	0.097	0.090	0.101	0.073	0.066	0.097	0.093	0.058	0.072	0.069	0.077
14	0.068	0.083	0.056	0.059	0.071	0.062	0.045	0.033	0.081	0.065	0.058	0.082	0.057	0.052	0.063	0.052	0.048	0.041	0.031	0.055
15	0.054	0.084	0.042	0.035	0.048	0.018	0.022	0.040	0.035	0.041	0.035	0.050	0.072	0.045	0.044	0.053	0.041	0.023	0.047	0.066
16	0.085	0.025	0.029	0.031	0.031	0.011	0.022	0.018	0.035	0.020	0.025	0.025	0.054	0.050	0.068	0.044	0.029	0.015	0.014	0.031
17	0.054	0.017	0.021	0.007	0.021	0.018	0.006	0.018	0.013	0.017	0.016	0.017	0.038	0.040	0.034	0.029	0.019	0.009	0.018	0.015
18	0.036	0.020	0.007	0.011	0.020	0.006	0.016	0.011	0.006	0.013	0.013	0.007	0.018	0.018	0.016	0.035	0.029	0.011	0.013	0.016
19	0.013	0.014	0.007	0.008	0.019	0.017	0.009	0.014	0.011	0.007	0.018	0.007	0.014	0.014	0.007	0.016	0.021	0.009	0.015	0.005
20	0.010	0.010	0.004	0.007	0.010	0.011	0.003	0.008	0.006	0.002	0.004	0.003	0.013	0.002	0.011	0.003	0.021	0.010	0.000	0.010
21+	0.073	0.026	0.020	0.026	0.016	0.008	0.033	0.028	0.031	0.021	0.017	0.006	0.008	0.025	0.031	0.009	0.043	0.028	0.034	0.018

Table 16: Proportions of ling at age by fishing year (labelled as year-ending) in the commercial line fishery. Higher values have darker shading.

Age	2003	2006	2007	2012	2015
5	0.000	0.011	0.011	0.000	0.000
6	0.001	0.031	0.021	0.000	0.000
7	0.020	0.067	0.052	0.006	0.009
8	0.032	0.104	0.026	0.024	0.040
9	0.040	0.113	0.084	0.040	0.104
10	0.059	0.112	0.062	0.058	0.119
11	0.092	0.136	0.071	0.074	0.162
12	0.127	0.092	0.065	0.079	0.187
13	0.105	0.053	0.058	0.073	0.134
14	0.087	0.056	0.051	0.078	0.089
15	0.064	0.060	0.039	0.074	0.044
16	0.056	0.057	0.129	0.095	0.030
17	0.063	0.040	0.024	0.056	0.029
18	0.045	0.025	0.099	0.070	0.021
19	0.031	0.016	0.013	0.081	0.010
20	0.022	0.004	0.008	0.050	0.010
21	0.010	0.009	0.046	0.055	0.008
22	0.008	0.002	0.064	0.030	0.000
23+	0.138	0.012	0.080	0.057	0.004

Table 17: Proportions of ling at age by fishing year (labelled as year-ending) in the research trawl surveys. Higher values have darker shading.

Age	2000	2012	2013	2016
3	0.021	0.044	0.034	0.029
4	0.043	0.048	0.073	0.073
5	0.048	0.043	0.048	0.057
6	0.036	0.028	0.031	0.030
7	0.032	0.050	0.044	0.044
8	0.103	0.061	0.084	0.065
9	0.061	0.076	0.106	0.071
10	0.200	0.096	0.129	0.098
11	0.094	0.087	0.079	0.092
12	0.079	0.072	0.090	0.125
13	0.103	0.060	0.072	0.067
14	0.028	0.054	0.046	0.073
15	0.039	0.042	0.024	0.044
16	0.019	0.037	0.022	0.012
17	0.025	0.019	0.014	0.034
18	0.012	0.045	0.023	0.013
19	0.020	0.036	0.023	0.009
20	0.006	0.027	0.020	0.010
21	0.004	0.023	0.013	0.012
22	0.013	0.020	0.011	0.007
23+	0.015	0.035	0.016	0.037

The previous assessment initially assumed separate sexes, with a common *M*, and estimated large sex-specific differences in selectivities. The DWFAWG rejected this assumption, and a model with combined sexes was developed. Following the assessment, Horn (2015) examined empirical data on fish size and sex ratio along with potential covariates for sample location, depth, and time, for ling from Chatham Rise and the West Coast South Island. For the West Coast South Island, the trend in fish size was broadly and positively correlated with the trend in sex ratio (proportion male), which declined to 1995, then increased to 1998, then declined until 2004. This result seems contrary to expectations because females grow larger than males, therefore larger fish might be expected to have a lower proportion male. No areal or temporal influences on sex ratio were found. Horn (2015) recommended that the West Coast South Island assessment should continue to be conducted assuming combined sexes. Horn (2015) also examined the trends in ling sex ratio found on Chatham Rise, and found that this was influenced by relatively large changes in abundance of large females. For Chatham Rise ling, Horn (2015) recommended including sex in the assessment model partition, but investigating estimating the proportion male in the first age (*pmale*) with a prior (mean 0.5, CV 0.15), and also recommended that not all data sets should be included by sex (e.g., line should use unsexed catch composition).

Edwards (2017) described various methods for estimating *M* for ling. Using established age-based methods he obtained *M* estimates for this West Coast South Island stock of 0.13 – 0.20 yr^{-1}, with negligible difference between males and females. However, Edwards (2017) concluded that these estimates were too biased to be credible, because the maximum age was hard to accurately sample (because the oldest fish are rare), the estimates of maximum age for the West Coast South Island stock had decreased over time, and the mortality rates were total mortality (*Z*), rather than *M*, and the fishery had started more than a decade before the age data were available. Edwards (2017) therefore applied two alternative approaches based upon fish length, growth, and maturity. These were, (1) an empirical approach where *M* was estimated from a regression model relating, for many species, *M* estimates to the von Bertalanffy growth formula parameters *K* and L_∞ and the mean length at first maturity; and (2) a theoretical approach where *M* was predicted from the von Bertalanffy growth formula L_∞ and the estimated length at first maturity; this method related the natural mortality rate to the theoretical optimum age and size at which maturity takes place. The empirical *M* estimates for the West Coast South Island stock were 0.17 yr^{-1} (95% CI 0.04 – 0.77) in males, and 0.13 yr^{-1} (0.04 – 0.67) in females, and the theoretical *M* estimates 0.3 yr^{-1} (0.26 –– 0.35) for males, and 0.15 yr^{-1} (0.14 – 0.17) for females. The difference in theoretical *M* estimates by sex were therefore pronounced. However, Edwards (2017) noted that the theoretical *M* for males was inconsistent with an observed longevity of over 30 years, so this estimate was discarded. Edwards (2017) recommended that the theoretical value for females could be applied, and a prior placed on the difference in *M* between males and females, although no prior was developed (further research was recommended). We also noted (in Section 3.2) that the growth parameters for LIN 7WC have been variable, and so it is not entirely clear which growth parameters should be used. The accepted *M* estimate for ling (0.2 yr^{-1}; Table 12) is a little higher than the Edwards (2017) estimates. When a single *M* has been assumed in assessments modelling separate sexes, the selectivities for each sex have been estimated to be different (capped logistic or domed in males, logistic or domed in females; Dunn et al. 2013). A similar selectivity pattern was found in assessments of Australian ling stocks; with a combined sex *M* estimated to be 0.23 or 0.25 yr^{-1}, the model estimated sex-specific differences in selectivities (domed in males, logistic in females), although *M* was not estimated "with any degree of confidence" (Morison et al. 2012). Selectivites and *M* can be confounded, of course, but different behaviour and availability of ling sexes is also plausible, and research into the role of ling refuges was recommended by Morison et al. (2012). Time-varying growth and trawl fishery selectivity have also been assumed in Australian stock assessments (Morison et al., 2012). An investigation of sex-specific *M* was also recommended after the SubAntarctic ling stock assessment completed in 2015 (Roberts 2016).

Francis & Fu (2015) conducted a literature review on assumptions around modelling recruitment (year class strength), and concluded that there was near unanimous scientific support for assuming a lognormal prior. Deviations from this were recommended only when (1) there was evidence that year class strengths had a distribution clearly different from lognormal (a *genuine* prior), or (2) it was necessary in order to obtain an acceptable assessment (a *tactical* prior). In cases where a uniform or near-uniform prior had been assumed in New Zealand stock assessments, Francis & Fu (2015) found that different ways of parameterising the year class strengths were more important than the choice of prior. Francis & Fu (2015) also recommended using only the Haist parameterisation in CASAL, with a strong penalty to encourage the year class scalars to have a mean of one. However, the strong penalty can adversely affect Bayesian Markov Chain Monte Carlo (MCMC) convergence, which may have been the reason why they had been omitted in some MCMC runs (Francis & Fu 2015).

4.2 Model structure and investigative runs

Model parameters were estimated using Bayesian estimation implemented using the CASAL v2.30 software. For all model runs, the joint posterior distribution was sampled using MCMC methods, based upon the Metropolis-Hastings algorithm. Full details of the CASAL software and methods are given by Bull et al. (2012).

The starting point for this assessment was the model accepted by the DWFAWG in 2013, the derivation of which was described in detail by Dunn et al. (2013). The 2013 stock assessment model partitioned the population into 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 18. The model did not have sex in the partition, and all observations (age frequencies) and associated parameters (selectivities), and biological parameters (growth, maturity etc), were unsexed (combined sexes).

Table 18: 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.

The *Tangaroa* survey and trawl fishery selectivity ogives were assumed to have a double normal parameterisation, and the line fishery selectivity ogive was assumed to be logistic. Selectivities were assumed to be constant. Natural mortality rate was estimated or fixed in the model. The maximum exploitation rate allowed by the model was assumed to be 0.6 (although this was never achieved).

Lognormal error, with known CVs per year, was assumed for the CPUE and research trawl survey indices. A process error CV of 0.2 was added to the research biomass surveys, and process error CV estimated for the CPUE indices, following Francis (2011). The proportions-at-age observations from trawl and line fisheries were assumed to have a multinomial error distribution. Effective sample sizes were estimated using rule-of-thumb, and method TA1.8 described in Francis (2011).

A small ageing error was also added, which was normal with a CV of 0.05. Year class strengths were assumed known (and equal to 1) for years before 1978 and after 2008, when inadequate or no catch-at-age data were available. Otherwise, year class strengths were estimated using the Haist parameterisation, under which the estimates from the model average 1. The steepness of the Beverton-Holt recruitment model was assumed to be 0.84 (Shertzer & Conn 2012).

Assumed prior distributions used in the assessment are given in Table 19. 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]. This prior for M was informed by expert opinion, to be centred around 0.2 with 95% confidence intervals of 0.15–0.25.

Table 19: LIN 7WC assumed prior distributions and bounds for all 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 were strongly penalised. A penalty was also 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 20×10^6 iterations, with sampling of every 1000th sample after a burn-in length of 1×10^6 iterations.

4.2.1 New input data and initial data weighting

The influence of the addition of new data to the Dunn et al. (2013) base model is shown in Figure 24. Updating and adding catches made negligible difference to the biomass estimates or stock status estimates. Adding the two new years of research trawl biomass surveys, and age compositions, made little difference to recent stock trajectory, and slightly increased stock status in 2016, from 53% to 57% B_0, although changed historical stock status substantially.

The Combined CPUE index indicated very large and rapid changes in biomass; initially about 20-fold over three years (Table 11; Figure 25). Such large biomass changes do not seem plausible, given little change in research trawl survey biomass, and observations of older fish present throughout the fishery, which are suggestive of a more lightly-fished stock. Following Francis (2011), the CV of the CPUE was therefore inflated by adding 0.40 to the observation error CV, resulting in a average annual CV of around 0.41 (initial CVs were very low; Table 11); this is equivalent to saying that we expect the stock assessment model to fit these data as well as the smoother with a CV of 0.4, thereby heavily smoothing the large rapid fluctuations in the CPUE index (Figure 25).

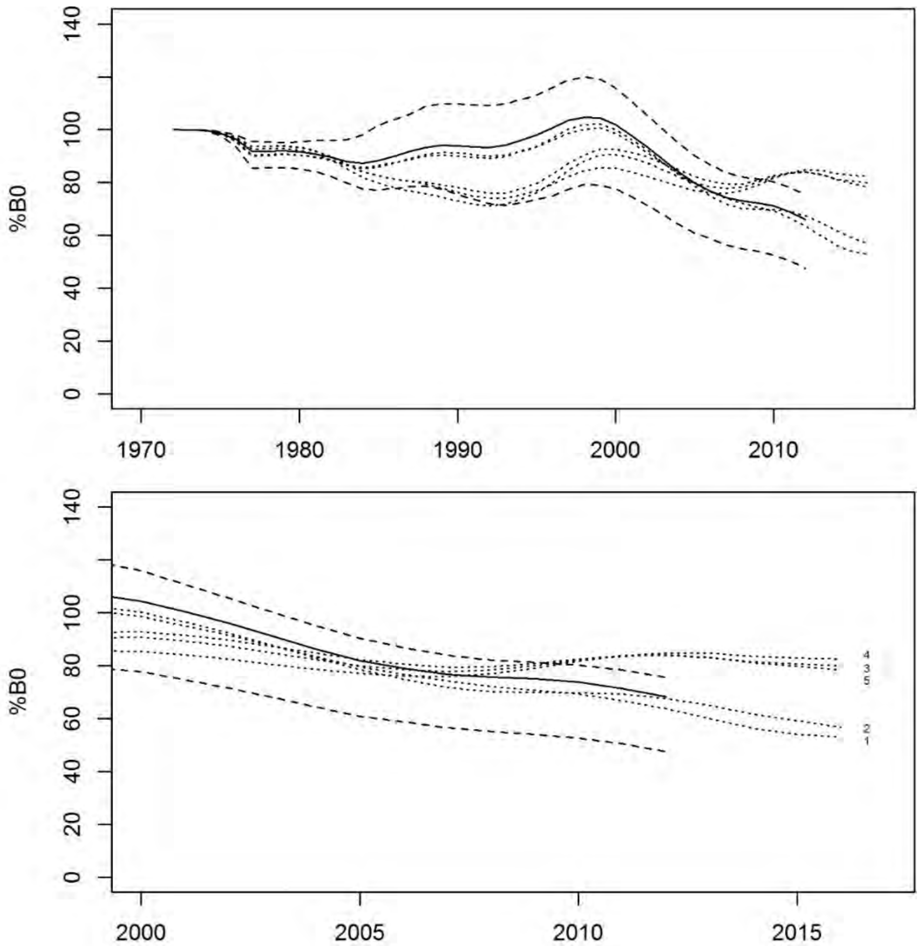


Figure 24: LIN 7WC stock status estimates for the entire time period (top panel) and recent years (bottom panel). Solid line indicates the previous assessment (Dunn et al. 2013) with 95% CI (dashed lines). Dotted lines indicate the new model runs, and are sequentially (1) adding catches, (2) adding research trawl biomass and age compositions, (3) adding trawl CPUE, (4) adding commercial fishery catch at age, and (5) reweighting.

Adding the revised combined CPUE biomass index to the previous model had a relatively large influence on recent model quantities, and increased stock status, with the stock status in 2016 being 82% B_0 (Figure 24). The subsequent addition of the new commercial fishery (trawl and line) catch-at-age data then had little impact.

The initial multinomial effective sample sizes (EFS) used were the mean of historical values (Dunn et al. 2013). Model reweighting then followed Francis (2011), with rule-of-thumb for the multinomial EFS for the *Tangaroa* and longline catch-at-age because these consisted of only four and five years of data respectively. For the line fishery age compositions, the EFS were the number of otoliths read each year scaled to be on average one quarter of the mean EFS for the trawl fishery age compositions (previously one third; Dunn et al. 2013); this downweighting was intentional (see Section 3.5). The research trawl age compositions were assumed to be of relatively high quality because this was a scientific survey, albeit with narrow temporal coverage, and therefore the EFS for these observations were set to be the number of otoliths read each year scaled to be on average three times the mean EFS of the trawl fishery (they were previously about eight times the mean EFS of the trawl fishery, but in this assessment the number of observations was doubled). The re-weighted effective sample sizes are given in Table 20. The sensitivity of model results to assumed effective sample sizes was examined in later model runs. The reweighted model reduced stock status in 2016, and changed the historical stock trajectory a little (Figure 24); in the previous assessment the stock status increased beyond 100%, but in the updated model this did not happen. B_0 in the previous assessment was about 95 kt, and in the revised assessment run 118 kt.

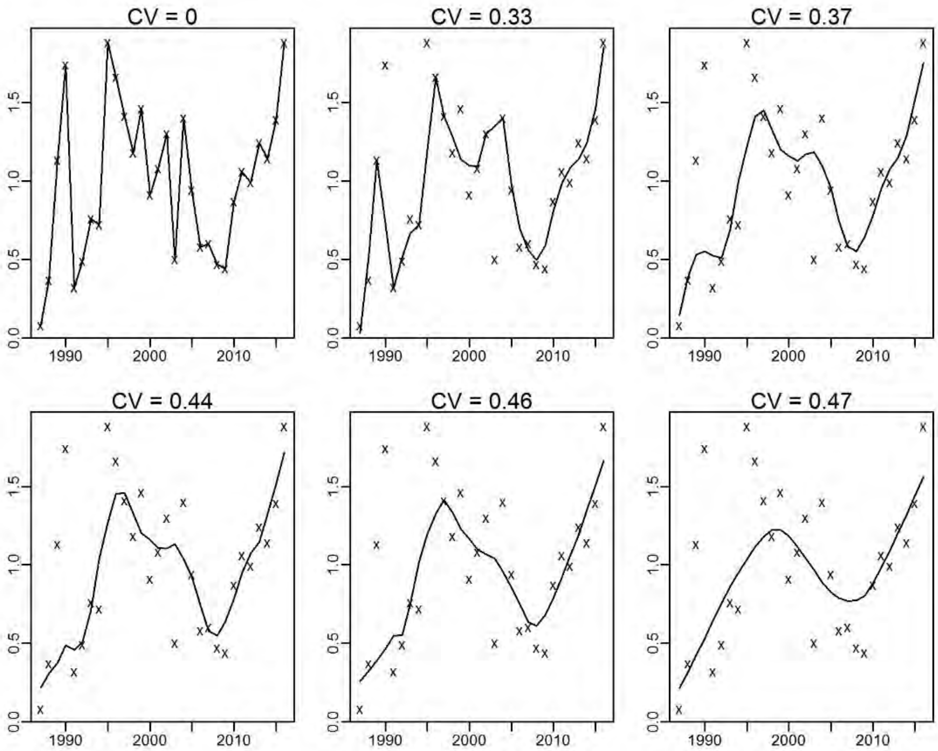


Figure 25: The fit of a data smoother (loess) to the ling trawl CPUE combined index using different degrees of data smotthing, labelled with the resultant CV of the residuals.

Table 20: Multinomial effective sample size (EFS) by year and source: TRL, commercial trawl fishery, LL, commercial longline fishery, TAN, *Tangaroa* trawl survey; KAH, *Kaharoa* trawl survey; C@A, catch-at-age; C@L, catch-at-length. The *Kaharoa* survey data are described in Section 4.2.2, and were not included in initial model reweighting.

Fishing year	TRL C@A	LL C@A	TAN C@A	KAH C@L	Fishing year	TRL C@A	LL C@A	TAN C@A	KAH C@L
1990–91	19	–	–	–	2003–04	49	–	–	–
1991–92	–	–	–	22	2004–05	38	–	–	8
1992–93	–	–	–	–	2005–06	21	6	–	–
1993–94	22	–	–	24	2006–07	11	6	–	8
1994–95	29	–	–	28	2007–08	26	–	–	–
1995–96	17	–	–	–	2008–09	–	–	–	9
1996–97	43	–	–	8	2009–10	–	–	–	–
1997–98	33	–	–	–	2010–11	–	–	–	14
1998–99	33	–	–	–	2011–12	33	8	105	–
1999–00	25	–	96	5	2012–13	36	–	89	14
2000–01	25	–	–	–	2013–14	36	–	–	–
2001–02	46	–	–	–	2014–15	25	6	–	10
2002–03	38	4	–	9	2015–16	–	–	78	–

4.2.2 Model investigations for 2017

The following model runs used MPD ("best fit") estimates rather than MCMC posteriors. The model development and evaluation had six broad themes:

(1) Growth assumptions
(2) Selectivity for the trawl survey catch-at-age
(3) Alternative CPUE indices
(4) Adding the R.V. *Kaharoa* inshore trawl survey
(5) Productivity assumptions (e.g., *M* and stock-recruit assumptions)
(6) "Drop data set" and data weighting sensitivity runs

4.2.2.1 Growth assumptions

Minor updates to the base model included the assumed von Bertalanffy growth model parameters and the ageing error. Changing the assumed growth model parameters made negligible difference to the outcome, with no change in selectivity parameters, negligible change in fits to observations (a total difference of 0.20 likelihood units), and negligible (1%) change in B_0 (compare Runs 1, 2, and 3; Table 21). In following runs, the revised growth growth curve parameters were assumed (Run 2 in Table 21). Increasing the ageing error (following observations in Section 3.5) slightly downweighted the age composition data, but the difference in model outcome was negligible (compare Runs 2 and 4; Table 21).

Table 21: LIN 7WC, CASAL MPD parameter estimates and likelihood values, for alternative model runs. *, fixed parameter; TAN, research trawl; TRL, commercial trawl, LN, line; sel, selectivity parameters; c@a, catch at age; YCS, year class strength (recruitment). Selectivities suffixed "sel", with three parameters being A1, $A50_{lhs}$, $A50_{rhs}$; two parameters being logistic A50, Ato95.

		1. Reweighted base	2. Revised growth ($L\infty$ = 168.5, K = 0.070, t_0 = -1.50)	3. Edwards (2017) growth	4. Increasing ageing error (0.05 to 0.1)
Parameters	B_0	114 680	113 546	114 109	109 717
	M	0.219	0.219	0.219	0.219
	TANsel	18.8, 7.5, 200	18.8, 7.5, 200	18.8, 7.5, 200	18.4, 7.2, 200
	TRLsel	13.3, 4.3, 9.8	13.3, 4.3, 9.8	13.3, 4.3, 9.9	13.3, 4.3, 8.8
	LNsel	11.4, 4.2	11.4, 4.2	11.4, 4.2	11.4, 3.9
	qTAN	0.032	0.033	0.033	0.034
Likelihood components	TAN	-5.07	-5.07	-5.07	-5.07
	TRL	10.62	10.80	10.61	10.28
	TANc@a	167.96	167.97	167.96	141.86
	TRLc@a	352.53	352.53	352.53	353.79
	LNc@a	47.54	47.54	47.54	47.36
	Prior qTAN	-3.02	-3.03	-3.02	-3.04
	Prior qTRL	-11.22	-11.20	-11.21	-11.13
	Prior B_0	11.65	11.64	11.64	11.61
	Prior M	0.29	0.28	0.29	0.29
	Prior YCS	-12.99	-13.00	-12.99	-12.58
	Penalty YCS	0.84	0.83	0.84	0.84
	Penalty catch	0	0	0	0
Quantities	$\%B_0$	82	81	82	80

4.2.2.2 Selectivity for the trawl survey catch-at-age

In the previous model (Dunn et al. 2013), the research trawl survey catch-at-age were fitted assuming a logistic ogive. However, in the revised assessment the bimodal nature of these age composition was more apparent, and the use of the logistic ogive questioned. Three alternative selectivity assumptions were tested, all of which fitted the catch-at-age data by estimating that immature fish had a lower selectivity than mature fish. This would be consistent with known ontogentic structure, where immature ling have been found inshore of the adults with abundance decreasing beyond 500 m, whereas adults have peak abundance at depths of around 600 m (Hurst et al. 2000). The three solutions considered to fit the research trawl catch-at-age compositions were:

(1) an "increasing" ogive, with a selectivity parameter estimated for each age, but constrained to be the same or greater than at the previous age;
(2) maturity added to the partition, and for the trawl survey separate ogives fitted to immature (capped logistic or double normal ogive) and mature (logistic ogive);
(3) maturity added to the partition, and an ogive fitted to immature fish, with all mature fish assumed to be selected.

A model assuming independent selectivity at each age (CASAL "all values") was also attempted, but poor model convergence was found.

The double normal ogive for the trawl fishery was estimated with a right hand side A_{to95} of 200 years (at the bound), suggesting that the ogive was effectively logistic (parameter TANsel; Table 21). Assuming a logistic instead of domed selectivity for the trawl fishery made for a more parsimonious model (i.e., one fewer parameter), and actually made small improvements to the fit to survey catch-at-age (-2.34 units), and trawl fishery catch-at-age (-0.38 units), although worse to the line catch-at-age (+0.56 units). The line catch-at-age were considered *a priori* least reliable, and subsequent models assumed a default logistic selectivity for the trawl fishery.

Model runs with the "increasing" ogive gave a much improved fit compared to a simple logistic ogive (Figure 26; Table 22). However, the selectivity parameters were not well determined, even when the number of parameters was reduced by assuming all mature fish (age 12 and above) were fully selected (Figure 27). Trials of Run 5 having different starting values for ogive parameters converged at different solutions, indicating local minima.

Table 22: LIN 7WC, CASAL MPD parameter estimates and likelihood values, for alternative model runs. *, fixed parameter; TAN, research trawl; TRL, commercial trawl, LN, line; sel, selectivity parameters; c@a, catch at age; YCS, year class strength (recruitment). Log, logistic; dbl nml, double normal. Capped logistic parameters A50, Ato95, and cap.

		5. TANsel "increasing" over ages 3–12	6. Mature log, immature dbl nml	7. Mature log, immature capped log	8. Mature = mature, immature capped log
Parameters	B_0	97 827	96 638	96 220	107 717
	M	0.252	0.247	0.248	0.211
	TANsel	See Fig. 28	–	–	–
	TANselI	–	191.4, 90.8, 4.9	2.0, 1, 0.05	3, 0, 0.16
	TANselM	–	11.9, 7.6	12.2, 8.1	=maturation
	TRLsel	9.5, 4.5	9.3, 4.5	9.3, 4.5	8.4, 4.3
	LNsel	12.8, 4.6	12.2, 4.3	12.3, 4.3	11.3, 4.2
	qTAN	0.060	0.044	0.046	0.022
Likelihood components	TAN	-5.10	-5.05	-5.06	-5.28
	TRL	11.14	11.32	11.30	12.13
	TANc@a	132.17	135.46	135.28	146.23
	TRLc@a	353.86	354.65	354.53	362.22
	LNc@a	47.81	47.72	47.73	47.29
	Prior qTAN	-2.81	-3.03	-3.01	-2.65
	Prior qTRL	-11.03	-11.09	-11.08	-11.37
	Prior B_0	11.49	11.48	11.47	11.59
	Prior M	2.16	1.78	1.82	0.09
	Prior YCS	-13.05	-13.17	-13.20	-13.06
	Penalty YCS	0.85	0.85	0.86	0.85
	Penalty catch	0	0	0	0
Quantities	$\%B_0$	82	81	82	74

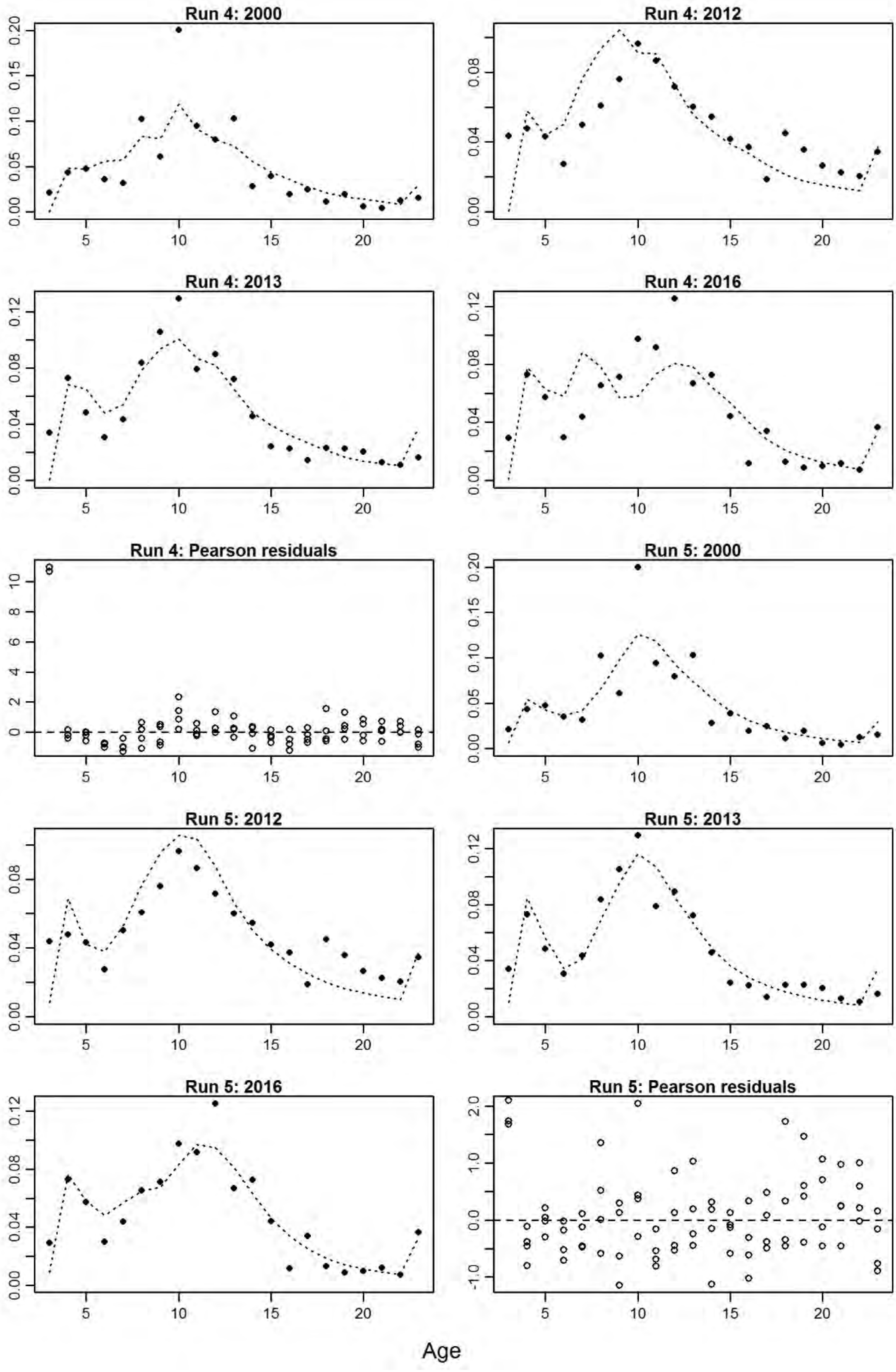


Figure 26: LIN 7WC model run fits (broken lines) to observed catch-at-age (points), followed by the Pearson residuals for all years combined, for Model Runs 4 and 5.

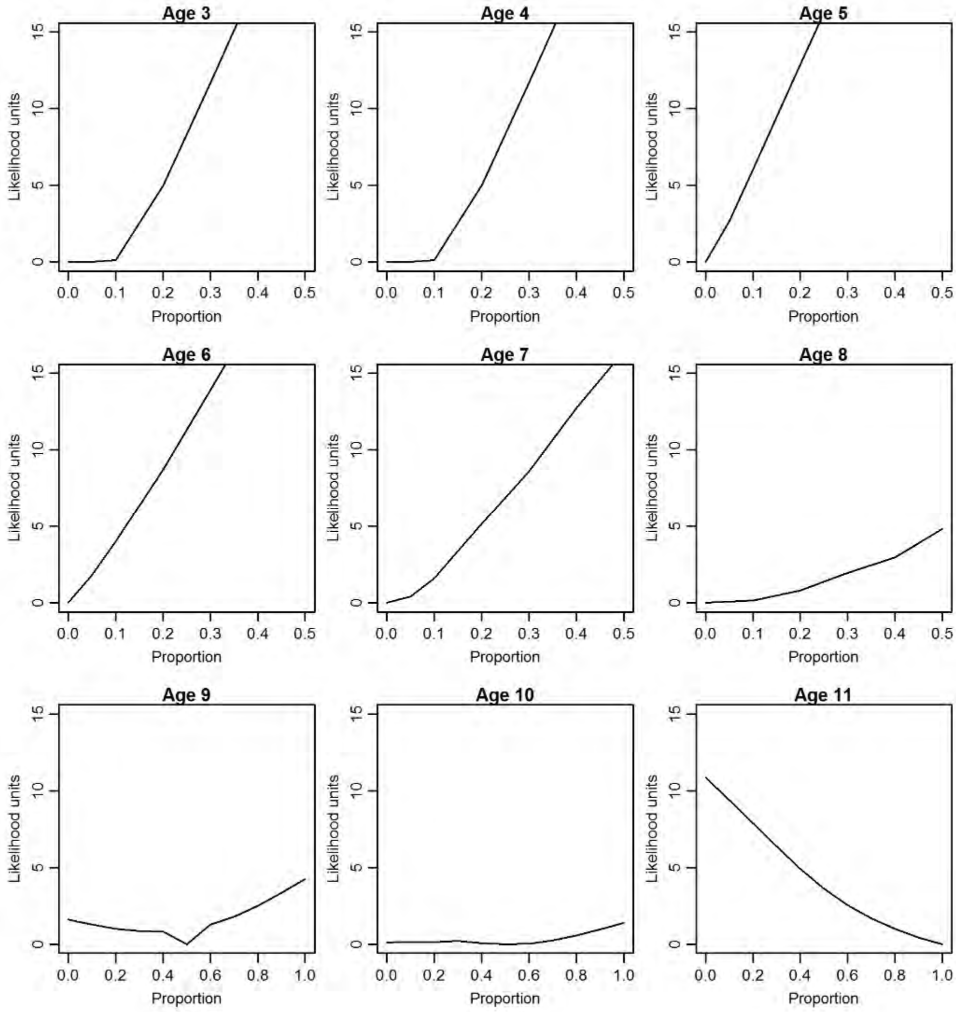


Figure 27: LIN 7WC likelihood profiles for parameters of the "increasing" selectivity ogive (one for each age), fitted to proportion at age estimated for the *Tangaroa* research trawl survey in Model Run 5.

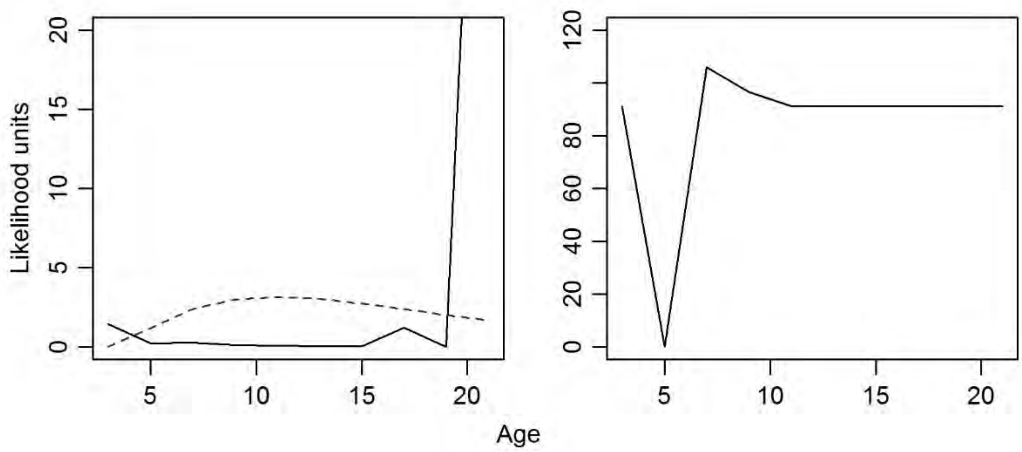


Figure 28: LIN 7WC, likelihood profiles for the model run assuming double normal ogive for immature fish and logistic for mature (Run 7). Left panel: solid line, A_{50} for mature logistic; broken line, A_{to95} for mature logistic. Right panel: a_1 for the immature double normal. Some parameter estimates reach bounds at age 17 in the left panel, and age 11 in the right panel (e.g., B_0 reaches 500 kt).

When maturity was added to the partition, the double normal and capped logistic ogives applied to the immature fish produced a similar outcome (Table 22). The double normal ogive for immature fish produced a low and almost flat selectivity, and was therefore similar in appearance to the capped logistic ogive; because the latter ogive was more consistent with this shape it was preferred. However, model runs and likelihood profiles for both models showed the parameter estimates to be again over-fitted and most likely confounded (Figure 29).

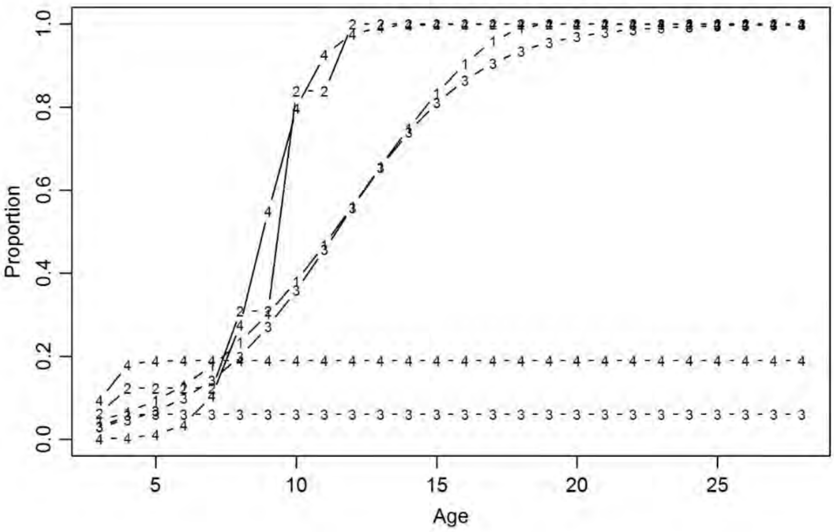


Figure 29: LIN 7WC estimated selectivity ogives from the Tangaroa research trawl survey catch-at-age. 1, logistic (Run 4); 2, "increasing" ogive; 3, immature capped logistic and mature logistic (Run 9); immature capped logistic and mature logistic with *M* fixed at 0.15 (Run 19; see Section 4.2.2.5).

One solution was to fix parameters, and check that this had negligible impact on the model outcome. In this case, the A_{50} and A_{to95} of the immature capped logistic ogive were fixed, leaving just the cap as an estimable parameter. The first peak in the catch-at-age observations was persistently at age four, therefore the A_{50} and A_{to95} parameters were fixed at ages 3 and 1. The ogive parameters were then better estimated (Figure 30), and the fit to the data was equally good (Figure 31; changes in estimated ogives for these runs shown in Figure 29), adequately capturing the bimodal appearance of the catch-at-age observations, and remained good when productivity assumptions were changed (Figure 31; see also Section 4.2.2.5). Model outcomes were also unchanged (compare Run 7 Table 22, and Run 9 Table 23).

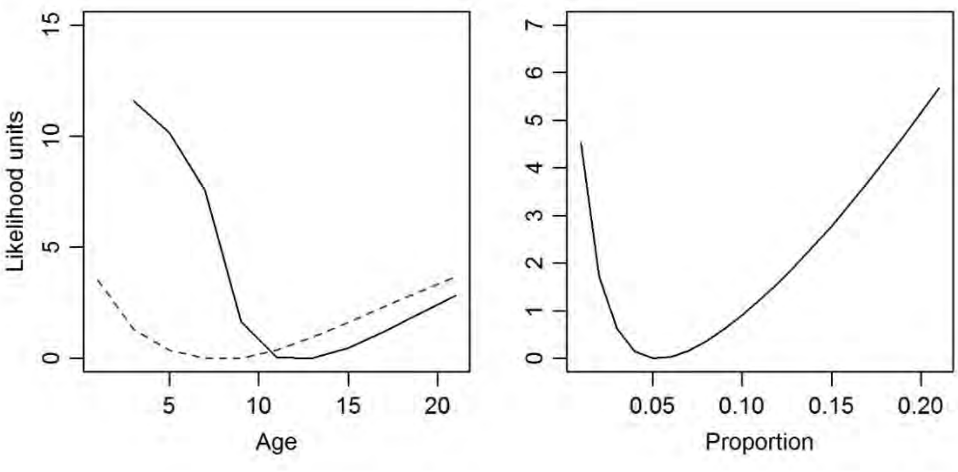


Figure 30: LIN 7WC, likelihood profiles for the selectivity parameter estimates for Model Run 9. Right panel: solid line, A_{50} for mature logistic; broken line, A_{to95} for mature logistic. Right panel: cap for immature capped logistic.

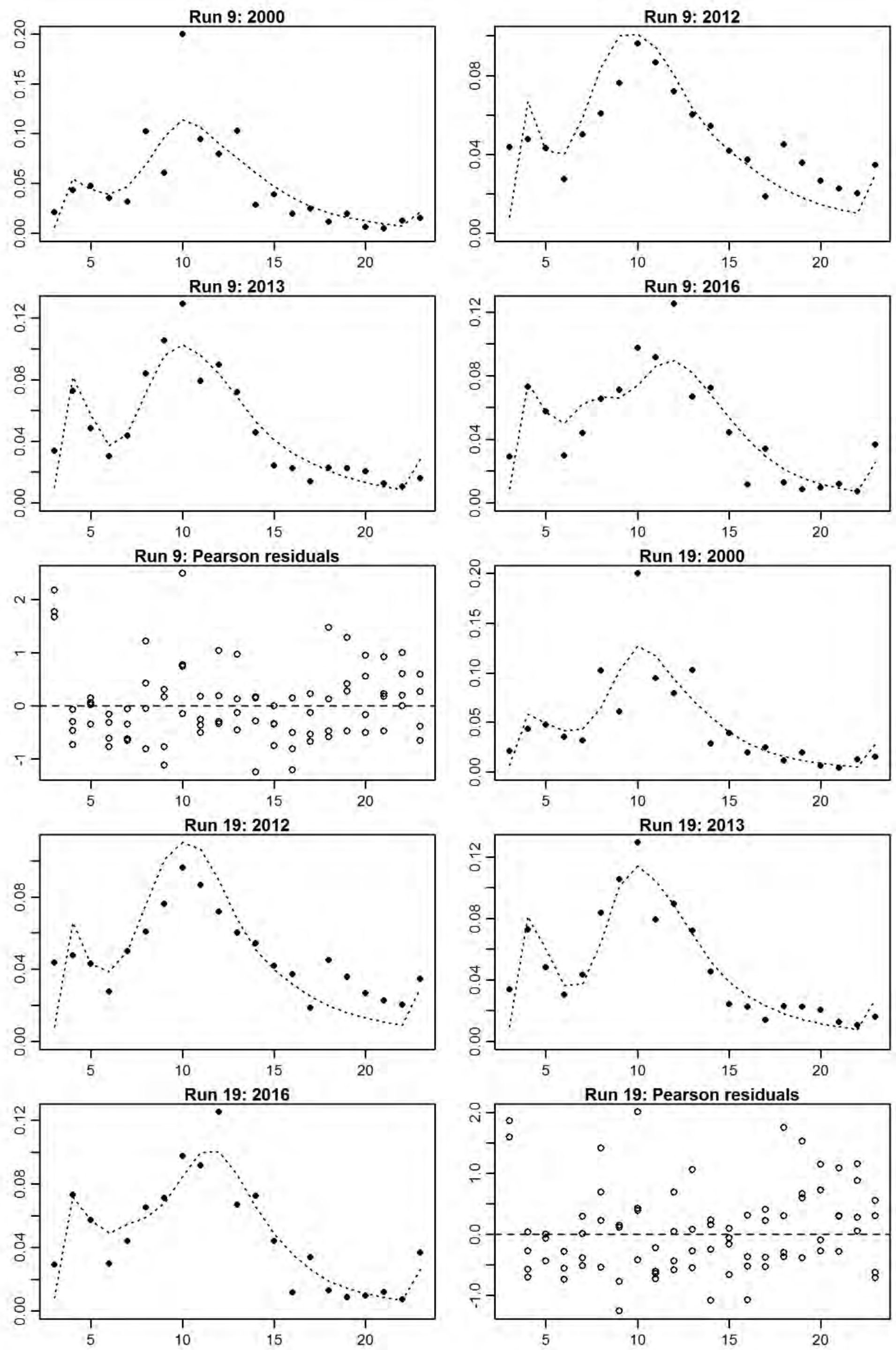


Figure 31: LIN 7WC model run fits (broken lines) to observed catch-at-age (points), followed by the Pearson residuals for all years combined, for Model Runs 9 and 19 (*M* = 0.15; see Section 4.2.2.5).

Model runs assuming that mature selectivity was equal to the maturity ogive gave a relatively poor fit to the observed catch-at-age (Figure 32), and suggested that maturity took place a year or two earlier than the increase in selectivity. All subsequent runs therefore assumed the fixed capped logistic (i.e., based upon Run 9; Table 23).

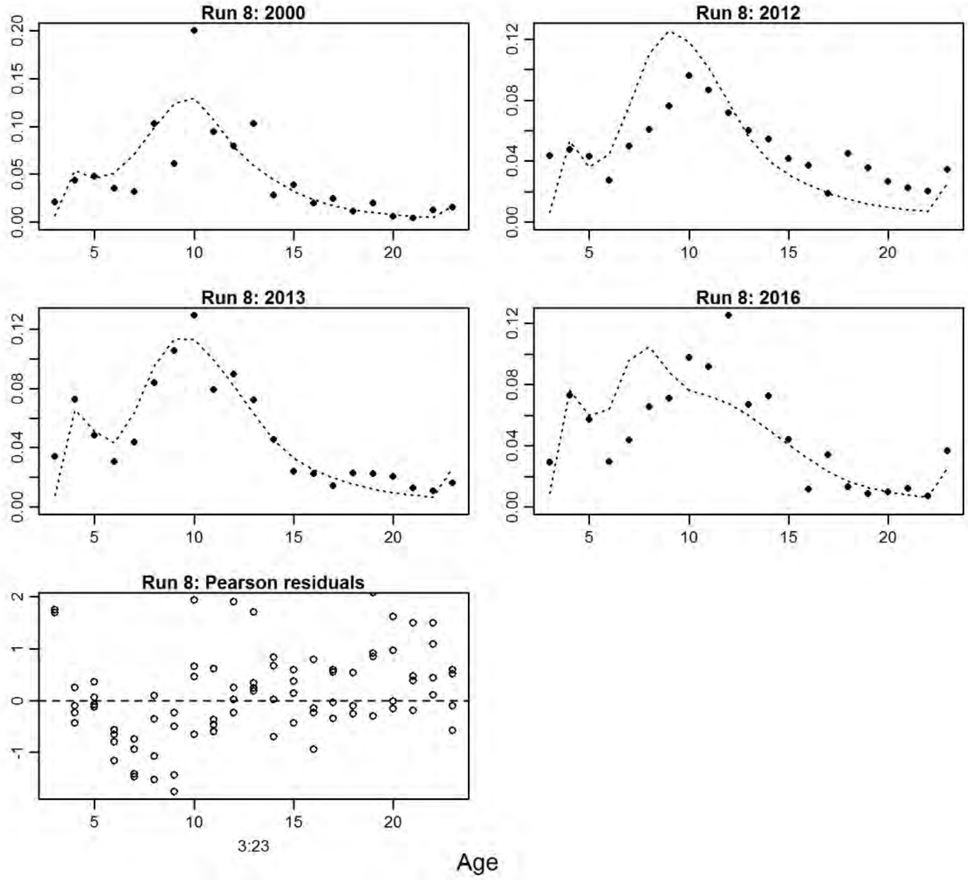


Figure 32: LIN 7WC model run fits (broken lines) to observed catch-at-age (points), followed by the Pearson residuals for all years combined, for Model Run 8.

Table 23: LIN 7WC, CASAL MPD parameter estimates and likelihood values, for alternative model runs. *, fixed parameter; TAN, research trawl; TRL, commercial trawl, LN, line; sel, selectivity parameters; c@a, catch at age; YCS, year class strength (recruitment).

		9. TANsel logistic & est. cap	10. lognormal CPUE	11. lognormal CPUE add. CV=0.3	12. CPUE combined, add. CV = 0.2
Parameters	B_0	98 512	72 057	68 144	165 804
	M	0.248	0.235	0.228	0.271
	TANselI	3*, 1*, 0.06	3*, 1*, 0.06	3*, 1*, 0.06	3*, 1*, 0.04
	TANselM	11.4, 7.2	11.8, 7.4	11.6, 7.2	13.5, 9.1
	TRLsel	13.3, 4.2, 150.0	13.2, 4.2, 148.2	13.4, 4.3, 148.4	13.0, 3.9, 148.7
	LNsel	12.1, 4.2	12.0, 4.1	12.0, 4.1	12.1, 4.1
	qTAN	0.041	0.069	0.072	0.029
Likelihood components	TAN	-5.05	-4.83	-4.96	-4.95
	TRL	11.13	-21.90	-22.44	71.26
	TANc@a	135.31	144.07	143.36	136.99
	TRLc@a	354.73	372.08	371.87	357.53
	LNc@a	47.64	43.41	43.36	47.99
	Prior qTAN	-3.05	-2.62	-2.56	-2.96
	Prior qTRL	-11.16	-10.68	-10.57	-11.80
	Prior B_0	11.50	11.19	11.12	12.02
	Prior M	1.45	0.98	0.62	4.04
	Prior YCS	-13.18	-12.77	-13.01	-11.36
	Penalty YCS	0.85	0.80	0.80	0.89
	Penalty catch	0	0	0	0
Quantities	$\%B_0$	81	67	65	93

4.2.2.3 Alternative CPUE indices

The *Tangaroa* biomass index, *Tangaroa* catch-at-age, and line fishery catch-at-age, all indicated a B_0 greater than 50–60 kt, and the *q* prior on the *Tangaroa* surveys and trawl CPUE biomass index both indicated a higher B_0, with the CPUE most influential (Figure 33). However, none of the observational data sets contained much information on the upper bound to B_0; the only information on the upper limit to B_0 came from the prior on *M*, and the trawl fishery catch-at-age, which both suggested a B_0 around 50–60 kt. The trawl fishery CPUE was found to be dominant on the model outcome (Figure 33). Some members of the DWFAWG were concerned about the veracity of the CPUE index, given its substantial influence, and therefore the lognormal CPUE index was tested as an alternative.

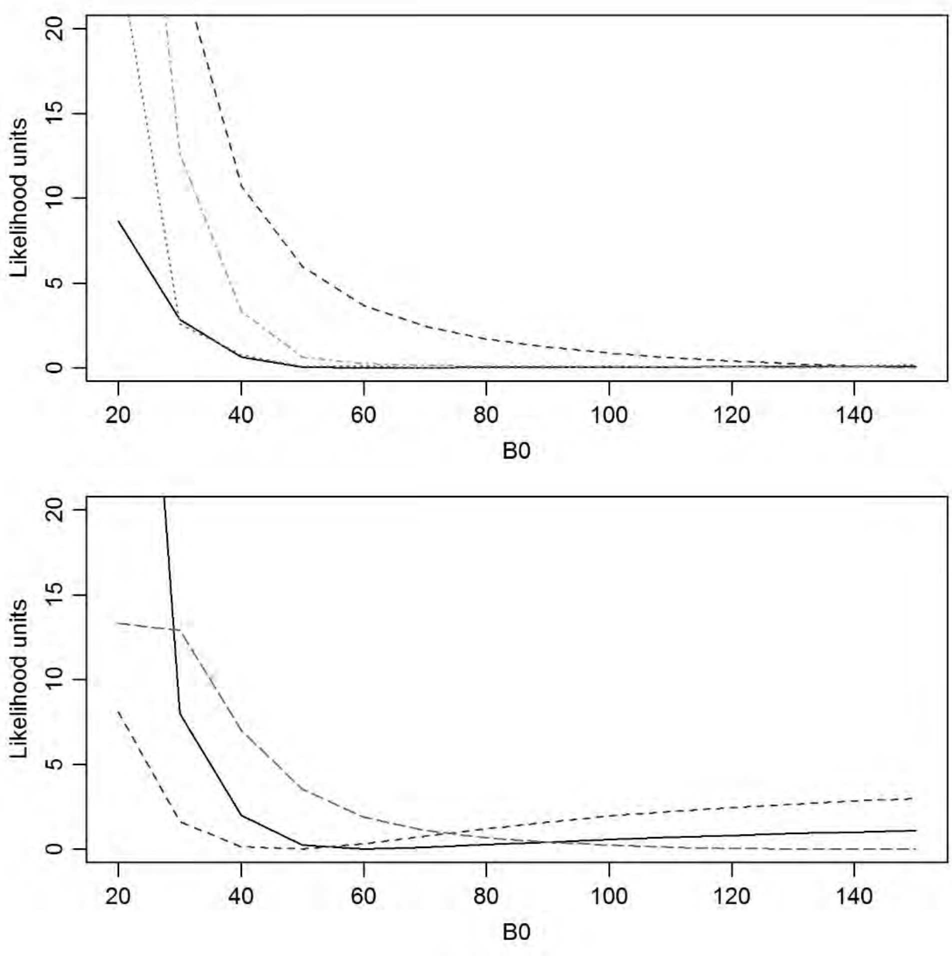


Figure 33: B_0 likelihood profiles for Run 9 (Table 23). Top panel, from left to right: research trawl survey biomass index, research trawl survey catch-at-age, longline catch-art-age, trawl fishery CPUE. Bottom panel from left to right: *M* prior, trawl fishery catch-at-age, research survey prior.

The model using the alternative lognormal CPUE index was reweighted following Francis (2011). The index fluctuated less than the combined index, and an additional process error of 0.2 was selected (Figure 34). However, this resulted in CVs that were less than the *Tangaroa* survey biomass index, which did not seem reasonable *a priori*, therefore alternative model runs added an arbitrary additional CV of 0.3. The fits of the two alternative indices were not materially different, and neither was particularly good (Run 9 versus Run 10; Figure 35). Likelihoods for the two model runs were not comparable due to model reweighting, but estimated selectivity parameters were very similar, even though model outcomes (B_0 and $\%B_0$) were quite different (runs 9 and 10; Table 23).

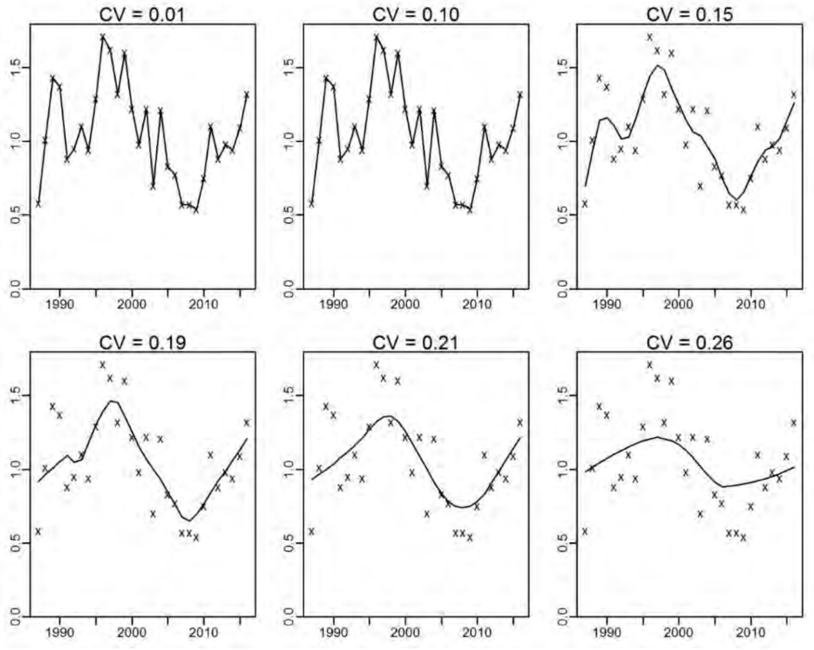


Figure 34: The fit of a data smoother (loess) to the ling trawl CPUE lognormal index using different degrees of data smotthing, labelled with the resultant CV of the residuals.

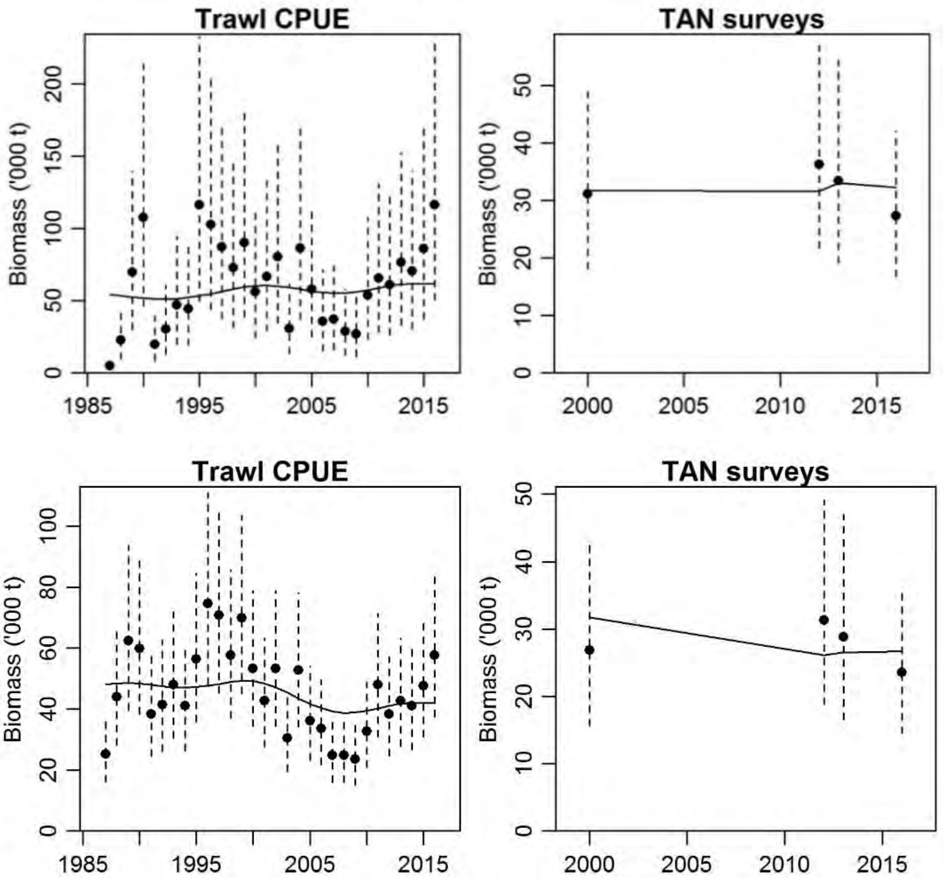


Figure 35: LIN 7WC fits (lines) to the observed trawl fishery CPUE (Trawl CPUE) and *Tangaroa* trawl surveys (TAN surveys). Vertical broken lines indicate 95% CI on observations. Top panels, model run using combined CPUE index (Run 9); bottom panels, model run using lognormal CPUE index (Run 10).

When the additional CV for the lognormal CPUE index was increased from 0.2 (Run 10) to 0.3 (Run 11) the CPUE index was downweighted, resulting in a small change in parameter estimates and decrease in stock size (Table 23).

When the additional error applied to the trawl fishery CPUE combined index was reduced (from 0.4 to 0.2) and the CPUE was upweighted, the biomass trend began to follow the CPUE trend (although still did not fit it; Figure 36), and the stock was estimated to be larger with an implausibly high *M* (Run 12; Table 23). When the trawl CPUE were dropped entirely, the fit to the research trawl survey biomass index was not materially changed (Figure 36, see Run 31).

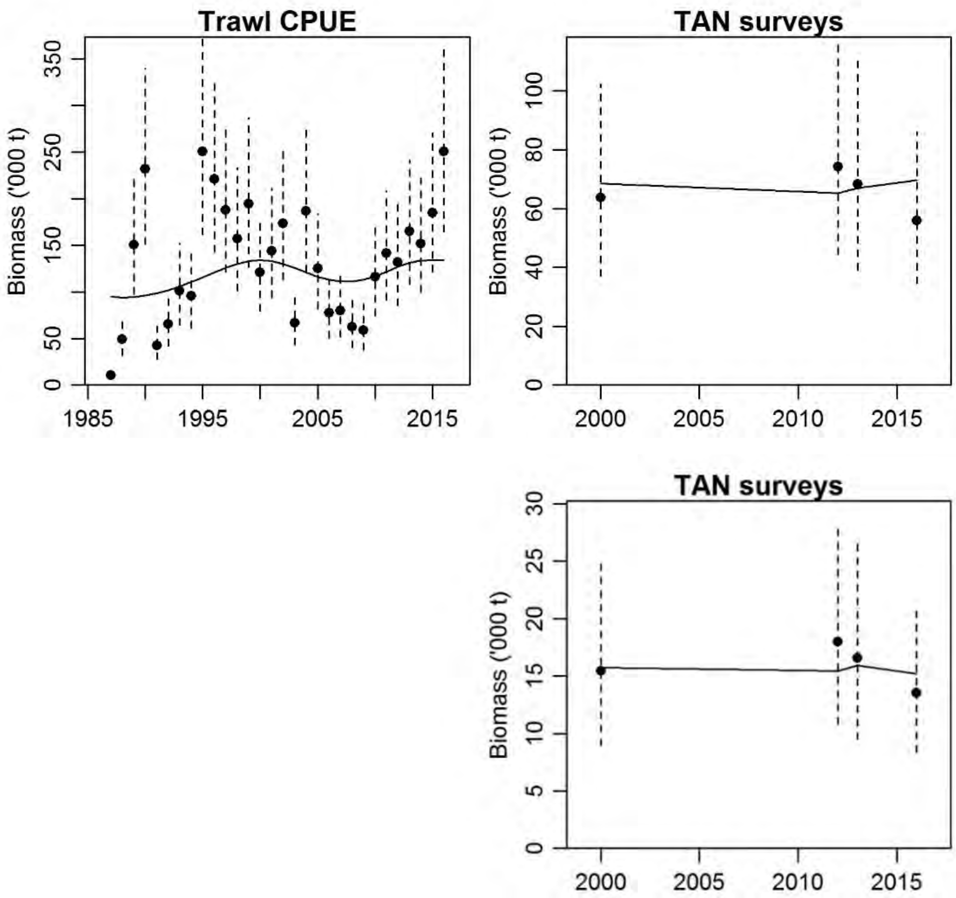


Figure 36: LIN 7WC fits (lines) to the observed trawl fishery CPUE (Trawl CPUE) and *Tangaroa* trawl surveys (TAN surveys). Vertical broken lines indicate 95% CI on observations. Top panels, model run using combined CPUE index with reduced additional CV of 0.1 (Run 11); Bottom panel, model run with trawl CPUE dropped (Run 31).

Although changing the CPUE index made some difference to model outcome (B_0 changed by 37% and %B_0 by 14%), the changes in model fits to the catch-at-age data were minor, and generally visually indistinguishable; in general, a similar fit despite changes in assumptions was found throughout this assessment (Figures 37–39). Poor fits to the catch-at-age for the longline fishery were seen in all model runs, but these data were *a priori* deemed unreliable (Section 3.5), therefore this lack of fit was not considered a concern. Changes to *M* and selectivity parameter estimates were also small (Table 23). Consequently, there was little evidence from the assessment model to prefer one CPUE index over another.

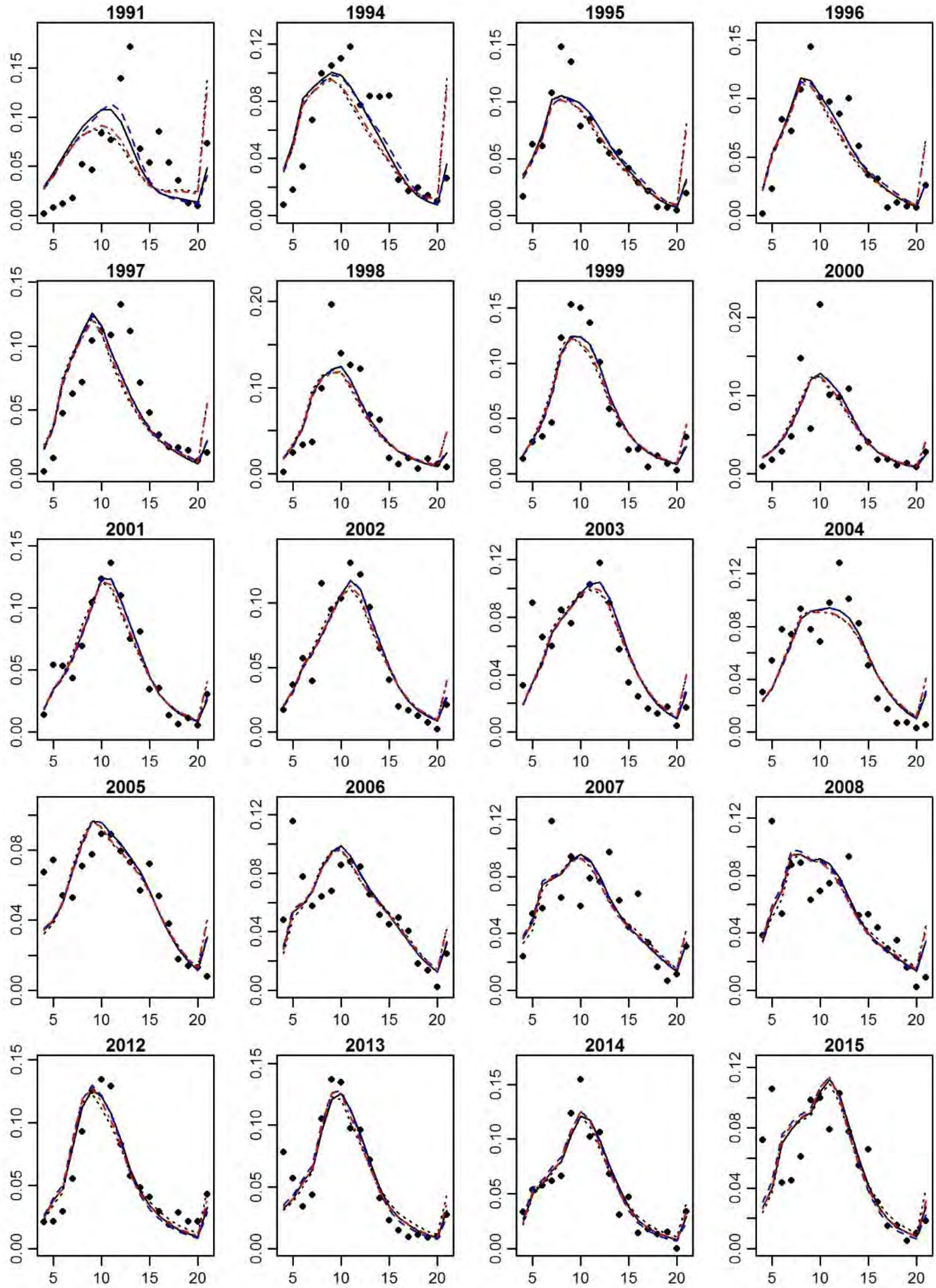


Figure 37: LIN 7WC fits (lines) to the observed trawl fishery catch-at-age (points). Solid black line, CPUE combined index; dashed blue line, CPUE lognormal index (these first two series are the ones close together in the top left panel); broken red line, CPUE lognormal index with *M*=0.15; dotted line, CPUE combined index with *M*=0.15.

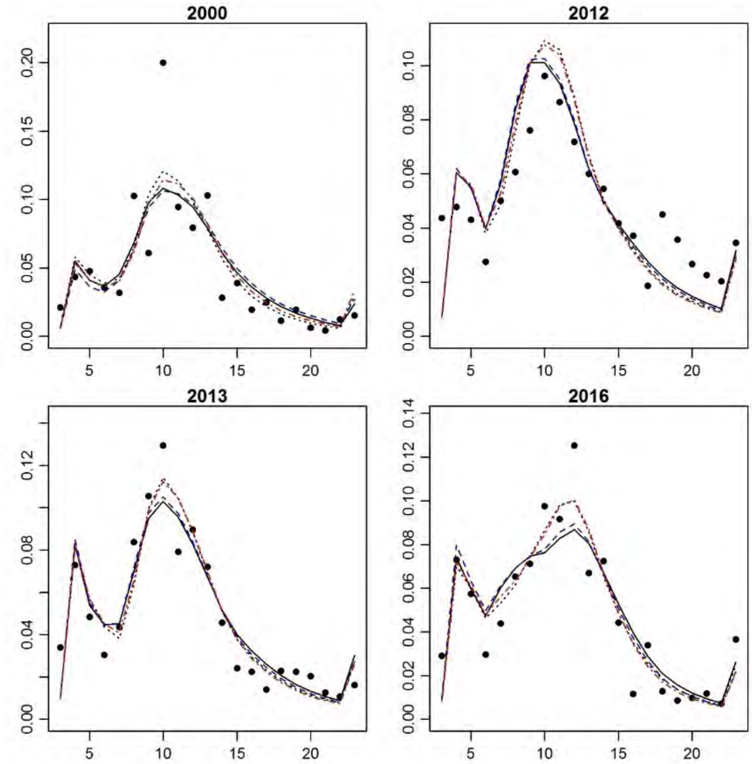


Figure 38: LIN 7WC fits (lines) to the observed *Tangaroa* survey catch-at-age (points). Solid black line, CPUE combined index; dashed blue line, CPUE lognormal index; broken red line, CPUE lognormal index with *M*=0.15; dotted line, CPUE combined index with *M*=0.15.

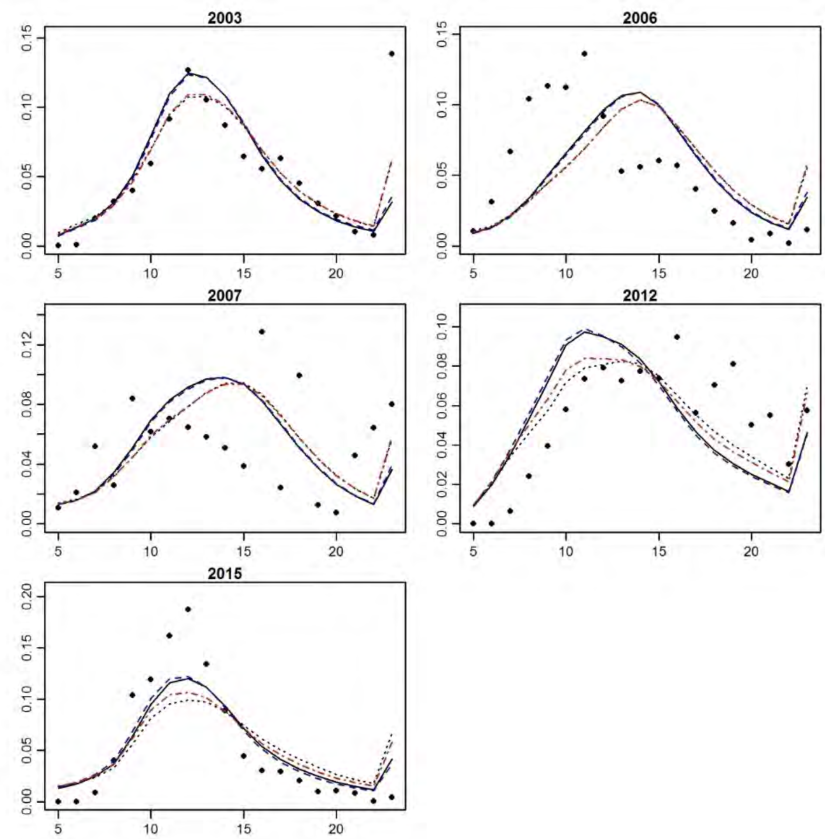


Figure 39: LIN 7WC fits (lines) to the observed longline fishery catch-at-age (points). Solid black line, CPUE combined index; dashed blue line, CPUE lognormal index; broken red line, CPUE lognormal index with *M*=0.15; dotted line, CPUE combined index with *M*=0.15.

4.2.2.4 *Adding the R.V.* Kaharoa *inshore trawl survey*

Additional biomass and catch composition data were available for ling from the *Kaharoa* west coast South Island inshore trawl survey (Stevenson & MacGibbon 2015). These had not been used in previous ling assessments (Ministry for Primary Industries 2017). This was because (a) the survey largely fished inshore at depths too shallow for ling, (b) the sizes of ling caught by the survey were relatively small and estimated to be selected for only a few years, therefore any biomass information contained in the data was relatively sparse, and (c) survey catches of ling were often small, and therefore subject to bias. Nevertheless, the DWFAWG requested runs in 2017 to determine if the survey data might contain some information on biomass or recruitment that would improve the assessment. The initial EFS for the *Kahaora* catch-at-length were set as the number of fish observed. The EFS and CVs for data in previous model runs were left unchanged, and the *Kaharoa* catch-at-length EFS reweighted following Francis (2011) (see Table 20). The *Kaharoa* catch-at-length were fitted assuming a double normal selectivity ogive. The trawl survey biomass index was given an additional CV of 0.2 (the same as the *Tangaroa* index).

Adding the *Kaharoa* data resulted in a B_0 estimate about 30 kt higher, and $\%B_0$ about 8% higher (compare Run 9,Table 23, with Run 13 Table 24). When lower productivity was assumed, the B_0 was reduced and the difference between model runs with or without the *Kaharoa* data accordingly reduced (compare Run 15 Table 24, with Run 20 Table 26). The fit to the *Kaharoa* biomass index was not particularly good, regardless of which CPUE index was included (Runs 13 and 14; Table 24; Figures 39 and 40). Despite the introduction of potential data on young ling, the estimated year class strength changed little (Figure 41). Likelihood profiles showed that the *Kaharoa* data contained little additonal information about stock biomass (Figure 42); the fit to the catch-at-length data was virtually unchanged in model sensitivity runs despite other parameter estimates and outcomes being quite different (Figure 43).

Table 24: LIN 7WC, CASAL MPD parameter estimates and likelihood values, for alternative model runs. *, fixed parameter; TAN, research trawl; TRL, commercial trawl, LN, line; sel, selectivity parameters; c@a, catch at age; YCS, year class strength (recruitment).

		13: Kaharoa data included	14. Kaharoa data included: lognormal CPUE index	15: Kaharoa data included, M=0.15
Parameters	B_0	128 938	87 071	62 290
	M	0.256	0.249	0.15*
	TANselI	3*, 1*, 0.05	3*, 1*, 0.05	3*, 1*, 0.18
	TANselM	12.1, 7.9	12.1, 7.5	8.9, 2.7
	TRLsel	13.4, 4.1, 146.6	13.3, 4.1, 147.3	8.2, 4.5
	LNsel	12.0, 4.1	12.1, 4.1	12.7, 5.2
	KAHsel	0.1, 2.0, 8.7	0.1, 2.0, 8.3	0.1, 2.0, 6.6
	qTAN	0.033	0.056	0.069
	qKAH	0.0033	0.0056	0.098
Likelihood components	TAN	-4.97	-4.81	-5.15
	TRL	10.37	-22.38	19.63
	KAH	-5.86	-6.19	-5.06
	TANc@a	136.40	145.06	143.49
	TRLc@a	354.78	372.42	383.01
	LNc@a	47.72	43.46	43.38
	KAHlgth	111.22	111.90	112.97
	Prior qTAN	-3.03	-2.89	-2.63
	Prior qTRL	-11.45	-10.91	-10.40
	Prior qKAH	-5.73	-5.21	-3.70
	Prior B_0	11.77	11.37	11.04
	Prior M	2.54	1.95	–
	Prior YCS	-12.60	-12.23	-12.00
	Penalty YCS	0.85	0.79	0.86
	Penalty catch	0	0	0
Quantities	$\%B_0$	89	75	47

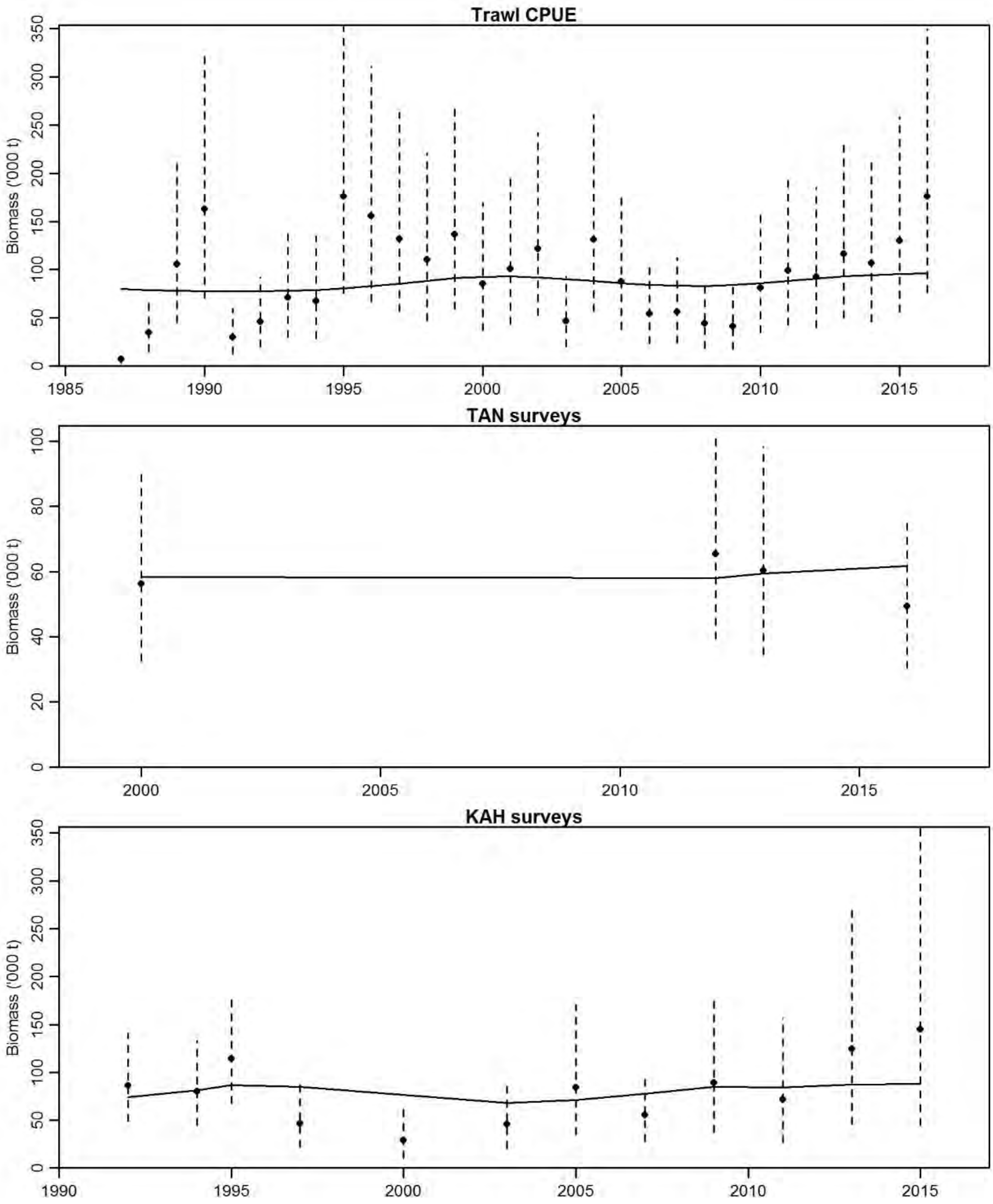


Figure 39: LIN 7WC, fits (lines) of model Run 13 to observed biomass indices (points, with vertical broken lines indicating 95% CI); this model run uses the CPUE combined index.

Although the *Kaharoa* data were not contributing useful information to the estimation of stock biomass and status, the data did confirm that younger ling were inshore of older ling, and that negligible amounts of ling older than age nine were caught in inshore waters. Some years of *Kaharoa* catch-at-length also suggested a bimodal distribution, potentially analgous to that seen in the *Tangaroa* survey, and were not fitted well using the double normal selectivity ogive (Figure 43). Because the *Kaharoa* survey added little biomass or year class strength information these data were not included in final model runs (as in previous assessments).

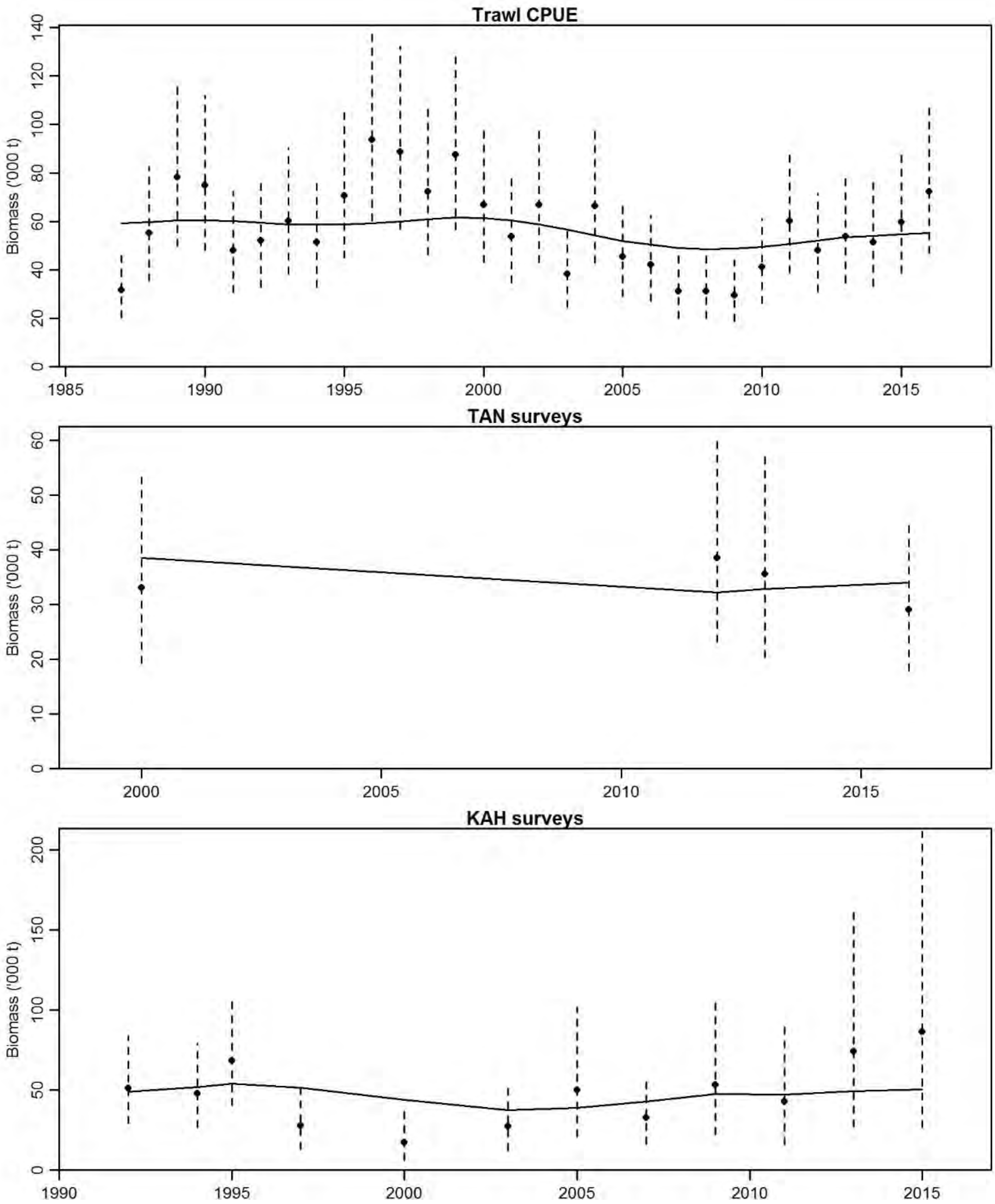


Figure 40: LIN 7WC, fits (lines) of a model Run 14 but using the CPUE lognormal index, to the observed biomass indices (points, with vertical broken lines indicating 95% CI) ; this model run uses the CPUE lognormal index.

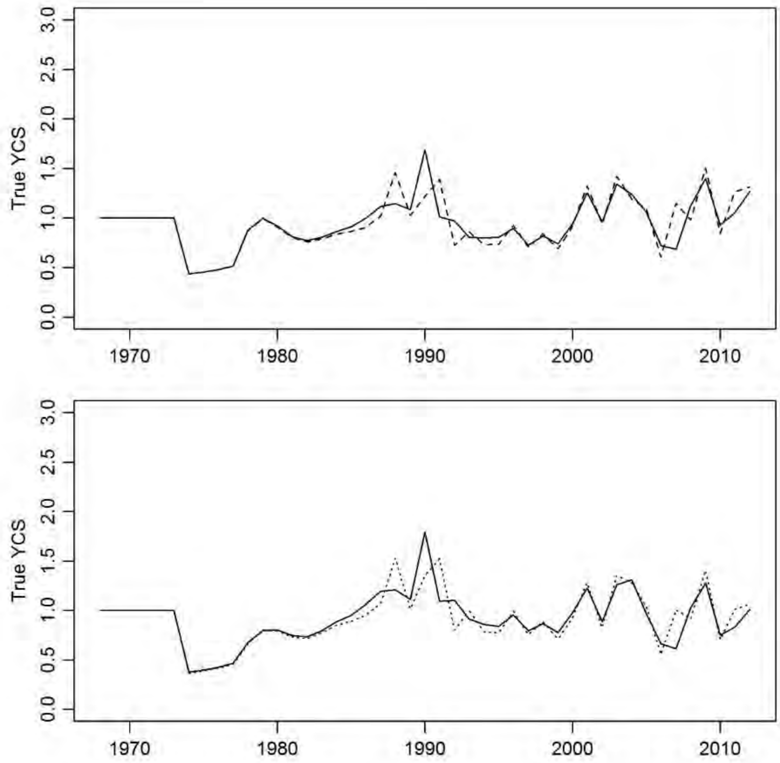


Figure 41: LIN 7WC, estimated year class strengths. Top panel; solid line, model Run 9 (without *Kaharoa* data), broken line, model Run 13 (with *Kaharoa* data). Bottom panel; solid line, model Run 19 (M=0.15, without *Kaharoa* data), dotted line model Run 15 (M=0.15, with *Kaharoa* data).

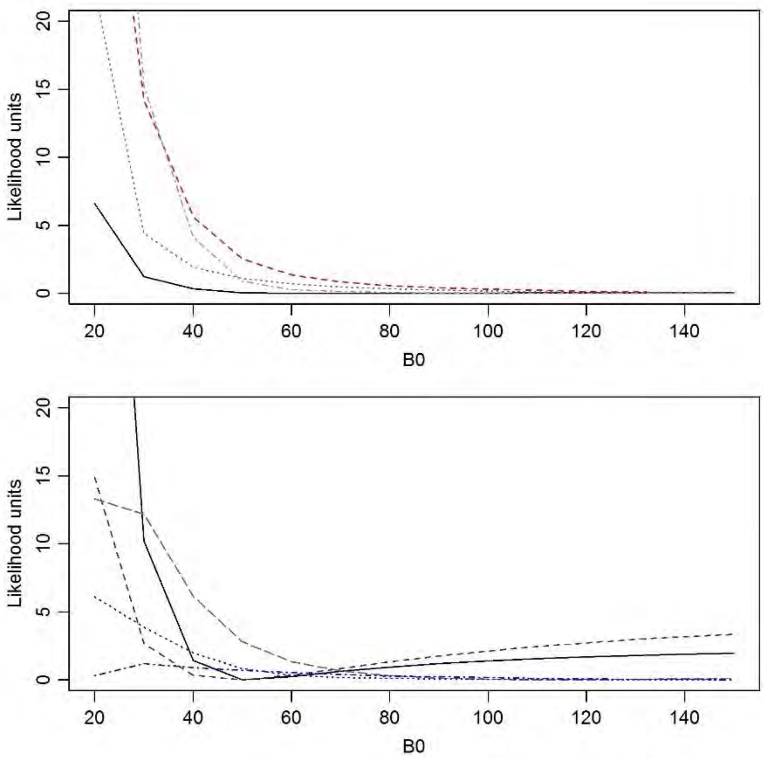


Figure 42: LIN 7WC, likelihood profiles for B_0 and model Run 13. Top panel; from right to left, *Tangaroa* biomass index (solid line), *Tangaroa* catch-at-age (dotted grey line), longline catch-at-age (dashed grey line), trawl CPUE (red dashed line). Bottom panel, from bottom left to upper right, *Kaharoa* catch-at-length (blue dot-dash line; at *Tangaroa q* prior bound at B_0 of 20kt), *M* prior (dashed grey line), *Kaharoa* biomass index (blue dotted line), trawl fishery catch-at-age (solid line), *Tangaroa q* prior (dashed grey line).

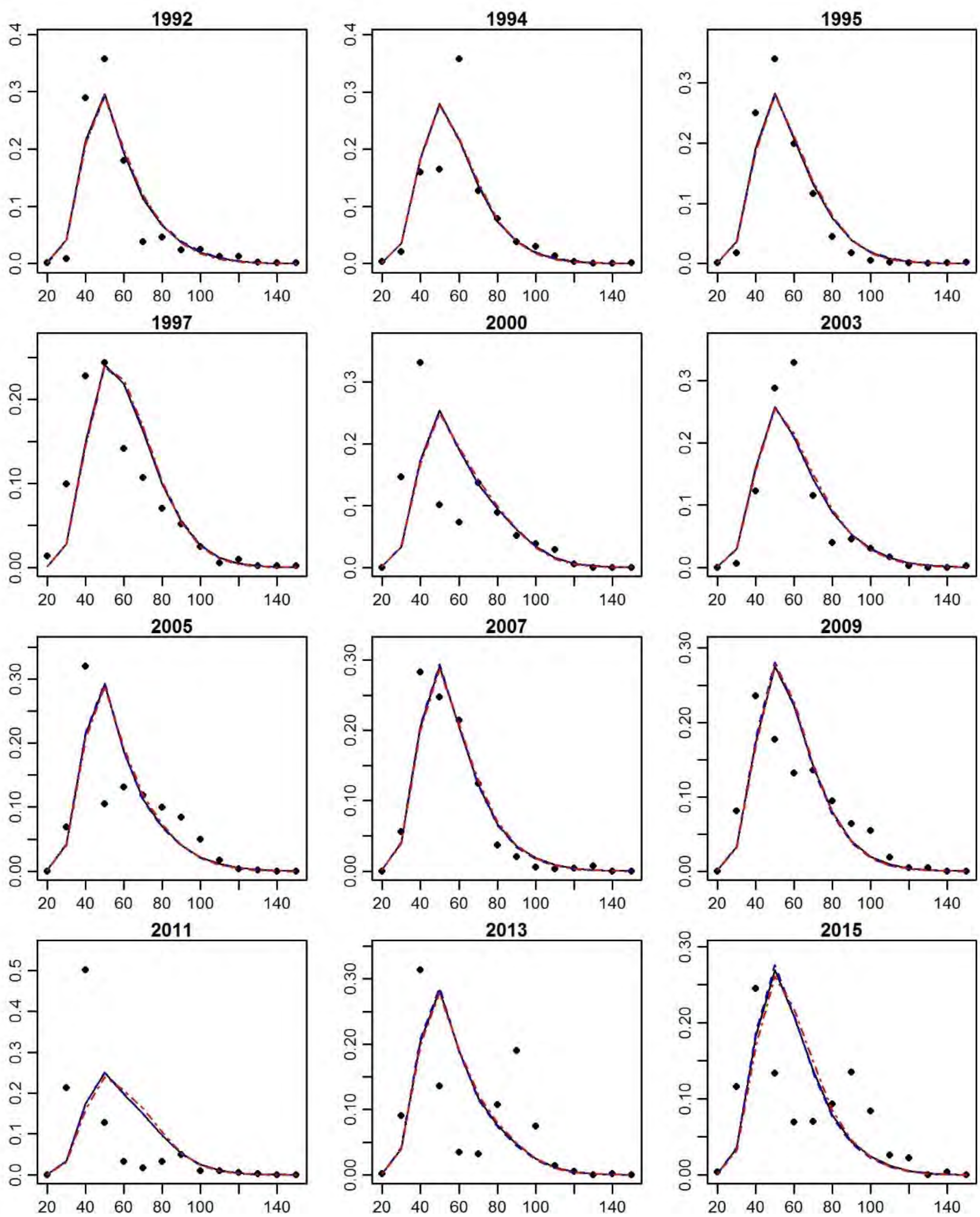


Figure 43: LIN 7WC, fits (lines) to the *Kaharoa* survey catch-at-length, by year. The fits from four model runs are plotted, but they are all overlapping. Model runs use the CPUE combined or lognormal index, with *M* estimated or fixed to 0.15.

4.2.2.5 Productivity assumptions

Edwards (2017) suggested that male and female ling might experience different values of *M*. To see if this assumption might improve the 2017 assessment, a model with sex added to the partition was fitted to unsexed observations, to see if adding separate sex parameters improved fits to combined sex data. When separate sex growth was assumed there was no material difference in model fit or outcome, and when assuming separate sex growth and *M* (females = 0.15; males = 0.30) the fits to observed data got worse (Table 25). A separate sex model was therefore abandoned in favour of a single (combined) sex model. This agreed with the findings of Dunn et al. (2013) and recommendations of Horn (2015).

Table 25: LIN 7WC, CASAL MPD parameter estimates and likelihood values, for alternative model runs. *, fixed parameter; TAN, research trawl; TRL, commercial trawl, LN, line; sel, selectivity parameters; c@a, catch at age; YCS, year class strength (recruitment).

		16. Separate sex growth	17. Separate sex growth & *M* (F = 0.15, M = 0.3)
Parameters	B_0	94 916	61 229
	M	0.243	0.15*, 0.3*
	TANselI	3*, 1*, 0.06	3*, 1*, 0.13
	TANselM	11.4, 7.8	8.8, 3.3
	TRLsel	13.3, 4.2, 148.4	12.7, 4.1, 148.0
	LNsel	12.1, 4.2	12.2, 4.6
	qTAN	0.042	0.063
Likelihood	TAN	-5.04	-5.17
components	TRL	11.04	17.18
	TANc@a	135.46	135.01
	TRLc@a	354.70	360.09
	LNc@a	47.65	47.41
	Prior qTAN	-3.04	-2.75
	Prior qTRL	-11.16	-10.51
	Prior B_0	11.46	11.02
	Prior M	1.47	–
	Prior YCS	-13.15	-12.91
	Penalty YCS	0.85	0.87
	Penalty catch	0	0
Quantities	%B_0	81	51

Likelihood profiles of *M* from Run 9 revealed that the trawl CPUE (combined index) and trawl catch-at-age favoured relatively high *M*, with the upper range of *M* only restricted by the *M* prior, and a very small influence from the *Tangaroa* catch-at-age (Figure 44). A fixed *M* value of 0.15 (based upon Edwards 2017) resulted in a substantial change in model outcome, with B_0 reduced from 98 512 t (Run 9, Table 23) to 61 424 t, and stock status almost halved, having reduced from 81% to 46% B_0 (Table 25). A fixed *M* of 0.18, the DWFAWG accepted value (Ministry for Primary Industries, 2017), produced a similar result but a slightly less depleted stock (Run 22 Table 27). Assuming an *M* of 0.15 degraded the model fits to the trawl CPUE, and the trawl catch-at-age, by a total of around 16 likelihood units (Tables 23 and 25). Although changing the CPUE index from combined to lognormal made a difference to model outcome when *M* was estimated, it made little difference when assuming M=0.15 (Table 26; Runs 18 and 20), but changing the weight on the CPUE index remained influential (Table 26; Runs 20 and 21).

No sensitivity runs were completed assuming the Beverton-Holt recruitment model and varying steepness (h), because the stock was not depleted and this would therefore not be expected to have any impact. An assumption of a Ricker rather than Beverton-Holt recruitment model could be supported by diet information from Chatham Rise that indicated that ling were often cannibalistic (M. Dunn, unpublished data). Assuming Ricker with h=0.84 technically produced the best overall fit (likelihood was 1.78 lower than the run assuming Beverton-Holt; Run 9), although the visual difference in fits between these two models was hard to detect (Table 27). The model run assuming Ricker allowed compensation in recruitment with initial stock depletion (Figure 45), and as a result estimated a higher stock status. The DWFAWG did not select a model assuming a Ricker curve as a final assessment model run, because the outcome was not considered materially different from the model runs assuming Beverton-Holt (i.e., in that both options estimated a stock well above management limit reference points).

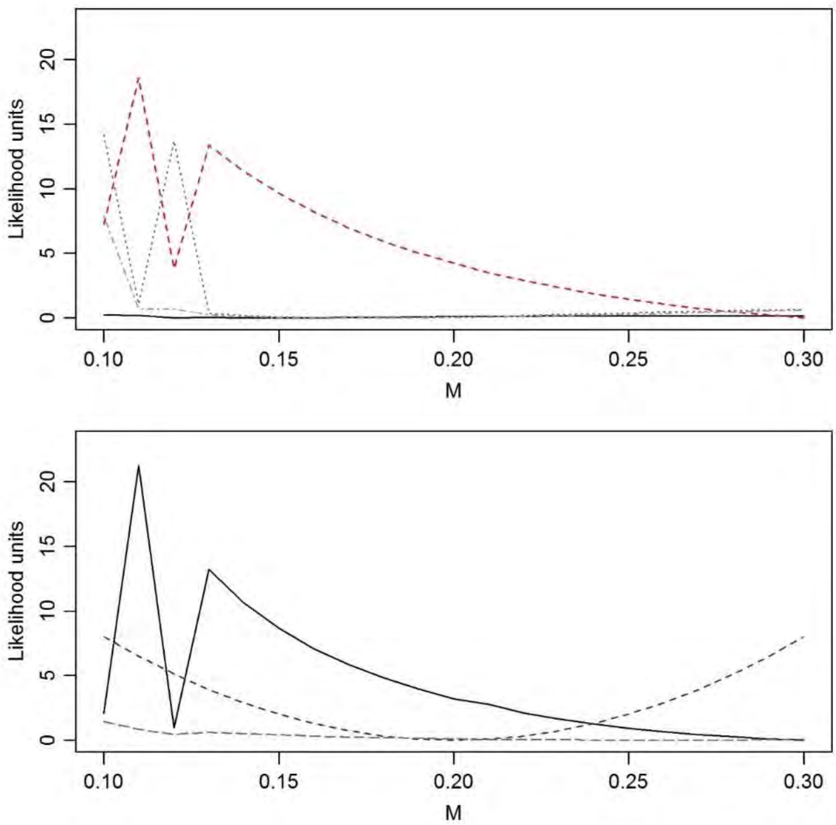


Figure 44: LIN 7WC Run 9 likelihood profile for *M*. Top panel: from top right to bottom left; red dashed line, trawl CPUE; dotted grey line, *Tangaroa* catch-at-age; dot-dash line, longline catch-at-age; solid line, *Tangaroa* biomass index. Bottom panel: solid line, trawl fishery catch-at-age; dashed grey line, *M* prior; long dash grey line, *Tangaroa q* prior.

Table 26: LIN 7WC, CASAL MPD parameter estimates and likelihood values, for alternative model runs. *, fixed parameter; TAN, research trawl; TRL, commercial trawl, LN, line; sel, selectivity parameters; c@a, catch at age; YCS, year class strength (recruitment).

		18. *M*=0.15	19. *M*=0.15, TRLsel logistic	20. *M*=0.15, lognormal CPUE	21. *M*=0.15, lognormal CPUE, add. CV = 0.3
Parameters	B_0	61 424	60 846	61 285	56 153
	M	0.15*	0.15*	0.15*	0.15*
	TANselI	3*, 1*, 0.19	3*, 1*, 0.19	3*, 1*, 0.10	3*, 1*, 0.14
	TANselM	8.8, 2.4	8.8, 2.5	13.7, 200	9.5, 4.3
	TRLsel	12.4, 4.2, 148.5	8.2, 4.5	7.9, 4.4	8.4, 4.7
	LNsel	12.4, 5.1	12.4, 5.0	13.0, 5.6	12.3, 4.7
	qTAN	0.068	0.070	0.110	0.095
Likelihood	TAN	-5.20	-5.21	-5.13	-5.03
components	TRL	19.05	19.61	-16.01	-19.42
	TANc@a	135.07	135.17	153.52	143.42
	TRLc@a	362.10	363.32	384.20	379.49
	LNc@a	47.52	47.51	43.62	43.14
	Prior qTAN	-2.65	-2.62	-1.56	-2.03
	Prior qTRL	-10.43	-10.39	-10.35	-10.03
	Prior B_0	11.03	11.02	11.02	10.94
	Prior M	–	–	–	–
	Prior YCS	-12.57	-12.53	-12.81	-12.81
	Penalty YCS	0.87	0.87	0.85	0.85
	Penalty catch	0	0	0	0
Quantities	$\%B_0$	46	46	44	39

Table 27: LIN 7WC, CASAL MPD parameter estimates and likelihood values, for alternative model runs. *, fixed parameter; TAN, research trawl; TRL, commercial trawl, LN, line; sel, selectivity parameters; c@a, catch at age; YCS, year class strength (recruitment).

		22. *M*=0.18, lognormal CPUE	23. Ricker *h* = 0.84	24. Ricker *h* = 0.75
Parameters	B_0	56 853	72 018	76 251
	M	0.18*	0.230	0.233
	TANselI	3*, 1*, 0.10	3*, 1*, 0.06	3*, 1*, 0.06
	TANselM	10.2, 5.7	11.4, 7.2	11.4, 7.2
	TRLsel	13.1, 4.4, 148.3	13.4, 4.2, 148.9	13.4, 4.2, 148.9
	LNsel	12.0, 4.4	12.0, 4.2	12.0, 4.2
	qTAN	0.088	0.052	0.049
Likelihood	TAN	-5.07	-5.03	-5.03
components	TRL	-19.17	10.11	10.27
	TANc@a	135.71	135.30	135.30
	TRLc@a	355.59	354.63	354.63
	LNc@a	47.43	47.67	47.66
	Prior qTAN	-2.20	-2.95	-2.98
	Prior qTRL	-10.20	-10.90	-10.95
	Prior B_0	10.85	11.18	11.24
	Prior M	–	0.73	0.86
	Prior YCS	-13.31	-13.20	-13.21
	Penalty YCS	0.83	0.85	0.85
	Penalty catch	0	0	0
Quantities	$\%B_0$	49	89	87

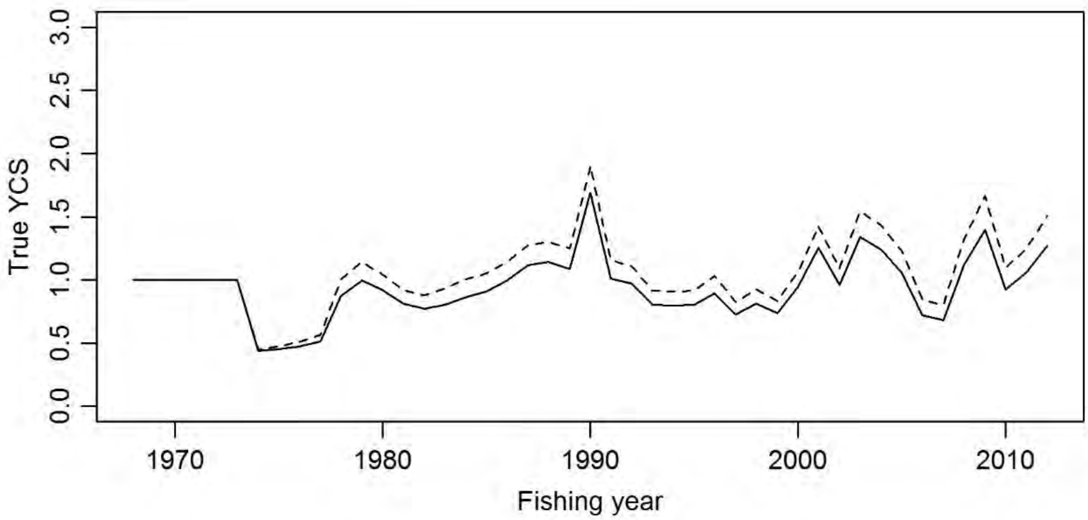


Figure 45: LIN 7WC, estimated year class strengths (YCS) for model runs assuming a Beverton-Holt stock-recruitment model (solid line; Run 9) and Ricker stock-recruitment model (broken line; Run 22).

The influence of the assumed prior on recruitments was investigated by changing the assumed standard deviation of the prior (σ_R), and by using an uniform prior (Table 28). The differences in model parameters and outcome between different σ_R assumptions were negligible, with the greatest changes in likelihood occurring for the trawl CPUE (Table 28). The higher σ_R gave a very slightly better fit (by 0.44 likelihood units across all observed data), and allowed greater variability in YCS, but this was only noticeable at the start of the time series (Figure 46). When the uniform prior was assumed, YCS oscillated around the previously estimated trend, and suggested that the 1979 year class might be underestimated.

Table 28: LIN 7WC, CASAL MPD parameter estimates and likelihood values, for alternative model runs. *, fixed parameter; TAN, research trawl; TRL, commercial trawl, LN, line; sel, selectivity parameters; c@a, catch at age; YCS, year class strength (recruitment).

		24. CPUE lognormal, YCS σ_R=0.7	25. CPUE lognormal, YCS σ_R=0.5	26. CPUE lognormal, YCS σ_R=0.9	27. CPUE lognormal, YCS uniform
Parameters	B_0	72 057	71 489	72 522	74 218
	M	0.235	0.236	0.234	0.236
	TANselI	3*, 1*, 0.06	3*, 1*, 0.06	3*, 1*, 0.05	3*, 1*, 0.05
	TANselM	11.8, 7.4	11.3, 7.3	11.9, 7.4	12.0, 7.5
	TRLsel	13.2, 4.2, 148.2	13.3, 4.2, 148.2	13.2, 4.2, 148.1	13.2, 4.1, 147.7
	LNsel	12.0, 4.1	12.0, 4.1	12.0, 4.1	12.1, 4.2
	qTAN	0.069	0.067	0.070	0.069
Likelihood	TAN	-4.83	-4.87	-4.82	-4.76
components	TRL	-21.90	-21.29	-22.26	-22.81
	TANc@a	144.07	144.31	143.95	143.22
	TRLc@a	372.08	372.26	372.09	371.72
	LNc@a	43.41	43.37	43.43	43.49
	Prior qTAN	-2.62	-1.67	-2.60	-2.62
	Prior qTRL	-10.68	-10.70	-10.67	-10.71
	Prior B_0	11.19	11.18	11.19	11.21
	Prior M	0.98	1.02	0.93	1.06
	Prior YCS	-12.77	-5.40	-20.55	–
	Penalty YCS	0.80	0.32	1.41	2×10^{-6}
	Penalty catch	0	0	0	0
Quantities	$\%B_0$	67	68	66	67

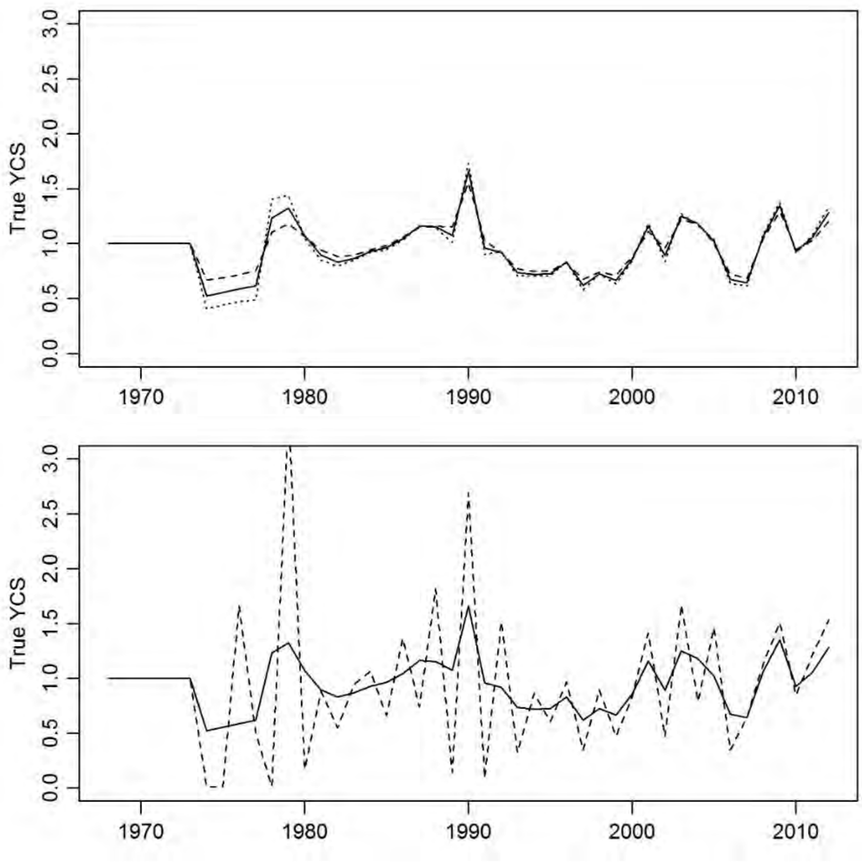


Figure 46: LIN 7WC estimated year class strengths (YCS) assuming different assumed priors for YCS: Top panel; solid line, σ_R=0.7; dashed line, σ_R=0.5; dotted line, σ_R=0.9. Bottom panel: solid line, σ_R=0.7; dashed line, uniform prior.

The year class strengths estimated from the model run assuming uniform priors were approximately lognormal (Figure 47). In subsequent runs, the initial assumption of a lognormal prior with σ_R of 0.7 was maintained.

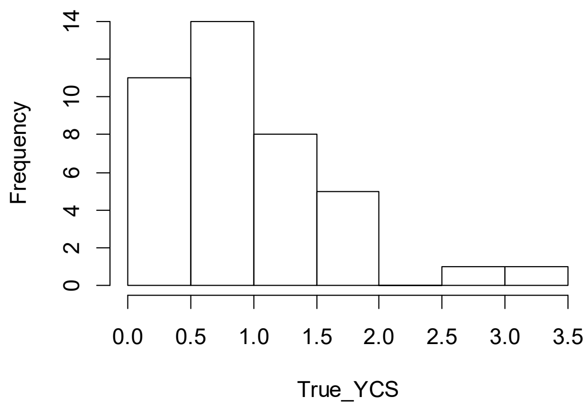


Figure 47: LIN 7WC frequency of YCS estimated from the model run with a uniform prior on YCS (model Run 27).

4.2.2.5 Drop-one runs and data weighting sensitivities

For the purposes of these sensitivity runs, the "base" model is that using the lognormal CPUE index (Run 10, reproduced for comparisons here in Table 29). The prior on the research trawl survey was found to be influential (Table 29). The prior was discussed by the DWFAWG, which concluded that it seemed reasonable, therefore there was no consensus to modify or reconsider this prior.

Table 29: LIN 7WC, CASAL MPD parameter estimates and likelihood values, for alternative model runs. *, fixed parameter; TAN, research trawl; TRL, commercial trawl, LN, line; sel, selectivity parameters; c@a, catch at age; YCS, year class strength (recruitment).

		10. CPUE lognormal, mean of qTan prior = 0.07	28. Mean of qTan prior = 0.02	29. Mean of qTan prior = 0.16	30. Drop TAN biomass index
Parameters	B_0	72 057	119 066	63 035	60 693
	M	0.235	0.250	0.231	0.230
	TANselI	3*, 1*, 0.06	3*, 1*, 0.07	3*, 1*, 0.04	3*, 1*, 0.04
	TANselM	11.8, 7.4	10.3, 5.2	13.5, 9.0	14.3, 9.5
	TRLsel	13.2, 4.2, 148.2	12.8, 4.0, 147.6	13.5, 4.3, 148.3	13.6, 4.3, 145.6
	LNsel	12.0, 4.1	11.6, 3.9	12.1, 4.1	12.2, 4.2
	qTAN	0.069	0.028	0.108	–
Likelihood components	TAN	-4.83	-4.75	-4.89	–
	TRL	-21.90	-22.20	-21.74	-21.94
	TANc@a	144.07	143.33	144.39	144.56
	TRLc@a	372.08	374.01	371.28	371.13
	LNc@a	43.41	43.26	43.55	43.61
	Prior qTAN	-2.62	-3.21	-2.17	–
	Prior qTRL	-10.68	-11.35	-10.47	-10.41
	Prior B_0	11.19	11.69	11.05	11.01
	Prior M	0.98	2.01	0.75	0.74
	Prior YCS	-12.77	-12.61	-12.82	-12.79
	Penalty YCS	0.80	0.79	0.81	0.81
	Penalty catch	0	0	0	0
Quantities	$\%B_0$	67	77	63	62

Moving the mean of the *Tangaroa q* prior to the lower 90% percentile of the original prior reduced stock size and status a little, but increasing the mean of the prior to the 90% percentile increased stock size and status substantially (Table 29). Whilst the model had other information that constrained the lower estimates of B_0, there was less information to constrain the upper limit. When the *Tangaroa* biomass index and prior were dropped entirely, the changes to model fits other data were negligible, although the B_0 and stock status dropped a little (Table 29).

The influence of up-weighting the trawl CPUE was shown in Run 12 (Table 23). When the CPUE index was dropped, the changes in fits to other data were again negligible, and the outcome was similar to dropping the *Tangaroa* biomass index, although the *M* was lower and close to the centre of the prior (Run 31; Table 30).

Table 30: LIN 7WC, CASAL MPD parameter estimates and likelihood values, for alternative model runs. *, fixed parameter; TAN, research trawl; TRL, commercial trawl, LN, line; sel, selectivity parameters; c@a, catch at age; YCS, year class strength (recruitment).

		31. Drop CPUE index	32. Drop longline catch@age	33. Halve EFS trawl catch@age	34. Double EFS trawl catch@age
Parameters	B_0	63 503	71 000	81 389	67 131
	M	0.219	0.236	0.229	0.239
	TANselI	3*, 1*, 0.06	3*, 1*, 0.05	3*, 1*, 0.08	3*, 1*, 0.04
	TANselM	11.7, 7.3	12.1, 7.6	10.3, 5.2	13.1, 8.5
	TRLsel	13.8, 4.4, 149.3	13.3, 4.2, 148.2	12.7, 4.0, 148.8	13.6, 4.3, 148.4
	LNsel	12.1, 4.2	12.0*, 4.1*	11.4, 3.8	12.2, 4.2
	qTAN	0.081	0.074	0.048	0.092
Likelihood components	TAN	-5.11	-4.83	-4.74	-4.89
	TRL	–	-22.05	-22.16	-21.19
	TANc@a	142.37	144.17	142.89	145.05
	TRLc@a	371.92	371.85	265.56	504.16
	LNc@a	43.43	–	43.24	43.57
	Prior qTAN	-2.36	-2.53	-3.00	-2.12
	Prior qTRL	–	-10.66	-10.89	-10.54
	Prior B_0	11.06	11.17	11.31	11.11
	Prior M	0.30	1.06	0.66	1.23
	Prior YCS	-13.11	-12.72	-12.94	-12.32
	Penalty YCS	0.81	0.80	0.81	0.79
	Penalty catch	0	0	0	0
Quantities	$\%B_0$	64	67	69	66

When the longline catch-at-age data were dropped there was very little change in model parameters, and the stock status ($\%B_0$) was unchanged, consistent with the intentional down-weighting of these data (Run 32; Table 30). The trawl fishery catch-at-age were more influential, and doubling the weight on these data resulted in a 7% smaller stock, and halving the weight on these data resulted in a 12% larger stock, although the stock status only varied by by 1–2% (Runs 33 and 34; Table 30). By comparison, the *Tangaroa* catch-at-age data were less influential, with doubling the weight resulting in a 2% smaller stock, and halving the weight a 9% larger stock (Runs 35 and 36; Table 31).

Removing the informed prior on *M* resulted in a very large, very productive, and less depleted stock, having an implausibly high *M* of 0.32; the support for this result (greatest gains in the likelihood) came from the trawl CPUE (2.24 units), then catch-at-age data (1.32 units), with changes in the priors effectively cancelling each other out (Table 31).

Table 31: LIN 7WC, CASAL MPD parameter estimates and likelihood values, for alternative model runs. *, fixed parameter; TAN, research trawl; TRL, commercial trawl, LN, line; sel, selectivity parameters; c@a, catch at age; YCS, year class strength (recruitment).

		35. Halve EFS TAN catch@age	36. Double EFS TAN catch@age	37. Uniform *M* prior	38. *M*=0.15, dbl normal trawl selectivity
Parameters	B_0	69 564	77 665	202 107	56 685
	M	0.234	0.234	0.323	0.15*
	TANselI	3*, 1*, 0.06	3*, 1*, 0.06	3*, 1*, 0.02	3*, 1*, 0.15
	TANselM	11.9, 7.5	10.8, 5.9	14.1, 9.0	9.3, 3.8
	TRLsel	13.3, 4.2, 147.4	13.1, 4.1, 148.5	14.0, 4.1, 147.7	12.7, 4.3, 148.6
	LNsel	12.2, 4.2	11.6, 3.9	12.8, 4.2	12.3, 4.8
	qTAN	0.074	0.055	0.037	0.091
Likelihood components	TAN	-4.81	-4.83	-4.77	-5.02
	TRL	-22.88	-20.21	-24.14	-19.79
	TANc@a	106.90	192.42	144.22	143.19
	TRLc@a	371.51	374.14	371.32	378.52
	LNc@a	43.46	43.34	43.82	43.13
	Prior qTAN	-2.52	-2.90	-3.06	-2.13
	Prior qTRL	-10.63	-10.80	-11.76	-10.13
	Prior B_0	11.15	11.26	12.22	10.95
	Prior M	0.94	0.93	–	–
	Prior YCS	-12.92	-12.29	-12.23	-12.88
	Penalty YCS	0.81	0.79	0.77	0.85
	Penalty catch	0	0	0	0
Quantities	$\%B_0$	66	68	85	39

The change in assumed trawl fishery selectivity was found to make little difference when *M* was fixed, and the CPUE combined index was applied (Table 25). The same result was found when the CPUE lognormal index was used, with negligible change in the parameter estimates and model outcome (compare Run 21, Table 26 with Run 38, Table 31).

4.3 MCMC final model runs

Overall, the sensitivity runs showed that large changes in model outcome could be achieved with little to negligible changes in fits to the observed data. The changes in model outcome were driven by the inclusion or weighting given to some data, notably the CPUE index, and equally by assumptions such as *M* and the *Tangaroa* survey *q*. The data were informative about the lower bound of B_0, but less certain as to the upper bound. Within the range of model assumptions tested, the data provided little information to estimate *M*, and therefore *M* needed to be constrained by an informed prior (centred on $M = 0.2$), or set based on a value from studies outside of the model (e.g., $M = 0.18$).

The parameter estimates for a number of models were estimated using MCMC, and from these the DWFAWG chose three as representative models. The chosen model runs were: Final run 1 - the combined CPUE index, with *M* estimated (variant of Run 9); Final run 2 - the lognormal CPUE index, with *M* estimated (variant of Run 11); and Final run 3 - the lognormal CPUE index, with *M* fixed at 0.18 (variants of Run 22). There was no agreed most likely, or "base", run.

We also report in Appendix A a fourth model, assuming the lognormal CPUE, with *M* fixed at 0.15 (variant of Run 21). This run was not used for management advice, because the DWFAWG had concerns about the veracity of the $M = 0.15$ estimate, but is reported here because it represented the most pessimistic model run encountered during MPD investigations.

Permutations to these runs included (a) assuming an additional CV for the CPUE index of 0.3 or 0.4, with a final choice assumed to be the same across all runs for consistency; and (b) assuming a logistic or double normal selectivity ogive for mature fish in the *Tangaroa* survey (in all runs the trawl fishery selectivity was assumed double normal, and longline fishery selectivity assumed logistic).

The final run estimating *M* (a relatively high *M*) and allowing old ling to be cryptic to the trawl fishery (double normal selectivity ogive) was essentially a "high productivity, hide them" run, and should be a relatively optimistic option. The run fixing *M* at 0.18 (or 0.15), and assuming all ling were available to the fisheries (logistic selectivity ogive), was a "low productivity, kill them" run, and a relatively pessimistic option.

The final runs presented here included the most pessimistic sensitivity run obtained (Run 21), but not the most optimistic run (which had the CPUE up-weighted, or assumed a Ricker stock-recruitment model). These runs were not requested as final runs; from a management point of view, the optimistic run (Run 9; MPD stock status of 81% B_0) was considered to be "optimistic enough".

The first MCMC chains run had problems mixing (exploring the parameter space). An attempt was made to alleviate this by (a) allowing sufficient adaptive step-size changes to ensure an acceptance rate of around 20% was obtained, (b) extending the chains (first chains were 10 million in length; this was extended to 20 million), (c) re-estimating the covariance matrix from the posterior of the first chain (length 10 million), and then starting the chain again (length 20 million), and (d) re-running the chains omitting the average-to-one penalty on the YCS. None of these changes made marked improvements to MCMC performance. Despite reservations about MCMC performance, the the final runs were considered to be acceptable by the DWFAWG for management advice.

The model runs reducing the process error (CV) on the CPUE from 0.4 to 0.3 seemed to increase problems with chain mixing (Figure 48). In addition, an additional CV of 0.3 for runs using the combined CPUE index seemed *a priori* too low, given the large changes in CPUE over short preiods of time, which were implausible given other data and suggested high process error in the CPUE. Therefore final model runs all assumed an additional CV of 0.4. The assumption of logistic or double normal ogive for the mature fish caught by the *Tangaroa* trawl survey made negligible difference to the outcome (Table 32). The DWFAWG advised that the final model runs should assume the double normal ogive (versions (b) in Table 32), such that the assumption of selectivity for older fish was consistent between the trawl fishery and trawl survey.

Table 32: MCMC model runs. LN, lognormal CPUE index; C, combined CPUE index. Runs 1–3 were accepted for management adice by the MPI Working Group. Diagnostics for Run 4 shown in Appendix B.

	Tangaroa mature selectivity	CPUE	*M*	B_0 (000t)	B_{2016}/B_0
Run 1 (a)	Logistic	C	0.23 (0.19–0.27)	99.3 (63.4–195.5)	0.79 (0.61–0.96)
(b)	Double normal	C	0.23 (0.18–0.27)	98.3 (63.5–198.2)	0.78 (0.61–0.95)
Run 2 (a)	Logistic	LN	0.22 (0.19–0.26)	68.9 (51.6–114.2)	0.66 (0.48–0.82)
(b)	Double normal	LN	0.23 (0.19–0.27)	69.3 (51.6–122.0)	0.66 (0.50–0.83)
Run 3 (a)	Logistic	LN	0.18	62.3 (49.3–118.1)	0.54 (0.40–0.74)
(b)	Double normal	LN	0.18	62.8 (48.9–114.5)	0.54 (0.39–0.74)
Run 4	Logistic	LN	0.15	63.2 (52.3–87.0)	0.45 (0.32–0.61)

Despite the attempts to improve MCMC performance, the chains often did not mix well (Figures 49–51), although the median quantities of interest from the three chains were estimated to be within 10% of each other, or better (Figures 52–54).

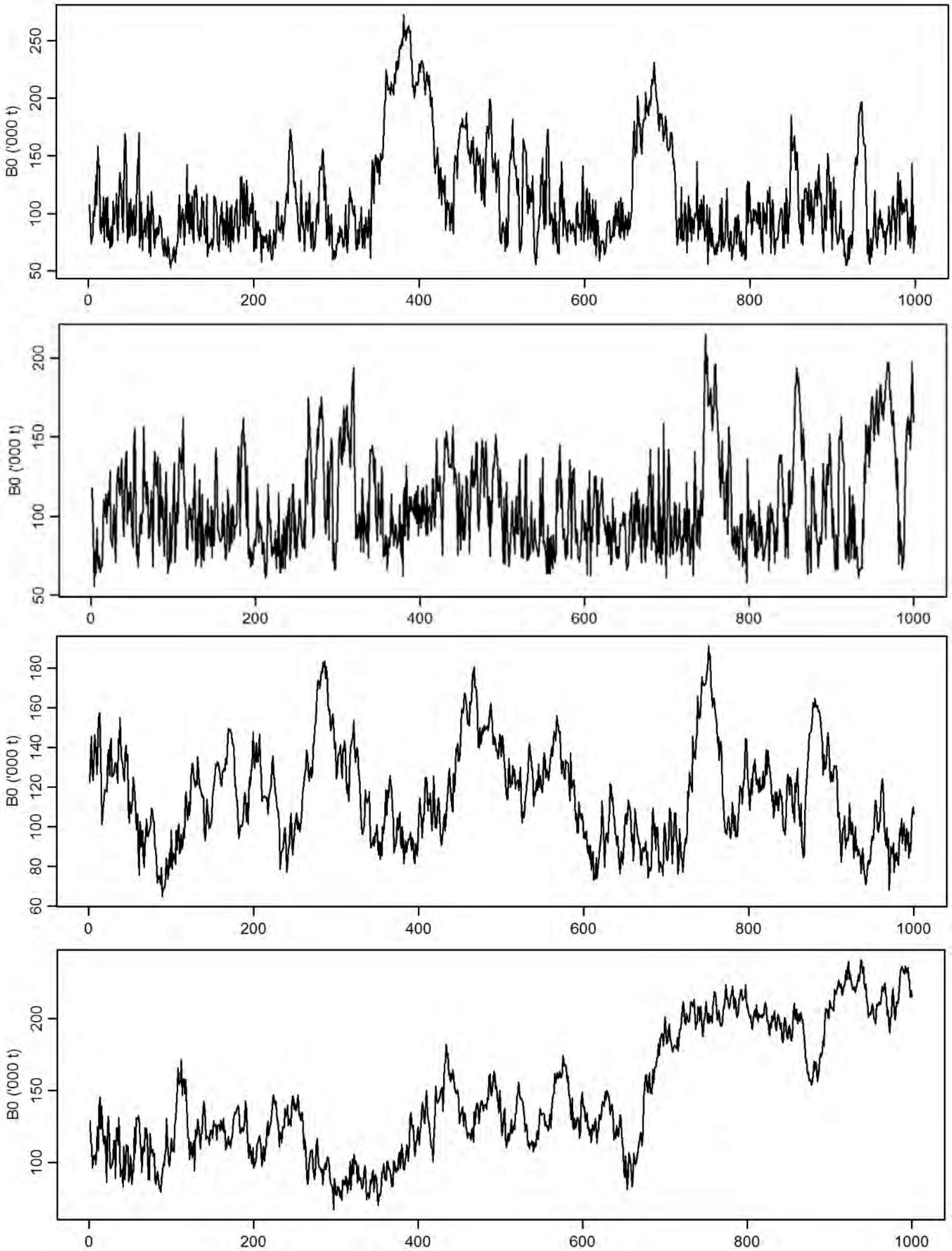


Figure 48: Example MCMC chains for B_0 for verions of Run 1, using the Combined CPUE index, assuming an additional process error CV of 0.4 (samples from two separate chains shown in top two panels) or 0.3 (samples from two seperate chains shown in bottom two panels).

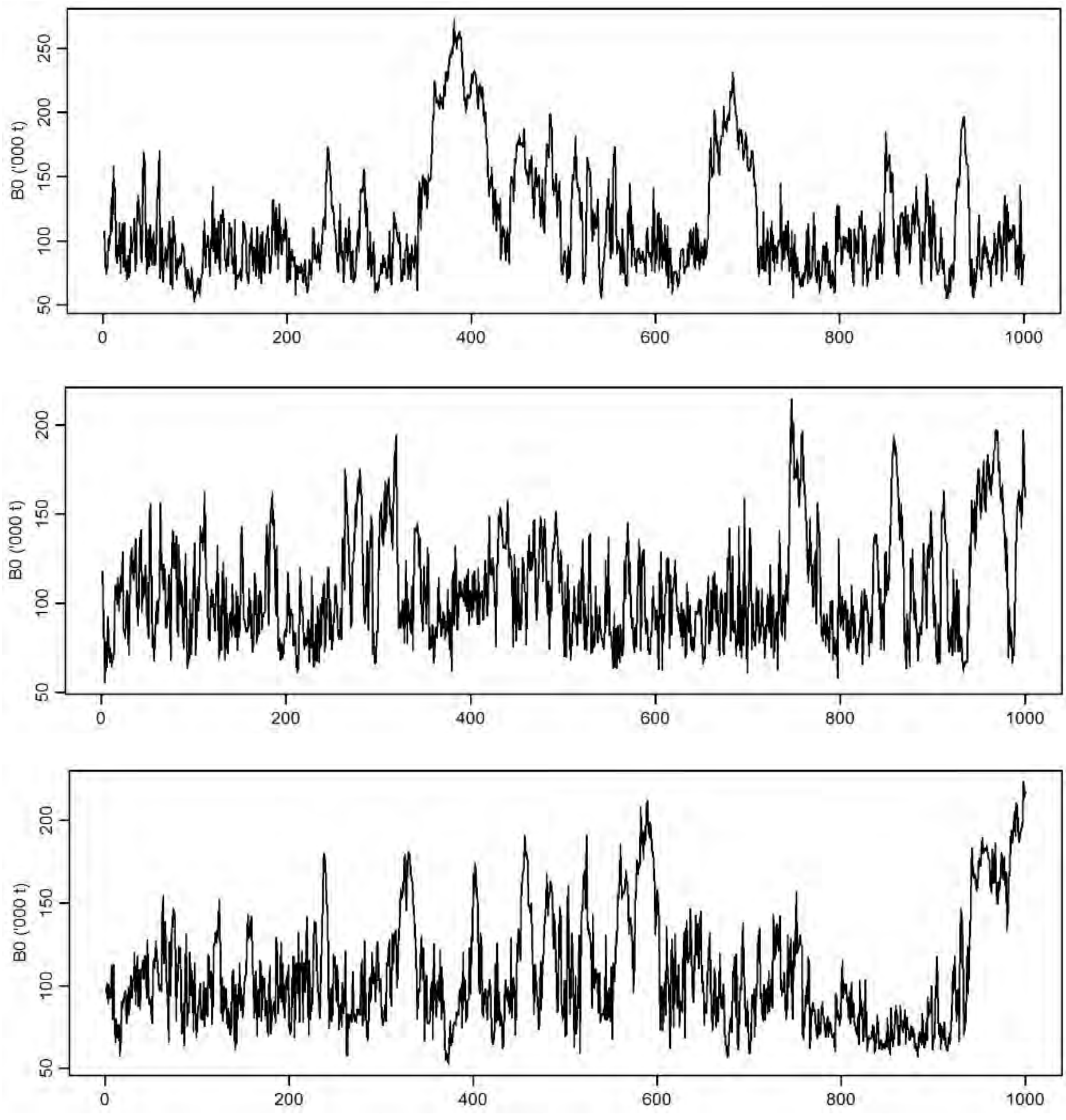


Figure 49: B_0 estimates of 1000 samples from the three MCMC chains for final Run 1: Combined CPUE.

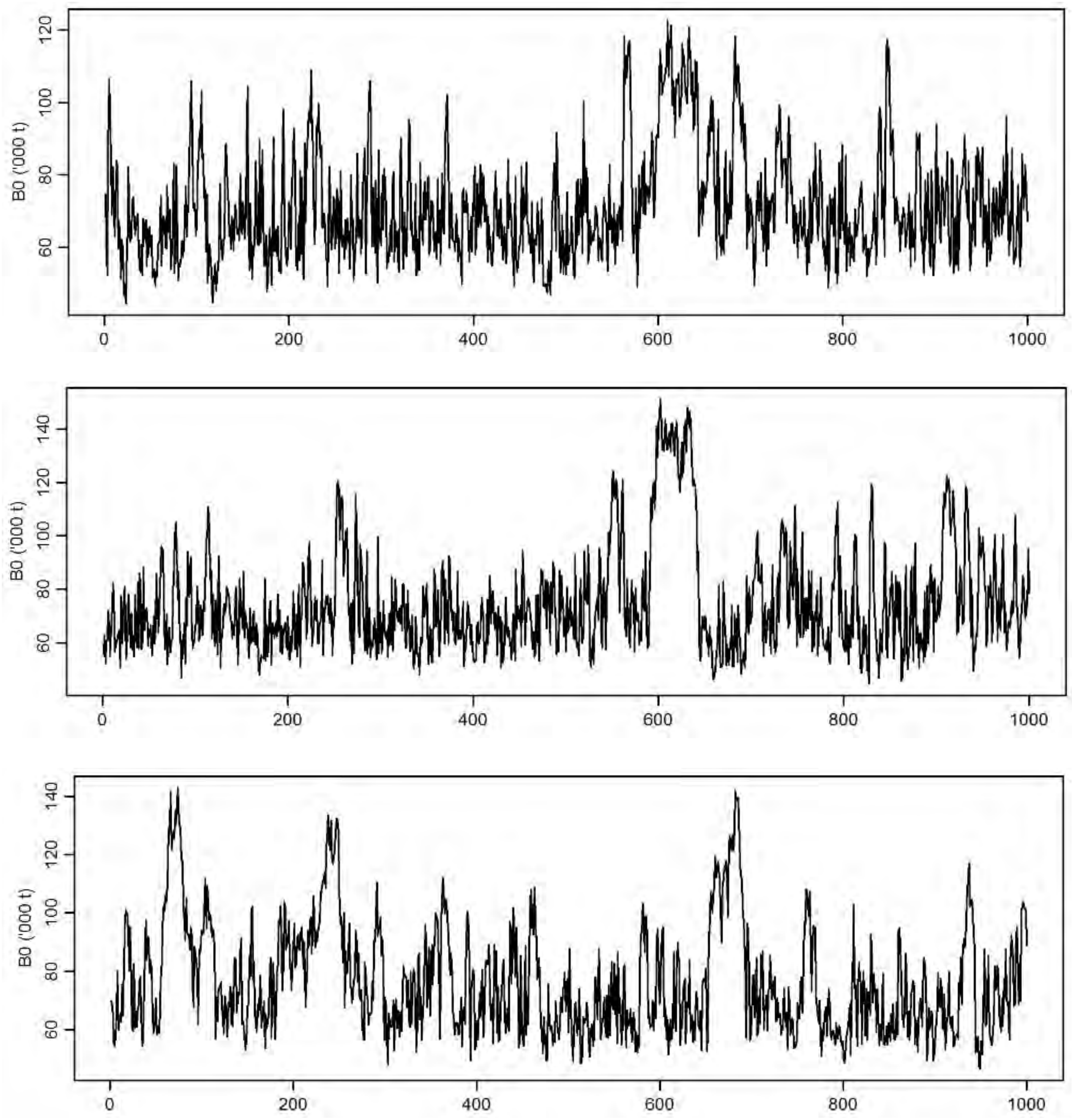


Figure 50: B_0 estimates of 1000 samples from the three MCMC chains for final Run 2: Lognormal CPUE.

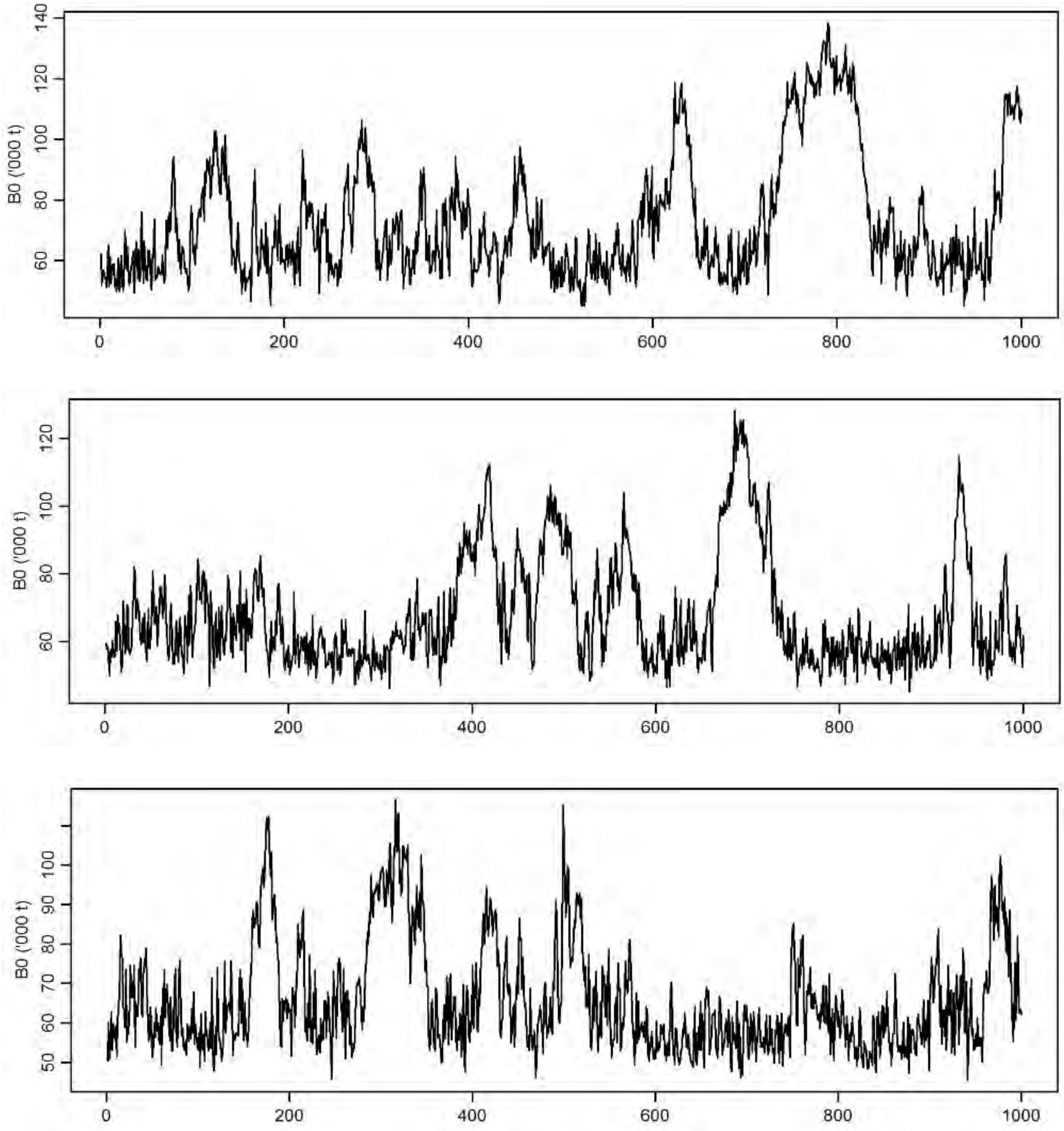


Figure 51: B_0 estimates of 1000 samples from the three MCMC chains for final Run 3: Lognormal CPUE & *M* = 0.18.

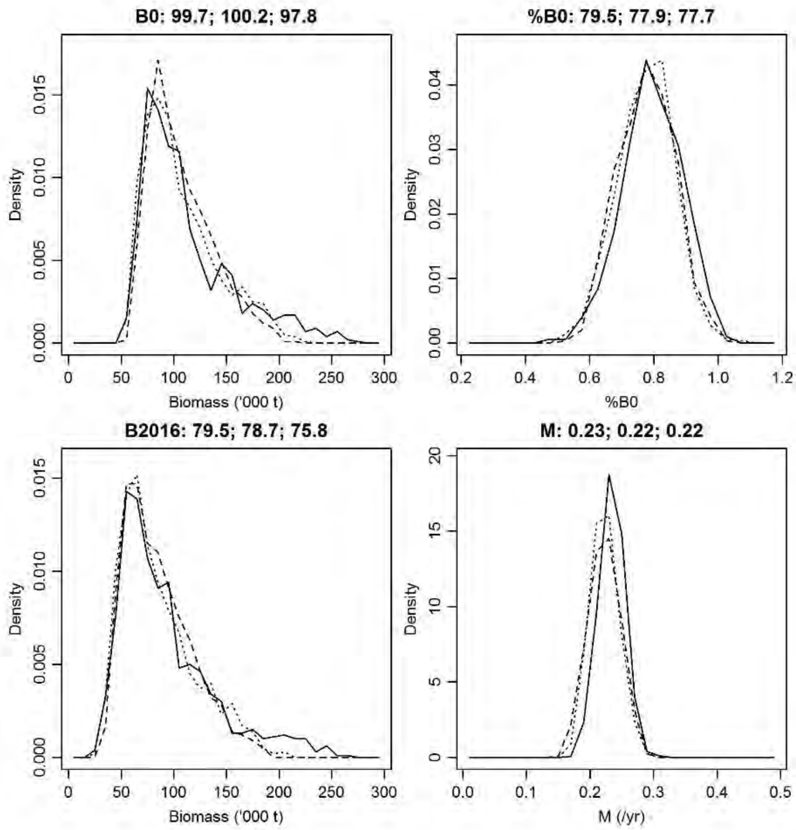


Figure 52: Joint posterior estimates of B_0, $\%B_0$, B_{2016} and *M* from 3000 samples from the three MCMC chains (1000 from each chain), for final Run 1: Combined CPUE.

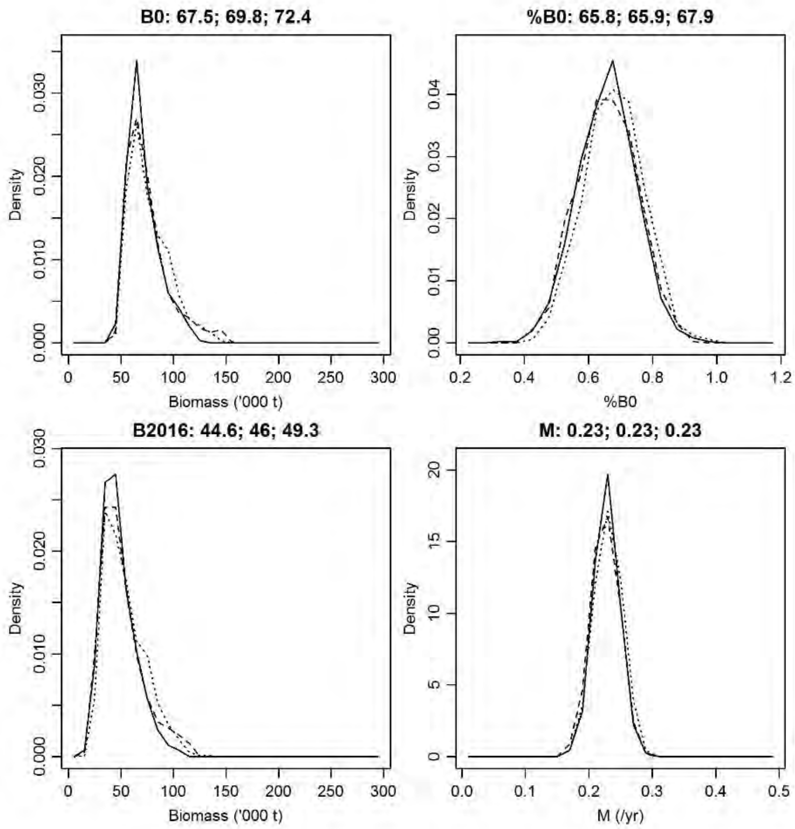


Figure 53: Joint posterior estimates of B_0, $\%B_0$, B_{2016} and *M* from 3000 samples from the three three MCMC chains (1000 from each chain), for final Run 2: Lognormal CPUE.

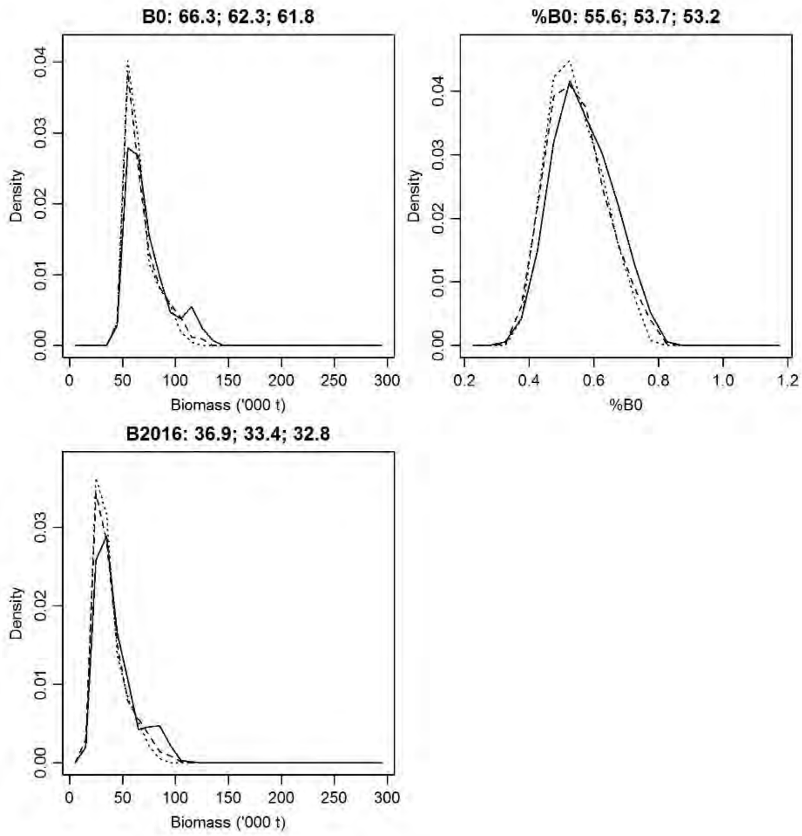


Figure 54: Joint posterior estimates of B_0, $\%B_0$, and B_{2016} from 3000 samples from the three MCMC chains (1000 from each chain), for final Run 3: Lognormal CPUE & *M* = 0.18.

There was very little difference in residuals to the *Tangaroa* biomass index between the three model runs (Figure 55). Neither CPUE index was fitted well (Figure 55). With the additional process error CV of 0.4, the residuals for the Combined CPUE index extended beyond two S.D., whereas the residuals for the Lognormal CPUE index were better. This suggested that the process error might reasonably be increased on the Combined CPUE index. However, it seems very unlikely that the large observed changes in CPUE could be adequately fitted by any model having the demographic characteristics assumed for ling.

The joint posterior distribution of the *Tangaroa q* prior was lower than the prior for the Combined CPUE index model run, and a little higher than the prior for the Lognormal CPUE runs (Fgure 56). The mode of the posterior distribution for *M* was a little higher than the prior, with the upper limit of the posterior (presumably) constrained to be less than 0.3 by the prior (Figure 56).

The selectivity for the *Tangaroa* mature fish was approximately lognormal in posterior samples for all three runs (Figures 57–59). The selectivity for the trawl fishery was most often domed in the Combined CPUE and Lognormal CPUE & *M* = 0.18 runs, but approximately logistic in the Lognormal CPUE run. The age at 50% selectivity was similar in the Combined CPUE and Lognormal CPUE runs, with selectivity first to the trawl fishery at about age 9, then to the longline fishery at about age 13. The selectivity for immature fish to the *Tangaroa* surey was fixed (at age 3), but the mature fish were selected at about age 12 in the Combined CPUE and Lognormal CPUE runs, and age 9 in the Lognormal CPUE and *M* = 0.18 run. The age at 50% maturity was estimated outside of the model at about age 7, therefore the fisheries (and *Tangaroa* mature selectivity) selected fish after the age of first maturity, resulting in a proportion of the mature biomass that could not be caught (a "cryptic" SSB).

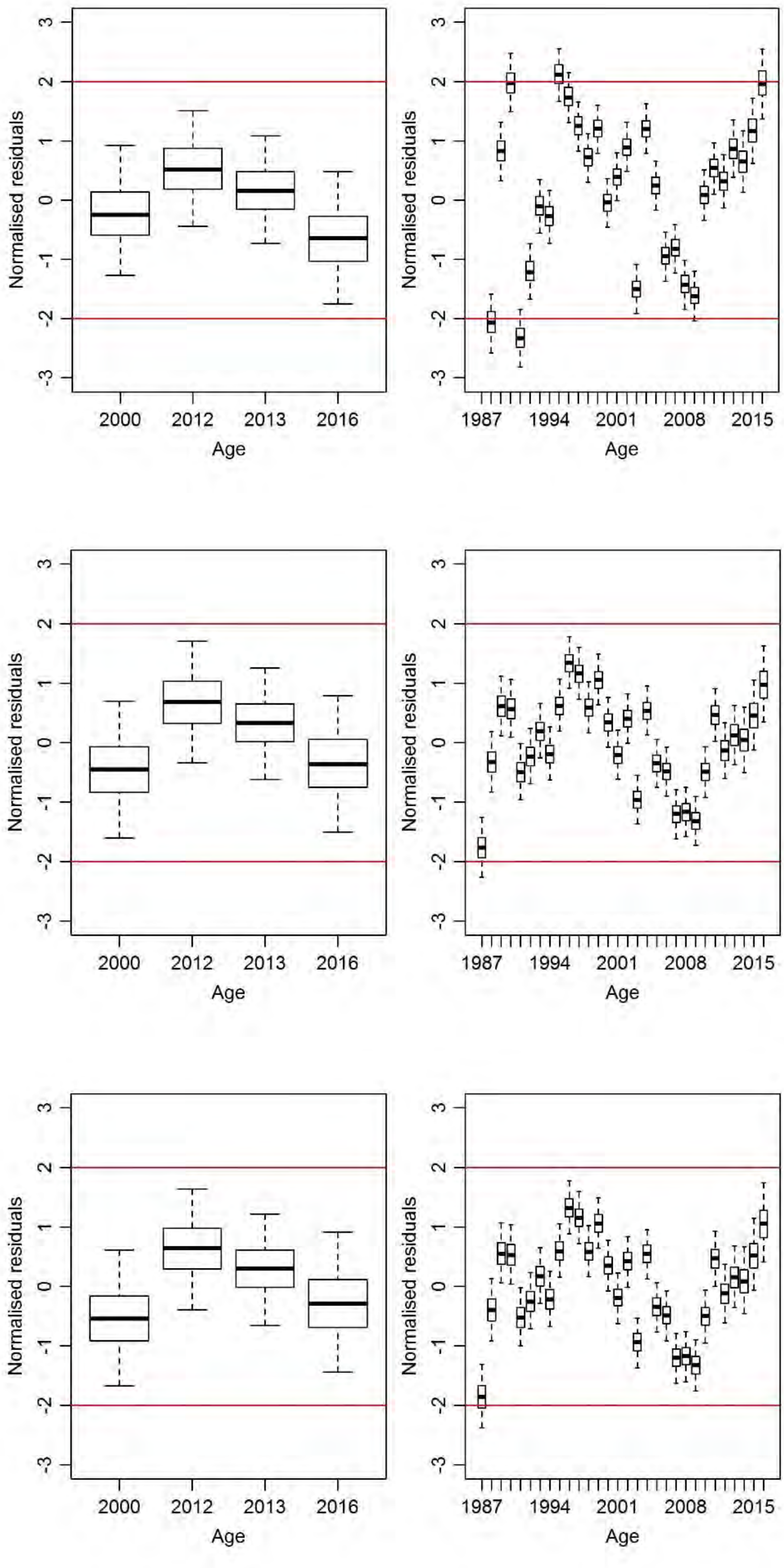


Figure 55: Pearson residuals from the "fits" to the *Tangaroa* biomass index (left panels) and CPUE index (right panels), from the combined MCMC chain samples for Run 1: Combined CPUE (top panels), Run 2. Lognormal CPUE (middle panels), and Run 3. Lognormal CPUE & M = 0.18 (bottom panels). Box plots show the median (solid line), interquartile range (box), and 95% credible intervals (whiskers).

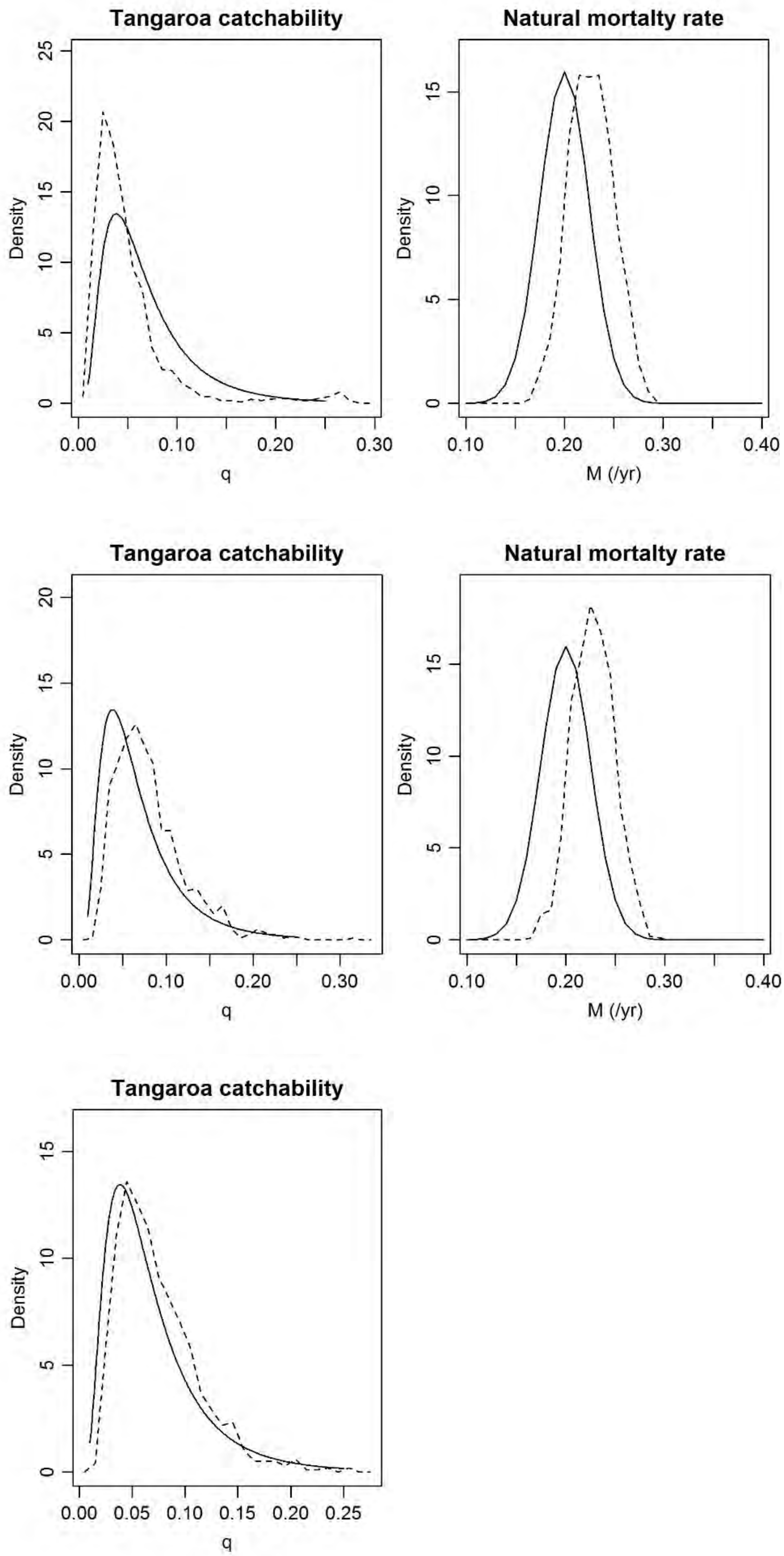


Figure 56: Posterior joint distributions (broken lines) and priors (solid lines) for the Tangaroa catchability (*q*) and *M*, from the combined MCMC chain samples for Run 1: Combined CPUE (top panels), Run 2. Lognormal CPUE (middle panels), and Run 3. Lognormal CPUE & *M* = 0.18 (bottom panels).

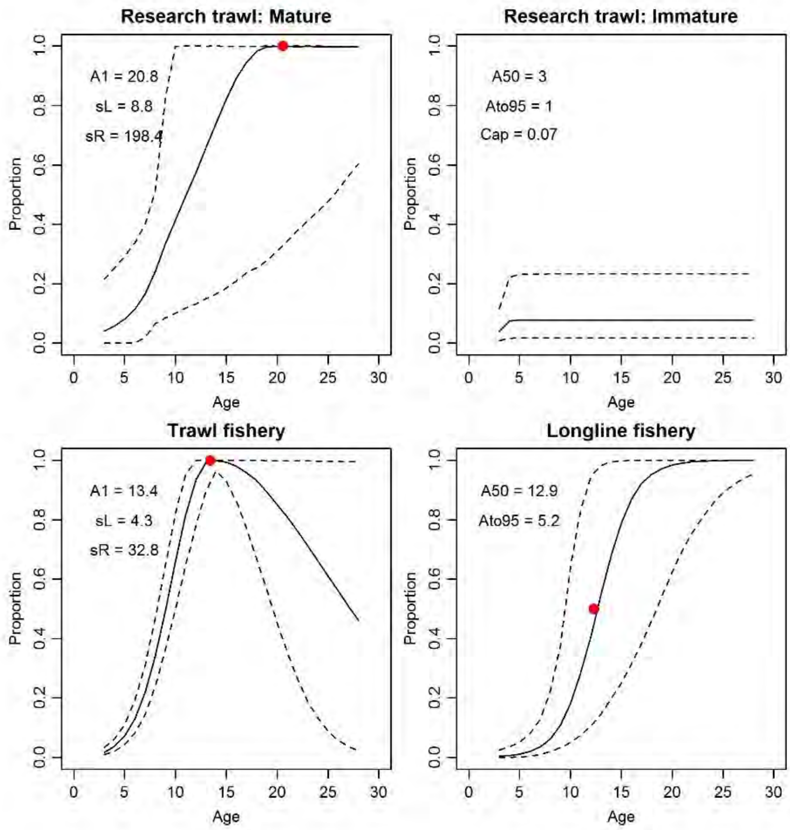


Figure 57: Joint posterior estimates of selectivities, and selectivity parameters, from 3000 samples of the MCMC chains for Run 1: Combined CPUE. Red dots indicate MPD parameter estimates (A_1 or A_{50}).

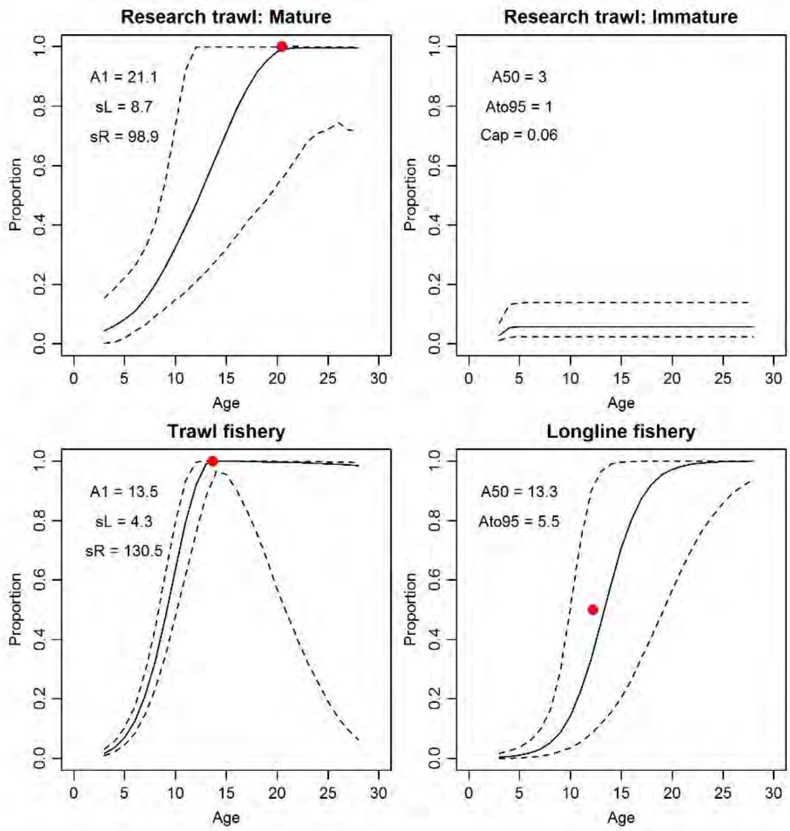


Figure 58: Joint posterior estimates of selectivities, and selectivity parameters, from 3000 samples of the MCMC chains for Run 2: Lognormal CPUE. Red dots indicate MPD parameter estimates (A_1 or A_{50}).

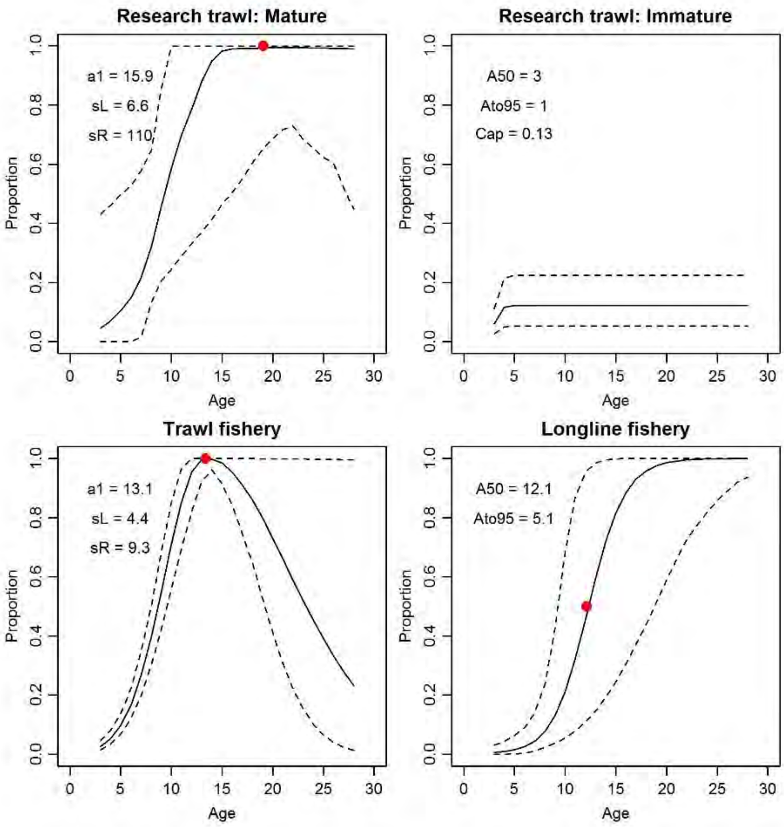


Figure 59: Joint posterior estimates of selectivities, and selectivity parameters, from 3000 samples of the MCMC chains for Run 3: Lognormal CPUE & *M* = 0.18. Red dots indicate MPD parameter estimates (A_1 or A_{50}).

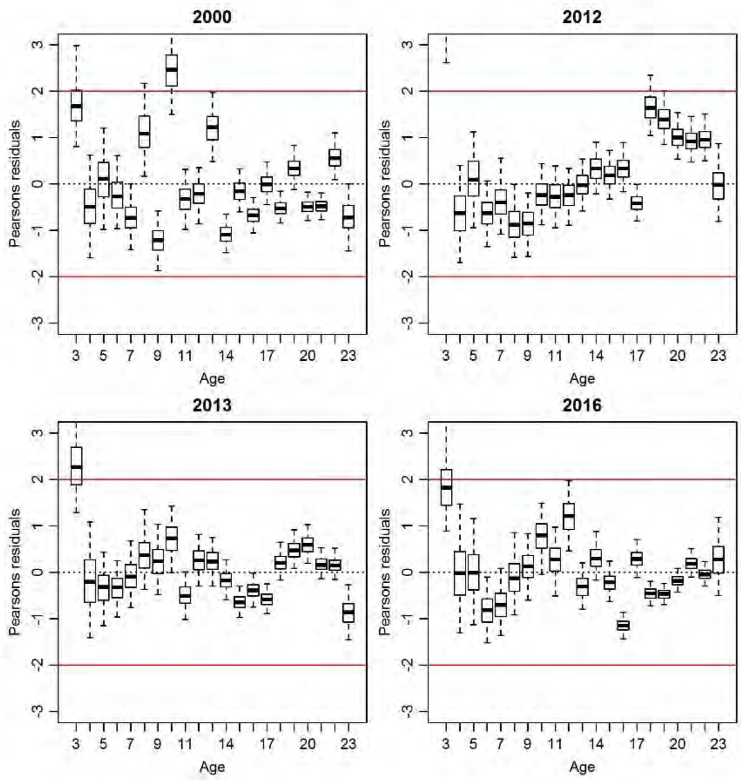


Figure 60: Pearson residuals from the "fits" to the *Tangaroa* catch-at-age observations, from the combined MCMC chain samples for Run 1: Combined CPUE. Box plots show the median (solid line), interquartile range (box), and 95% credible intervals (whiskers).

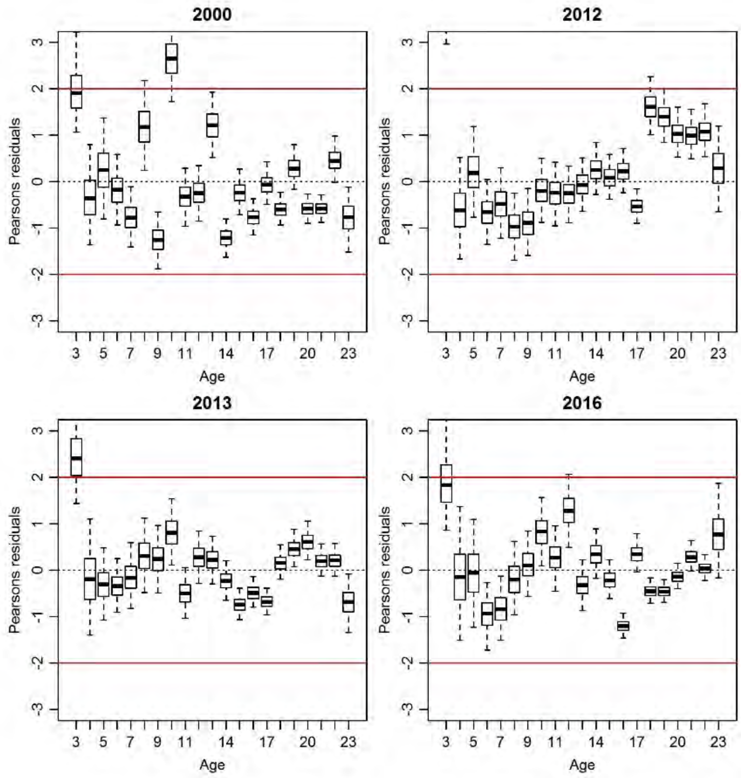


Figure 61: Pearson residuals from the "fits" to the *Tangaroa* catch-at-age observations, from the combined MCMC chain samples for Run 2: Lognormal CPUE. Box plots show the median (solid line), interquartile range (box), and 95% credible intervals (whiskers).

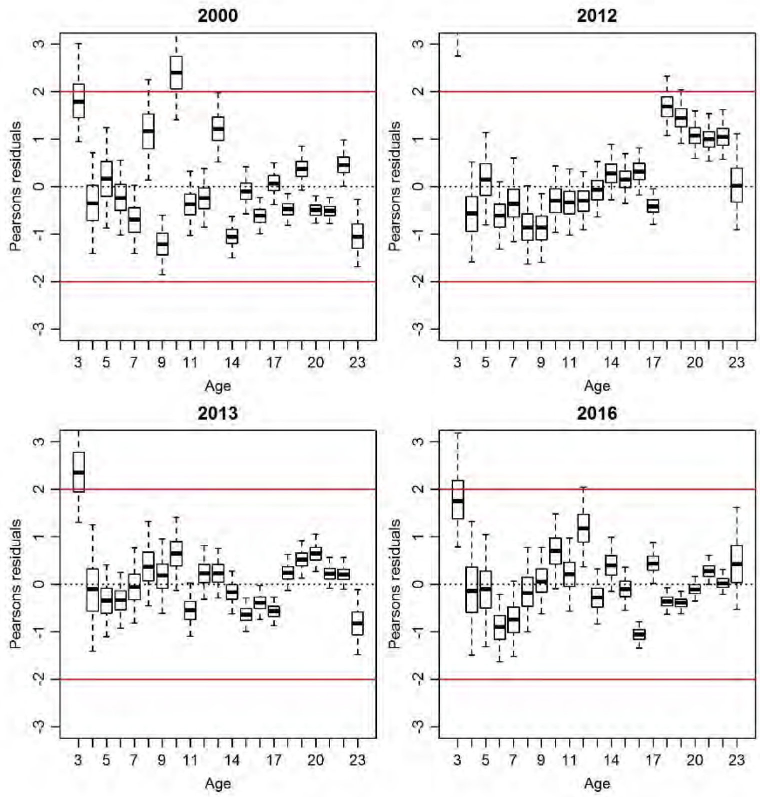


Figure 62: Pearson residuals from the "fits" to the *Tangaroa* catch-at-age observations, from the combined MCMC chain samples for Run 3: Lognormal CPUE & M = 0.18. Box plots show the median (solid line), interquartile range (box), and 95% credible intervals (whiskers).

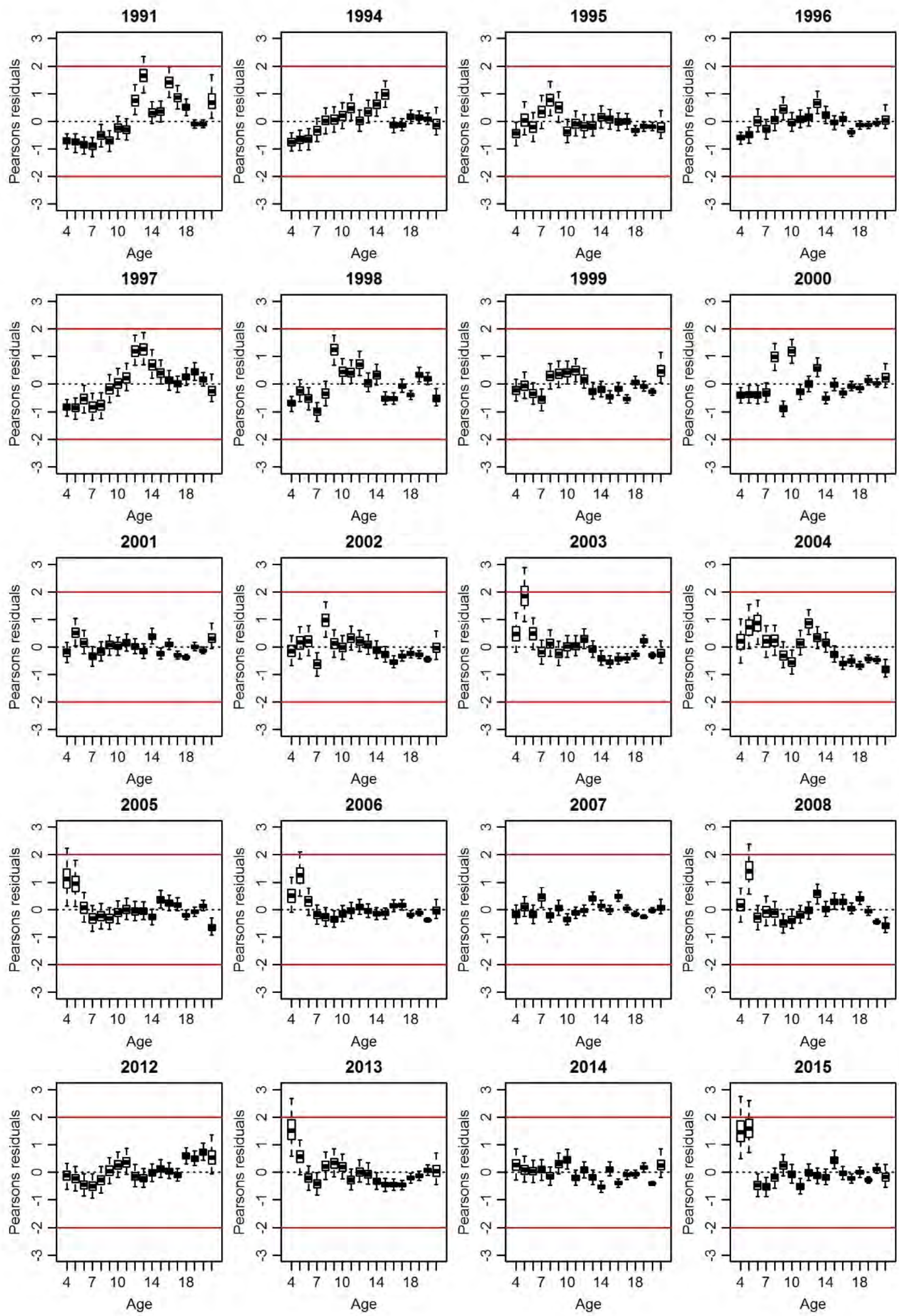


Figure 63: Pearson residuals from the "fits" to the commercial trawl fishery catch-at-age observations, from the combined MCMC chain samples for Run 1: Combined CPUE. Box plots show the median (solid line), interquartile range (box), and 95% credible intervals (whiskers).

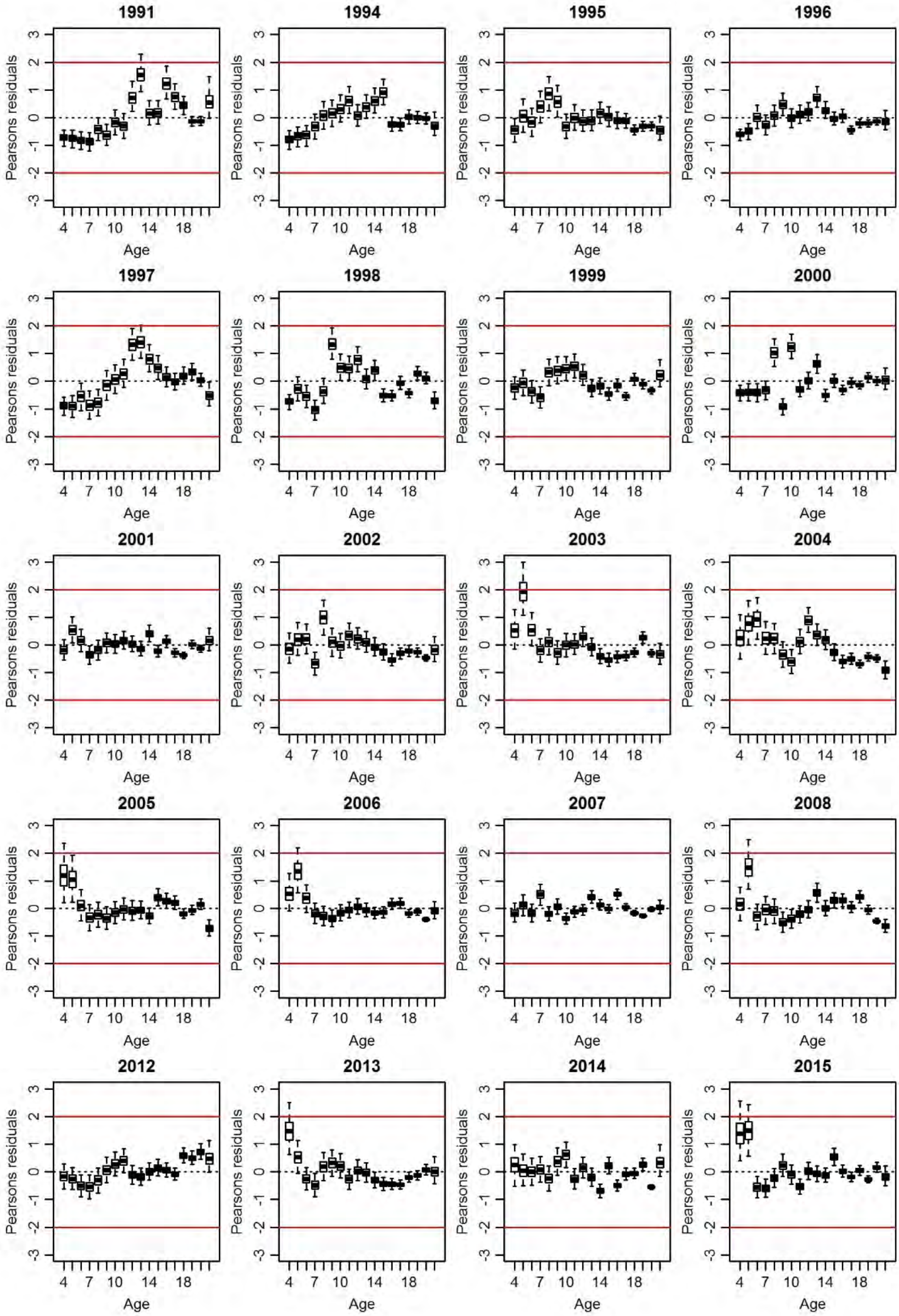


Figure 64: Pearson residuals from the "fits" to the commercial trawl fishery catch-at-age observations, from the combined MCMC chain samples for Run 2: Lognormal CPUE. Box plots show the median (solid line), interquartile range (box), and 95% credible intervals (whiskers).

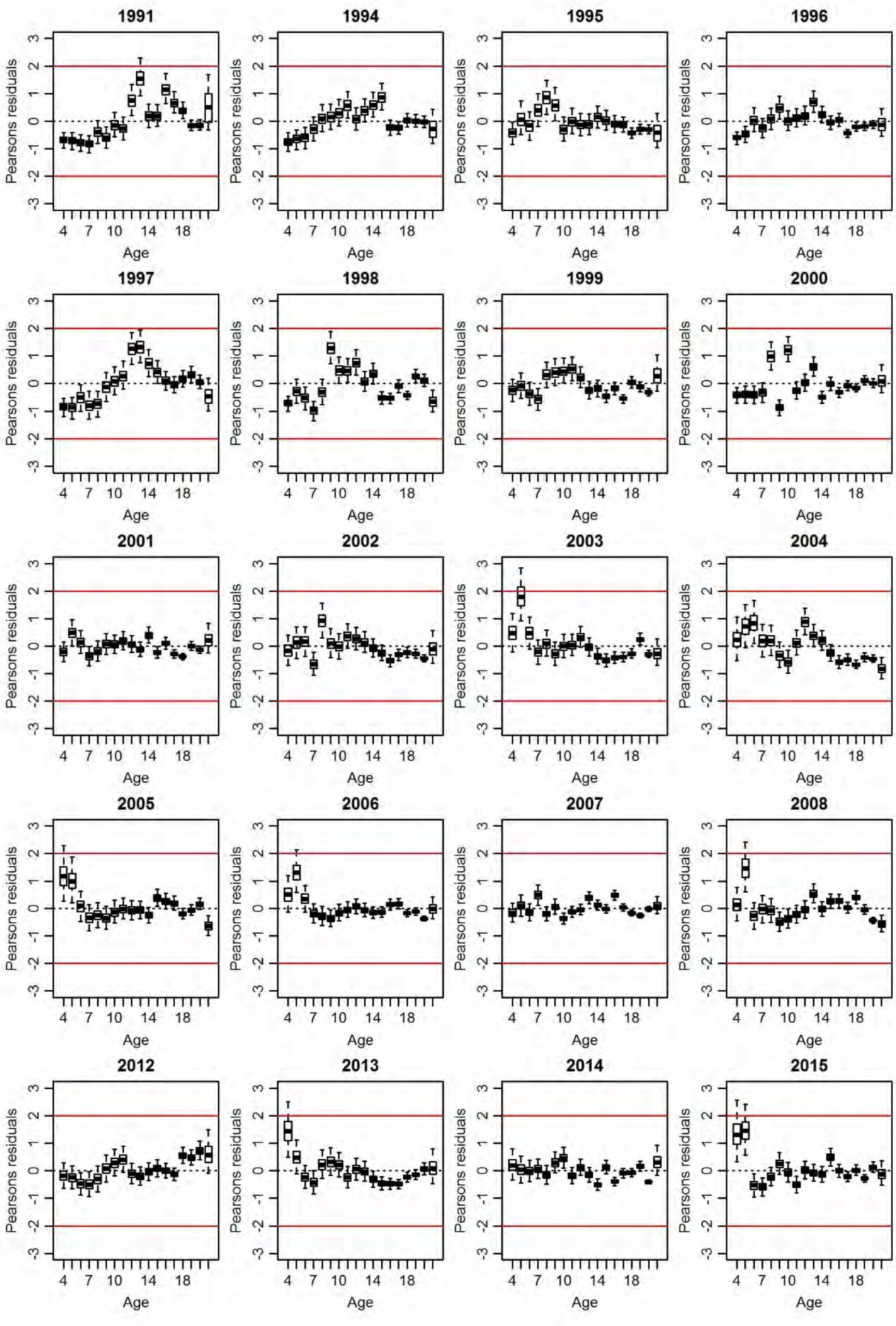


Figure 65: Pearson residuals from the "fits" to the commercial trawl fishery catch-at-age observations, from the combined MCMC chain samples for Run 3: Lognormal CPUE & M = 0.18. Box plots show the median (solid line), interquartile range (box), and 95% credible intervals (whiskers).

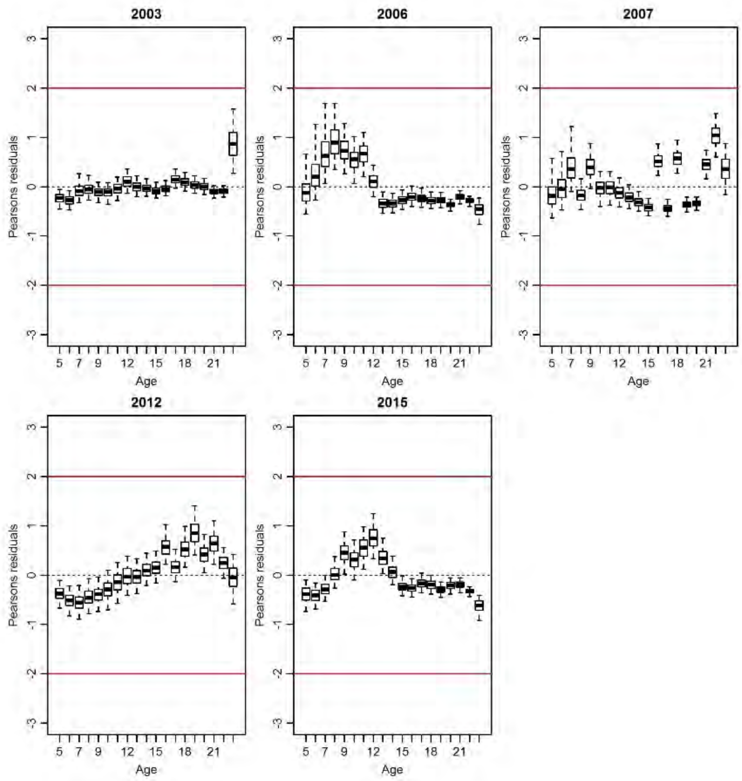


Figure 66: Pearson residuals from the "fits" to the commercial longline fishery catch-at-age observations, from the combined MCMC chain samples for Run 1: Combined CPUE. Box plots show the median (solid line), interquartile range (box), and 95% credible intervals (whiskers).

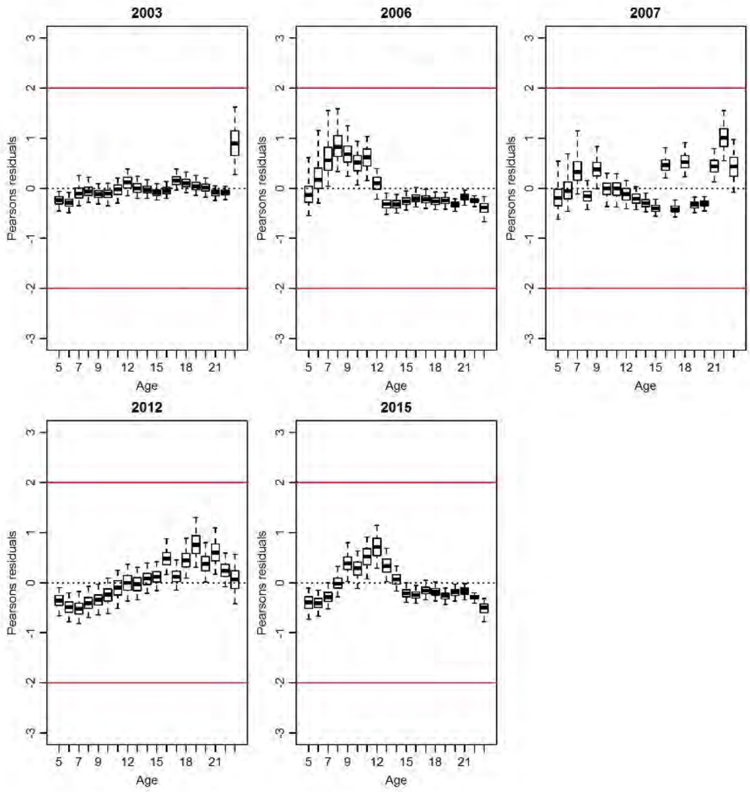


Figure 67: Pearson residuals from the "fits" to the commercial longline fishery catch-at-age observations, from the combined MCMC chain samples for Run 2: Lognormal CPUE. Box plots show the median (solid line), interquartile range (box), and 95% credible intervals (whiskers).

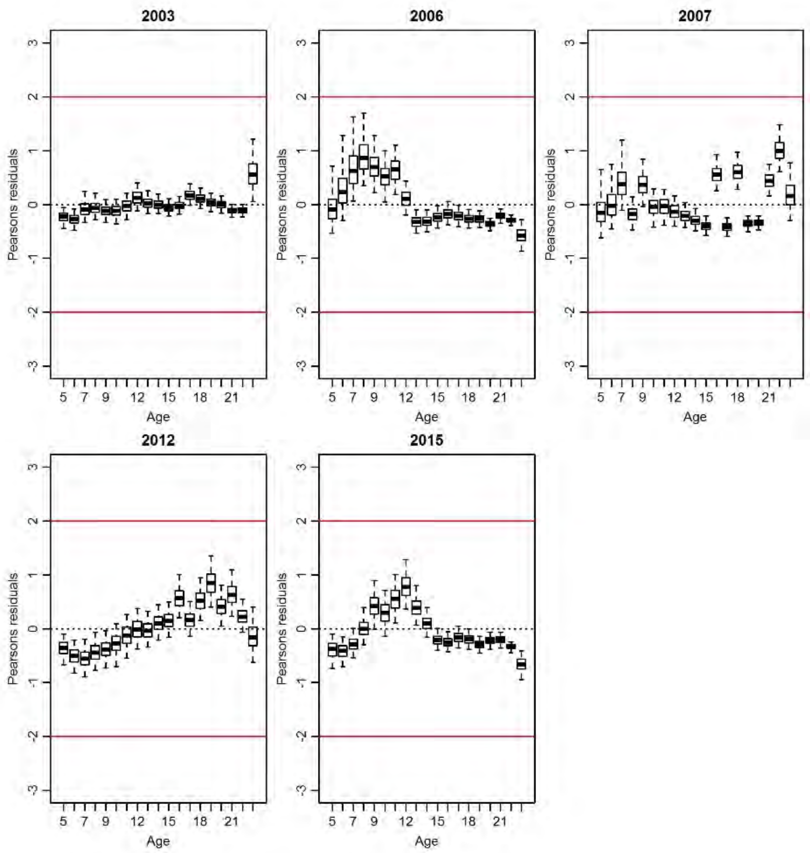


Figure 68: Pearson residuals from the "fits" to the commercial longline fishery catch-at-age observations, from the combined MCMC chain samples for Run 3: Lognormal CPUE & *M* = 0.18. Box plots show the median (solid line), interquartile range (box), and 95% credible intervals (whiskers).

The residuals for the *Tangaroa* age compositions were similar across all three model runs (Figure 60–62). The residuals for 2000, 2013 and 2016 were adequate, except for at age three where the proportion at age was underestimated by the models, and also age ten in 2000. There was a clear trend in residuals for 2012, where the relative abundance at ages 14+ was underestimated.

The residuals for the trawl fishery age composition were generally good, but showed a trend in 1991, where the proportion at ages 4–7 were overestimated and ages 12+ underestimated; a similar but less pronounced trend was present in some other years early in the data set, notably 1997 and 1998 (Figures 63–65). In several years from 2003, the proportion at ages four and five (and occasionally up to age eight) were underestimated; this might indicate a change in selectivity from the early 2000s onwards.

The residuals for the longline fishery age compositions were relatively poor across all three models, and all years showed trends suggestive of relatively poor fits (Figures 66–68).

The pattern of YCS was similar across all final model runs (Figure 69), with relatively high year classes estimated around 1990 (1987–91), in the 2000s (2001, 2003–04, 2009, and 2012), and particularly low recruitment in 2006–07.

The Combined CPUE model run indicated a biomass decline until 1992, followed by fluctuating but stable biomass until 2016, whereas the Lognormal CPUE model runs both indicated slow overall biomass declines (Figures 70–72). The vulnerable biomass was around 20% lower than the SSB. All model runs estimated recent trawl fishing pressure to be stable, and recent longline fishing pressure to have been relatively high in 2013–14 and 2014–15 (Figures 70–72; note the different y-axis scales on the fishing pressure plots).

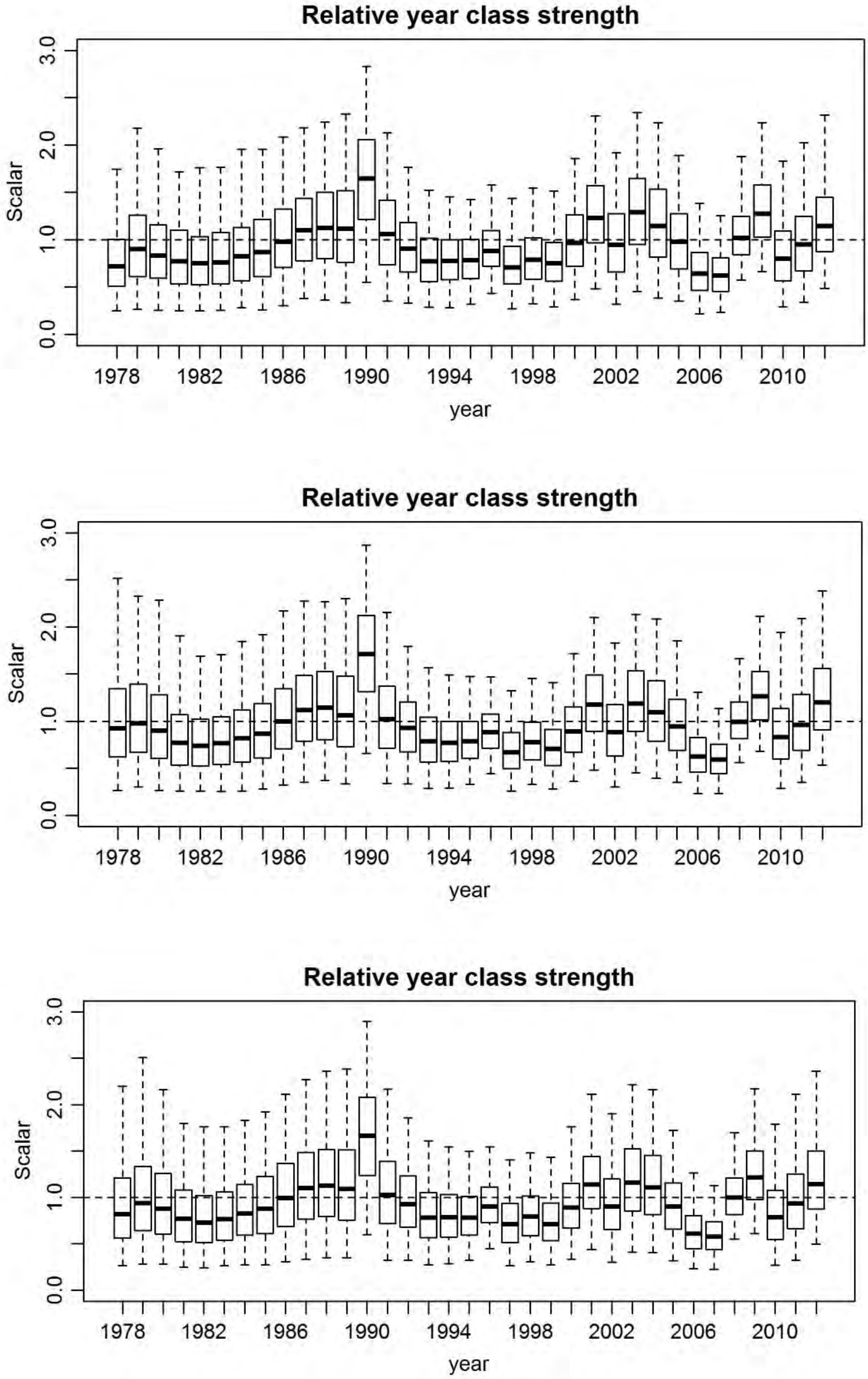


Figure 69: Posterior joint distributions for relative year class strength (YCS scalars), from the combined MCMC chain samples for Run 1: Combined CPUE (top panel), Run 2. Lognormal CPUE (middle panel), and Run 3. Lognormal CPUE & M = 0.18 (bottom panel). Box plots show the median (solid line), interquartile range (box), and 95% credible intervals (whiskers).

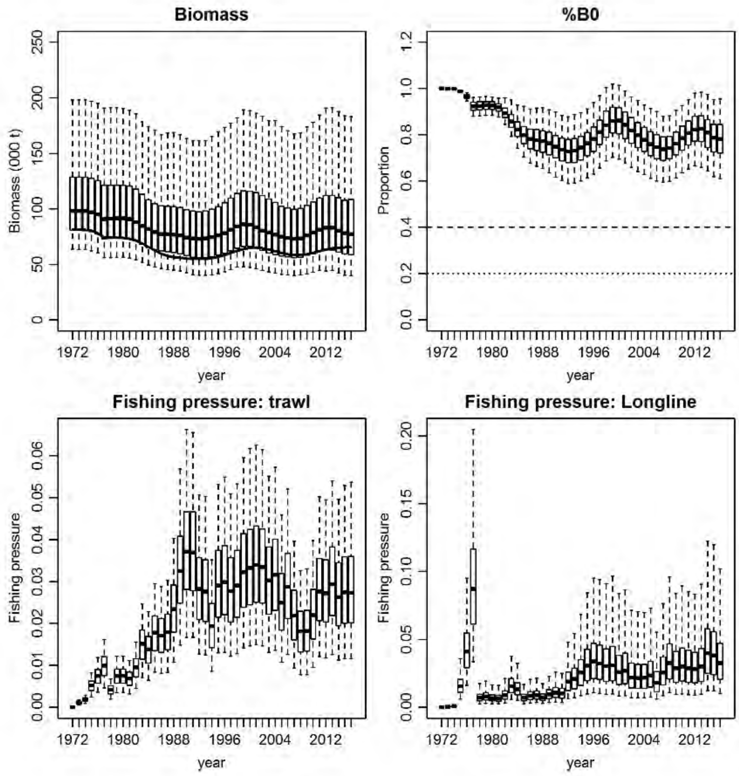


Figure 70: Joint posterior estimates of spawning stock biomass (Biomass), %B$_0$, and fishing pressure by fleet, from the combined MCMC chain samples for Run 1: Combined CPUE. The solid line in the Biomass panel (near the lower quartile of the boxplot) indicates vulnerable biomass. Box plots show the median (solid line), interquartile range (box), and 95% credible intervals (whiskers).

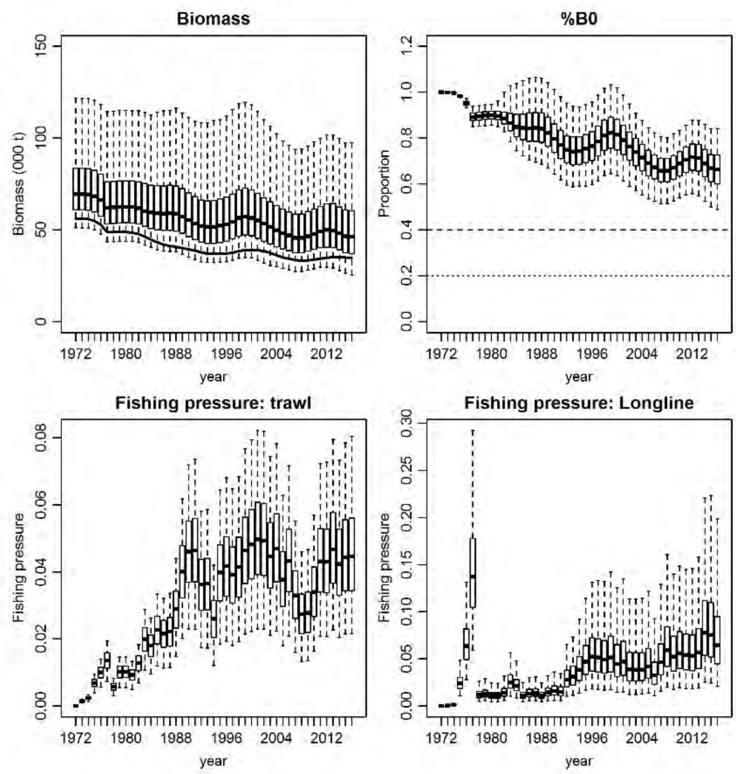


Figure 71: Joint posterior estimates of spawning stock biomass (Biomass), %B$_0$, and fishing pressure by fleet, from the combined MCMC chain samples for Run 2: Lognormal CPUE. The solid line in the Biomass panel (near the lower quartile of the boxplot) indicates vulnerable biomass. Box plots show the median (solid line), interquartile range (box), and 95% credible intervals (whiskers).

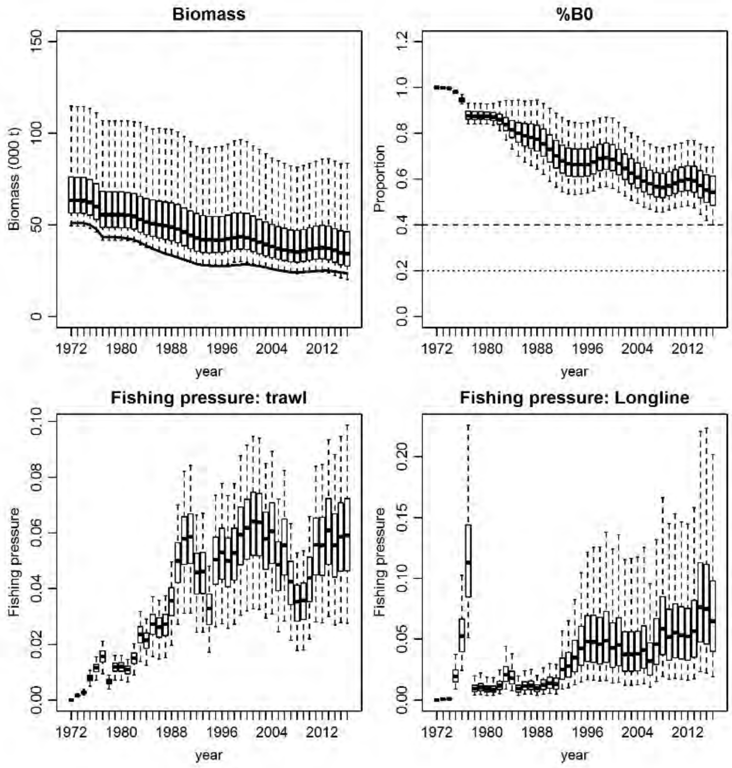


Figure 72: Joint posterior estimates of spawning stock biomass (Biomass), %B_0, and fishing pressure by fleet, from the combined MCMC chain samples for Run 3: Lognormal CPUE & M = 0.18. The solid line in the Biomass panel (near the lower quartile of the boxplot) indicates vulnerable biomass. Box plots show the median (solid line), interquartile range (box), and 95% credible intervals (whiskers).

Biomass projections out to 2022 indicated that biomass was likely to remain about the same with future catches equal to recent previous catch levels, or if catches for LIN 7WC were to increase modestly (by around 10%) to the overall LIN 7 fishstock level (Table 33). The final models covered a wide range of potential stock sizes, with the median of the Lognormal & M = 0.18 run below the 95% credible intervals of the Combined CPUE run (Figure 73).

Table 33: LIN 7WC biomass projections under deterministic recruitment and constant catch scenarios, for the three final model runs.

Model run	Future catch (t)	B_{2022} (000 t)	B_{2022} / B_0	P(B_{2022} < 0.2B_0)	P(B_{2022} < 0.4B_0)
1. Combined CPUE	2 700	78.8 (38.5–187.4)	0.81 (0.56–1.07)	0	0
	2 980	77.3 (37.8–185.5)	0.79 (0.56–1.06)	0	0
	3 300	76.6 (35.5–183.7)	0.78 (0.54–1.04)	0	0
2. Lognormal CPUE	2 700	48.8 (23.3–97.8)	0.72 (0.45–0.99)	0	0.01
	2 980	47.4 (21.6–97.3)	0.70 (0.41–1.00)	0	0.02
	3 300	45.9 (20.7–96.9)	0.68 (0.37–0.97)	0	0.03
3. Lognormal & M = 0.18	2 700	39.4 (18.3–99.4)	0.58 (0.35–0.84)	0	0.05
	2 980	38.1 (17.3–97.9)	0.57 (0.33–0.85)	0	0.09
	3 300	36.4 (15.9–95.9)	0.54 (0.32–0.82)	0	0.14

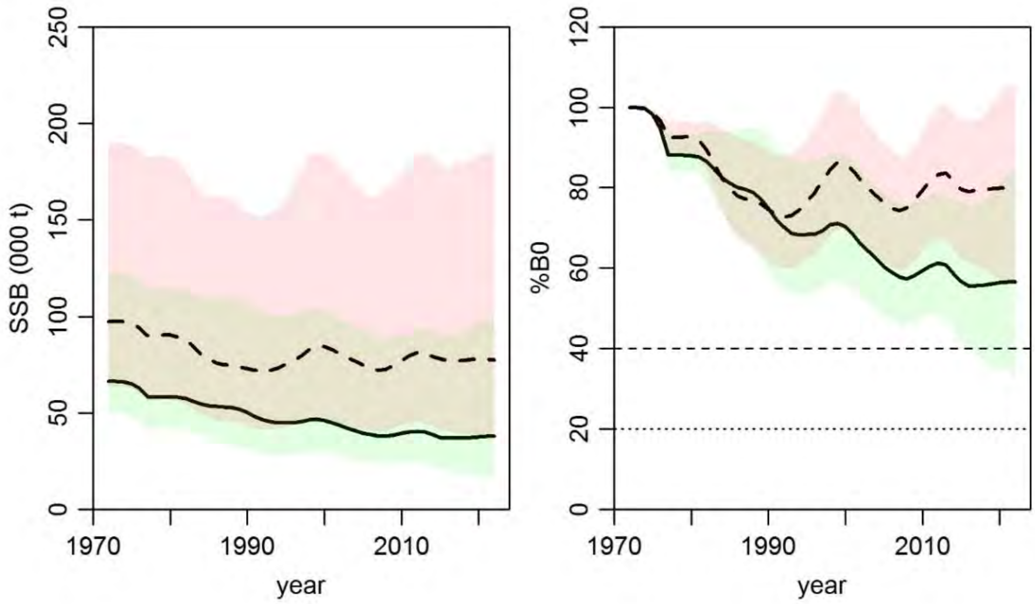


Figure 73: Biomass estimates for the Combined CPUE (broken line, median; red shading, 95% credible intervals) and Lognormal & M = 0.18 run (solid line, median; green shading, 95% credible intervals). Brown shading occurs where the 95% CIU overlap. Broken lines on the left panel indicate the MPI target (40% B_0) and management soft limit (20% B_0).

5. DISCUSSION

The 2017 assessment revealed some interesting selectivity patterns in both research trawl surveys, which were separate in time and space. A solution to adequately fitting the bimodal age composition data was found, but it was not clear how or why the stock might be structured to produce this pattern. Further examination of the spatial and temporal distribution by fish age may reveal structure and hypotheses not yet identified. Other techniques, such as analyses of otoliths, might also be helpful in resolving stock structure (Ladroit et al. 2017).

The CPUE were influential in the assessment, but variability between years suggested either very high process error, or that the series was not reliable. It may be that the CPUE series should be split into two because of fishery changes (age composition suggested a potential selectivity change around 2000). Further investigation of the fishery, and alternative data CPUE selections, may improve the veracity of these data.

Some fine-tunning of the data weighting would be desirable. The MCMC residuals suggested that the CPUE and *Tangaroa* catch-at-age composition may be over-weighted. The outcome of the models were, however, sensitive to assumptions such as data weighting, but resulted in small to negligible differences in model fit to observed data. As a result, there needs to be a plausible and defensible rationale for model structure and data weighting assumptions.

The uncertainty about *M* for ling seems to remain, and this parameter was highly influential in determining stock size and status. Until further information about *M* is available, it seems prudent to keep different (including fixed) *M* runs in the final runs supplied to management, to be interpreted with equal weight. The importance of the *Tangaroa q* was also recognized in this assessment, and it may be useful to also review this prior.

The model MCMC performance was not good. Quite why this occurred was not determined during the assessment, but it may be some over-parameterisation, conflict in data/uninformative data, or limits to the performance of the MCMC algorithm. Some of these problems may not have been identified during the previous assessment, when shorter chains were run. The MCMCs revealed that uncertainty in the assessment was large, especially the upper bound to B_0; uncertainty was nevertheless likely to be underestimated because some processes, such as growth (length at age, variability in length at age, length to weight conversion), remained fixed.

After the assessment, the assessment was converted from CASAL into the newer Casal2 format, and a comparison of model parameter estimates was made; the model estimates were the same (Appendix B).

After the assessment model runs and review were completed and accepted for fishery management advice by MPI, as reported above, MPI requested a re-run of the models with an alternative catch history (supplied by MPI). These sensitivity runs are documented elsewhere.

6. MANAGEMENT IMPLICATIONS

The assessment was accepted by the DFAWG, with reservations. B_{2017} was estimated to be about 79% B_0, 66% B_0, and 54% B_0; in all cases very likely (>90% probability) to be at or above the target (40% B_0). In all cases, stock status was exceptionally unlikely (<1%) to be below the limit reference points (20% B_0 and 10% B_0). There has been no specific TACC for the LIN 7WC stock (it is part of the management area LIN 7), but even if all of the LIN 7 catch TACC were taken from LIN 7WC the projections indicated the stock status would be unlikely to change over the next five years.

7. ACKNOWLEDGMENTS

We thank members of the DWFAWG for comments and suggestions on these assessments, Craig Marsh for technical help, Dan McGibbon for providing data, and Peter Horn for providing data and a useful review of the draft report. This work was funded by the Ministry for Primary Industries project DEE2016/10.

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APPENDIX A

This appendix describes the MCMC results for a run equivalent to the Lognormal CPUE & *M* = 0.18 run, but assuming *M* = 0.15. This run was not used for management advice, because some members of the MPI Working Group had concerns about the veracity of the *M* estimates, and preferred the default value for ling of 0.18 yr^{-1}. The 0.18 estimate was derived from the lowest total mortality rate estimated in earlier studies of ling, which were estimated from maximum observed age (A_{max}) using $M = \ln(100)/A_{max}$, and gave estimates of 0.17 – 0.20 yr^{-1} (Horn 1993). For males and females on the west coast of the South island the total mortality (*Z*) estimates were 0.20 yr^{-1}, from a sample of 371 fish aged from a single commercial trawl sample in 1991 (Horn 1993). The composition of the 1991 sample was substantially different from subsequent samples, and not well fitted well by any model run, suggesting that it may not have been representative. In addition, catches from LIN 7WC were notable (over 100 t per year) from the mid 1970s, and persistently exceeded 2000 t per year from 1987–88 (Ministry for Primary Industries 2017). Therefore, a *Z* of 0.20 and *M* of 0.18 in 1991 would imply a large stock that was very lightly fished (an *F* about one seventh of *M*); an *M* of 0.15 would imply an *F* of 0.05, about a third of *M*.

The model run estimated a B_0 of 63.2 kt (95% CI 52.3–87.0 kt), and stock status of 45% B_0 (95% CI 32–61%). Median stock size was about the same as the Lognormal CPUE and *M* = 0.18 run. However, median stock status was lower than the Combined CPUE & *M* = 0.18 run (which had a stock status of 54% B_0). The stock in 2017 was likely (p = 0.77) to be above the biomass target of 40% B_0, and exceptionally unlikely (p < 0.01) to be below the soft limit of 20% B_0.

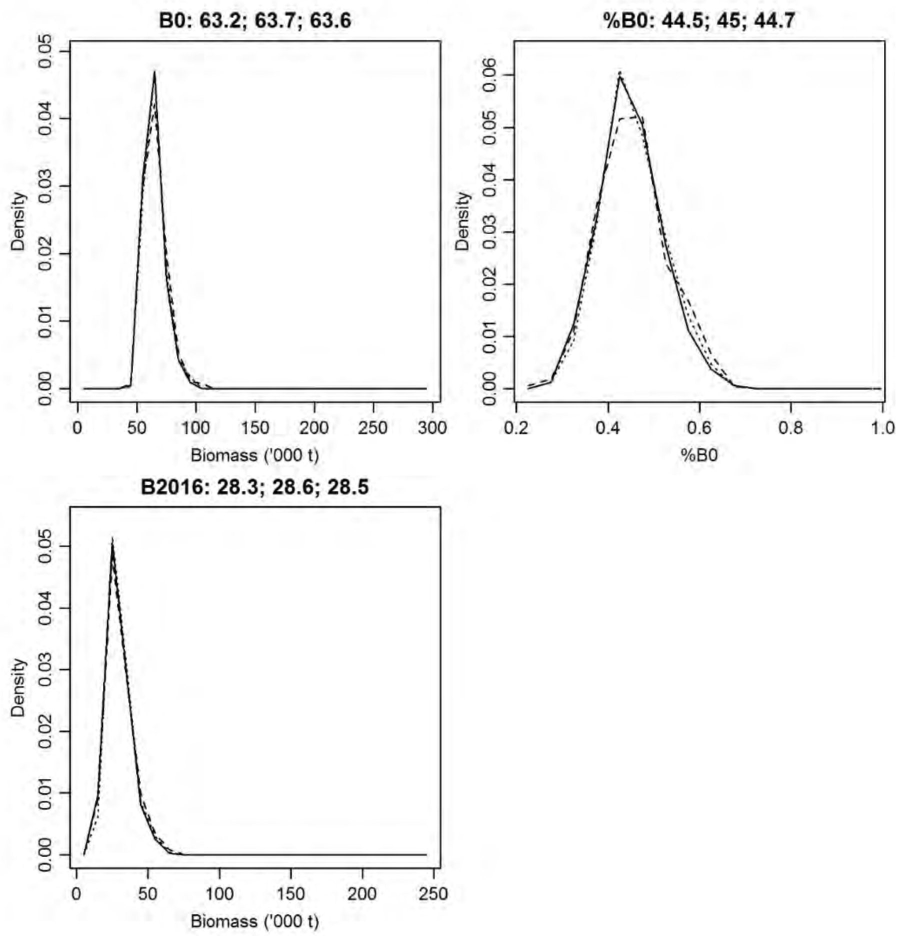

Figure A1: Joint posterior estimates of B_0, %B_0, and B_{2016}, from 3000 samples from the three MCMC chains (1000 from each chain), for the Lognormal CPUE & *M* = 0.15 model run.

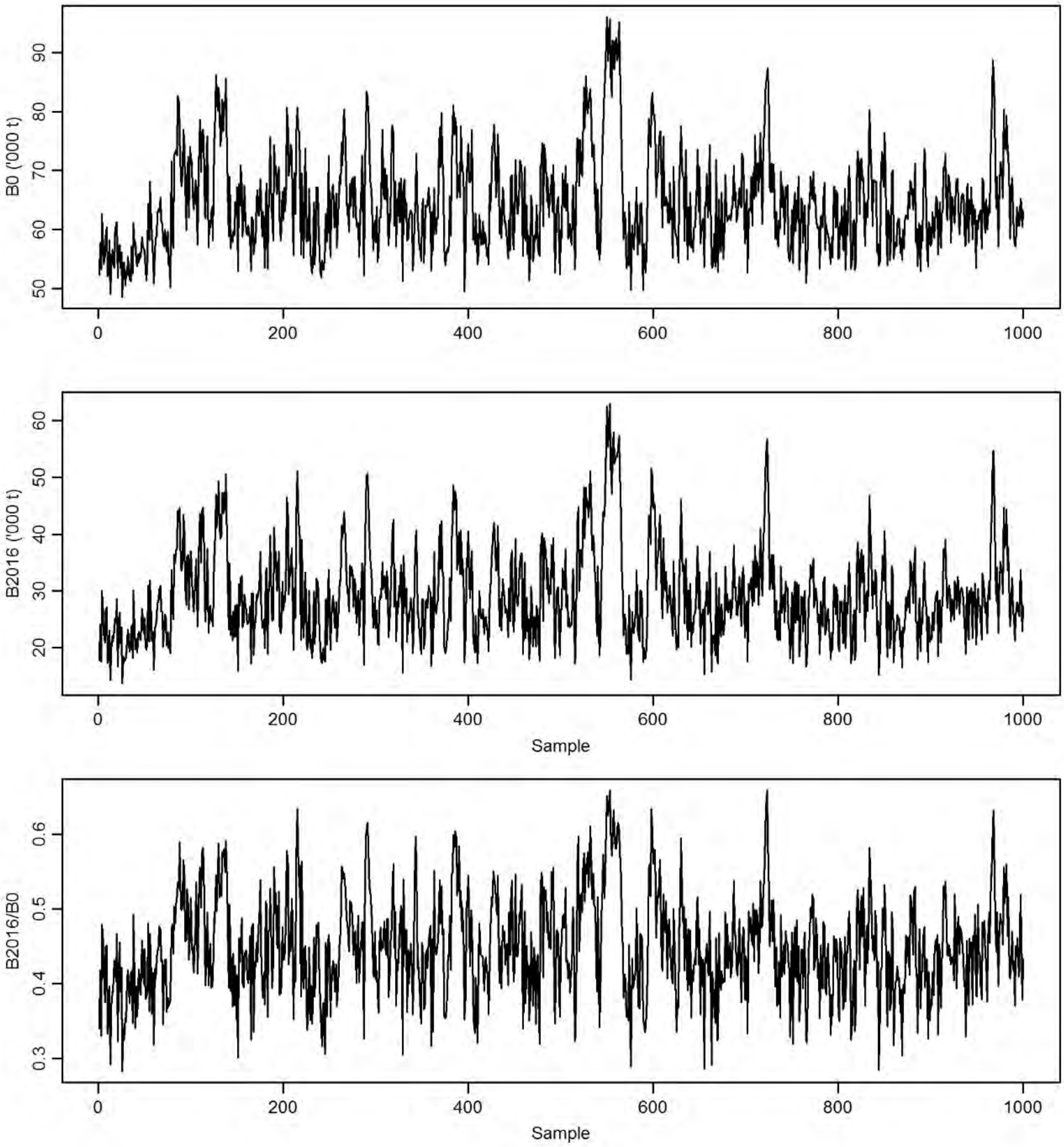

Figure A2: B_0, B_{2016}, and B_{2016}/B_0 estimates from 1000 samples from the first MCMC chain for the Lognormal CPUE & *M* = 0.15 model run.

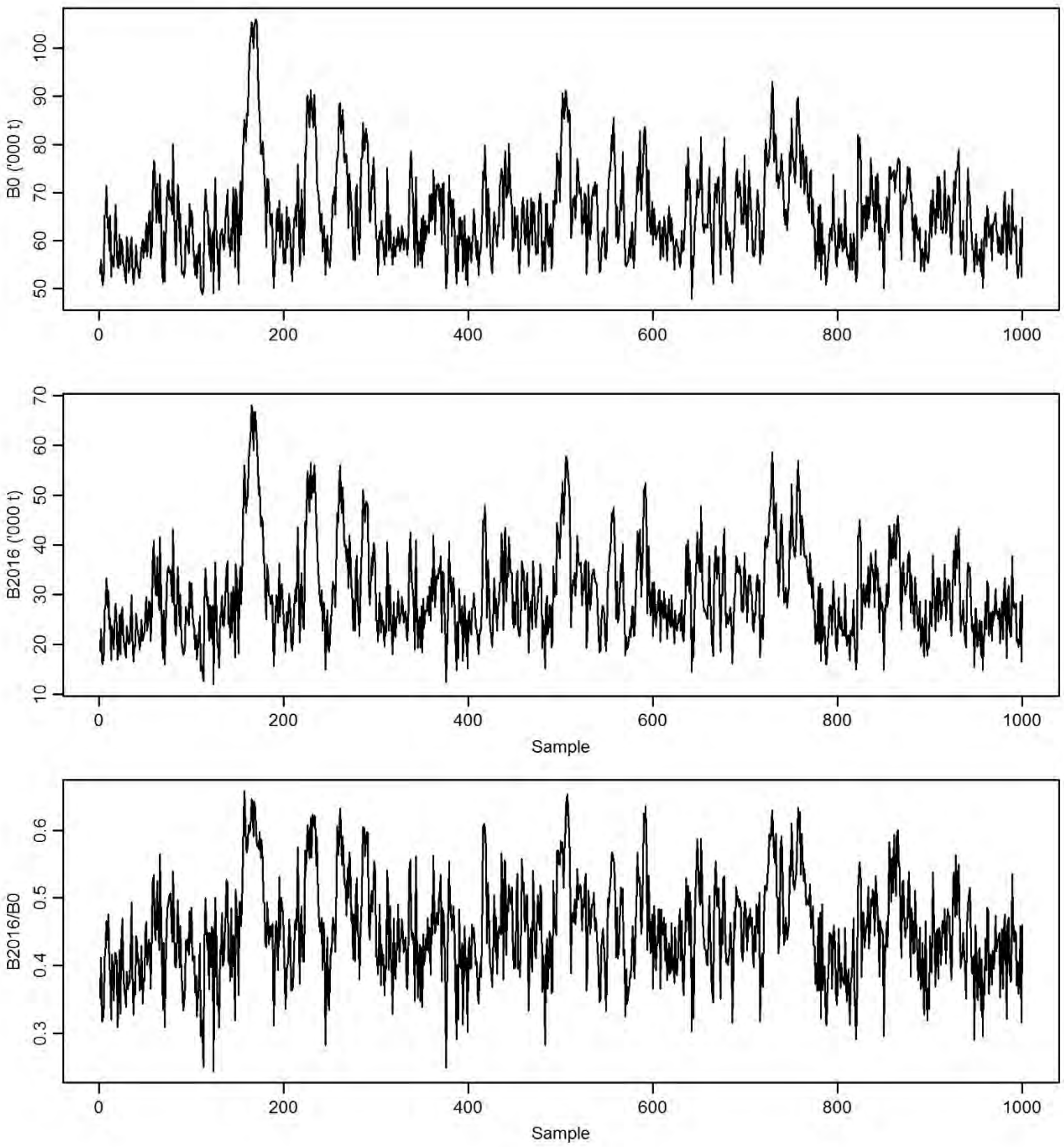

Figure A3: B_0, B_{2016}, and B_{2016}/B_0 estimates from 1000 samples from the second MCMC chain for the Lognormal CPUE & *M* = 0.15 model run.

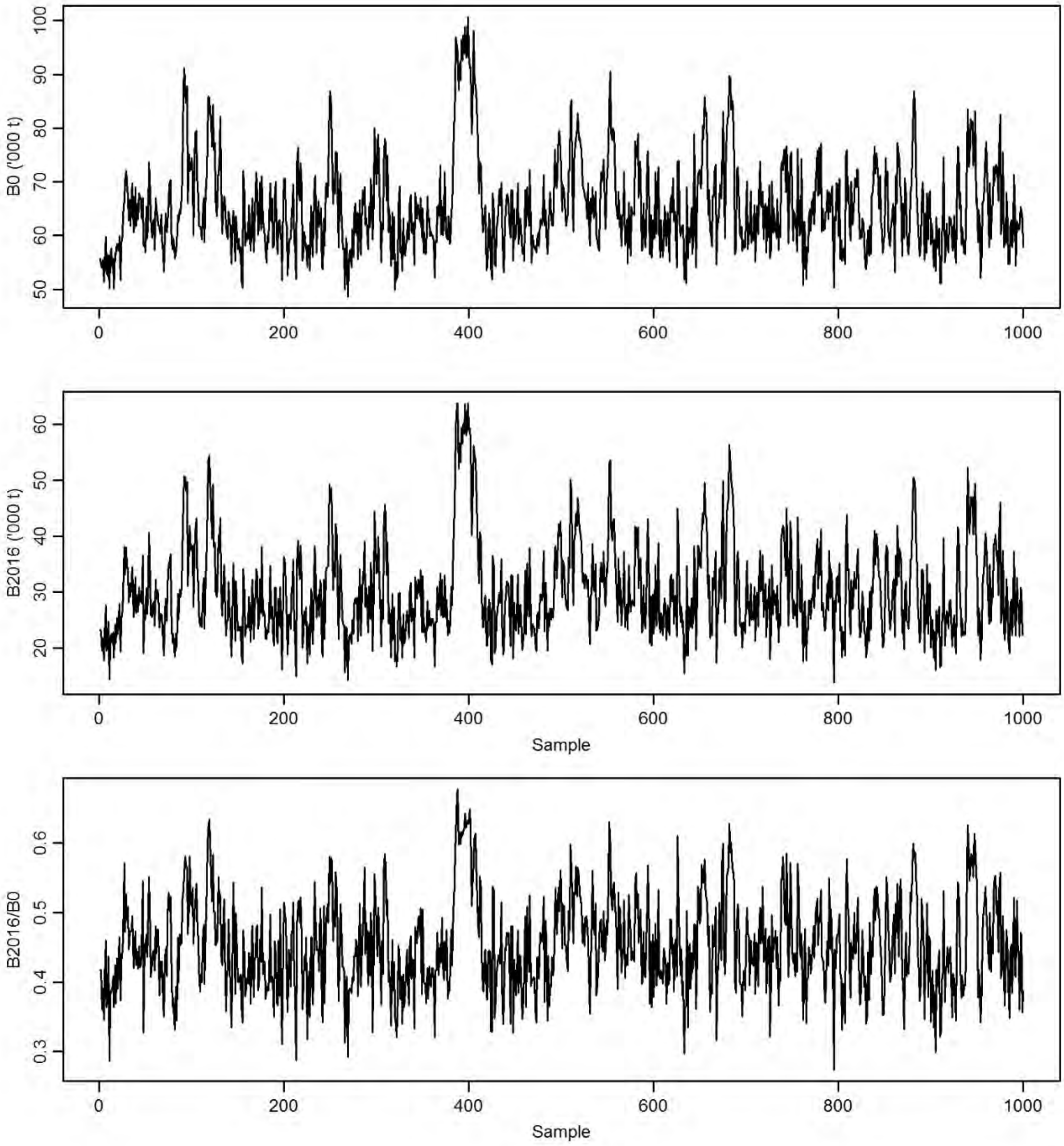

Figure A4: B_0, B_{2016}, and B_{2016}/B_0 estimates from 1000 samples from the third MCMC chain for the Lognormal CPUE & *M* = 0.15 model run.

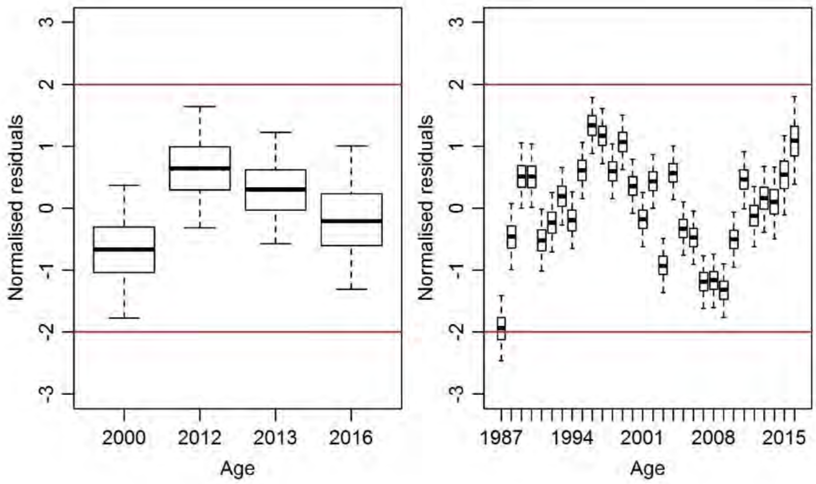

Figure A5: Pearson residuals from the "fit" to the *Tangaroa* trawl survey biomass index (left panel) and lognormal CPUE index (right panel), for the combined MCMC chain samples (n = 3000) from the Logormal CPUE & *M* = 0.15 model run.

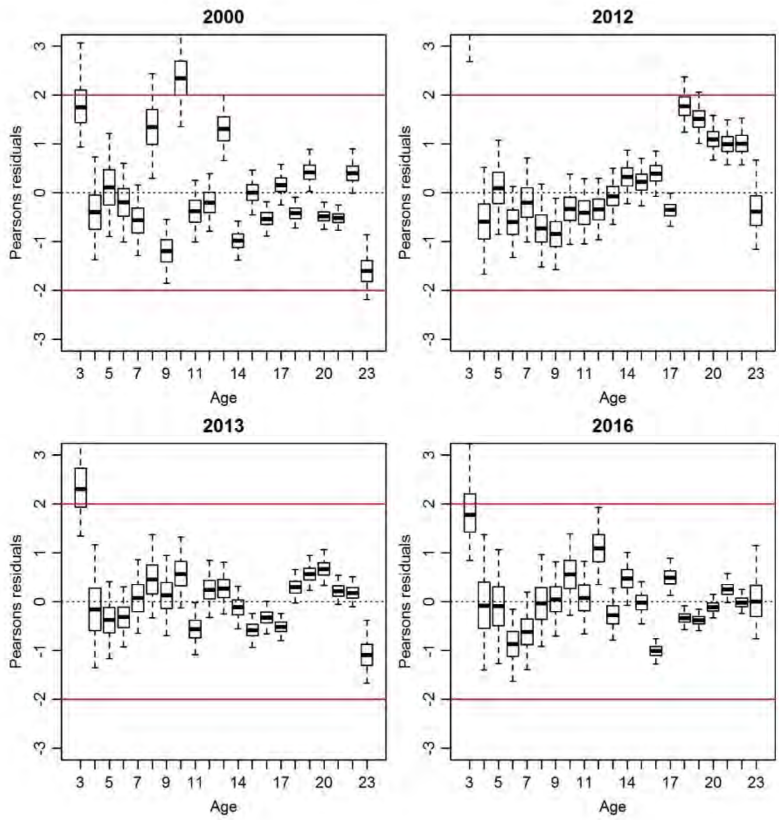

Figure A6: Pearson residuals from the "fit" to the *Tangaroa* catch-at-age observations, from the combined MCMC chain samples (n = 3000) for the Logormal CPUE & *M* = 0.15 model run.

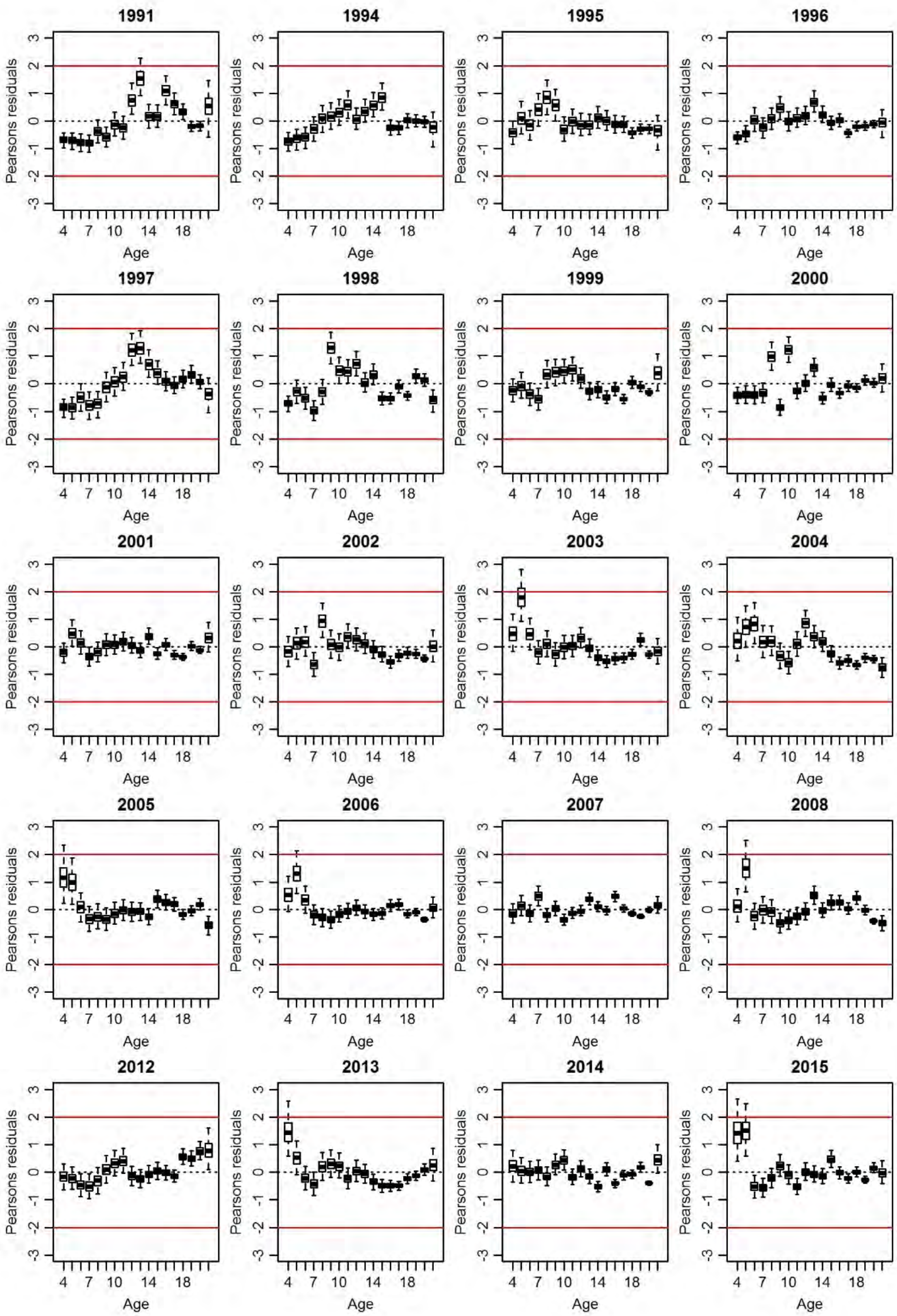

Figure A7: Pearson residuals from the "fit" to the commercial trawl catch-at-age observations, from the combined MCMC chain samples (n = 3000) for the Logormal CPUE & *M* = 0.15 model run.

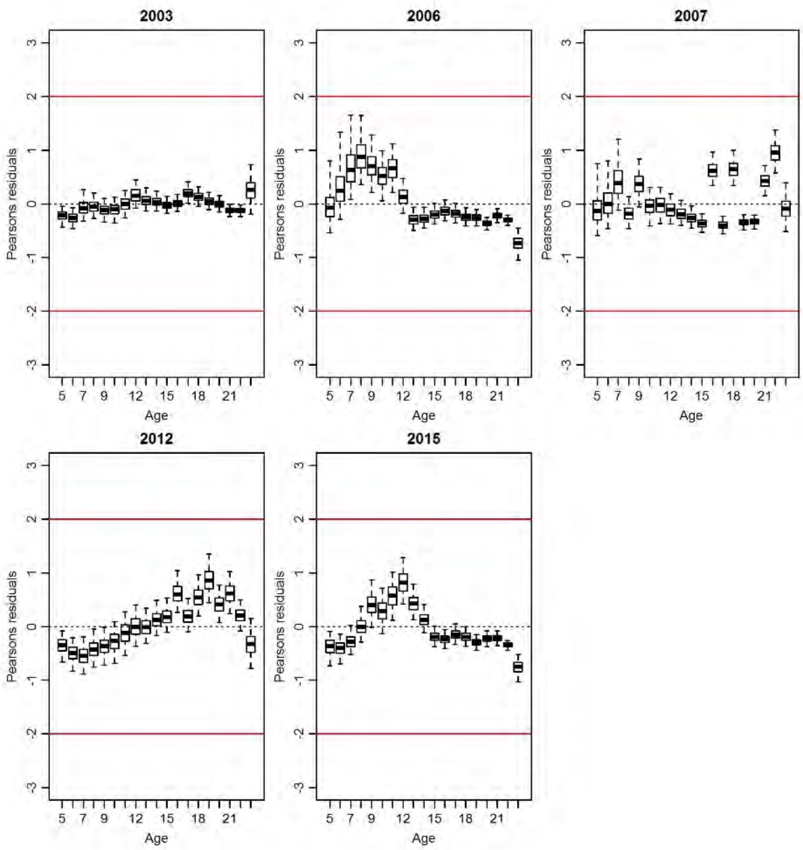

Figure A8: Pearson residuals from the "fit" to the commercial longline fishery catch-at-age observations, from the combined MCMC chain samples (n = 3000) for the Logormal CPUE & *M* = 0.15 model run.

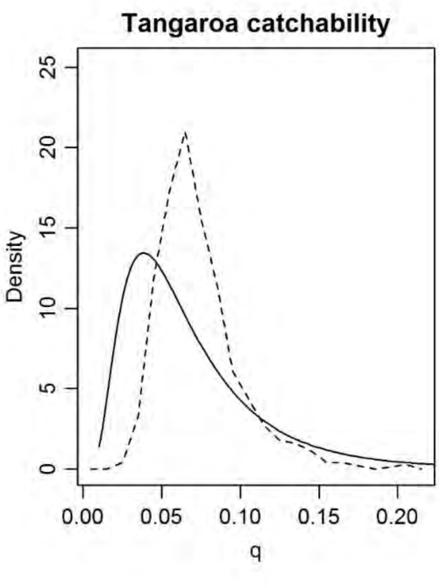

Figure A9: Posterior joint distribtions (broken line) and prior (solid line) for the *Tangaroa q*, from the combined MCMC chain samples (n = 3000) for the Logormal CPUE & *M* = 0.15 model run.

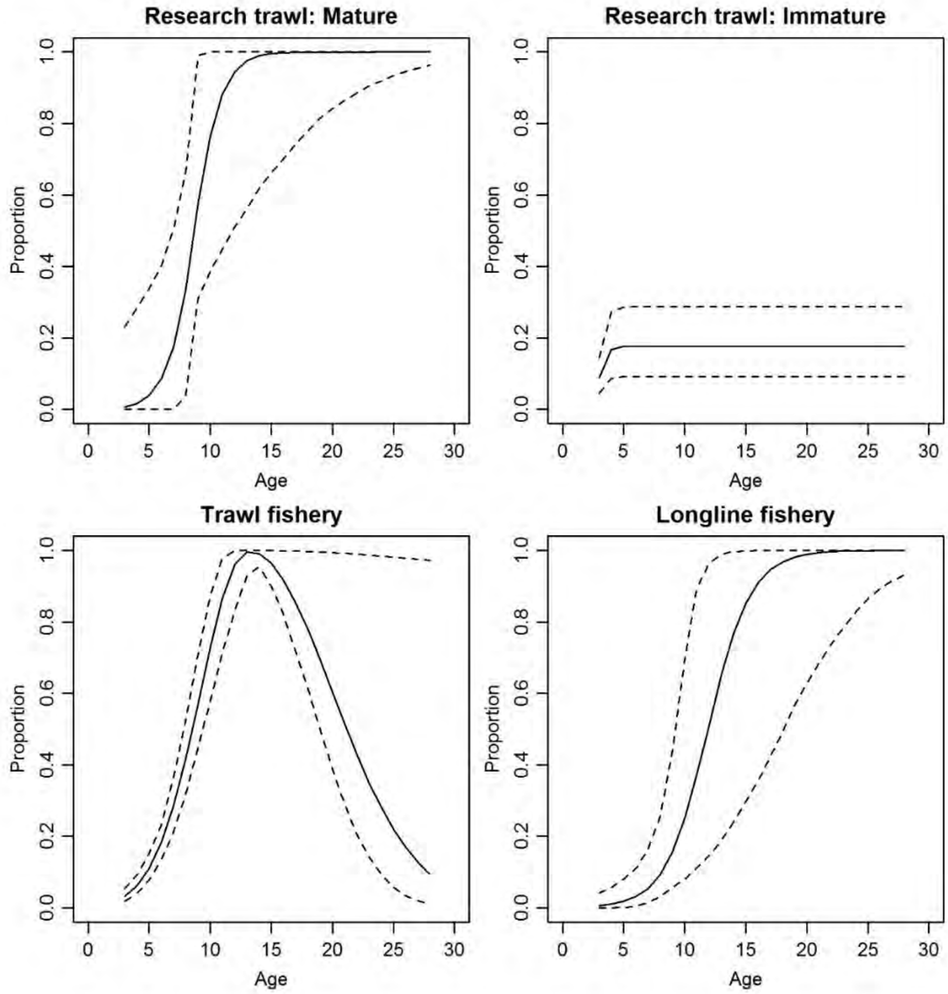

Figure A10: Joint posterior estimates of selectivities, from the combined MCMC chain samples (n = 3000) for the Logormal CPUE & M = 0.15 model run.

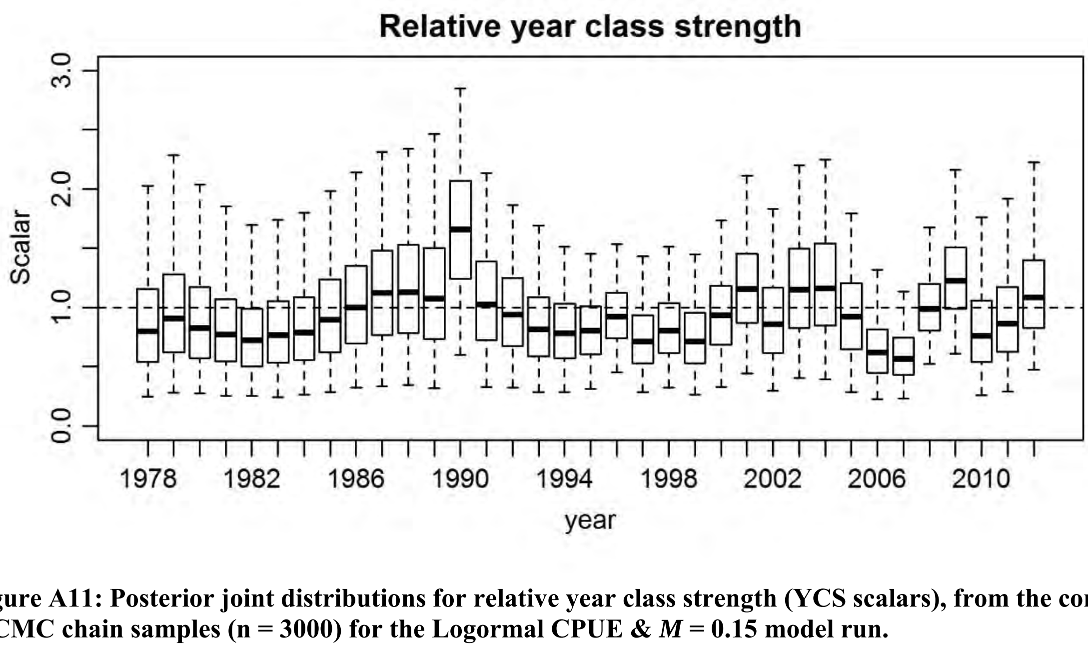

Figure A11: Posterior joint distributions for relative year class strength (YCS scalars), from the combined MCMC chain samples (n = 3000) for the Logormal CPUE & M = 0.15 model run.

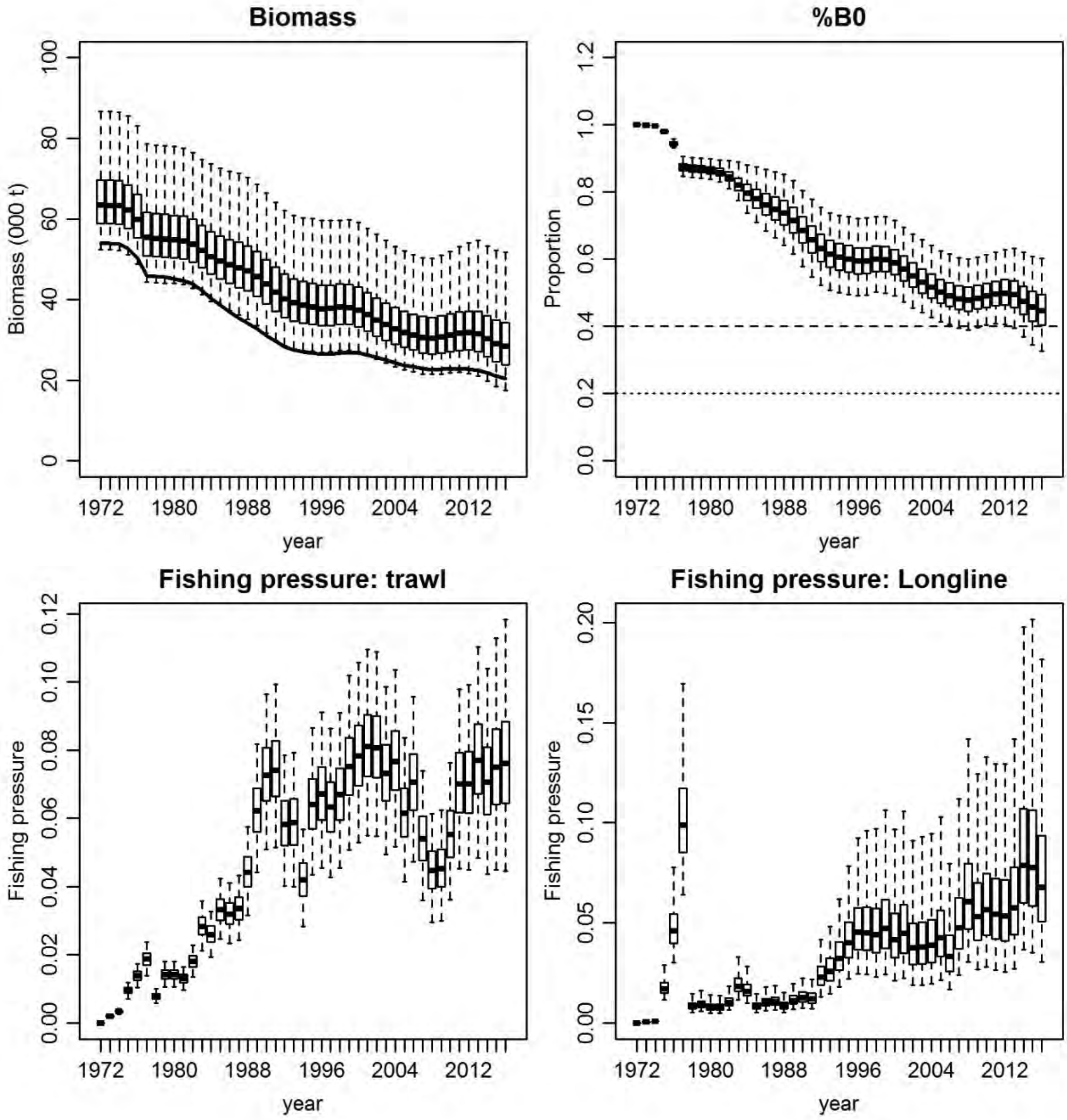

Figure A12: Posterior joint distributions of B_0, $\%B_0$, and fishing pressure by fleet, from the combined MCMC chain samples (n = 3000) for the Logormal CPUE & *M* = 0.15 model run. The solid line in the Biomass panel indicates vulnerable biomass.

APPENDIX B

A comparison of CASAL and Casal2 parameter estimates is shown in Table B.1. The MPD run with Casal2 produced a different B_0 estimate from the CASAL run (Run 9). Further investigation revealed that Casal2 had converged to a slightly better minimum than CASAL. The CASAL run was then repeated with a lower tolerance, and it then replicated the Casal2 result (as shown below). This difference in MPD is consistent with the likelihood profiles, where the likelihood surface for higher values of B_0 is relatively flat.

Table B.1: Comparison of the MPD estimates of model parameters for the Combined CPUE model run in CASAL and Casal2.

	CASAL	Casal2
B0	128900	128900
wcsiTANq	0.021455	0.021455
wcsiTRLcpueq	1.23E-05	1.23E-05
M	0.204268	0.204268
selectivity[wcsiTANsel_mature].mu	11.3846	11.3846
selectivity[wcsiTANsel_mature].sigma_l	2.49815	2.49815
selectivity[wcsiTANsel_mature].sigma_r	39.7624	39.7624
selectivity[wcsiTANsel_immature].alpha	0.141059	0.141059
selectivity[wcsiTRLsel].mu	12.9595	12.9595
selectivity[wcsiTRLsel].sigma_l	4.20751	4.20751
selectivity[wcsiTRLsel].sigma_r	7.79538	7.79538
selectivity[wcsiLLNsel].a50	10.6413	10.6413
selectivity[wcsiLLNsel].ato95	3.51749	3.51749
ycs_values{1974}	0.43923	0.43923
ycs_values{1975}	0.458119	0.458119
ycs_values{1976}	0.483469	0.483469
ycs_values{1977}	0.515896	0.515896
ycs_values{1978}	0.517392	0.517392
ycs_values{1979}	0.588192	0.588192
ycs_values{1980}	0.540148	0.540148
ycs_values{1981}	0.475493	0.475493
ycs_values{1982}	0.449889	0.449889
ycs_values{1983}	0.469241	0.469241
ycs_values{1984}	0.500968	0.500968
ycs_values{1985}	0.526569	0.526569
ycs_values{1986}	0.574966	0.574965
ycs_values{1987}	0.634491	0.634491
ycs_values{1988}	0.635845	0.635845
ycs_values{1989}	0.591082	0.591082
ycs_values{1990}	0.901280	0.901281
ycs_values{1991}	0.580755	0.580755
ycs_values{1992}	0.561346	0.561346
ycs_values{1993}	0.468372	0.468372
ycs_values{1994}	0.457375	0.457375
ycs_values{1995}	0.455953	0.455953
ycs_values{1996}	0.516623	0.516623
ycs_values{1997}	0.428013	0.428013
ycs_values{1998}	0.479451	0.479451
ycs_values{1999}	0.431984	0.431984
ycs_values{2000}	0.541075	0.541076
ycs_values{2001}	0.65908	0.65908
ycs_values{2002}	0.489636	0.489636
ycs_values{2003}	0.707622	0.707622
ycs_values{2004}	0.749413	0.749413
ycs_values{2005}	0.588527	0.588526
ycs_values{2006}	0.405366	0.405366
ycs_values{2007}	0.385194	0.385194
ycs_values{2008}	0.637899	0.637899
ycs_values{2009}	0.831015	0.831015
ycs_values{2010}	0.543634	0.543634
ycs_values{2011}	0.590693	0.590693
ycs_values{2012}	0.711652	0.711652