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EXECUTIVE SUMMARY

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Ling in QMAs 3–7 and part of QMA 2 are treated as five biological stocks for assessment purposes: Chatham Rise (LIN 3 and LIN 4), Campbell Plateau and Stewart-Snares shelf (LIN 5, and LIN 6 west of 176° E), Bounty Plateau (LIN 6 east of 176° E), west coast South Island (LIN 7 west of Cape Farewell), and Cook Strait (those parts of LIN 2 and LIN 7 making up statistical areas 16 and 17 in Cook Strait). These stocks are subsequently referred to as LIN 3&4, LIN 5&6, LIN 6B, LIN 7WC, and LIN 7CK, respectively.

New model input data for all stocks are reported here. Updated Bayesian assessments are presented for LIN 3&4 and LIN 7WC, implemented as a two stock model using the general-purpose stock assessment program CASAL v2.01. The assessments incorporated all relevant biological parameters, the commercial catch histories, updated CPUE series, and series of catch-at-age and catch-at-length data. The model structure allows the input of catch histories and relative abundance indices attributable to different fishing methods, seasons, areas, and stocks.

The status of the west coast South Island ling stock (LIN 7WC) is poorly known, primarily because the assessment is driven by trawl fishery catch-at-age data moderated by CPUE indices that may not reliably index abundance. It is not known if recent landings and the current TACC are sustainable in the long term, or are at levels which will allow the stocks to move towards a size that will support the MSY. The stock assessment model results do not provide reliable estimates of current biomass as a percentage of B_0, but at least one of the model runs is clearly too pessimistic. The relatively constant catch history since 1989, relatively flat CPUE indices, and relatively low estimates of *F* from the catch curve all suggest that future catches at the current level are probably sustainable, at least in the short term. There are no reliable estimates of yield for the LIN 7WC stock.

In contrast, the stock status of ling on the Chatham Rise (LIN 3&4) appears to be reasonably well determined. The biomass was estimated to have reached its minimum level of about 49% of B_0 in 2001 after increased levels of exploitation following the development of the auto-line fishery. However, recent reductions in catch and the recruitment of some relatively strong year classes have resulted in a stock recovery. Current biomass from the base case model run is estimated to be 58% B_0, with a 95% credible interval (CI) of 52–65%. At current catch levels, projected biomass in 2009 is estimated to have increased to 69% B_0 (58–81% CI). Sensitivity analyses gave similar results to the base case run. All estimates of MCY are greater than the combined TACCs for the LIN 3 and LIN 4 stocks.

1. INTRODUCTION

This document reports the results of Objective 2 of Ministry of Fisheries Project LIN2003/01. The project objectives were as follows.

1. To update the standardised catch and effort analyses from the ling longline and trawl bycatch fisheries in LIN 3 & 4, 5 & 6, and 7, with the addition of data up to the end of the 2002–03 fishing year.
2. To update the stock assessments of ling in LIN 3 & 4, 5 & 6, and 7, including estimating biomass and yields.
3. To collate the available information from scientific observers logbooks on the operation of the ling longline fishery up to 2002–03.

The results from Objective 1 have been reported by Horn (2004c) and from Objective 3 by Horn (2004b).

Ling are managed as eight administrative QMAs, although five of these (LIN 3, 4, 5, 6, and 7) (Figure 1) currently produce about 95% of landings. Research has indicated that there are at least four major biological stocks of ling in New Zealand waters (Horn & Cordue 1996): the Chatham Rise, the Campbell Plateau (including the Stewart-Snares shelf and Puysegur Bank), the Bounty Platform, and the west coast of the South Island. The stock affinity of ling in Cook Strait is unknown.

In the stock assessment process, five biological stocks of ling are recognised in New Zealand waters, defined as follows: Chatham Rise (LIN 3 and LIN 4), Campbell Plateau and Stewart-Snares shelf (LIN 5, and LIN 6 west of 176° E), Bounty Plateau (LIN 6 east of 176° E), west coast South Island (LIN 7 west of Cape Farewell), and Cook Strait (those parts of LIN 2 and LIN 7 making up statistical areas 16 and 17 in Cook Strait). These stocks are referred to as LIN 3&4, LIN 5&6, LIN 6B, LIN 7WC, and LIN 7CK, respectively. The most recent assessments of all these stocks were reported by Horn & Dunn (2003) and Horn (2004a). Although objective 2 of this project is to assess ling in LIN 3, 4, 5, 6, and 7, there was an understanding that not all stocks would be assessed, and that the stocks to be assessed would be determined by the Middle Depth Species Fishery Assessment Working Group. LIN 3&4 and LIN 7WC were the fishstocks chosen for full assessment. However, input files for all stocks were updated where possible (i.e., catch histories, CPUE series, catch-at-age, and catch-at-length).

The current assessments used CASAL v2.01, a generalised age- or length-structured fish stock assessment model (Bull et al. 2003). The LIN 3&4 assessment incorporates new catch-at-age and catch-at-length data, and an updated longline CPUE series. The LIN 7WC assessment incorporates new catch-at-age data, and updated line and trawl CPUE series. For the first time for ling, the assessment of these two stocks was implemented as a two stock model. Estimates of ling biomass from a trawl survey off WCSI in 2000 are also presented, but were not used in the modelling process.

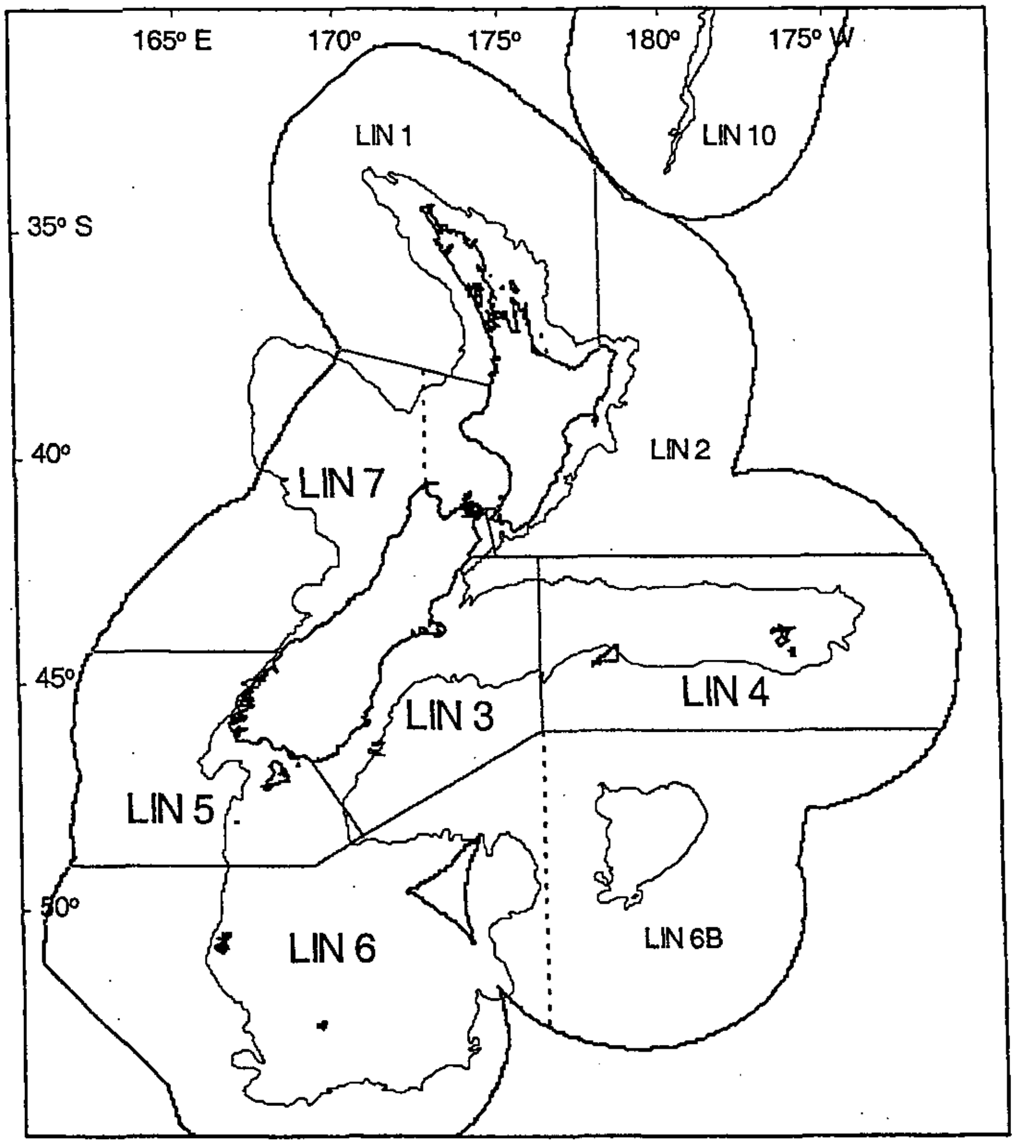


Figure 1: Area of Fishstocks LIN 3, 4, 5, 6, and 7. Adjacent ling fishstock areas are also shown, as is the 1000 m isobath. The boundaries used to separate biological stock LIN 6B from the rest of LIN 6, and the west coast South Island section of LIN 7 from the Cook Strait section, are shown as broken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

2. REVIEW OF THE FISHERY

Reported landings of ling are summarised in Tables 1 and 2. From 1975 to 1980 there was a substantial fishery on the Chatham Rise (and to a lesser extent in other areas) carried out by Japanese and Korean longliners. During the 1980s, most ling were taken by trawl. In the early 1990s a longline fishery developed, with a resulting increase in landings from LIN 3, 4, 5, and 6 (Table 2), although since about 2000 there has been a decline in the line catch in most areas. Landings on the Bounty Plateau are taken almost exclusively by longline. A small, but important, quantity of ling is also taken by setnet in LIN 3 and LIN 7 (Horn 2001). In the west coast South Island section of LIN 7, about two-thirds of ling landings are taken as a trawl bycatch, primarily of the hoki fishery. In Cook Strait, about 75% of ling landings are taken as a bycatch of the hoki trawl fishery, with the remaining landings generally made by the target line fishery (Horn 2001).

Under the Adaptive Management Programme (AMP), TACCs for LIN 3 and 4 were increased by about 30% for the 1994–95 fishing year to a level that was expected to allow any decline in biomass to be detected by trawl surveys of the Chatham Rise (with c.v. 10% or less) over the 5 years following the increase. The TACCs were set at 2810 and 5720 t, respectively. These stocks were removed from the AMP from 1 October 1998, with TACCs maintained at the increased level. Following a decline in catch rates (as indicated from the analysis of longline CPUE data) and assessment model results indicating that current biomass was about 25–30% of B_0, the TACCs for LIN 3 and LIN 4 were reduced to 2060 t and 4200 t, respectively, from 1 October 2000. The sum of these values was at the level of the combined CAY estimate of 6260 t for LIN 3&4 from Horn et al. (2000). Also under the AMP, the TACC for LIN 1 was increased to 400 t from 1 October 2002, within an overall TAC of 463 t.

TACCs for LIN 5 and 6 have been increased by about 20% to 3600 t and 8500 t, respectively, from 1 October 2004. This follows an assessment (Horn 2004a) indicating that current levels of exploitation have had little impact on the size of the Campbell Plateau stock.

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

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

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

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

Table 2: Reported landings (t) of ling by Fishstock from 1983–84 to 2002–03 and actual TACCs (t) from 1986–87 to 2002–03. Estimated landings for LIN 7 from 1987–88 to 1992–93 include an adjustment for ling bycatch of hoki trawlers, based on records from vessels carrying observers.

Fishstock	LIN 1		LIN 2		LIN 3		LIN 4		LIN 5	
QMA (s)	1 & 9		2		3		4		5	
	Landings	TACC	Landings	TACC	Landings	TACC	Landings	TACC	Landings	TACC
1983–84*	141	–	594	–	1 306	–	352	–	2 605	–
1984–85*	94	–	391	–	1 067	–	356	–	1 824	–
1985–86*	88	–	316	–	1 243	–	280	–	2 089	–
1986–87#	77	200	254	910	1 311	1 850	465	4 300	1 859	2 500
1987–88#	68	237	124	918	1 562	1 909	280	4 400	2 213	2 506
1988–89#	216	237	570	955	1 665	1 917	232	4 400	2 375	2 506
1989–90#	121	265	736	977	1 876	2 137	587	4 401	2 277	2 706
1990–91#	210	265	951	977	2 419	2 160	2 372	4 401	2 285	2 706
1991–92#	241	265	818	977	2 430	2 160	4 716	4 401	3 863	2 706
1992–93#	253	265	944	980	2 246	2 162	4 100	4 401	2 546	2 706
1993–94#	241	265	779	980	2 171	2 167	3 920	4 401	2 460	2 706
1994–95#	261	265	848	980	2 679	2 810	5 072	5 720	2 557	3 001
1995–96#	245	265	1 042	980	2 956	2 810	4 632	5 720	3 137	3 001
1996–97#	313	265	1 187	982	2 963	2 810	4 087	5 720	3 438	3 001
1997–98#	303	265	1 032	982	2 916	2 810	5 215	5 720	3 321	3 001
1998–99#	208	265	1 070	982	2 706	2 810	4 642	5 720	2 937	3 001
1999–00#	313	265	983	982	2 799	2 810	4 402	5 720	3 136	3 001
2000–01#	296	265	1 104	982	2 330	2 060	3 861	4 200	3 430	3 001
2001–02#	303	265	1 034	982	2 164	2 060	3 602	4 200	3 294	3 001
2002–03#	246	400	996	982	2 528	2 060	2 997	4 200	2 936	3 001

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

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

3. RESEARCH RESULTS

3.1 Catch-at-age

New catch-at-age distributions from the following samples are presented in Appendix A.

LIN 3&4: Trawl survey, Jan 2004
LIN 3&4: Commercial longline, Jul–Oct 2003
LIN 5&6: Trawl survey, Dec 2003
LIN 5&6: Commercial longline (spawning fishery), Oct–Dec 2002
LIN 5&6: Commercial longline (non-spawning fishery), Feb–Jul 2003
LIN 5&6: Commercial trawl, Jan–Jul 2003
LIN 7 (WCSI): Commercial trawl, Jun–Sep 2003
Cook Strait: Commercial trawl, Jun–Sep 2003

The mean weighted c.v.s for these samples ranged from 19 to 29%, all lower than the target of 30%.

Otoliths from all the commercial fishery samples were collected by observers, with the Cook Strait sample being augmented by some shed sampling. Otoliths from each sample were selected, prepared, and read as follows. Otoliths (for each sex separately) from each 1 cm length class were selected proportionally to their occurrence in the scaled length frequency, with the constraint that the number of otoliths in each length class (where available) was at least one. In addition, all otoliths from fish in the extreme right hand tail of the scaled length frequency (i.e., large fish constituting 2% of that length frequency) were fully sampled. This provides a sample with a mean weighted c.v. over all age classes similar to that from proportional sampling, but will do better than uniform sampling for the older age classes. Otoliths were prepared and read using the validated ageing method of Horn (1993). Catch-at-age and catch-at-length estimates scaled to the commercial catch by stratum were produced using the 'catch.at.age' software developed by NIWA (Bull & Dunn 2002). The software scales the length frequency of fish from each landing up to the landing weight, sums over landings in each stratum, and scales up to the total stratum catch, to yield length frequencies by stratum and overall. An age-length key is constructed from otolith data and applied to the length frequencies to yield age frequencies. The precision of each length or age frequency is measured by the mean weighted c.v., which is calculated as the average of the c.v.s for the individual length or age classes weighted by the proportion of fish in each class. Coefficients of variation are calculated by bootstrapping: fish are resampled within each landing, landings are resampled within each stratum, and otoliths are simply randomly resampled.

No catch-at-age data were available from the commercial trawl fishery on the Chatham Rise (LIN 3&4); the selectivity ogive for this fishery has previously been derived from numbers-at-length data (Horn & Dunn 2003). However, because the von Bertalanffy curves are relatively flat for ling older than about 14 years, the model cannot accurately determine the likely age of larger fish. Hence, the resulting ogives are poorly defined for fish older than about 14 years (Horn & Dunn 2003). The catch-at-length series has used data collected from November to May each year; this has been the period of most consistent observer coverage since the 1991–92 fishing year. Trawl surveys have been completed annually in the approximate middle of the November to May period (i.e., January), and samples of otoliths from these surveys have already been aged. Consequently, the length distributions from the trawl fishery since 1991 were applied to the corresponding trawl survey age-length key to produce estimates of numbers-at-age from the trawl fishery. A similar application of trawl survey age-length keys to commercial trawl length distributions was previously conducted on the LIN 5&6 stock, and produced more logical ogives than those derived solely from numbers-at-length data (Horn 2004a). It is assumed that any disadvantages from this process owing to differences between commercial and survey fishing gear will be outweighed by the better fitting of ogives to numbers-at-age, rather than numbers-at-length, data.

3.2 Catch-at-length

The initial formulation of series of numbers-at-length for ling from various trawl and longline fisheries was described by Horn (2002). These series are included in the stock assessment model where a lack of age data precludes their input as catch-at-age. In the present assessment, the catch from all the major trawl fisheries (i.e., LIN 3&4, 5&6, 7WC, and 7CK) could be converted into catch-at-age.

Previous length-frequency series for the longline fisheries have been derived using data from a logbook scheme set up in 1995 by SeaFIC (described by Langley 2001). SeaFIC logbook data were used to update the longline series for the 2002–03 fishing year. Data provided by SeaFIC from sampled sets in each fishery had simply been combined to produce distributions by sex; no scaling had been conducted. Series from the following fisheries were derived for use as model inputs:

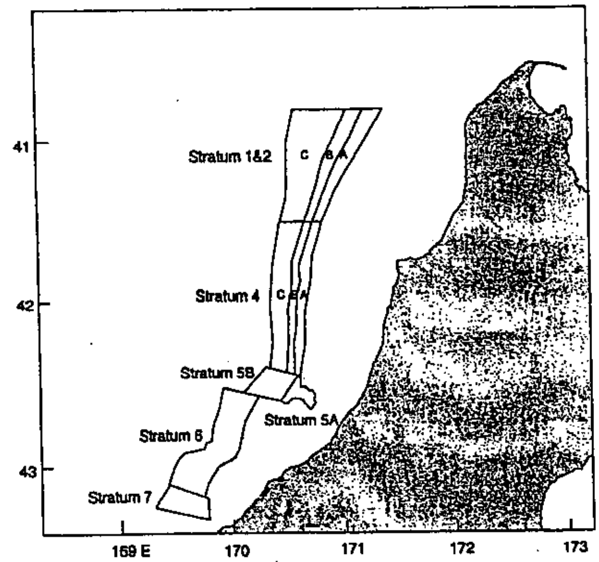
Chatham Rise (LIN 4 only) — June to October 2003
Puysegur (part of LIN 5) — October to December 2002
Pukaki/Campbell (part of LIN 6) — March to July 2003
Bounty Plateau (part of LIN 6) — November 2002 to February 2003

3.3 WCSI trawl survey biomass

No fishery-independent data are available for incorporation into the WCSI ling assessment. However, a combined acoustic and trawl survey of the hoki fishing grounds off WCSI was conducted in winter 2000 (O'Driscoll et al. 2004). The acoustics component of the survey covered depths between 300 and 650 m, from 40° 45' S to about 43° 20' S (Figure 2). However, the random bottom trawl component of the survey covered only the two strata north of the Hokitika Trench (i.e., north of about 42° 24' S). The bottom trawl gear used was the same as is used in the trawl surveys of hoki and middle depth species on the Chatham Rise and Campbell Plateau. Hence, the values of trawl catchability (q) for ling from the surveys in all three areas would be expected to be quite similar.

While the estimate of ling biomass from strata 1, 2, and 4 is relatively precise (i.e., c.v. = 17%), ling from the WCSI stock are clearly distributed to the north and south of the surveyed area, and also inshore of the 300 m contour (Horn 2001). It is also apparent from a CPUE analysis of the ling bycatch from the hoki target fishery that catch rates of ling (and, presumably, relative abundance of ling) vary with latitude (Horn 2004c). The CPUE analysis (Figure 3) indicates that, relative to the area of the trawl survey (40° 45' to 42° 24' S), ling are about 3 times as abundant in the Hokitika Trench (strata 5A and 5B, ~42° 24' S), and about 1.5 times as abundant in the surveyed area to the south (strata 6 and 7, 42° 40' to 43° 20' S).

Based on the estimate of biomass from the trawl survey, and estimates of surface area in depths of 200 to 650 m between 40° and 45° S, and making assumptions from the CPUE analysis about the relative abundance of ling in different strata, it is possible to construct 'trawl survey' biomass estimates for the entire WCSI ling stock. The mean ling biomass density from the two surveyed northern strata is 0.22 t/km^2. A 'minimum' survey biomass estimate was derived assuming ling occurred at this density in the strata not surveyed by trawl and in all areas south and inshore of the surveyed areas, and at half this density (i.e., 0.11 t/km^2) in the northern unsurveyed area. Data from inshore trawl surveys and the catch-effort database suggest that ling abundance is lower in the northern unsurveyed area than in areas south of about 41° S (author's unpublished data). A more 'likely' survey biomass was derived assuming densities similar to those used for the 'minimum' estimate, except in strata 5, 6, and 7 where they were increased by the CPUE factors noted above. Calculation of these two biomass estimates is shown in Table 3. These estimates are not used in the modelling process, but are compared to the model results.



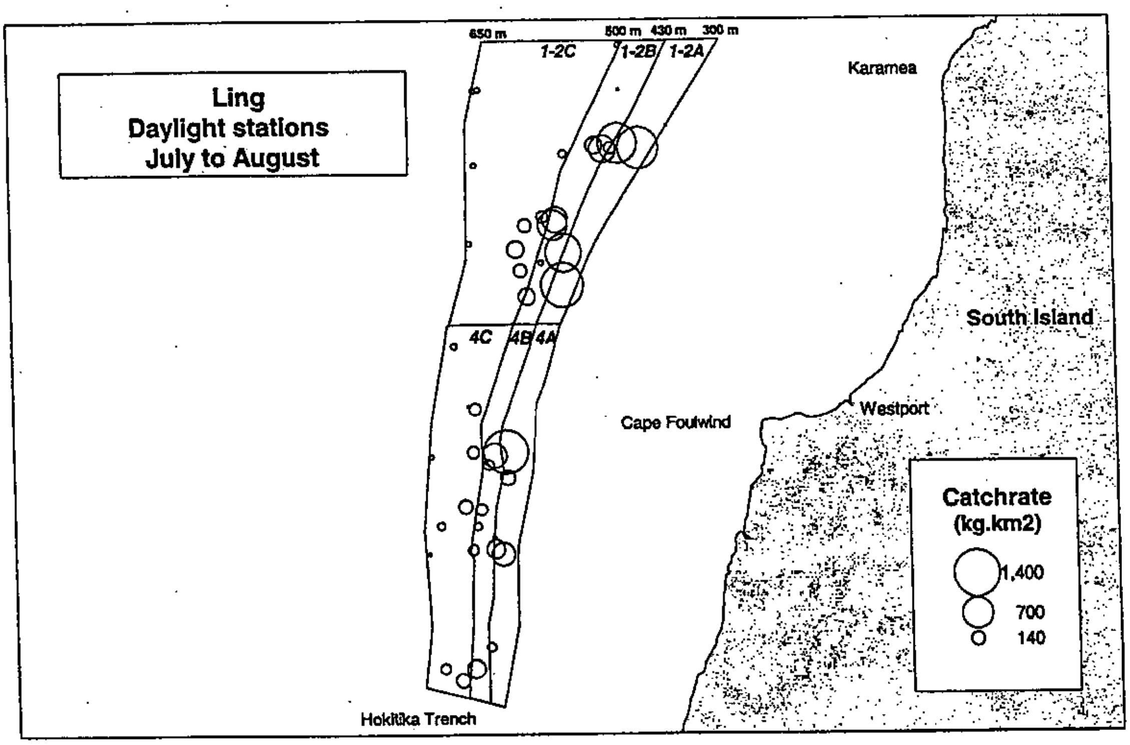


Figure 2: Stratum boundaries for the 2000 acoustic survey of hoki off WCSI, and the catch rates of ling in daytime random bottom trawls carried out in Strata 1&2 and 4 (from O'Driscoll et al. 2004).

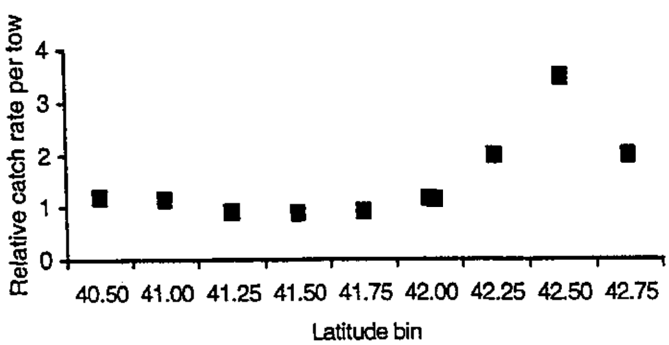


Figure 3: Expected relative catch rate of ling bycatch in the WCSI hoki target fishery, by latitude bin, as determined from a CPUE analysis of data collected by fishery observers.

Table 3: Estimates of ling relative biomass, by area, for the WCSI stock in winter 2000.

Area definition	Area (km^2)	'Minimum' biomass Density (t/km^2)	'Minimum' biomass Biomass (t)	'Likely' biomass Density (t/km^2)	'Likely' biomass Biomass (t)
Strata 1 & 2	3 786	0.26	974	0.26	974
Stratum 4	2 833	0.17	480	0.17	480
Stratum 5	783	0.22	172	0.22×3.0	516
Strata 6 & 7	2 443	0.22	537	0.22×1.5	806
200–300 m	2 400	0.22	528	0.22	528
Southern unsurveyed	350	0.22	77	0.22	77
Northern unsurveyed	7 500	0.11	825	0.11	825
Total			3 593		4 206

3.4 WCSI fishing mortality estimation

Ling catch-at-age distributions are available from the trawl fishery targeting hoki off WCSI in 1991 and 1994–2003. It was considered useful to derive estimates of instantaneous fishing mortality (*F*) from each of these years, by calculating total mortality (*Z*) and subtracting the currently accepted value of natural mortality (*M*) of 0.18. Estimates of instantaneous total mortality were derived using the Chapman-Robson estimator

$$Z = \log_e\left(\frac{1+a-1/n}{a}\right)$$

where *a* is the mean age above recruitment age and *n* is the sample size (Chapman & Robson 1960). For this estimator, age at recruitment is the age at which 100% of fish are vulnerable to the sampling method (rather than the often used age at 50% recruitment). So if the age at full selectivity is 11, then the mean (*a*) is created using age–11 for each fish in the sample. A frequency distribution of the calculated catch-at-age data from all years combined indicated that male ling at age 11 and female ling at age 13 were fully selected by the fishery (Figure 4). Subsequent estimates of *F* (i.e., assuming *M* = 0.18) were calculated each year for males, females, and both sexes combined (Figure 5). Estimated *F* exhibits an increasing trend from 1991 to 2003; *F* in 2003 is two to three times greater than it was in 1991. However, it could also be interpreted that *F* has been relatively constant at about 0.14 since 1998.

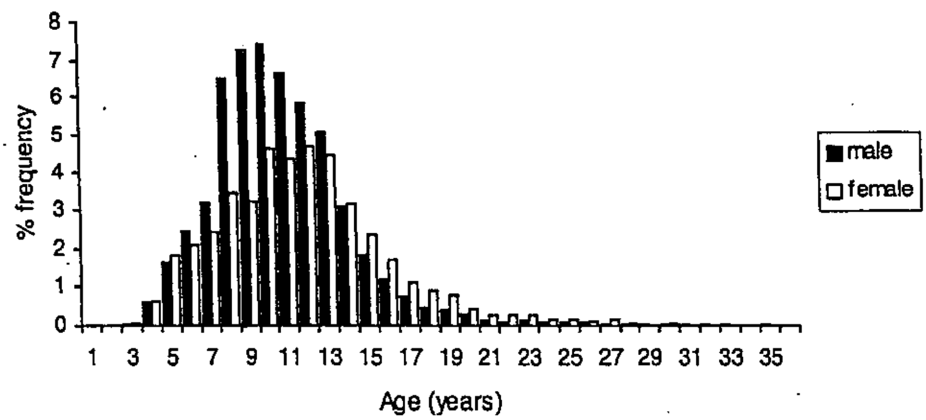


Figure 4: Percentage frequency distribution, by sex, of all the ling catch-at-age samples from the WCSI trawl fishery in 1991 and 1994–2003.

Note that these F estimates rely on the assumption that all fish above recruitment age are equally vulnerable to the fishing gear, and that M and recruitment have been constant. Estimated year class strengths before 1992 (i.e., the year classes used in this analysis) are relatively trendless (see Section 5.2), and there is no reason to believe that M would have varied markedly during the period investigated. However, there is less confidence that all fish above recruitment age are equally vulnerable to the trawl (see Section 5.2). It is noted that, in most years, the estimated F for males is higher than that for females (Figure 5). Because F would be expected to be reasonably constant between sexes, it is hypothesised that M for males is higher than for females (rather than being constant at 0.18 for both sexes). This is as would be expected for temperate teleost fishes. From a fishery management perspective, it is also pleasing that estimates of F for both sexes combined are lower than the assumed M in all years.

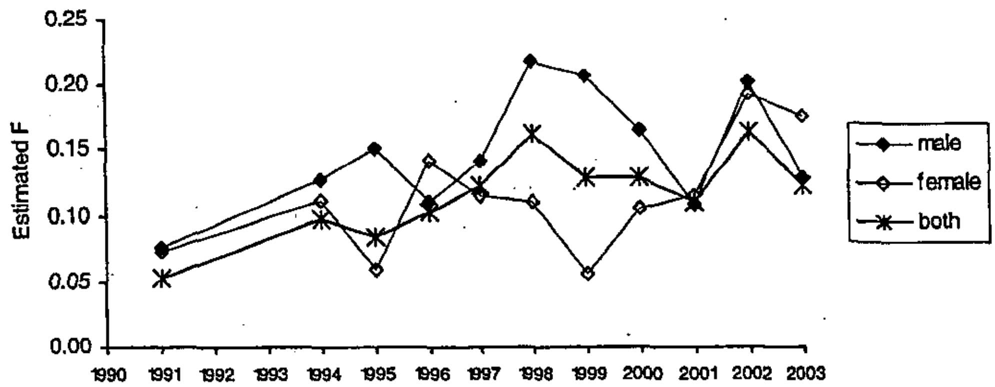


Figure 5: Estimates of instantaneous fishing mortality (F) by year, for males, females, and both sexes combined.

4. MODEL INPUTS, STRUCTURE, AND ESTIMATION

4.1 Model input data

Estimated commercial landings histories for the five stocks are listed in Table 4. The split between method (and pre-spawning and spawning seasons for the LIN 5&6 longline fishery) from 1983 to 2003 was based on reported estimated landings per month, pro-rated to equal total reported landings. Landings before 1983 were split into method and season, based on anecdotal information of fishing patterns at the time, as no qualitative information is available.

Estimates of biological parameters and of model parameters used in the assessments are given in Table 5. M was derived by Horn (2000). The maturity ogive represents the proportion of fish (in the virgin stock) that are estimated to be mature at each age. Ogives for LIN 3&4, LIN 5&6, and LIN 7WC were derived from gonad stage data (see Horn et al. 2000 and Horn & Dunn 2003). The LIN 6B and LIN 7CK ogives are assumed to be the same as for LIN 3&4 and LIN 7WC, respectively, in the absence of any data to otherwise determine them. The proportion spawning was assumed to be 1.0 in the absence of data to estimate this parameter. A stock-recruitment relationship (Beverton-Holt, with steepness 0.9) was assumed. Variability in the von Bertalanffy age-length relationship was assumed to be lognormal with a constant c.v. of 0.1.

Standardised CPUE series (see Horn 2004c) are listed in Tables 6 and 7. CPUE indices were used as relative biomass indices, with associated c.v.s estimated from the generalised linear model used to estimate relative year effects. Series of research trawl survey indices were available for LIN 3&4 and LIN 5&6 (Table 8). Biomass estimates from the trawl surveys were used as relative biomass indices, with associated c.v.s estimated from the survey analysis.

All the trawl survey catch data were also available as estimates of catch-at-age. For LIN 7WC, 11 years of commercial trawl catch-at-age data were available. For LIN 3&4, LIN 5&6, LIN 6B, and LIN 7CK, various series of catch-at-age and catch-at-length data from the commercial trawl and longline fisheries were available. Catch-at-age data were fitted to the model as proportions-at-age, where estimates of the proportions-at-age and associated c.v.s by age were estimated using the NIWA catch-at-age software by bootstrap (see Section 3.1). Zero values of proportion-at-age were replaced with 0.0001. This replacement was because zero values cannot be used with the assumed error distribution for the proportions-at-data (i.e., lognormal). Ageing error for the observed proportions-at-age data was assumed to have a discrete normal distribution with c.v.s as defined in Table 5. The c.v.s varied between stocks because of perceived differences between stocks in the difficulty of reading otoliths.

Table 4: Estimated catch histories (t) for LIN 3&4 (Chatham Rise), LIN 5&6 (Campbell Plateau excluding the Bounty Platform), LIN 6B (Bounty Platform), LIN 7WC (WCSI section of LIN 7), and LIN 7CK (Cook Strait sections of LIN 7 and LIN 2). Landings have been separated by fishing method (trawl or line), and, for the LIN 5&6 line fishery, by pre-spawning (Pre) and spawning (Spn) season. The 2004 value in each column is assumed, and was allocated to method and season based on 2003 landings. For LIN 6B, all landings up to 1990 were taken by trawl, and over 98% of all landings after 1990 were taken by line.

Year	LIN 3&4		LIN 5&6			LIN 6B	LIN 7WC		LIN 7CK	
	trawl	line	trawl	line Pre	line Spn	line	trawl	line	trawl	line
1972	0	0	0	0	0	0	0	0	0	0
1973	250	0	500	0	0	0	85	20	45	45
1974	382	0	1 120	0	0	0	144	40	45	45
1975	953	8 439	900	118	192	0	401	800	48	48
1976	2 100	17 436	3 402	190	309	0	565	2 100	58	58
1977	2 055	23 994	3 100	301	490	0	715	4 300	68	68
1978	1 400	7 577	1 945	494	806	10	300	323	78	78
1979	2 380	821	3 707	1 022	1 668	0	539	360	83	83
1980	1 340	360	5 200	0	0	0	540	305	88	88
1981	673	160	4 427	0	0	10	492	300	98	98
1982	1 183	339	2 402	0	0	0	675	400	103	103
1983	1 210	326	2 778	5	1	10	1 040	710	97	97
1984	1 366	406	3 203	2	0	6	924	595	119	119
1985	1 351	401	4 480	25	3	2	1 156	302	116	116
1986	1 494	375	3 182	2	0	0	1 082	362	126	126
1987	1 313	306	3 962	0	0	0	1 105	370	97	97
1988	1 636	290	2 065	6	0	0	1 428	291	107	107
1989	1 397	488	2 923	10	2	9	1 959	370	255	85
1990	1 934	529	3 199	9	4	11	2 205	399	362	121
1991	2 563	2 228	4 534	392	97	172	2 163	364	488	163
1992	3 451	3 695	6 237	566	518	1 430	1 631	661	498	85
1993	2 375	3 971	7 335	1 238	474	1 575	1 609	716	307	114
1994	1 933	4 159	5 456	770	486	875	1 136	860	269	84
1995	2 222	5 530	5 348	2 355	338	387	1 750	1 032	344	70
1996	2 725	4 863	6 769	2 153	531	588	1 838	1 121	392	35
1997	3 003	4 047	6 923	3 412	614	333	1 749	1 077	417	89
1998	4 707	3 227	6 032	4 032	581	569	1 887	1 021	366	88
1999	3 282	3 818	5 593	2 721	489	771	2 146	1 069	316	216
2000	3 739	2 779	7 089	1 421	1 161	1 319	2 247	923	317	131
2001	3 467	2 724	6 629	818	1 007	1 153	2 304	977	258	80
2002	2 979	2 787	9 970	426	1 220	623	2 250	810	230	171
2003	3 375	2 150	7 205	183	892	932	1 980	807	280	180
2004	3 400	2 200	7 200	200	900	900	2 000	800	280	180

Table 5: Biological and other input parameters used in the ling assessments.

1. Natural mortality (M)

	Female	Male
All stocks	0.18	0.18

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

	Female		Male	
	a	*b*	*a*	*b*
LIN 3&4	0.00114	3.318	0.00100	3.354
LIN 5&6	0.00128	3.303	0.00208	3.190
LIN 6B	0.00114	3.318	0.00100	3.354
LIN 7WC	0.00094	3.366	0.00125	3.297
LIN 7CK	0.00094	3.366	0.00125	3.297

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

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

4. Maturity ogives (proportion mature at age)

Age	4	5	6	7	8	9	10	11
LIN 3&4 (and assumed for LIN 6B)								
Male	0.0	0.100	0.20	0.35	0.50	0.80	1.0	1.0
Female	0.0	0.001	0.10	0.20	0.35	0.50	1.0	1.0
LIN 5&6								
Male	0.0	0.10	0.30	0.50	0.80	1.00	1.0	1.0
Female	0.0	0.05	0.10	0.30	0.50	0.80	1.0	1.0
LIN 7WC (and assumed for LIN 7CK)								
Male	0.0	0.05	0.20	0.60	0.90	1.00	1.00	1.0
Female	0.0	0.00	0.10	0.20	0.40	0.60	0.80	1.0

5. Miscellaneous parameters

Stock	3&4	5&6	6B	7WC	7CK
Stock-recruitment steepness	0.9	0.9	0.9	0.9	0.9
Recruitment variability c.v.	0.6	0.6	1.0	0.6	0.7
Ageing error c.v.	0.05	0.06	0.05	0.05	0.07
Proportion by sex at birth	0.5	0.5	0.5	0.5	0.5
Proportion spawning	1.0	1.0	1.0	1.0	1.0
Spawning season length	0	0.25	0	0	0
Maximum exploitation rate (U_{max})	0.6	0.6	0.6	0.6	0.6

Table 6: Unstandardised (Unstd) and standardised (Std, with 95% confidence intervals and c.v.s) CPUE year effects for the ling target line fisheries on the Chatham Rise, Campbell Plateau, Bounty Plateau, and WCSI.

Year	Unstd	Std	95% CI	c.v.	Unstd	Std	95% CI	c.v.
	Chatham Rise (LIN 3&4)				Campbell Plateau (LIN 5&6)			
1990	0.22	1.62	1.38–1.89	0.08	–	–	–	–
1991	0.47	1.31	1.20–1.43	0.05	0.85	0.96	0.78–1.18	0.11
1992	1.55	1.79	1.64–1.96	0.04	0.90	1.26	1.07–1.49	0.08
1993	1.36	1.31	1.21–1.42	0.04	0.80	1.25	1.07–1.47	0.08
1994	1.29	1.27	1.18–1.36	0.04	0.77	0.99	0.87–1.13	0.07
1995	1.93	1.28	1.19–1.37	0.04	1.20	1.17	1.03–1.34	0.07
1996	1.64	1.08	1.01–1.17	0.04	1.15	1.04	0.92–1.18	0.06
1997	0.96	0.77	0.72–0.82	0.03	1.12	1.11	1.01–1.23	0.05
1998	1.01	0.76	0.71–0.83	0.04	0.97	1.00	0.91–1.10	0.05
1999	0.75	0.67	0.62–0.73	0.04	0.90	0.76	0.68–0.85	0.06
2000	1.01	0.78	0.71–0.85	0.04	1.10	0.86	0.75–0.99	0.07
2001	1.56	0.76	0.70–0.84	0.05	1.29	0.98	0.84–1.13	0.07
2002	0.96	0.63	0.58–0.69	0.04	1.28	1.01	0.87–1.19	0.08
2003	1.03	0.77	0.70–0.86	0.05	0.84	0.75	0.61–0.93	0.10
	Bounty Plateau (LIN 6B)				WCSI (LIN 7WC)			
1990	–	–	–	–	0.63	0.95	0.84–1.09	0.07
1991	–	–	–	–	0.80	1.16	1.04–1.29	0.05
1992	1.01	1.73	1.35–2.21	0.12	0.91	1.15	1.05–1.26	0.05
1993	0.93	1.52	1.25–1.85	0.10	1.04	0.93	0.84–1.03	0.05
1994	0.82	1.03	0.80–1.33	0.13	1.07	0.97	0.88–1.06	0.04
1995	1.06	1.09	0.84–1.40	0.13	1.07	0.98	0.90–1.07	0.04
1996	0.86	1.00	0.80–1.26	0.11	0.94	0.77	0.71–0.84	0.04
1997	0.77	0.82	0.64–1.05	0.13	1.04	0.85	0.78–0.93	0.04
1998	1.34	1.00	0.79–1.27	0.12	1.31	0.96	0.88–1.05	0.04
1999	1.28	1.02	0.83–1.27	0.11	1.14	0.98	0.89–1.08	0.05
2000	1.18	0.93	0.77–1.13	0.10	1.12	0.98	0.89–1.07	0.05
2001	0.92	0.80	0.66–0.97	0.10	1.19	1.13	1.03–1.24	0.05
2002	0.90	0.71	0.59–0.86	0.10	1.03	1.08	1.00–1.22	0.05
2003	1.09	0.76	0.63–0.92	0.09	1.01	1.17	1.07–1.28	0.05
	Cook Strait (LIN 7CK)							
1990	0.88	0.75	0.55–1.02	0.15				
1991	0.60	1.09	0.85–1.39	0.13				
1992	0.70	1.01	0.81–1.25	0.11				
1993	0.55	0.73	0.59–0.90	0.10				
1994	0.36	0.65	0.53–0.80	0.10				
1995	0.43	0.62	0.50–0.77	0.11				
1996	0.62	0.77	0.60–0.98	0.13				
1997	0.76	1.07	0.75–1.52	0.18				
1998	0.61	0.70	0.52–0.93	0.14				
1999	4.34	1.43	0.98–2.07	0.19				
2000	2.21	1.42	0.98–2.05	0.18				
2001	3.44	1.45	0.97–2.15	0.20				
2002	2.14	1.74	1.37–2.21	0.12				
2003	1.57	1.41	1.07–1.85	0.13				

Table 7: Unstandardised (Unstd) and standardised (Std, with 95% confidence intervals and c.v.s) CPUE year effects for the ling bycatch in the hoki target trawl fishery off WCSI and in Cook Strait.

Year	Unstd	Std	95% CI	c.v.	Unstd	Std	95% CI	c.v.
	WCSI (LIN 7WC)				Cook Strait (LIN 7CK)			
1986	0.86	1.10	0.96–1.25	0.07	–	–	–	–
1987	0.56	0.59	0.54–0.66	0.05	–	–	–	–
1988	0.93	0.84	0.76–0.91	0.05	–	–	–	–
1989	1.05	1.06	0.94–1.18	0.06	–	–	–	–
1990	1.40	1.21	1.09–1.34	0.05	1.94	1.60	1.44–1.77	0.05
1991	0.92	0.77	0.68–0.88	0.06	1.46	1.39	1.28–1.39	0.04
1992	0.98	0.66	0.57–0.77	0.07	1.31	1.28	1.17–1.39	0.04
1993	0.91	1.08	0.96–1.22	0.06	1.36	1.33	1.23–1.45	0.04
1994	0.47	0.80	0.72–0.89	0.05	1.05	0.92	0.85–0.99	0.04
1995	1.07	1.10	0.97–1.25	0.06	0.96	0.80	0.75–0.86	0.03
1996	0.99	1.27	1.13–1.43	0.06	0.96	0.80	0.75–0.86	0.03
1997	0.80	1.40	1.24–1.58	0.06	0.81	0.75	0.71–0.79	0.03
1998	1.35	1.20	1.07–1.34	0.05	0.79	0.79	0.74–0.84	0.03
1999	1.35	1.47	1.33–1.64	0.05	0.69	0.75	0.71–0.79	0.03
2000	1.17	1.07	0.97–1.19	0.05	0.69	0.84	0.79–0.89	0.03
2001	1.05	0.93	0.83–1.04	0.06	0.75	1.03	0.97–1.10	0.03
2002	1.89	1.32	1.19–1.47	0.05	0.92	1.04	0.97–1.12	0.04
2003	1.08	0.72	0.64–0.81	0.06	0.96	1.13	1.05–1.21	0.04

Table 8: Series of relative biomass indices (t) from *Tangaroa* trawl surveys (with coefficients of variation, c.v.) available for the assessment modelling.

Fishstock	Area	Trip code	Date	Biomass	c.v. (%)
LIN 3&4	Chatham Rise	TAN9106	Jan-Feb 1992	8 930	5.8
		TAN9212	Jan-Feb 1993	9 360	7.9
		TAN9401	Jan 1994	10 130	6.5
		TAN9501	Jan 1995	7 360	7.9
		TAN9601	Jan 1996	8 420	8.2
		TAN9701	Jan 1997	8 540	9.8
		TAN9801	Jan 1998	7 310	8.3
		TAN9901	Jan 1999	10 310	16.1
		TAN0001	Jan 2000	8 350	7.8
		TAN0101	Jan 2001	9 350	7.5
		TAN0201	Jan 2002	9 440	7.8
		TAN0301	Jan 2003	7 260	9.9
		TAN0401	Jan 2004	8 250	6.0
LIN 5&6	Campbell Plateau	TAN9105	Nov-Dec 1991	24 090	6.8
		TAN9211	Nov-Dec 1992	21 370	6.2
		TAN9310	Nov-Dec 1993	29 750	11.5
		TAN0012	Dec 2000	33 020	6.9
		TAN0118	Dec 2001	25 060	6.5
		TAN0219	Dec 2002	25 630	10.0
		TAN0317	Nov-Dec 2003	22 170	9.0
LIN 5&6	Campbell Plateau	TAN9204	Mar-Apr 1992	42 330	5.8
		TAN9304	Apr-May 1993	33 550	5.4
		TAN9605	Mar-Apr 1996	32 130	7.8
		TAN9805	Apr-May 1998	30 780	8.8

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

A summary of all input data series, by stock, is given in Table 9. Data from trawl surveys could be input either as a) biomass and proportions-at-age, or b) numbers-at-age. For the ling assessments the preference was for a), i.e., entering trawl survey biomass and trawl survey age data as separate input series. [Francis et al. (2003) presented an argument against the use of numbers-at-age data for hoki from trawl surveys.] The c.v.s applied to each data set would then give appropriate weight to the signal provided by each series.

Table 9: Summary of the relative abundance series available for the assessment modelling, including source years (Years). The process error that was added to the observation error in the two stocks that were modelled is also listed.

Data series	Years	Process error c.v.
LIN 3&4		
Trawl survey proportion at age (*Amaltal Explorer*, Dec)	1990	0.01
Trawl survey biomass (*Tangaroa*, Jan)	1992–2004	0.1
Trawl survey proportion at age (*Tangaroa*, Jan)	1992–2004	0.15
CPUE (longline, all year)	1990–2003	0.11
Commercial longline proportion-at-age (Jul–Oct)	2002–03	0.5
Commercial longline length-frequency (Jul–Oct)	1995–03	0.6
Commercial trawl proportion-at-age (Nov–May)	1992, 1994–2003	0.3
LIN 5&6		
Trawl survey proportion at age (*Amaltal Explorer*, Nov)	1990	
Trawl survey biomass (*Tangaroa*, Nov–Dec)	1992–94, 2001–04	
Trawl survey proportion at age (*Tangaroa*, Nov–Dec)	1992–94, 2001–04	
Trawl survey biomass (*Tangaroa*, Mar–May)	1992–93, 1996, 1998	
Trawl survey proportion at age (*Tangaroa*, Mar–May)	1992–93, 1996, 1998	
CPUE (longline, all year)	1991–2003	
Commercial longline length-frequency (Puysegur, Oct–Dec)	1993, 1996,1999–2002	
Commercial longline proportion-at-age (Puysegur, Nov–Dec)	2000–03	
Commercial longline length-frequency (Campbell, Apr–Jul)	1998–2003	
Commercial longline proportion-at-age (Campbell, Jun)	1999, 2001, 2003	
Commercial trawl length-frequency (Jan–Jul)	1991, 1994–95, 1999–2002	
Commercial trawl proportion-at-age (Jan–Jul)	1992–93, 1996, 1998, 2003	
LIN 6B		
CPUE (longline, all year)	1992–2003	
Commercial longline length-frequency (Nov–Feb)	1996, 2000–03	
Commercial longline proportion-at-age (Dec–Feb)	2000–01	
LIN 7WC		
CPUE (longline, all year)	1990–2003	0.15
CPUE (hoki trawl, Jun–Sep)	1986–2003	0.3
Commercial trawl proportion-at-age (Mar–Sep)	1991, 1994–2003	0.25
LIN 7CK		
CPUE (hoki trawl, all year)	1990–2003	
CPUE (longline, all year)	1990–2003	
Commercial trawl proportion-at-age (Mar–Sep)	1999–2003	

4.2 Model structure

Two of the biological ling stocks were assessed in 2004 (LIN 3&4 and LIN 7WC), but, for the first time, in a two stock model. The stock assessment model partitions the Chatham Rise and WCSI population into sexes and age groups 3–30, with a plus group. There are two fisheries (trawl and longline) in each stock. Each stock was considered to reside in a single area, with no interaction between the stocks. Unlike the models up to 2003 (Horn 2004a), the current model estimates both stocks simultaneously. This offers the option of simultaneous estimation of parameters common to both stocks (i.e., natural mortality, longline fishery ogive). It also enables sensitivity analyses, with common parameters, to be estimated across both stocks simultaneously. The model's annual cycle for each stock is described in Table 10.

Table 10: Annual cycles of the assessment models for each stock, showing the processes taking place at each time step, their sequence within each time step, and the available observations of relative abundance. Any fishing and natural mortality within a time step occur after all other processes, with half of the natural mortality for that time step occurring before and after the fishing mortality. An age fraction of 0.5 for a time step means that a 6+ fish is treated as being of age 6.5 in that time step. Trawl surveys and CPUE indices occur during the fishing time step. The last column (%*M*) shows the proportion of that time step's mortality that is assumed to have taken place when each observation is made (see Table 9 for descriptions of the observations).

	Approx.		*M*	Age	Observations	
Step	months	Processes	fraction	fraction	Description	%*M*
LIN 3&4						
1	Dec-Aug	recruitment non-spawning fisheries (trawl & line)	0.8	0.5	Trawl survey (summer) Line CPUE	0.2 0.5
2	Sep-Nov	increment ages	0.2	0.0	–	
LIN 7WC						
1	Oct-Jun	recruitment fishery (line)	0.8	0.5	Line CPUE	0.5
2	Jul-Sep	increment ages fishery (trawl)	0.2	0.0	Trawl CPUE	0.5

All selectivity ogives (i.e., for trawl surveys and commercial fisheries) in all but one of the model runs were age-based and were estimated in the model, separately by sex. The exception was a sensitivity run where single sex, length-based ogives were estimated for the surveys and the fisheries. No length or age data are available from the LIN 7WC longline fishery. Consequently, a single longline ogive was estimated for the fisheries in the LIN 3&4 and LIN 7WC stocks, as ling on the Chatham Rise have lengths-at-age similar to those off west coast South Island. The estimated trawl survey and trawl fishery ogives were assumed to be double normal; longline fishery ogives were assumed to be logistic shaped. In all cases, male selectivity curves were estimated relative to female selectivity. The parameterisations of the double normal and logistic curves were given by Bull et al. (2003). In each fishery, selectivities were assumed constant over all years, i.e., there was no allowance for annual changes in selectivity. On the Chatham Rise, trawl survey selectivities for *Amaltal Explorer* and *Tangaroa* were assumed to be the same.

Maximum exploitation rates were assumed to be 0.6 for both stocks. The choice of the maximum exploitation rate has the effect of determining the minimum possible virgin biomass allowed by the model. This value was set relatively high as there was little external information from which to determine it.

4.3 Model estimation

Model parameters were estimated using Bayesian estimation implemented using the CASAL v2.01 software (Bull et al. 2003). However, only the mode of the joint posterior distribution (MPD) was estimated in preliminary runs. For final runs, the full posterior distribution was sampled using Markov Chain Monte Carlo (MCMC) methods, based on the Metropolis-Hastings algorithm.

Lognormal errors, with known c.v.s, were assumed for all relative biomass, proportions-at-age, and proportions-at-length observations. The c.v.s available for those observations of relative abundance and catch allow for sampling error only. However, additional process variance, assumed to arise from differences between model simplifications and real world variation, was added to the sampling variance. The process error was estimated in early runs of the model, using all available data, from MPD fits. Hence, the overall c.v. assumed in the initial model runs for each observation was calculated by adding process error and observation error. The process errors added to each input series are listed in Table 9.

Year class strengths were assumed known (and equal to 1) when inadequate or no catch-at-age data were available, i.e., before 1973 and after 1999 in the Chatham Rise stock, and before 1974 and after 1997 in the WCSI stock. Otherwise, year class strengths were estimated under the assumption that the estimates from the model must average 1. However, in biomass projections, the assumption that the relative year class strengths were equal to 1 was relaxed. Here, relative year class strengths from 2000 (Chatham stock) and 1998 (WCSI stock) were assumed unknown, with a lognormal distribution with mean 1.0 and standard deviation set equal to the standard deviation of the previously estimated year class strengths from the particular stock.

MCMC chains were estimated using a burn-in length of 3×10^5 iterations, with every 1000^{th} sample taken from the next 10^6 iterations (i.e., a final sample of length 1000 was taken from the Bayesian posterior). Single chain convergence tests of Geweke (1992) and Heidelberger & Welch (1983) were applied to resulting chains to determine evidence of non-convergence. The tests used a significance level of 0.05 and the diagnostics were calculated using the Bayesian Analysis Output software (Smith 2003).

4.4 Prior distributions and penalty functions

The assumed prior distributions used in the assessment are given in Table 11. Most priors were intended to be relatively uninformed, and were estimated with wide bounds. The exceptions were the choice of informative priors for the trawl survey q, and natural mortality (when estimated). The survey q priors were the same as those used by Dunn (2004) for the Chatham Rise survey series in the hake assessment, and 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 (0.01–0.50). The prior of the mean of male and female natural mortality assumed that the current estimate of M was a reasonable approximation to the true value, but that the true value could differ from the current point estimate by about 0.1.

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

Table 11: Assumed prior distributions and bounds for estimated parameters in the LIN 3&4 and LIN 7WC assessments. Parameter values are mean (in natural space) and c.v. for lognormal.

Parameter description	Stock	Distribution	Parameters		Bounds	
B_0	3&4	uniform-log	–	–	30 000	500 000
	7WC	uniform-log	–	–	10 000	400 000
Year class strengths	Both	lognormal	1.0	0.7	0.01	100
CPUE q	Both	uniform-log	–	–	1e-8	1e-3
Trawl survey q	3&4	lognormal	0.16	0.79	0.01	0.4
Selectivity	Both	uniform	–	–	0	20–200
Process error c.v.	Both	uniform-log	–	–	0.001	2
M (mean)	Both	lognormal	0.18	0.2	0.07	0.4
M (difference)	Both	normal	0.0	0.05	-0.15	0.15

5. MODEL ESTIMATES

Estimates of spawning stock biomass and year class strengths were derived for the two assessed stocks using the fixed parameters (see Table 5) and the series of input data (see Table 9) described earlier. The base case run used all available data for both stocks, excluding the WCSI longline CPUE series. Horn (2004c) found that the WCSI line and trawl fishery CPUE series exhibited contradictory trends, and concluded that the line CPUE was probably the least reliable of the two LIN7WC relative abundance series. Several sensitivity runs were completed, so the full list of model runs was as follows.

- Base case — all available data excluding the WCSI line CPUE series (because there was considerable uncertainty about all the WCSI runs, this run was simply named 'trawl CPUE only' for LIN 7WC rather than 'base case')
- M estimation — estimation of natural mortality M over both stocks simultaneously
- Length based sel — estimation of single length-based selectivity ogives for each fishery/survey
- Double process error — incorporated double the base case process error on the WCSI series (reported for LIN 7WC only)
- No CPUE — excluded all CPUE series from both stocks
- Both CPUE series — incorporated both the LIN7WC CPUE series (reported for LIN 7WC only)

For each model run, MPD fits were obtained and quantitatively evaluated. Objective function values (negative log-likelihood) for the model runs are shown in Table 12. Summary plots of the base case MPD model fit for both stocks are given as Appendix B. MCMC estimates of the posterior distribution were obtained for all model runs and these are presented below.

Convergence diagnostics for the model runs are given in Table 13. Diagnostics were run on chains of final length 10^6 iterations (following a burn-in period), after systematically subsampling ("thinning") to 1000 samples. The Geweke (1992) convergence diagnostic is based on a test that compares the means of the first 10% and last 50% of a Markov chain. Under the assumption that the samples were drawn from the stationary distribution of the chain, the two means are equal and Geweke's statistic has an asymptotically standard normal distribution. The resulting test statistic is a standard Z-statistic, with the standard error estimated from the spectral density at zero. Values of the Z-statistic that have a p-value less than 0.05 indicate that, at the 5% significance level, there is evidence that the samples were not drawn from a stationary distribution.

Heidelberger & Welch (1983) proposed two linked tests. The first is a stationarity test that uses the Cramer-von-Mises statistic to test the null hypothesis that the sampled values come from a stationary distribution. The test is successively applied, first to the whole Markov chain, then after discarding the first 10, 20, etc, percent of the chain until, either the null hypothesis is accepted, or 50% of the chain has been discarded. If more than 50% of the chain is discarded, then the test returns a failure of the stationarity test. Otherwise, the number of iterations to keep is reported. The second test is the half-width test that calculates a 95% confidence interval for the chain mean, using the portion of the chain that passed the Heidelberger & Welch stationarity test. Half the width of this interval is compared with the estimate of the mean. If the ratio between the half-width and the mean is lower than 2% of the mean, the half width test is passed.

No evidence of lack of convergence was found in the estimates of B_0 for either stock (Table 13). Some estimates of selectivity parameters and YCS showed evidence of lack of convergence in both stocks. Trace diagnostics of B_0 from the base case model runs are shown in Figure 6.

Table 12: Objective function values (negative log-likelihood) for MPD fits to data, priors, penalties resulting from penalties to catch (Catch) and to year class strengths averaging to one (YCS), and the total objective function (negative log-likelihood) value.

Stock	Run	Data	Priors	Penalties		Total
				Catch	YCS	
Both	Base case	523.64	19.34	0	0	542.98
	M estimation	538.35	20.21	0	0	558.55
	Length based sel	337.83	18.49	0	0	356.32
	Double process error	486.43	18.95	0	0	505.38
	No CPUE	497.31	-2.58	0	0	494.73
	Both CPUE series	537.45	29.55	0	0	567.00

Table 13: Percentage of parameters that passed the Geweke (1992) and Heidelberger & Welch (1983) convergence diagnostics tests for selected parameters from the MCMC chains of the base case runs for both stocks. *n*, number of parameters estimated.

Stock/Run	Parameter	*n*	Geweke (%)	Heidelberger & Welch (%)	
				Stationarity	Half width test
LIN 3&4	B_0	1	100	100	100
	Selectivity	19	89	89	100
	YCS	27	89	100	100
LIN 7WC	B_0	1	100	100	100
	Selectivity	7	71	86	100
	YCS	24	79	96	100

Two stochastic yields, Maximum Constant Yield (MCY) and Current Annual Yield (CAY), were determined for each stock using sample-based simulations. In this process the set of Bayesian posteriors expresses the uncertainty in the free parameters. One simulation run is done for each sample from the posterior, ultimately producing a single estimate of yield that has been averaged over all samples. Each run extended over 150 years with stochastic recruitment (assuming a Beverton and Holt stock recruit relationship), but with the first 100 of those years discarded to allow the population to stabilise under the chosen harvest rate. Yield calculation was based on the procedures of Francis (1992), where yields were maximised, under either constant-catch or constant-mortality-rate harvesting, subject to the constraint that spawning stock biomass should not fall below 20% of B_0 more than 10% of the time.

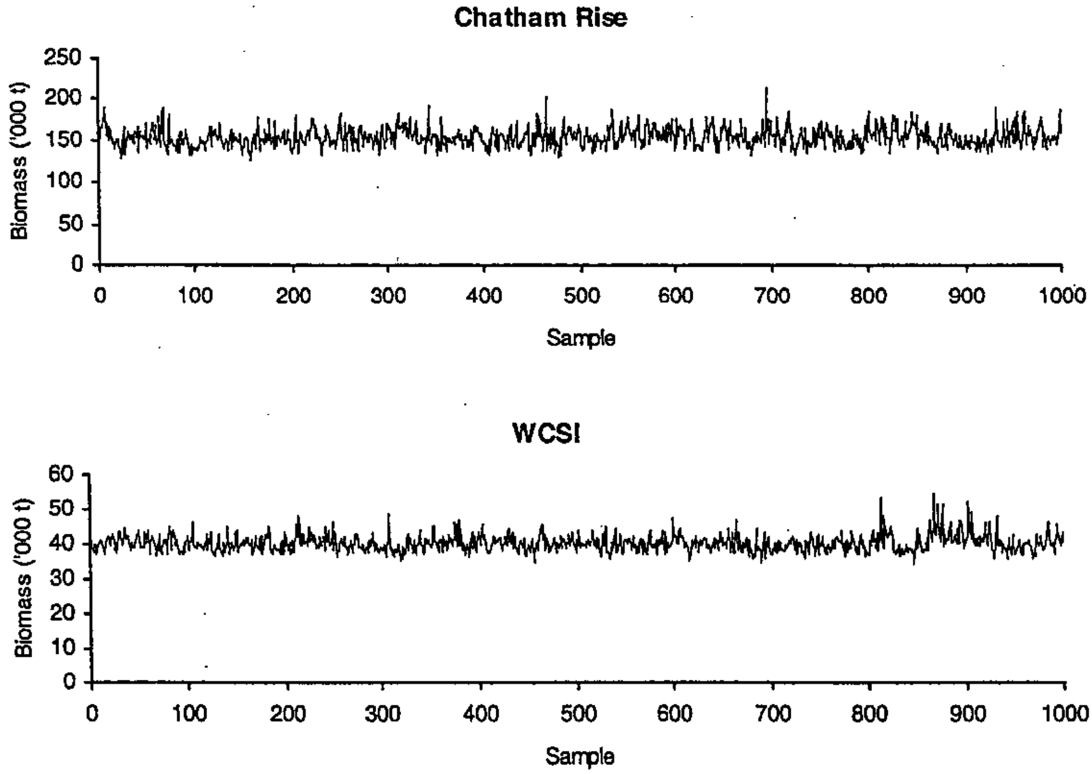


Figure 6: Trace diagnostic plot of the MCMC chains for estimates of B_0 for the LIN 3&4 base case and LIN 7WC trawl CPUE only model runs.

5.1 LIN 3&4

The estimated MCMC marginal posterior distributions for selected parameters for the LIN 3&4 stock base case are shown in Figures 7–11. Selectivity ogives all appear to be generally well estimated (Figure 7). There is an improvement on the previous assessment (Horn & Dunn 2003) in the precision of the trawl fishery ogives owing to these ogives now being based on catch-at-age rather than catch-at-length data. The ogives derived for the commercial trawl fishery are now much closer in shape to those for the research trawl survey. The trawl fishery ogives calculated by Horn & Dunn (2003) had broad posterior distributions at most ages and sharply declining right-hand limbs.

The posterior distribution of the summer trawl survey *q* (Figure 8) has a median value of 0.066 and a narrow 95% credible interval (0.053–0.080). Informed priors were used for this parameter for the first time, but its estimated median value has changed little since the modelling of this stock began. The median *q* for the longline CPUE series also has narrow bounds (Figure 8).

Year class strengths were not well estimated before about 1979 when only data from older fish were available to determine age class strength (Figure 9). The estimates suggest periods of generally higher than average recruitment throughout the mid-late 1970s and in the mid-late 1990s, with generally lower than average recruitment in the intervening period. Exploitation rates (i.e., the catch as a proportion of the selected biomass) were high in 1976 and 1977 (Figure 10), but very low throughout the 1980s. Since the early 1990s, it is estimated that annual fishing pressure by the trawl and line fisheries combined has averaged just less than 0.1.

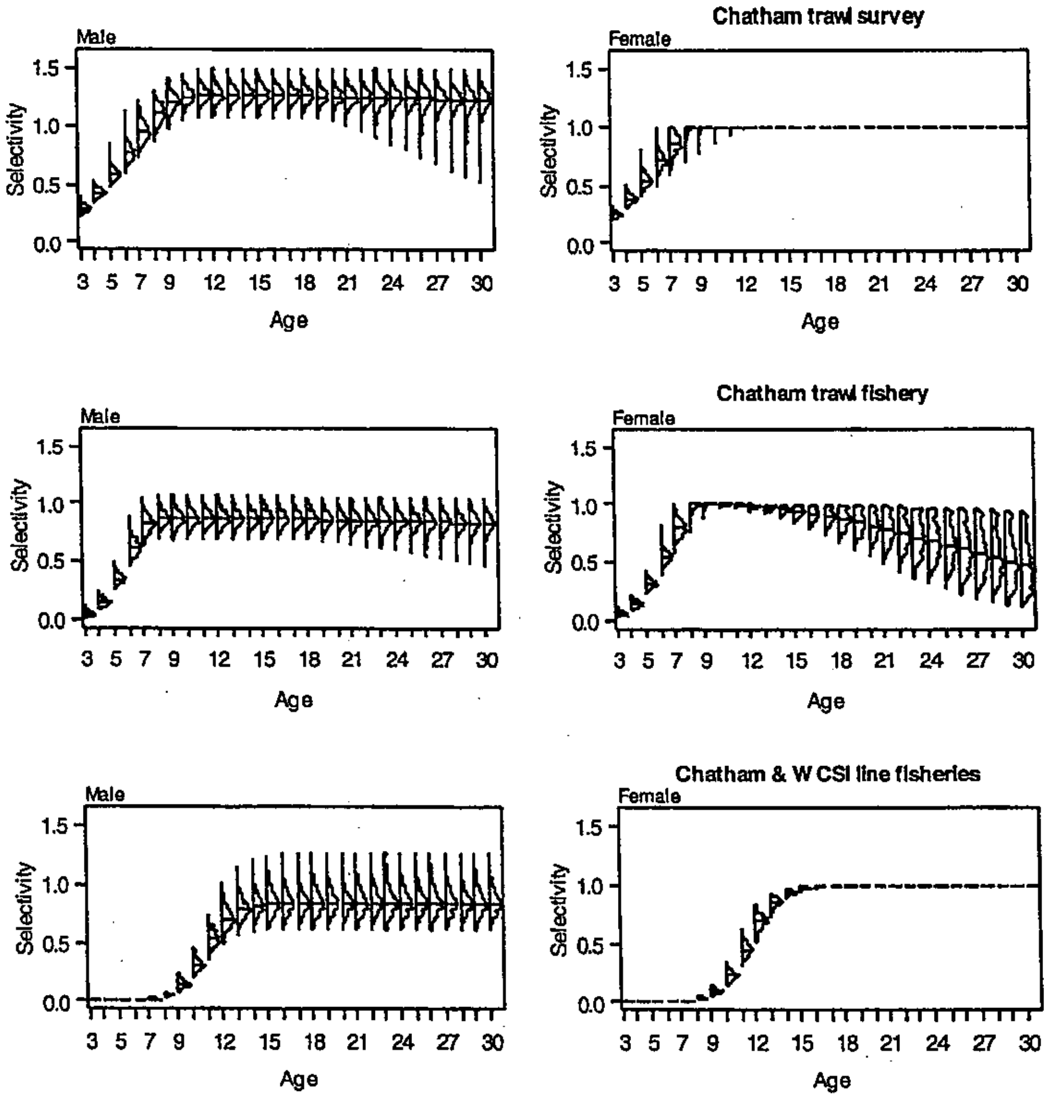


Figure 7: LIN 3&4 base case — Estimated posterior distributions of relative selectivity, by age and sex, for the trawl survey series, the trawl fishery, and the line fishery. Individual distributions show the marginal posterior distribution, with horizontal lines indicating the median.

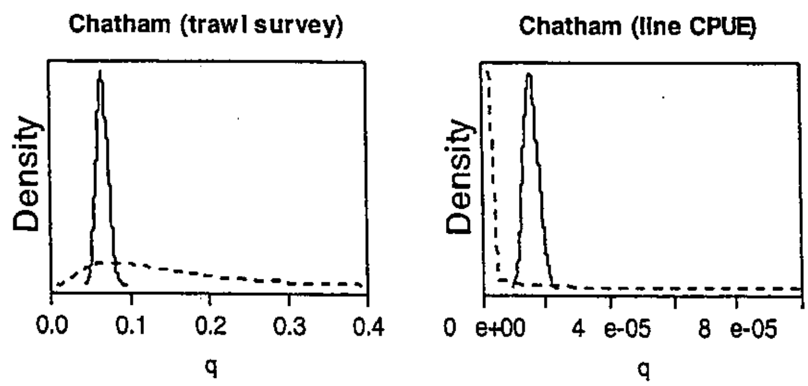


Figure 8: LIN 3&4 base case — Estimated posterior distributions (solid lines) of catchability constants (q) for the summer trawl survey series, and the longline CPUE series. The distributions of the priors are shown as dashed lines.

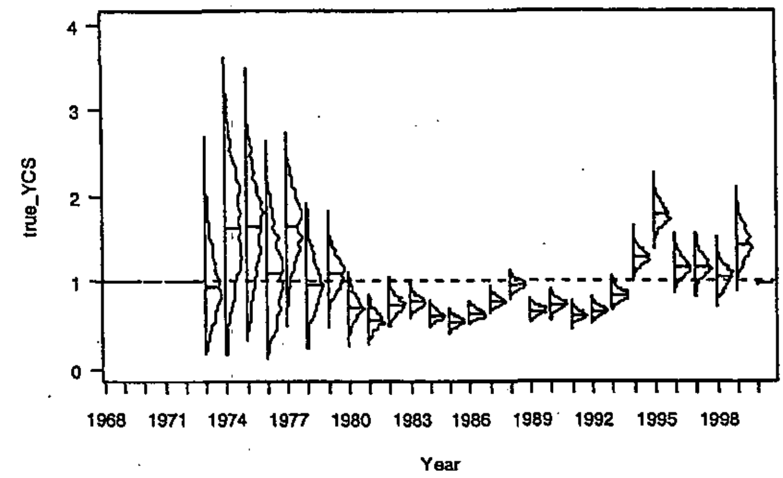


Figure 9: LIN 3&4 base case — Estimated posterior distributions of year class strength. The horizontal line indicates a year class strength of 1. Individual distributions show the marginal posterior distribution, with horizontal lines indicating the median.

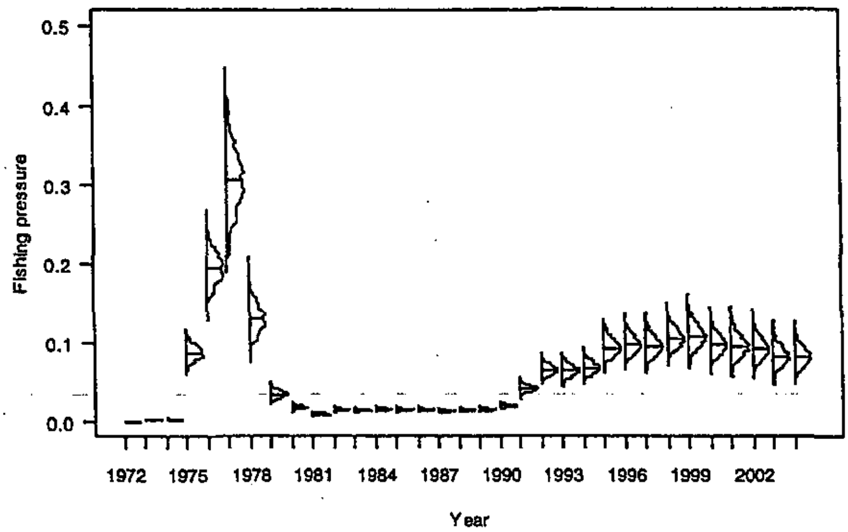


Figure 10: LIN 3&4 base case — Estimated posterior distributions of exploitation rates. Individual distributions show the marginal posterior distribution, with horizontal lines indicating the median.

The LIN 3&4 biomass in 2000–01 was estimated to be at its lowest level since fishing began (Figure 11), but the median has slightly increased since then. The stock appears to be healthy, with estimated current biomass at about 58% of B_0, with a 95% credible interval of 52–65% (Table 14). Estimated stock size has fluctuated markedly since the fishery began. The most marked decline occurred after high exploitation levels by foreign vessels in the mid 1970s. There was some stock recovery throughout the 1980s owing to low exploitation and the recruitment of some relatively strong year classes. Increased exploitation throughout the 1990s, combined with the recruitment of the weaker year classes spawned in the 1980s, resulted in the stock declining to about 50% B_0 by 2000. However, a subsequent reduction in exploitation level (owing to a TACC reduction from the 2000–01 fishing year) and the recruitment of the stronger year classes spawned in the mid-late 1990s has resulted in an increasing stock size. The stock is projected to continue increasing, although at a decreasing rate, over the next five years at catch levels of 5600 t annually (Figure 11, Table 15).

Table 14: Bayesian median and 95% credible intervals (in parentheses) of B_0, B_{2004}, and B_{2004} as a percentage of B_0 for all model runs for LIN 3&4 and LIN 7WC.

Model run	B_0		B_{2004}		B_{2004} (%B_0)	
LIN 3&4						
Base case	152 440	(134 440–180 110)	88 080	(70 710–115 930)	58	(52–65)
M estimation	146 770	(125 900–188 070)	88 500	(63 350–131 400)	60	(50–71)
Length based sel	131 730	(121 160–144 950)	67 210	(55 950–81 170)	51	(46–56)
No CPUE	151 710	(130 280–189 090)	87 300	(65 580–124 800)	58	(50–66)
LIN 7WC						
No CPUE	36 020	(33 620–39 480)	8 540	(5 670–12 300)	24	(17–31)
Trawl CPUE only	40 000	(36 510–46 160)	13 570	(9 680–19 790)	34	(26–43)
Both CPUE series	68 220	(47 080–160 400)	42 510	(22 050–133 020)	62	(47–82)
M estimation	48 870	(41 500–62 850)	22 370	(13 210–37 940)	46	(32–61)
Length based sel	37 850	(35 100–43 440)	11 130	(7 910–16 860)	29	(22–39)
Double process error	38 540	(34 850–46 210)	11 560	(7 430–19 330)	30	(21–42)

Table 15: Bayesian median and 95% credible intervals (in parentheses) of projected B_{2009}, B_{2009} as a percentage of B_0, and B_{2009}/B_{2004} (%) for LIN 3&4 and LIN 7WC model runs. Future annual catches are assumed equal to recent catch levels in LIN 3&4 (5 600 t) and LIN 7WC (2 800 t).

Model run	Future catch (t)	B_{2009}		B_{2009} (%B_0)		B_{2009}/B_{2004} (%)	
LIN 3&4							
Base case	5 600	105 000	(79 880–141 170)	69	(58–81)	119	(108–134)
M estimation	5 600	104 590	(71 840–161 110)	71	(56–89)	118	(106–133)
Length based sel	5 600	79 550	(62 280–101 380)	60	(50–72)	118	(104–134)
No CPUE	5 600	104 650	(73 970–151 230)	69	(56–83)	118	(106–134)
LIN 7WC							
No CPUE	2 800	6 340	(3 620–11 610)	18	(11–30)	75	(53–104)
Trawl CPUE only	2 800	12 390	(6 970–20 870)	31	(19–46)	91	(70–113)
Both CPUE series	2 800	45 680	(21 700–144 040)	67	(46–91)	106	(95–119)
M estimation	2 800	22 490	(10 960–42 350)	46	(26–67)	99	(80–118)
Length based sel	2 800	8 940	(4 700–16 340)	23	(13–38)	80	(56–104)
Double process error	2 800	10 330	(4 700–20 350)	27	(13–45)	88	(59–116)

Three sensitivity runs were conducted to 1) examine the effects of estimating *M*, 2) use length-based selectivity ogives, and 3) exclude the fishery-dependent relative abundance series (i.e., the longline CPUE). Estimates of B_0, B_{2004}, and projected B_{2009} from these runs are listed in Tables 14 and 15, and biomass trajectories are plotted in Figure 12.

The estimation of *M* within the model resulted in some changes to the selectivity ogives (Figure 13). All male selectivity ogives were markedly lower over all ages (relative to females), the trawl survey age at full selectivity for females increased by about 5 years, and the trawl fishery female selectivity increased at older ages. The estimated (median) natural mortality rates for males and females were 0.17 y^{-1} (95% credible intervals 0.15–0.19) and 0.20 y^{-1} (0.17–0.22), respectively (Figure 14). These estimates straddle the currently used value of 0.18 for both sexes. The model result indicating that *M* is higher for females than for males is contrary to expectations. It appears likely that the model has insufficient information to be able to distinguish between research and fishing selectivity estimates, and estimates of *M*. The effect on the biomass trajectory of estimating *M* in the model was small; the trajectory was lowered by less than 6000 t across its entire range, and current biomass is identical to the base case (see Figure 12).

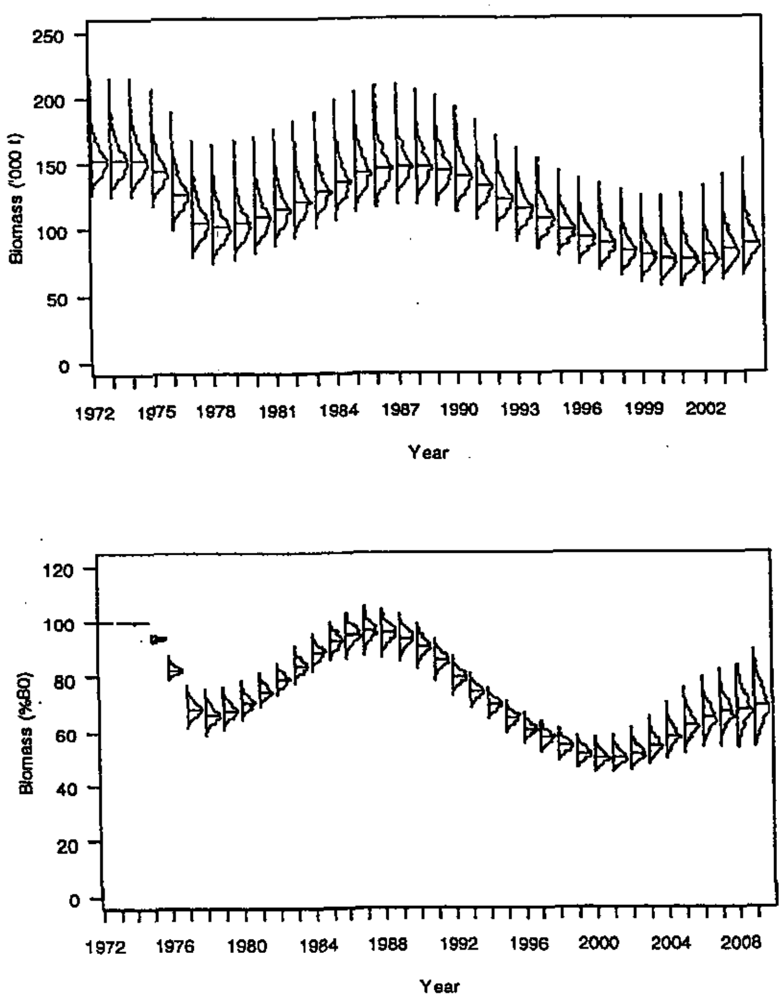


Figure 11: LIN 3&4 base case — Estimated posterior distributions of biomass trajectories (in tonnes, and as %B_0). Individual distributions show the marginal posterior distribution, with horizontal lines indicating the median. Projections (2005–09) are based on future annual catches equal to recent catch levels (5600 t).

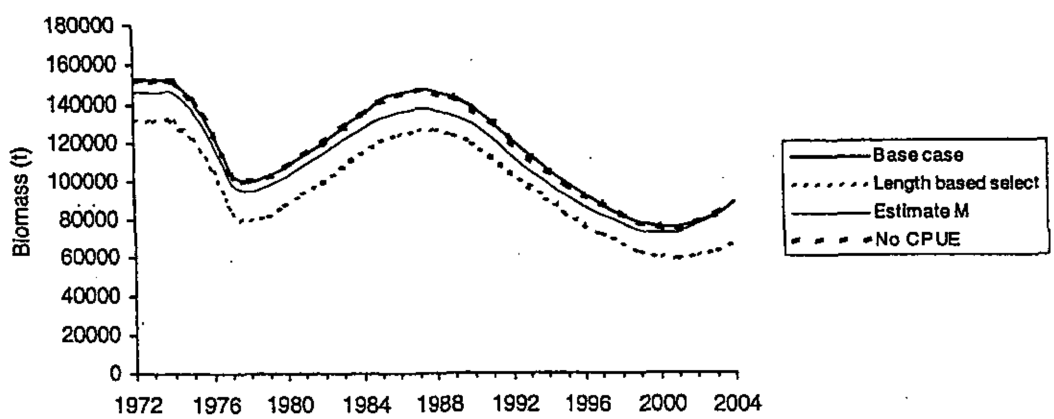


Figure 12: LIN 3&4 — Estimated spawning stock biomass median of the posterior distribution for the base case and three sensitivity runs.

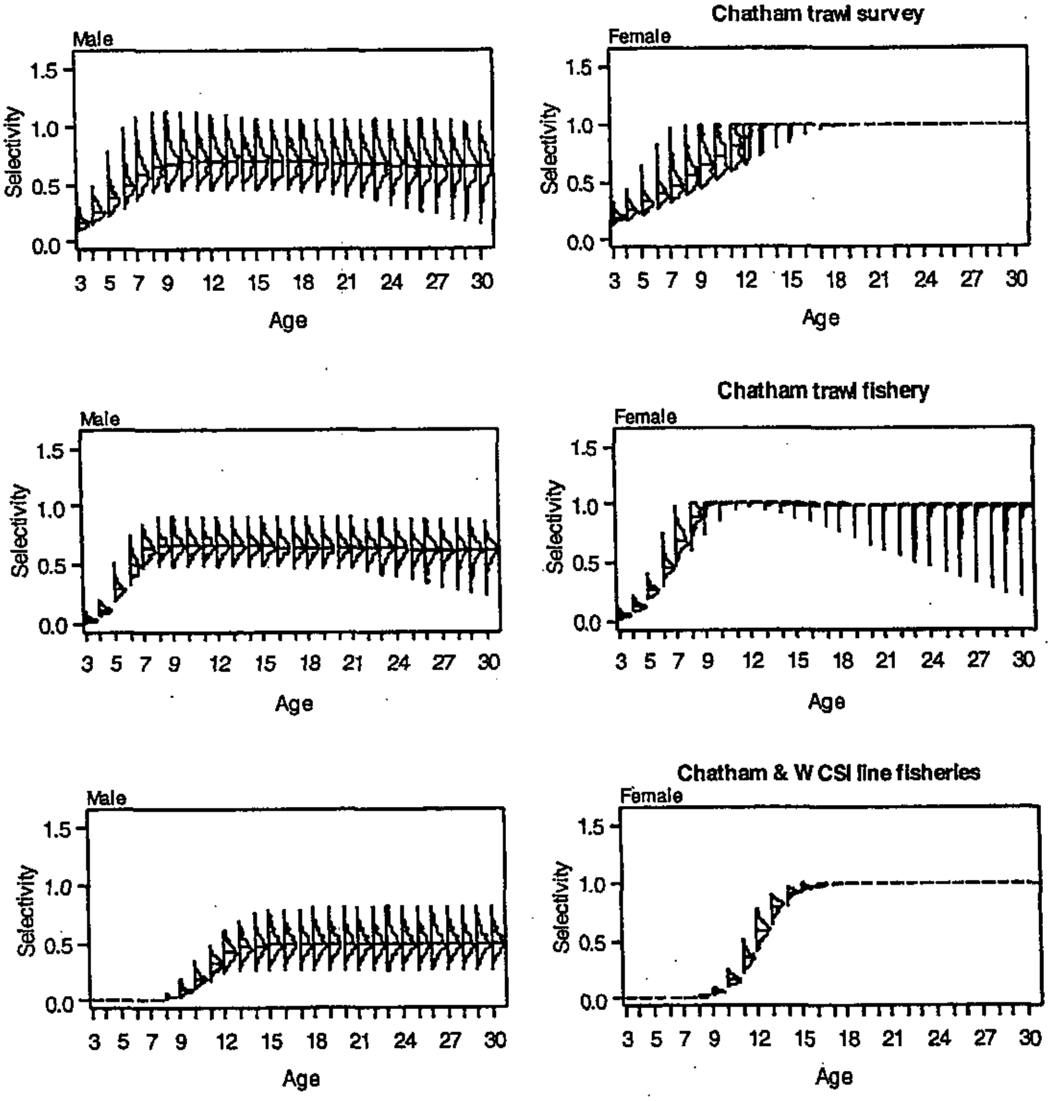


Figure 13: LIN 3&4 estimation of M — Estimated posterior distributions of relative selectivity, by age and sex, for the trawl survey series, the trawl fishery, and the line fishery. Individual distributions show the marginal posterior distribution, with horizontal lines indicating the median.

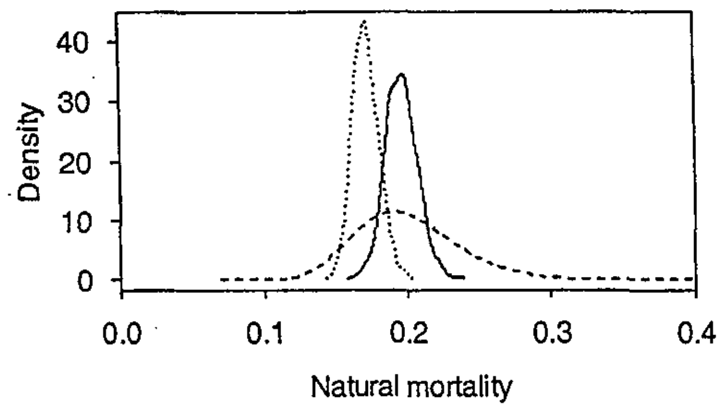


***Figure 14:* Estimated posterior distributions for male (dotted line) and female (solid line) natural mortality rates from the "estimate M" sensitivity run, for the Chatham Rise and WCSI stocks combined. The natural mortality prior (average of male and female M) is shown by the dashed line.**

Estimation of single sex, length-based ogives for the survey and fishery selectivities produced very precise curves (Figure 15). These could then be converted into two-sex, age-based ogives (Figure 16), and compared directly to ogives calculated in the base case run. The shapes of the trawl survey and trawl fishery ogives are quite similar from the two model runs (compare Figures 7 and 16). However, the line fishery ogives are very different. In the sensitivity run, the age at full selectivity for females is about 5 years higher, and males never attain full selectivity, relative to the base case run. It is also apparent from the MPD residual plots (see Appendix B, Figures B7 and B8) that, when using length-based selectivity, male residuals are generally positive and female residuals generally negative. The effect on the biomass trajectory of using size-based ogives in the model was moderate; the trajectory was lowered by about 20 000 t across its entire range (see Figure 12).

The sensitivity run excluding the fishery-dependent relative abundance series (i.e., the longline CPUE) was almost identical to the base case run in both selectivity ogives and biomass trajectory (see Figure 12).

The yield estimates from all model runs (Table 16) are higher than the current TACC for LIN 3 and LIN 4 combined (about 7200 t), as would be expected given the reasonably healthy estimates of B_{2004} as a percentage of B_0 (i.e., 46–71%). The estimates of MCY (8200–9600 t) are slightly higher than the current TACC, and the CAY estimates are two to three times the TACC. These data indicate that the LIN 3&4 stock could sustain catch levels higher than the current TACC, at least in the short to medium term.

Table 16: Yield estimates (MCY and CAY) and associated parameters for all model runs for LIN 3&4 and LIN 7WC.

Model run	B_{MCY} (t)	MCY (t)	B_{MAY} (t)	MAY (t)	F_{CAY}	CAY (t)
LIN 3&4						
Base case	55 740	9 180	38 240	10 040	0.25	23 440
M estimation	53 650	9 660	38 920	10 140	0.28	26 210
Length based sel	41 410	8 290	32 600	8 460	0.25	18 080
No CPUE	58 350	9 050	36 090	9 980	0.25	22 910
LIN 7WC						
No CPUE	13 520	2 050	8 980	2 240	0.25	2 090
Trawl CPUE only	15 310	2 270	9 910	2 500	0.25	3 500
Both CPUE series	43 280	3 230	19 030	4 800	0.25	13 530
M estimation	22 190	2 600	12 480	3 140	0.25	6 000
Length based sel	14 590	2 110	9 420	2 330	0.25	2 750
Double process error	15 410	2 170	9 440	2 430	0.26	3 100

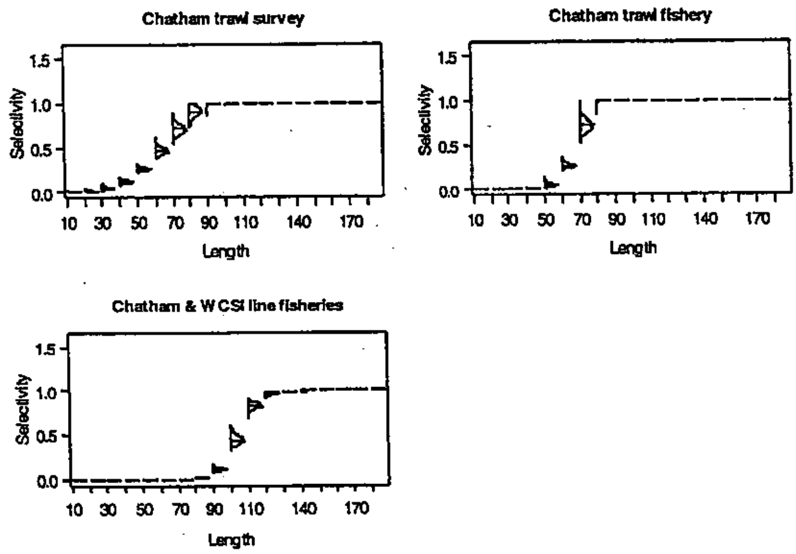


Figure 15: LIN 3&4 length-based selectivity — Estimated posterior distributions of relative selectivity, by length, for the trawl survey series, the trawl fishery, and the line fishery. Individual distributions show the marginal posterior distribution, with horizontal lines indicating the median.

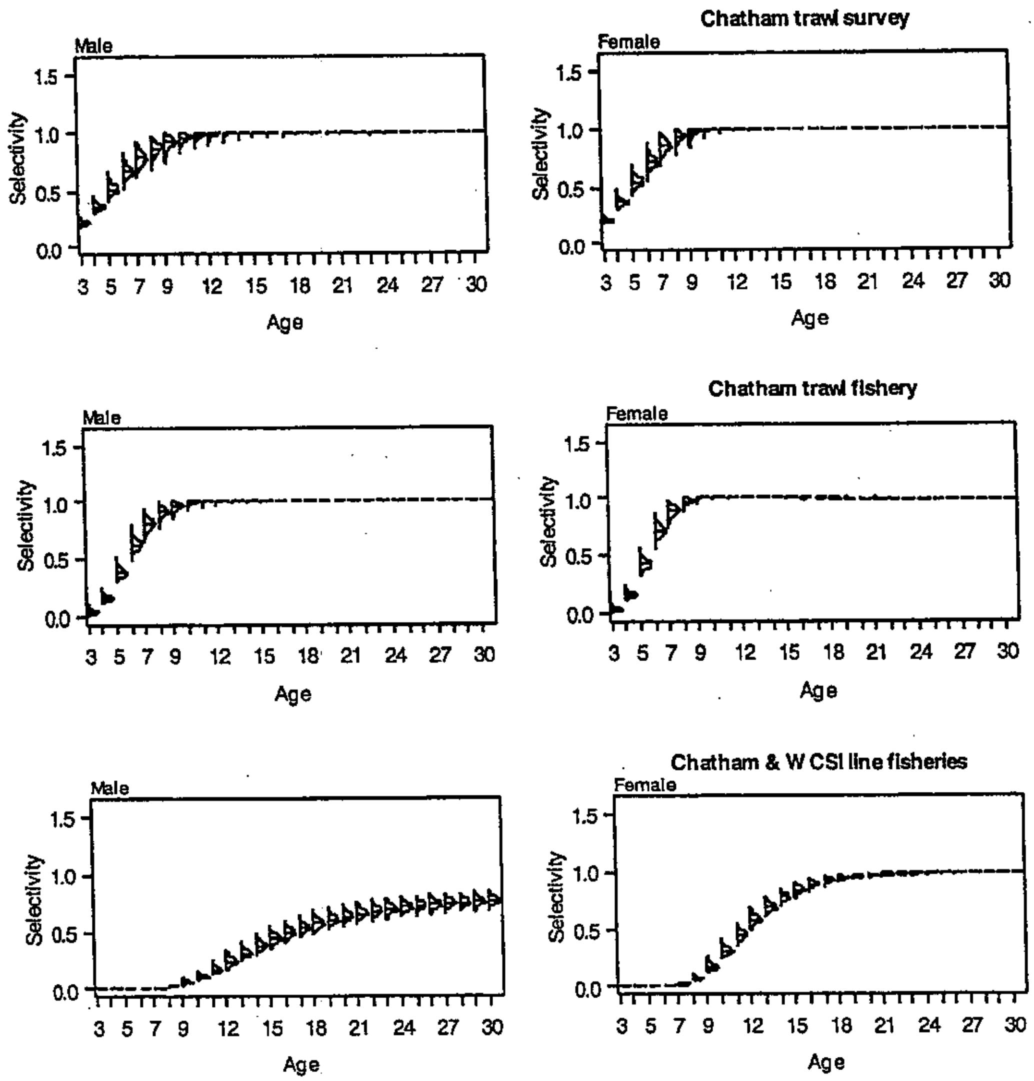


Figure 16: LIN 3&4 length-based selectivity — Estimated posterior distributions of relative selectivity, by age and sex, for the trawl survey series, the trawl fishery, and the line fishery. Individual distributions show the marginal posterior distribution, with horizontal lines indicating the median.

5.2 LIN 7WC

The estimated MCMC marginal posterior distributions for selected parameters for the LIN 7WC 'trawl CPUE only' run are shown in Figures 17–21. [This model run was initially selected by the author as the base case, but subsequent analyses indicated that the outcomes from all the LIN 7WC runs were very uncertain.] In all model runs, the longline fishery selectivity ogive for the WCSI ling stock is assumed to be identical to that calculated using data from the Chatham Rise fishery. The calculated ogives for the WCSI trawl fishery are generally well estimated, but there are marked differences between male and female selectivity (Figure 17). While female ling remain largely fully selected after age 15, male selectivity declines sharply after this age. The posterior distribution of the trawl CPUE q has a clear mode, but its bounds are much broader than those for the Chatham longline CPUE q (compare Figures 8 and 18). Year class strengths were poorly estimated before about 1982 when only data from older fish were available to determine age class strength (Figure 19). The most recently estimated year class (1997) is also relatively poorly estimated. There are no clear trends over time in recruitment. Exploitation rates were very low up to the late 1980s, except in 1977 (Figure 20). However, concurrent with the development of the hoki fishery, it is estimated that fishing pressure on ling has steadily increased over the last 10–15 years to a rate of about 0.2 y^{-1} in the trawl fishery (Figure 20).

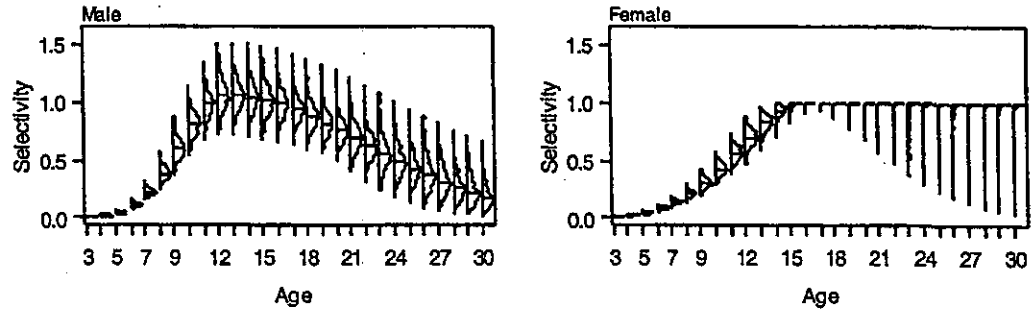


Figure 17: LIN 7WC 'trawl CPUE only' run — Estimated posterior distributions of relative selectivity, by age and sex, for the trawl fishery. Individual distributions show the marginal posterior distribution, with horizontal lines indicating the median.

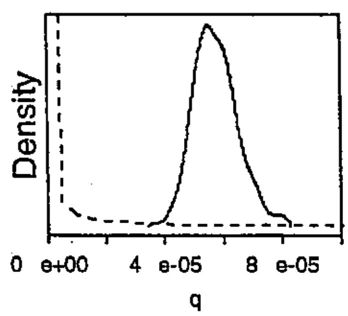


Figure 18: LIN 7WC 'trawl CPUE only' run — Estimated posterior distribution (solid line) of the relativity constant for the trawl CPUE series. The distribution of the priors is shown as a dashed line.

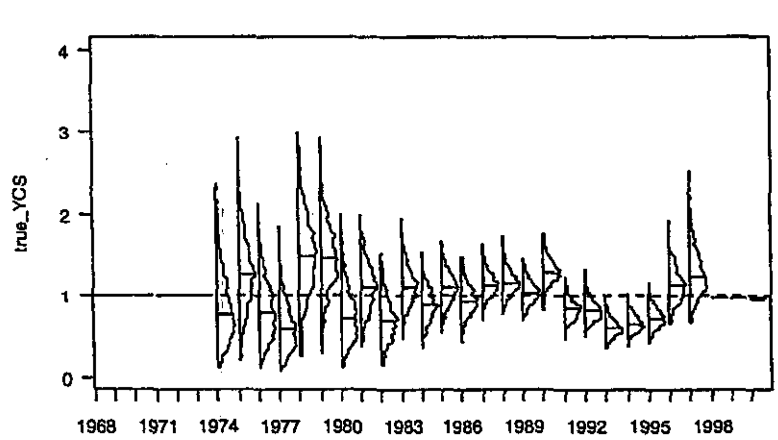


Figure 19: LIN 7WC 'trawl CPUE only' run — Estimated posterior distributions of year class strength. The horizontal line indicates a year class strength of 1. Individual distributions show the marginal posterior distribution, with horizontal lines indicating the median.

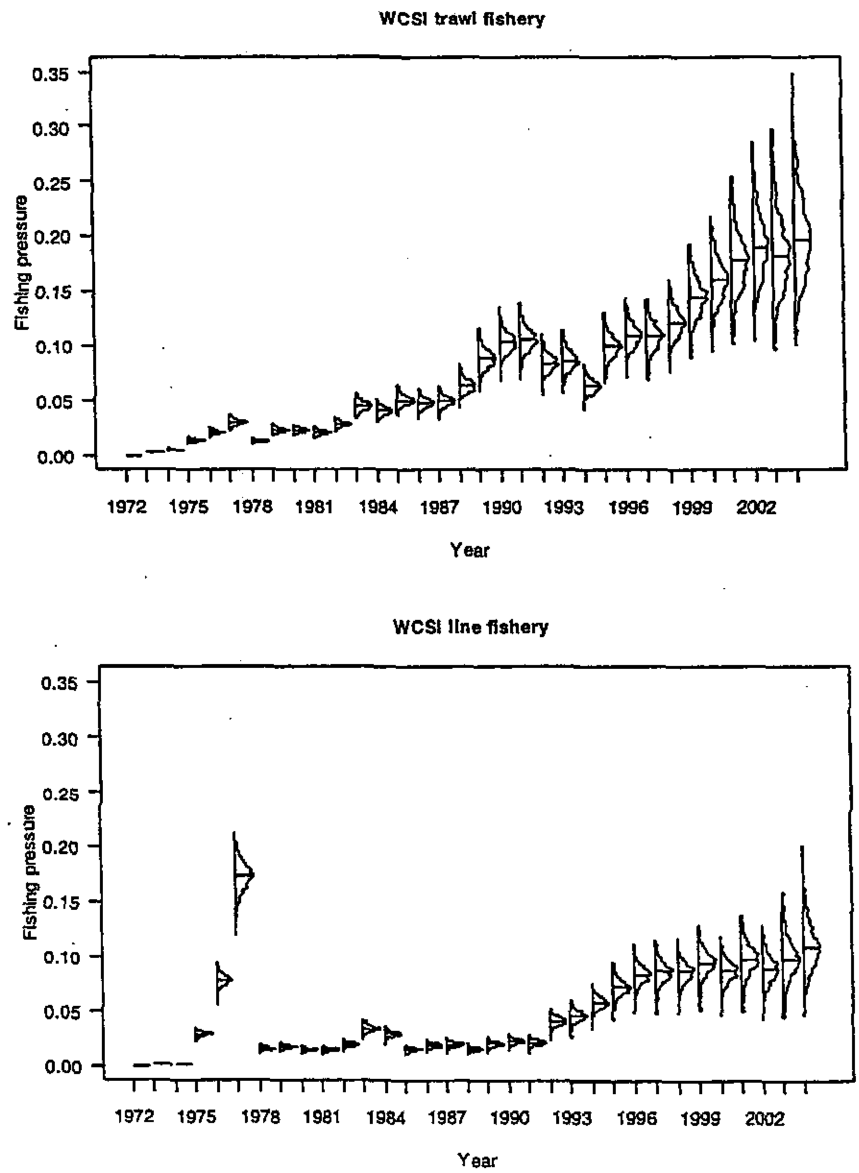


Figure 20: LIN 7WC 'trawl CPUE only' run — Estimated posterior distributions of exploitation rates in the trawl fishery (spawning season) and line fishery (non-spawning season). Individual distributions show the marginal posterior distribution, with horizontal lines indicating the median.

Biomass in 2004 was estimated to be at its lowest level since fishing began (Figure 21) at about 34% of B_0, with a 95% credible interval of 26–43% (Table 14). Estimated stock size has steadily declined since the fishery began. The most marked decline occurred after high exploitation levels by foreign vessels in the mid 1970s. Although exploitation rates are believed to have been low between 1978 and 1988, there is no evidence of stock recovery during that period. The development of the hoki fishery from the late 1980s, with a consequent bycatch of ling, started a second phase of stock decline. The stock is projected to continue declining, although at a decreasing rate, over the next five years at catch levels of 2800 t annually (Figure 21) to reach a level of 31% B_0 in 2009 (Table 15).

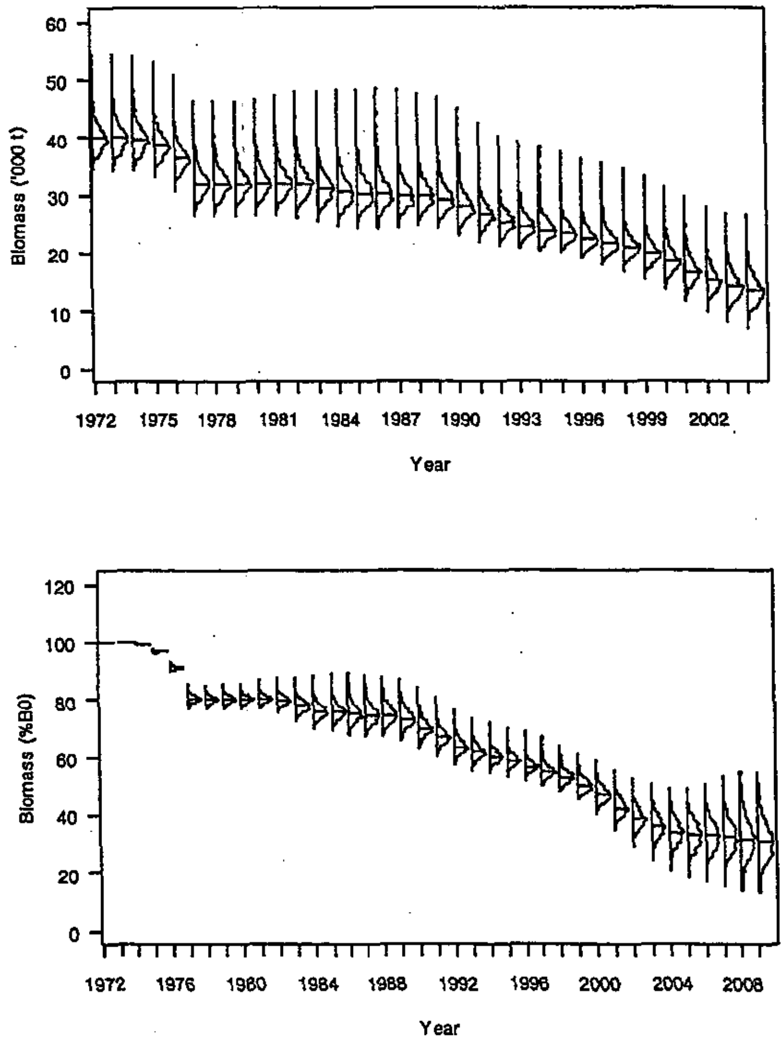


Figure 21: LIN 7WC 'trawl CPUE only' run — Estimated posterior distributions of biomass trajectories (in tonnes, and as $\%B_0$). Individual distributions show the marginal posterior distribution, with horizontal lines indicating the median. Projections (2005–09) are based on future annual catches equal to recent catch levels (2800 t).

Five additional runs were conducted to 1) examine the effects of estimating *M*, 2) use length-based selectivity ogives, 3) double the process error on the input data series, 4) exclude the fishery-dependent relative abundance series (i.e., the CPUE), and 5) use both the trawl and longline CPUE series. Estimates of B_0, B_{2004}, and projected B_{2009} from these runs are listed in Tables 14 and 15, and biomass trajectories are plotted in Figure 22.

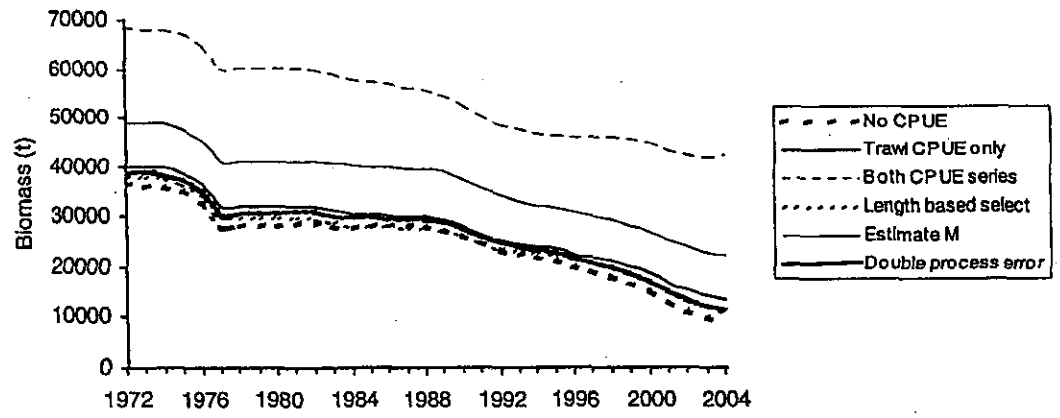


Figure 22: LIN 7WC — *Estimated spawning stock biomass median of the posterior distribution for the* base case and five sensitivity runs.

The estimates of natural mortality were described above; *M* was estimated over both stocks simultaneously. This sensitivity run resulted in little change to the trawl fishery female selectivity ogive, but male selectivity was markedly reduced over all ages (Figure 23). Estimated biomass from this run was higher than the 'trawl CPUE only' run by about 9000 t across the entire modelled period (Figure 22).

Estimation of a single sex, length-based ogive for the trawl fishery produced a curve that was relatively precise up to a length of about 140 cm, but was poorly defined for larger fish (Figure 24). The resulting two-sex, age-based ogives (Figure 23) were well defined over the entire age range. This model run was the only one where male selectivity did not decline with increasing age after an initial peak. Estimated biomass from this run was lower by about 2000 t than that predicted by the 'trawl CPUE only' run across the entire modelled period (see Figure 22).

Doubling the process error on the input series resulted in the estimated biomass trajectory being generally less than 1000 t lower than for the 'trawl CPUE only' run (see Figure 22). The trawl selectivity ogive for females was little different to the 'trawl CPUE only' run, but the male ogive was poorly defined with wide selectivity ranges possible at most ages (see Figure 23). The increased process error allowed slightly improved fits to the catch-at-age data (Appendix B, Figure B11) but worse fits to the trawl CPUE series (Figure B10).

Removal of the trawl CPUE from the model left only the trawl fishery catch-at-age, i.e., there were no series of relative abundance. The trawl selectivity ogive for females was little different to that derived from the 'trawl CPUE only' run, but male selectivity was higher (and less precise) at ages greater than 8 (see Figure 23). Clearly, the catch-at-age data contain information indicative of a stock decline between 1991 and 2003. This is the most pessimistic of all the model runs; the biomass trajectory is about 3000–5000 t lower than for the 'trawl CPUE only' run across the entire range (see Figure 22).

The sensitivity test incorporating both available CPUE series (i.e., trawl and longline) was the most optimistic, but least precise, of all the model runs (see Table 14). This is a function of three conflicting input series. The trawl catch-at-age indicates a stock decline between 1991 and 2003, the trawl CPUE indicates a relatively constant stock size from 1984 to 2003, and the line CPUE indicates a slight stock recovery since about 1996. A large virgin biomass is often necessary to reconcile these three series. The posterior distributions of the trawl and line CPUE *q*s have very broad distributions (Figure 25). This model run was the only one where both male and female trawl selectivity declined with increasing age after an initial peak (see Figure 23).

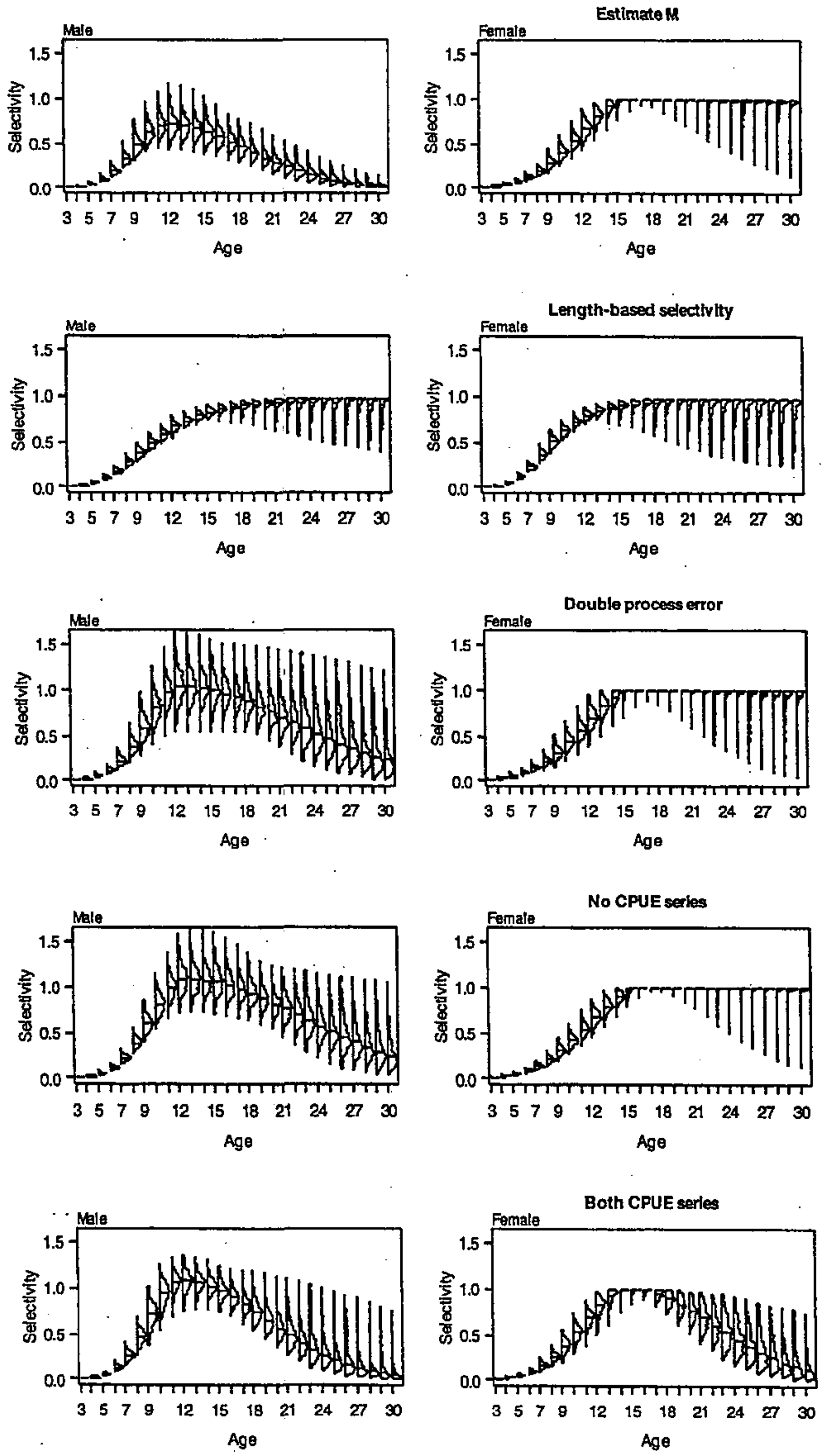


Figure 23: LIN 7WC sensitivity runs — Estimated posterior distributions of relative selectivity, by age and sex, for the trawl fishery from the sensitivity runs. Individual distributions show the marginal posterior distribution, with horizontal lines indicating the median.

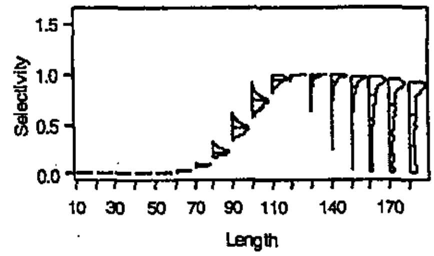


Figure 24: LIN 7WC length-based selectivity — Estimated posterior distributions of relative selectivity, by length, for the trawl fishery. Individual distributions show the marginal posterior distribution, with horizontal lines indicating the median.

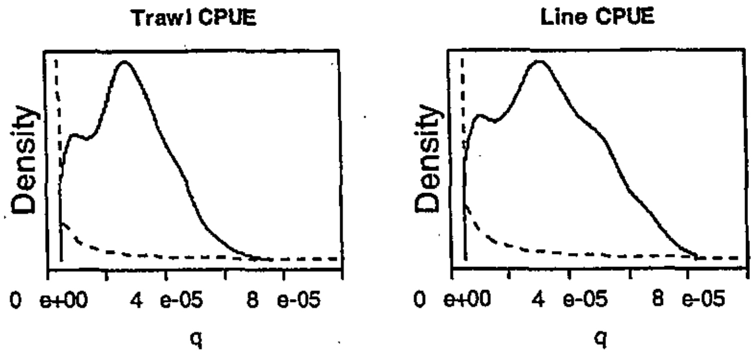


Figure 25: LIN 7WC 'both CPUE series' run — Estimated posterior distributions (solid lines) of relativity constants for the trawl and longline CPUE series. The distributions of the priors are shown as dashed lines.

The MCY estimates from four of the runs are close to the current TACC of 2225 t for the LIN 7 stock (Table 16). The other two estimates from the 'estimate *M*' run and the imprecise 'both CPUE series' run are higher than the current TACC. All but one of the CAY estimates are higher than the TACC (Table 16). The estimate from the 'no CPUE' run is 2090 t. However, it must be remembered that the LIN 7WC assessment does not include the ling stock in Cook Strait, which produces about 8% of the landings, and possibly makes up about 10% of the biomass in the LIN 7 administrative stock (Horn 2001).

6. DISCUSSION

Model estimates of the state of the LIN 3&4 stock indicate that current biomass is just over half the virgin level, and is likely to increase in the short term, following the reduction of the TACC in 2000 and the pending recruitment of some relatively strong year classes. The 95% credible interval around the absolute level of current biomass has bounds from 71 000 to 116 000 t. The stock experienced a relatively steady decline in biomass throughout the 1990s, following increased catch levels attributable to the development of the longline fishery. The two relative abundance series for this stock appear to show different trends: the longline CPUE series initially declined and then remained constant, whereas the trawl survey series fluctuated without an apparent trend. However, these results are not incompatible. The longline fishery primarily takes larger fish, and the CPUE indexes the fishing down of an accumulated biomass of larger, older ling. The trawl survey series comprehensively samples the population of ling older than about 5 years, so variations in recruitment can strongly influence this index, resulting in fluctuations in total biomass. Relative to the base case assessment, there are negligible changes to estimates of stock size and status if the CPUE series is excluded from the model.

For LIN 3&4, the model run estimating single-sex length-based selectivity ogives for the research surveys and commercial fisheries is the only one that produces estimates notably different from the base case. In this run, the selectivity-at-age for males is estimated to be much lower in the trawl survey and the line fishery, and, hence, overall biomass is higher than the base case estimate. However, the estimated selectivity ogives, particularly for the line fishery, have imbalanced residuals between the sexes, and are clearly inappropriate. Hence, this model run is probably the least reliable of those presented.

Current stock size of LIN 3&4 is estimated to be above both B_{MCY} and B_{MAY}. Catches at the level of the TACC are likely to be sustainable in the long term (assuming no exceptional decline in future recruitments).

The current LIN 3&4 assessment is very consistent with, although slightly more optimistic than, the previous assessment of this stock. That assessment (Horn & Dunn 2003) suggested that B_0 was about 149 000 t (ranging from 123 000 to 197 000 t), and that stock status would increase to about 63% of B_0 (48–78%) by 2007. The assessment of this stock could be influenced markedly by changes in the trawl survey q. However, the estimated median value of q has changed little since the modelling of this stock began. The history of recent assessments of LIN 3&4 is depicted in Figure 26. MIAEL (Minimised Integrated Average Expected Loss, Cordue 1998) assessments in 1999 and 2000 indicated that the stock was at 25% and 30% of B_0, respectively. These assessments precipitated a reduction in the TACC from the beginning of the 2000–01 fishing year. However, the 2001 MIAEL assessment estimated current biomass at about 45% B_0. The B_{min} and B_{max} bounds for all three assessments were quite similar, but only the 2001 trajectories are shown in Figure 26. The first CASAL assessment of LIN 3&4 was produced in 2002 to check the consistency of the two model methods (Horn & Dunn 2003). The estimates of B_{2001} from the two methods were close, and the CASAL trajectory was entirely within the MIAEL bounds. The current CASAL assessment produced a biomass trajectory consistent with previous assessments.

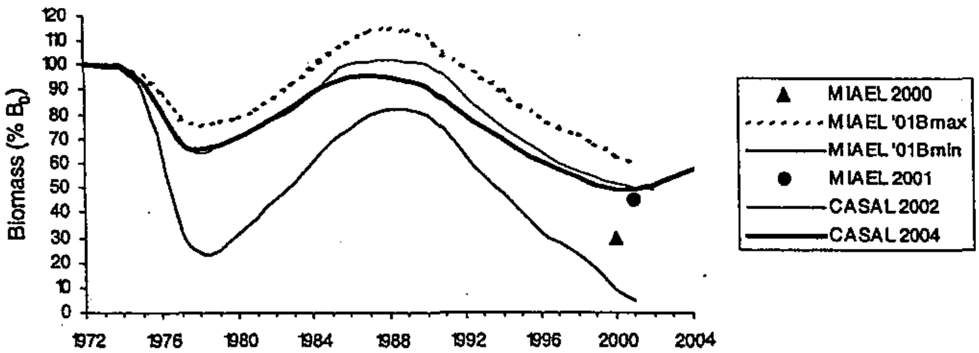


Figure 26: LIN 3&4 — Estimated spawning stock biomass trajectories from the base case runs of the last four assessments, i.e., the MIAEL assessments in 2000 and 2001, and the CASAL assessments in 2002 and 2004.

The size and status of the LIN 7WC stock are poorly known, even though the posterior distributions of absolute biomass by year for all but the 'both CPUE series' run have relatively narrow distributions with strong modes. The assessment is dominated by the catch-at-age data from the trawl fishery. The sensitivity run using only the catch history and the catch-at-age data clearly contains information that the stock has declined between 1991 and 2003. The inclusion of CPUE series only moderates the rate of the decline. Both CPUE series have shortfalls (see Horn 2004c), and they exhibit conflicting trends in recent years. The trawl series is believed to be the more credible of the two. The inclusion of the trawl CPUE series produced a slightly more optimistic assessment than the 'no CPUE' run, but when the process error on the input series was doubled, the greater volume of catch-at-age data swamped the trawl CPUE signal producing a less optimistic outcome. Including both the trawl and line CPUE series resulted in a slight stock recovery in the most recent year, but the median B_0 needed to be much higher than in the other runs to also accommodate the stock decline indicated by the catch-at-age data. Consequently this model run produced the most imprecise of all the assessments, with wide 95% credible intervals around the biomass estimates and very broad posterior distributions for the CPUE *qs*. However, it was the only run producing reasonable fits to the CPUE data (see Appendix B Figure B10).

Results from the five relatively consistent model runs (i.e., all runs excluding 'both CPUE series' and '*M* estimate') indicate that current biomass in LIN 7WC is about 30% B_0, with a credible interval of about 17–43%. Hence, there may be some sustainability issues pending for this stock. However, in contrast to this, the CPUE series are relatively flat (although possibly unreliable) and there has been no declining trend in catches. Annual landings have been consistently at or above 2800 t since 1996, and have averaged about 2700 t annually since 1989, which is indicative that future catches at the current level are probably sustainable, at least in the short term. This catch level is higher than the MCY from the same five model runs. Also, instantaneous fishing mortality (*F*) calculated (using the Chapman-Robson estimator) from trawl catch-at-age data from 1998 to 2003 averages 0.14, implying an annual exploitation by the trawl fishery of the selected stock of 13%. This value is low relative to the model estimate of exploitation of 23% from the 'no CPUE' run in the same fishery over the same years. However, direct comparisons are problematic because the trawl exploitation rate is calculated in the model using the biomass after the line fishery has occurred. Other model estimates of trawl exploitation rate for 1998 to 2003 are 7% from the 'both CPUE series' run and 17% from the 'trawl CPUE only' run.

The LIN 7WC trawl fishery catch-at-age data are estimated in a largely unstratified manner, i.e., there is a single time and area stratum. There are no clearly apparent variations between years in the temporal or spatial distribution of the sampled trawl tows (author's unpublished data). However, a tree-based regression of the commercial catch-at-age data should indicate whether any stratification is desirable, and this will be conducted before any future assessment of the LIN 7WC stock.

Interestingly, the LIN 7WC stock continued to decline slightly in the 10 years after the period of high exploitation in 1976–1977, even though annual extractions were believed to be only about 1200 t. This is in contrast to the Chatham Rise stock, which rebounded strongly even though its biomass had probably been reduced proportionately more after the mid 1970s exploitation than the LIN 7WC stock biomass.

The assessment of LIN 7WC is confounded by several difficulties. There are no fishery-independent series of relative abundance. CPUE series are available from the trawl and line fisheries, but they exhibit different trends. No age or length data are available from the line fishery, so the fishery ogive is assumed to be the same as that from the Chatham Rise line fishery. It is also known that the trawl fishery catch was under-reported in some years; some corrections have been made to account for this, but it is unknown how accurate they are. Deriving a more accurate catch history, calculating longline selectivity ogives from the LIN 7WC fishery, and reconciling the conflicts between the relative abundance series from the trawl and line fisheries are all likely to improve the estimation of stock status.

Estimates of relative abundance from a trawl survey of part of the LIN 7WC stock in 2000 were calculated in Section 3.3 above. After making various assumptions about the density of ling in unsurveyed areas, it was estimated that a minimum trawl survey estimate would be 3600 t, but that 4200 t was a more likely value. These values can be converted to absolute abundance indices by applying a trawl *q* of 0.07 (as calculated for the same vessel and trawl gear on the Chatham Rise) to produce estimates of 51 400 t and 60 000 t. The 'trawl CPUE only' model estimate of B_{2000} for LIN 7WC after selection by the trawl survey ogive is 20 340 t (with a 95% credible interval of 16 970 to 26 050 t). The survey estimates for 2000 are much higher than the model estimates; indeed, both survey estimates are higher than the medians from all the model runs, and higher than the upper bounds from all but the 'both CPUE series' run. It is known that the trawl survey *q* can vary seasonally: Horn (2004a) estimated that for ling in the Campbell Plateau stock, the survey *q* in autumn is about 1.5 times the summer survey q. If B_{2000} for LIN 7WC really is in the range 17 000–26 000 t, then survey estimates of 3600 and 4200 t imply survey qs of 0.14–0.21 and 0.16–0.25, respectively. These qs are 2–3.5 times the likely value for ling from the Chatham summer survey, and generally higher than those estimated using the same fishing gear for hake on the Chatham Rise (0.08–0.21, Dunn 2004) and for hoki on the Chatham Rise and Campbell Plateau (0.03–0.11, Francis 2004). While this exercise to develop an 'absolute' survey biomass estimate is based on several assumptions, most with weak justification, the overall impression is that most of the model estimates of B_{2000} are probably low.

Current stock size of LIN 7WC is uncertain. The biomass trajectory from the 'no CPUE' run is almost certainly too pessimistic; the implied F from this run is much higher than that calculated from the catch curves. The trajectory from the 'both CPUE series' run is probably too optimistic. Recent catch levels have been greater than all estimates of MCY, but these estimates are very uncertain. Estimates of CAY have been presented for the WCSI stock, but are not considered reliable either. Hence, the uncertainty of this assessment means it is not known whether the TACC or current catch levels are sustainable in the long term, or are at levels that will allow the stock to move towards a size that will support the MSY.

The LIN 7WC 'trawl CPUE only' assessment is quite consistent with, although slightly more optimistic than, the previous assessment of this stock using the trawl CPUE series only. That assessment (Horn 2004a) suggested that B_0 was about 36 000 t (ranging from 32 000 to 43 000 t), and that stock status would decline to about 90% of B_0 by 2008 with future annual catches of 2600 t.

The estimates of stock size for both stocks rely partially on the shape of the selectivity ogives. On the Chatham Rise, full selectivity occurs in the trawl survey and trawl fishery at about age 8–10, and several years later (14–16 years) in the longline fishery. A higher age at full selectivity is expected for the line fishery relative to the trawl fishery, but it would be expected that the age at full selectivity for the trawl survey would be lower than that for the trawl fishery because of the smaller mesh size used in the survey codend. Age at full selectivity in the WCSI trawl fishery is 11–13 years. A larger mean size (and age) in the WCSI trawl fishery relative to the Chatham Rise fishery might be expected because the WCSI fishery is essentially exploiting a spawning population. However, age at 100% maturity has been estimated to be about 8–10 years for WCSI fish. Based on age at maturity, and size at age, slightly lower ages at full selectivity would be expected in the two trawl fisheries and the trawl survey than are estimated within the models. Single-sex length-based ogives (when back-converted to two-sex age-based ogives) suggest similar ages at full selectivity to those described above. However, the fit diagnostics indicate that the two-sex age-based ogives fit the data better, indicating that there are real differences between sexes in selectivity at age and selectivity at length. Such differences are clearly apparent on the Campbell Plateau, where the sex-ratios of the catch from the spawning and non-spawning line fisheries vary markedly (Horn 2004a). Clearly, age-based ogives are preferable to length-based ones, but there is still potential for further refinement of the age-based ogives.

Selectivity will also be confounded by the estimate of instantaneous natural mortality, M. A single value of 0.18 is used for both sexes, and it appears likely that it is reasonably close to the true value. However, as for most teleosts, the true value for males is likely to be slightly higher than for females. The model run conducted to estimate M produced a value for females that was higher than the male value. It was concluded that the model has insufficient information to be able to distinguish between estimates of M, and research and fishing selectivity estimates. M could also vary between populations; the maximum age of ling from the Cook Strait population is much lower than for the other ling populations around the South Island (author's unpublished data).

7. ACKNOWLEDGMENTS

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Appendix A: New calculated catch-at-age distributions for ling

Table A1: Calculated numbers at age, separately by sex, with c.v.s, for ling caught during trawl surveys of the Campbell Plateau in December 2003 (survey TAN0317) and the Chatham Rise in January 2004 (survey TAN0401). Final line for each sample represents a plus group. Summary statistics for the samples are also presented.

				TAN0317					TAN0401
Age	Male	c.v.	Female	c.v.	Age	Male	c.v.	Female	c.v.
1	0	–	0	–	1	0	–	0	–
2	0	–	0	–	2	3 555	1.5888	15 425	1.0775
3	61 841	0.5781	24 747	0.8633	3	68 450	0.4014	60 524	0.4020
4	235 168	0.3136	215 841	0.3205	4	369 973	0.1602	254 487	0.2002
5	256 047	0.3481	576 927	0.2398	5	258 158	0.2015	154 890	0.2374
6	1 015 360	0.1785	569 728	0.2642	6	169 717	0.2198	197 126	0.1938
7	645 081	0.2401	802 046	0.2199	7	216 467	0.1924	191 688	0.2200
8	439 807	0.2409	930 250	0.1972	8	243 609	0.1890	158 389	0.2101
9	321 541	0.2753	698 429	0.1781	9	161 483	0.2493	139 871	0.2309
10	398 879	0.2528	350 540	0.2588	10	88 946	0.2947	118 026	0.2776
11	209 501	0.3552	238 667	0.2887	11	49 225	0.4073	75 384	0.2991
12	101 858	0.4055	272 528	0.2735	12	80 825	0.3054	43 427	0.4076
13	144 317	0.3880	191 787	0.3005	13	59 353	0.3410	34 822	0.4274
14	111 714	0.4272	198 090	0.3138	14	40 470	0.4053	45 660	0.3412
15	105 728	0.4419	177 936	0.3423	15	33 972	0.4176	26 067	0.4849
16	69 475	0.5046	96 338	0.3869	16	26 802	0.4615	13 289	0.5517
17	68 109	0.5438	48 679	0.6196	17	17 768	0.5119	10 375	0.6799
18	35 168	0.5870	49 267	0.5650	18	6 824	1.0485	9 827	0.6889
19	48 379	0.6953	57 683	0.5641	19	0	–	6 476	0.8367
20	18 031	1.0115	32 243	0.6635	20	12 507	0.7153	3 384	1.0470
21+	68 017	0.5186	125 283	0.3710	21+	50 295	0.3375	23 040	0.4005

	TAN0317	TAN0401
Measured males	1 270	865
Measured females	1 156	752
Aged males	242	300
Aged females	332	300
No. of tows	70	101
Meanweighted c.v. (sexes poled)	21.9	20.4

Table A2: Calculated numbers at age, separately by sex, with c.v.s, for ling caught during commercial longline operations on the Puysegur Bank in November–December 2002, and on the Campbell Plateau in February–July 2003. Final line for each sample represents a plus group. Summary statistics for the samples are also presented.

Puysegur Bank					Campbell Plateau				
Age	Male	c.v.	Female	c.v.	Age	Male	c.v.	Female	c.v.
1	0	–	0	–	1	0	–	0	–
2	0	–	0	–	2	0	–	0	–
3	0	–	0	–	3	0	–	0	–
4	0	–	0	–	3	0	–	0	–
5	0	–	98	1.4012	5	0	–	254	1.4931
6	1 026	0.5172	478	0.6405	6	3 318	0.4683	2 107	0.4982
7	4 641	0.2330	3 578	0.3106	7	5 340	0.4216	6 156	0.3569
8	8 296	0.1904	10 301	0.1783	8	8 465	0.2959	10 148	0.2375
9	5 296	0.2613	12 623	0.1563	9	4 507	0.3813	9 361	0.2495
10	4 363	0.2837	7 703	0.2067	10	2 942	0.5218	7 924	0.2927
11	4 405	0.2797	4 534	0.2711	11	761	0.8857	4 841	0.3568
12	2 838	0.3710	4 828	0.2603	12	1 820	0.5975	7 696	0.2609
13	3 702	0.2745	6 306	0.2071	13	1 649	0.6353	8 507	0.2395
14	2 336	0.4105	5 948	0.2189	14	1 140	0.7508	7 375	0.2612
15	1 652	0.4548	3 176	0.2615	15	2 146	0.6923	5 608	0.3316
16	1 856	0.4094	2 086	0.3455	16	931	0.9675	3 478	0.3687
17	1 029	0.5956	5 223	0.2182	17	1 686	0.5055	7 224	0.2701
18	2 427	0.3750	1 377	0.3878	18	911	1.1160	1 905	0.5287
19	2 572	0.3460	2 150	0.3092	19	1 286	0.6989	3 180	0.3591
20	2 615	0.3140	1 211	0.5281	20	389	1.9623	1 789	0.5915
21	2 882	0.3258	1 159	0.4625	21+	8 113	0.2880	5 837	0.2788
22+	2 706	0.2937	2 047	0.3081					

	Puysegur Bank	Campbell Plateau
Measured males	1 250	304
Measured females	1 687	611
Aged males	209	121
Aged females	306	269
No. of sets	214	43
Meanweighted c.v. (sexes poled)	19.8	29.4

Table A3: Calculated numbers at age, separately by sex, with c.v.s, for ling caught during commercial longline operations on the Chatham Rise in July–October 2003, and during commercial trawl operations on the Campbell Plateau in January–July 2003. Final line for each sample represents a plus group. Summary statistics for the samples are also presented.

			Chatham Rise longline					Campbell Plateau trawl	
Age	Male	c.v.	Female	c.v.	Age	Male	c.v.	Female	c.v.
1	0	–	0	–	1	0	–	0	–
2	0	–	0	–	2	1 991	1.5752	1 330	1.3387
3	0	–	0	–	3	15 114	0.7459	11 318	0.5496
4	0	–	7	1.6813	4	14 119	0.6606	19 812	0.3480
5	192	0.8036	40	0.9841	5	82 286	0.3865	82 905	0.3148
6	944	0.4682	557	0.4141	6	147 841	0.3060	98 712	0.3183
7	2 926	0.2228	511	0.5009	7	146 198	0.2910	172 679	0.2450
8	5 303	0.1960	2 540	0.2467	8	160 652	0.2699	292 506	0.1697
9	7 267	0.1695	2 779	0.2747	9	196 692	0.2187	232 303	0.1789
10	5 325	0.2204	2 822	0.2319	10	85 902	0.3829	133 102	0.2566
11	3 769	0.2430	2 592	0.2341	11	55 927	0.4750	80 161	0.3052
12	3 527	0.2500	3 762	0.1945	12	33 990	0.5059	66 544	0.3443
13	5 436	0.1832	4 438	0.1877	13	42 144	0.4312	48 614	0.4299
14	3 837	0.2185	5 248	0.1867	14	48 171	0.4275	51 803	0.4007
15	4 479	0.1986	3 520	0.2008	15	38 172	0.4476	42 035	0.4646
16	2 113	0.2918	1 651	0.3308	16	18 186	0.6282	28 612	0.5288
17	1 974	0.3045	1 689	0.3023	17	22 559	0.7129	25 851	0.5582
18	1 546	0.3542	1 851	0.3065	18	6 031	0.8486	4 995	1.3012
19	871	0.4212	902	0.3848	19	26 474	0.6160	29 995	0.6401
20	1 183	0.4039	439	0.6312	20+	133 446	0.2525	48 197	0.4514
21	1 783	0.3085	331	0.6233					
22	133	1.0975	349	0.6179					
23+	3 784	0.1813	1 461	0.2101					

	Chatham Rise longline	Campbell Plateau trawl
Measured males	3 038	745
Measured females	2 071	872
Aged males	334	210
Aged females	282	274
No. of sets/tows	429	130
Meanweighted c.v. (sexes poled)	19.1	25.7

Table A4: Calculated numbers at age, separately by sex, with c.v.s, for ling caught during commercial trawl operations off the west coast of the South Island (WCSI) and in Cook Strait, during June–September 2003. Final line for each sample represents a plus group. Summary statistics for the samples are also presented.

				WCSI					Cook Strait
Age	Male	c.v.	Female	c.v.	Age	Male	c.v.	Female	c.v.
1	0	–	0	–	1	0	–	0	–
2	55	1.8238	1 019	2.1551	2	29	2.0678	0	–
3	74	1.8053	1 163	1.8271	3	58	1.5065	175	0.9667
4	6 052	0.5616	7 024	0.4328	4	306	0.6638	128	0.7102
5	13 538	0.3793	18 674	0.3257	5	617	0.7131	653	0.4532
6	18 218	0.3115	13 568	0.3271	6	657	0.4308	701	0.3997
7	14 862	0.2843	11 101	0.3159	7	1 622	0.2916	1 679	0.3467
8	25 762	0.2163	7 807	0.3449	8	1 858	0.2456	2 352	0.2324
9	20 230	0.2419	8 914	0.3273	9	2 051	0.2443	3 770	0.2038
10	23 176	0.2098	13 491	0.2615	10	2 603	0.2121	2 906	0.2138
11	20 409	0.2100	21 043	0.2142	11	2 263	0.2563	2 210	0.2688
12	27 492	0.2014	17 637	0.2244	12	1 265	0.3006	1 606	0.2981
13	11 282	0.3170	25 376	0.1723	13	1 098	0.4023	2 008	0.2538
14	9 471	0.3069	14 424	0.2392	14	365	0.6180	505	0.4380
15	6 353	0.4000	8 887	0.3085	15	952	0.4187	512	0.4443
16	2 885	0.5148	6 188	0.3688	16	146	0.9865	65	1.5288
17	2 552	0.6772	4 038	0.4279	17+	751	0.4667	583	0.3969
18	0	0.0000	4 950	0.4483					
19	2 545	0.5700	3 891	0.4147					
20	1 578	0.8888	703	0.7591					
21+	4 113	0.4217	3 560	0.3616					
Measured males				1 191					430
Measured females				1 330					437
Aged males				285					277
Aged females				296					301
No. of tows/samples				347					56
Meanweighted c.v. (sexes poled)				22.8					24.5

Appendix B: Summary MPD model fits for LIN 3&4 and LIN 7WC

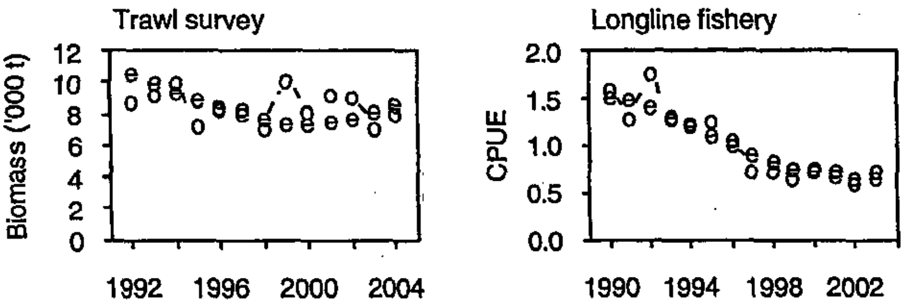

Figure B1: LIN 3&4 base case — MPD fits to the summer trawl survey biomass indices and the longline CPUE indices, where 'o' indicated the observed value and 'e' indicated the fitted (expected) value.

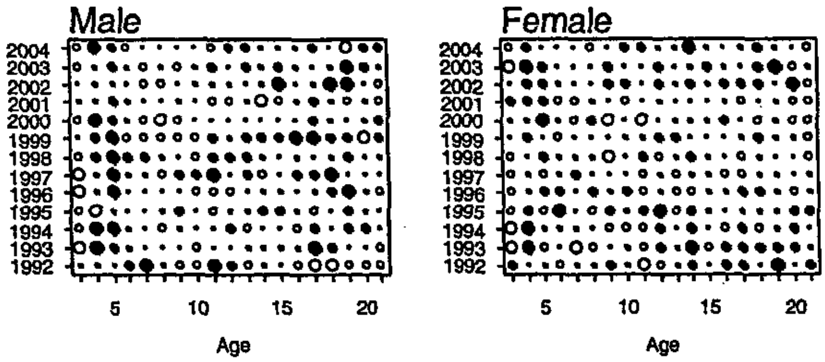

Figure B2: LIN 3&4 base case — MPD residual values for the proportions-at-age data for the summer trawl survey series. Symbol area is proportional to the absolute value of the residual, with black circles indicating positive residuals and open circles indicating negative residuals.

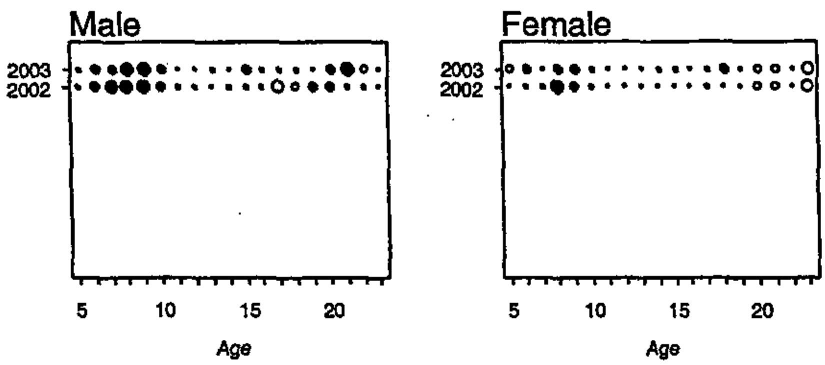

Figure B3: LIN 3&4 base case — MPD residual values for the proportions-at-age data for the longline fishery series. Symbol size and shading as in Figure B2.

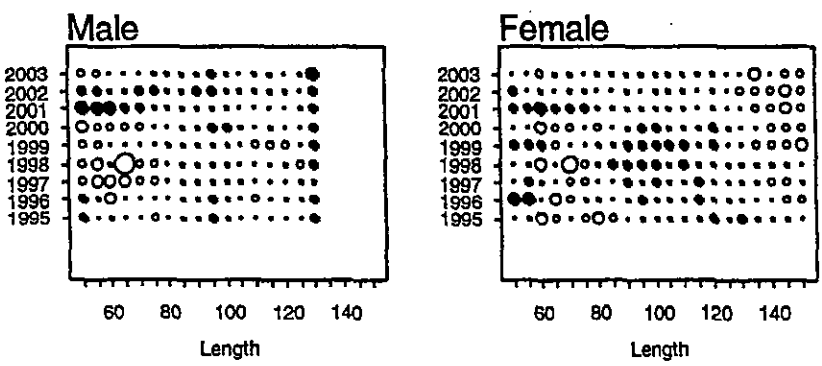

Figure B4: LIN 3&4 base case — MPD residual values for the proportions-at-length data for the longline fishery series. Symbol size and shading as in Figure B2.

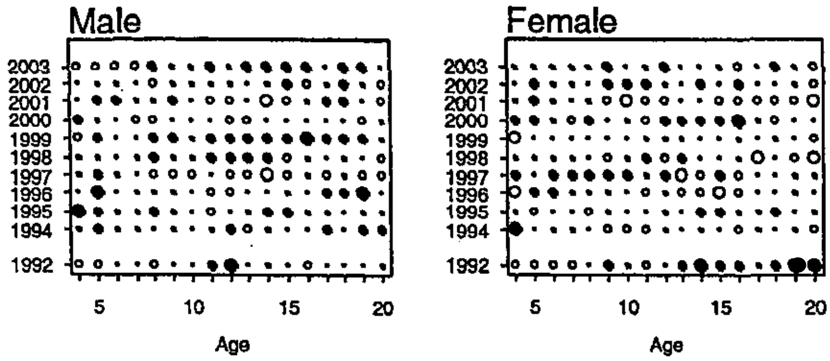

Figure B5: LIN 3&4 base case — MPD residual values for the proportions-at-age data for the trawl fishery series. Symbol size and shading as in Figure B2.

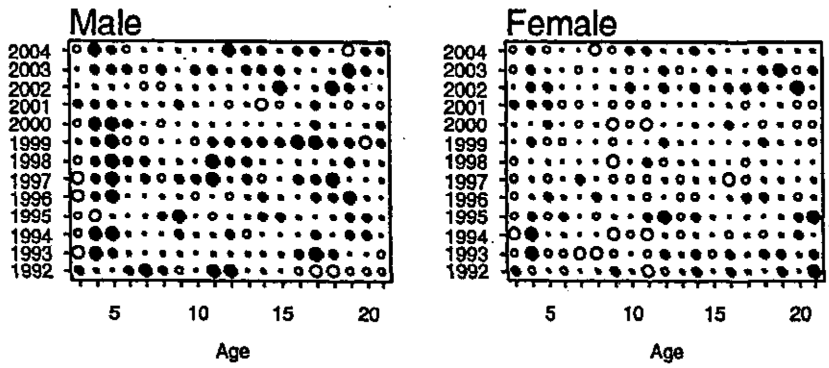

Figure B6: LIN 3&4 length-based selectivity — MPD residual values for the proportions-at-age data for the summer trawl survey series. Symbol size and shading as in Figure B2.

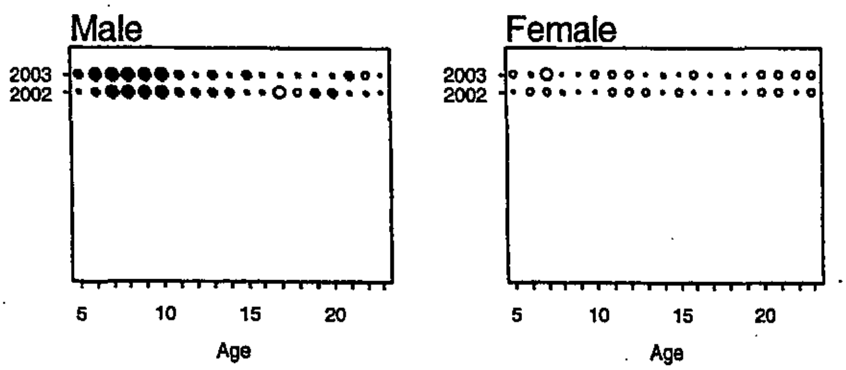

Figure B7: LIN 3&4 length-based selectivity — MPD residual values for the proportions-at-age data for the longline fishery series. Symbol size and shading as in Figure B2.

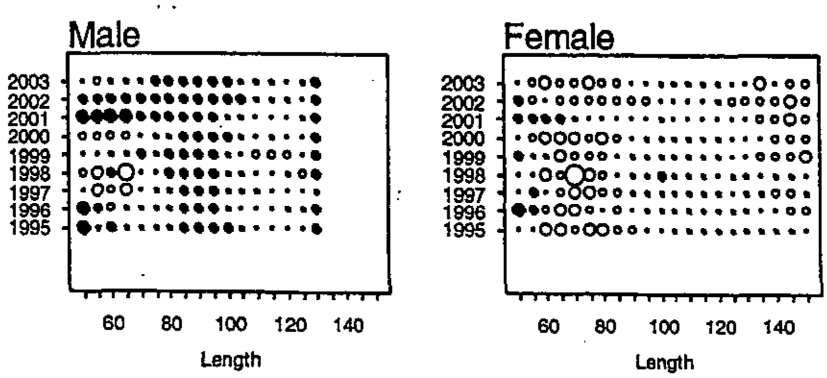

Figure B8: LIN 3&4 length-based selectivity — MPD residual values for the proportions-at-length data for the longline fishery series. Symbol size and shading as in Figure B2.

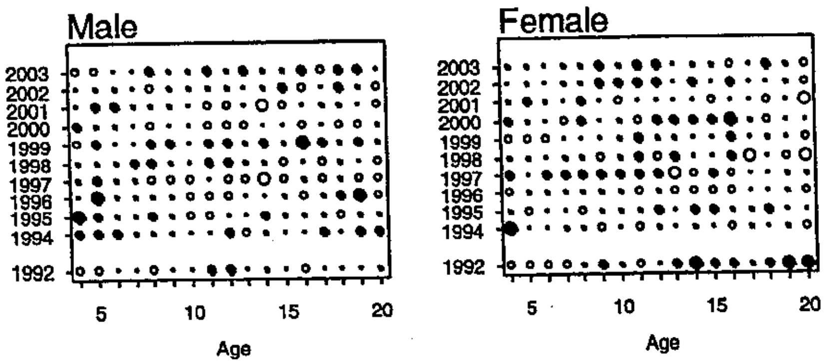

Figure B9: LIN 3&4 length-based selectivity — MPD residual values for the proportions-at-age data for the trawl fishery series. Symbol size and shading as in Figure B2.

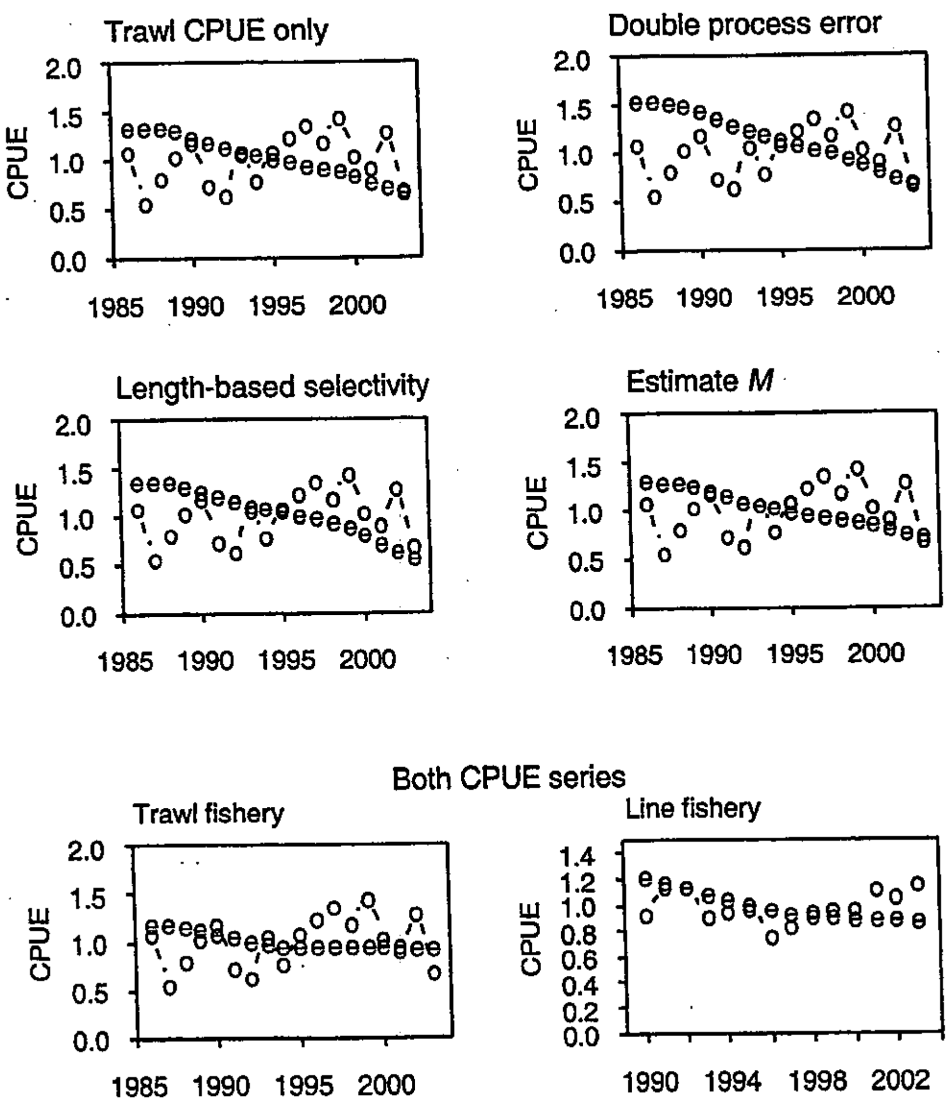

Figure B10: LIN 7WC — MPD fits to the trawl CPUE indices, where 'o' indicated the observed value and 'e' indicated the fitted (expected) value.

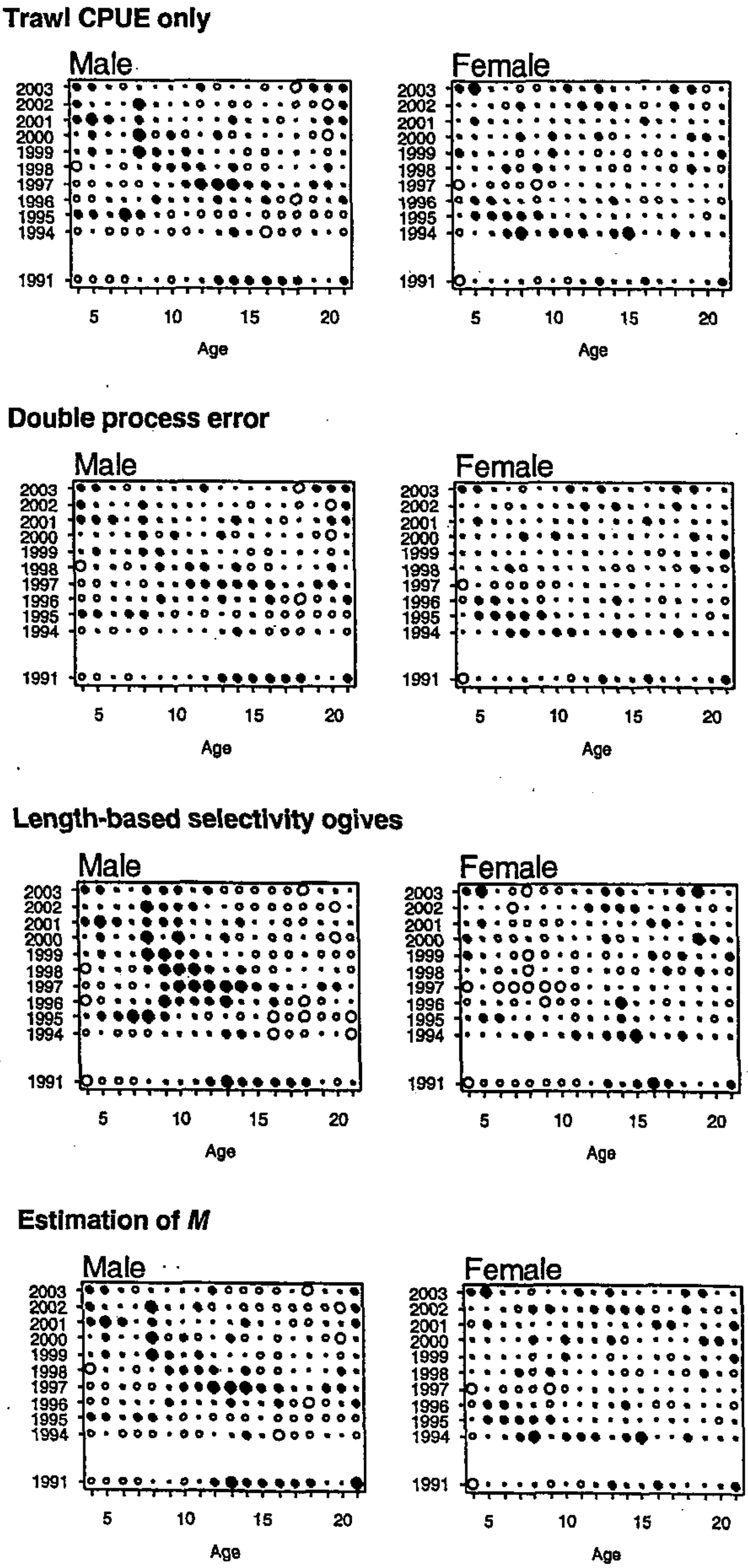

Figure B11a: LIN 7WC — MPD residual values for the proportions-at-age data for the commercial trawl fishery series. Symbol size and shading as in Figure B2.

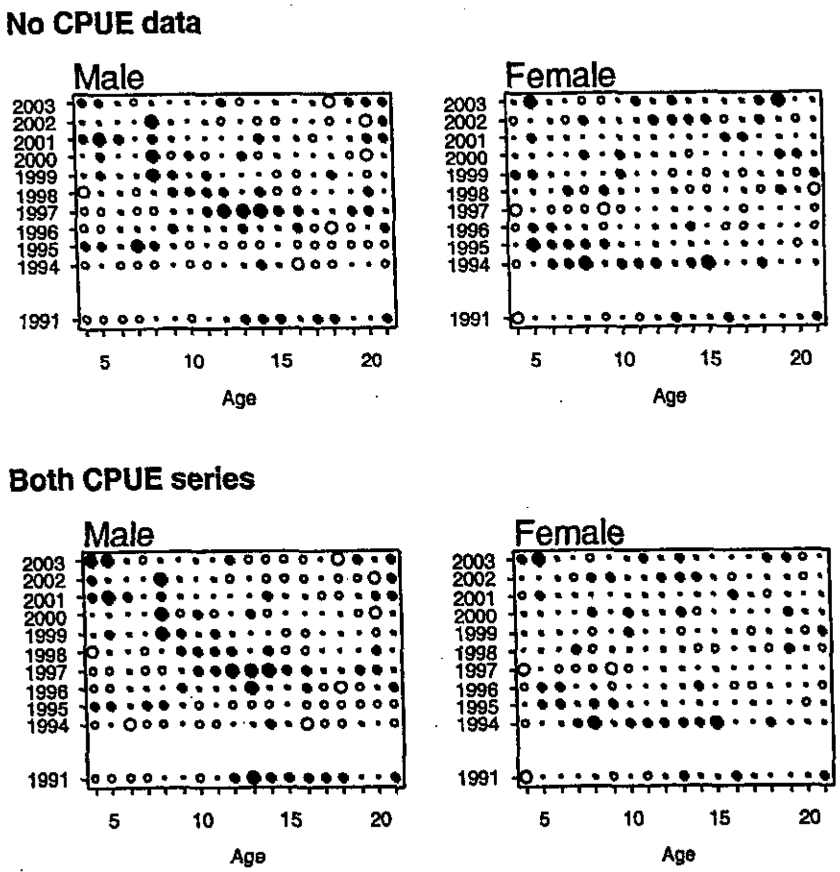

Figure B11b: LIN 7WC — MPD residual values for the proportions-at-age data for the commercial trawl fishery series. Symbol size and shading as in Figure B2.