NIWA

Taihoro Nukurangi

Catch-at-age data, and a review of natural mortality, for ling

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Final Research Report for Ministry of Fisheries Research Project MID9801 Objectives 1, 3, 4, & 5

National Institute of Water and Atmospheric Research

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Final Research Report

1.	**Date**	1 March 2000
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3.	**Project Title**	Catch-at-age data, and a review of natural mortality, for ling
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7. Executive Summary

This report describes the final results from Objectives 1, 3, 4, and 5 of project MID9801, relating to ling only. Results from Objective 2 were reported by Harley (1999). New series of catch-at-age data from trawl surveys and commercial longline samples are presented for ling from the Chatham Rise and Southern Plateau. It appears feasible to use the trawl survey samples to develop time series of recruitment indices. A comparison of age-length keys for ling caught by commercial longline and research trawl indicated no differences between fishing methods on the Southern Plateau, or for females on the Chatham Rise, but a clear difference for males from the Chatham Rise. Existing age data were used to review the estimate of natural mortality for ling. Although, no samples were available from unexploited stocks, it seems likely that the currently used value of 0.18 is probably close to the true value.

8. Objectives

1. To determine the catch at age from hake fisheries in HAK 1, 4 and 7 and ling fisheries in LIN 3 & 4, 5 & 6 and 7 in 1997/98 from samples collected at sea by Scientific Observers and from other sources, with a target coefficient of variation (c.v.) of 30 % for each Fishstock (mean weighted c.v. across all age classes).

2. To update the standardised catch and effort analyses from the ling longline fisheries (LIN 3 & 4, 5 & 6) with the addition of data up to the end of the 1997/98 fishing year.

3. To determine the feasibility of developing time series of recruitment indices for hake and ling from trawl survey data from Chatham Rise and Southern Plateau.

4. To determine ling age-length keys from trawl surveys and commercial longline fisheries.

5. To review the estimates of natural mortality for hake and ling based on ageing data from the fisheries.

6. To update the stock assessments of hake (HAK 1 and 4) and ling (LIN 3 & 4 and 5 & 6) including estimating biomass and yields.

9. Methods

1. To determine the catch at age from hake fisheries in HAK 1, 4 and 7 and ling fisheries in LIN 3 & 4, 5 & 6 and 7 in 1997/98 from samples collected at sea by Scientific Observers and from other sources, with a target coefficient of variation (c.v.) of 30 % for each Fishstock (mean weighted c.v. across all age classes).

As agreed in the "Exceptions and Deviations" section of the tender, no estimates of catch at age from 1997/98 were completed for LIN 5 & 6 as this had already been completed in 1998 under project MDT9701.

For LIN 3 & 4, the tender stated a preference to derive catch at age data from commercial longline samples in 1997/98, with a trawl survey sample from January 1999 being an acceptable alternative. No commercial longline otolith samples were available. A sample of 600 otoliths was selected from the survey collection so that the length and sex distribution of the aged fish was proportional to the scaled length frequency from the survey. Otoliths were prepared and read using the method of Horn (1993b). The age data were used to construct age-length keys, which were applied to the scaled length frequency obtained from the survey, to calculate the age structure of the ling population in this area.

For LIN 7, a sample of 600 otoliths was selected from the collection made by Scientific Observers on trawlers off west coast South Island between June and September 1998. The length and sex distribution of the aged fish was proportional to the scaled length frequency from the commercial fishery. Otoliths were prepared and read using the method of Horn (1993b). The age data were used to construct age-length keys, which were applied to the scaled length frequency to calculate the age structure of the ling taken by trawl in this area.

2. To update the standardised catch and effort analyses from the ling longline fisheries (LIN 3 & 4, 5 & 6) with the addition of data up to the end of the 1997/98 fishing year.

Full details of the analyses of CPUE data from longline fisheries in LIN 3&4, LIN 5&6, and LIN 6B are given by Harley (1999).

3. To determine the feasibility of developing time series of recruitment indices for hake and ling from trawl survey data from Chatham Rise and Southern Plateau.

Two trawl survey series which monitor stocks of ling on Chatham Rise and Campbell Plateau are currently being maintained, i.e., a January Chatham Rise survey conducted annually since 1992, and an April–May Campbell Plateau survey conducted four times since 1992. Catch at age data were already available from some of these surveys (*see* Horn 1997), and they were derived for the remaining surveys.

Otoliths from three Southern Plateau surveys (TAN9204, TAN9304, TAN9605) and four Chatham Rise surveys (TAN9212, TAN9401, TAN9501, TAN9601) were selected for ageing. Samples of 600 otoliths were selected from each survey sample so that the length and sex distribution of the aged fish was proportional to the scaled length frequency from the survey. Otoliths were prepared and read using the method of Horn (1993b). The age data were used to construct age-length keys, which were applied to the scaled length frequencies obtained from the surveys, to calculate age structures of the ling populations in these areas.

These series will be incorporated into stock models, and used to determine series of recruitment indices for ling from the two areas.

4. To determine ling age-length keys from trawl surveys and commercial longline fisheries.

To enable comparisons of commercial longline and research trawl age-length keys from the Chatham Rise and Campbell Plateau, two further samples were prepared and read. Two samples each of 550 otoliths were selected from commercial longline trips in LIN 5&6 in April–May 1998, and in LIN 3&4 in January 1999. The otoliths were selected so that the length and sex distribution of the aged fish was proportional to the scaled length frequency from the trip. The age data were used to construct age-length keys, which were applied to the scaled length frequencies, to calculate age structures. Both the sampled commercial trips occurred at the same times as trawl surveys of the respective areas (i.e., TAN9805, TAN9901).

Mean lengths at age were calculated separately by sex for ling from the two commercial longline trips and the two research trawl surveys conducted at the same time. Means were calculated only when there was a minimum of three fish at a particular age. Pairs of mean lengths at age from the same area and sex, but different fishing methods, were compared using *t*-tests.

5. To review the estimates of natural mortality for hake and ling based on ageing data from the fisheries.

Existing age data were used to review the estimation of natural mortality for ling. Estimates of M were derived using the methods of Hoenig (1983) and Chapman & Robson (1960), and from the slope of the right hand limb of the catch curve (Ricker 1975). Full details of the methods used are presented in Appendix B below.

6. To update the stock assessments of hake (HAK 1 and 4) and ling (LIN 3 & 4 and 5 & 6) including estimating biomass and yields.

Ling stocks LIN 3&4 and LIN 5&6 were modelled using the least squares and single-stock MIAEL estimation techniques of Cordue (1993, 1995, 1998). Both these stocks support trawl and longline fisheries, and it is apparent that these two methods have markedly different fishing selectivity ogives. The Middle Depth Species Fisheries Assessment Working Group considered that the use of a single selectivity ogive for a dual fishery was inappropriate. Subsequently, the MIAEL estimation procedure was modified so that catch histories and selectivities attributable to different fishing methods could be used separately. Modelling results will be presented later.

10. Results

1. To determine the catch at age from hake fisheries in HAK 1, 4 and 7 and ling fisheries in LIN 3 & 4, 5 & 6 and 7 in 1997/98 from samples collected at sea by Scientific Observers and from other sources, with a target coefficient of variation (c.v.) of 30 % for each Fishstock (mean weighted c.v. across all age classes).

The catch at age distribution for ling form the 1998 trawl survey of the Southern Plateau (TAN9805) is given in Appendix A (Table A1). The distribution from the 1999 Chatham Rise trawl survey (TAN9901) is listed in Appendix A (Table A2). The catch at age distribution form the 1997/98 trawl fishery in LIN 7 was presented by Horn & Ballara (1999).

All the catch at age samples had coefficients of variation of less than 30%.

2. To update the standardised catch and effort analyses from the ling longline fisheries (LIN 3 & 4, 5 & 6) with the addition of data up to the end of the 1997/98 fishing year.

Full details of the analyses of CPUE data from longline fisheries in LIN 3&4, LIN 5&6, and LIN 6B are given by Harley (1999).

3. To determine the feasibility of developing time series of recruitment indices for hake and ling from trawl survey data from Chatham Rise and Southern Plateau.

Appendix A contains catch at age data for ling from the series of four trawl surveys of the Campbell Plateau in autumn 1992, 1993, 1996, and 1998 (Table A1), and from the series of eight trawl surveys of the Chatham Rise conducted annually, in January, from 1992 to 1999 (Table A2).

These series will be incorporated into stock assessment models, and used to determine series of recruitment indices for ling from the two areas. (The series will be reported later with the stock assessment results.)

4. To determine ling age-length keys from trawl surveys and commercial longline fisheries.

Catch at age data for ling from two commercial longline trips (in LIN 5&6 in April–May 1998, and in LIN 3&4 in January 1999) are compared with data from trawl surveys conducted in the same areas and times (Appendix A, Table A3). It is apparent that, in both areas, the longline fishery catches a greater proportion of older fish than the trawl surveys (Figure A1).

Mean lengths at age were calculated separately by sex for ling from the two commercial longline trips and the two research trawl surveys conducted at the same time. Means were calculated only when there was a minimum of three fish at a particular age, and are shown in Appendix A (Figure A2). Pairs of mean lengths at age from the same area and sex, but different fishing methods, were compared using *t*-tests. There were no significantly different pairings for Campbell Plateau fish, or for females on the Chatham Rise. However, male ling on the Chatham Rise caught by longline appear to be consistently larger at a particular age than trawl-caught fish. Four individual pairings of means were statistically significant (i.e., ages 10, 11, 16, and 17), although for 15 of the 16 ages that could be compared, the mean length was smaller for the trawl survey fish

Age-length keys calculated for ling on the Campbell Plateau, and for female ling on the Chatham Rise, can probably be applied to length-frequency data from either the trawl or longline fisheries. For male ling from the Chatham Rise, the age-length keys appear to be fishery dependent.

5. To review the estimates of natural mortality for hake and ling based on ageing data from the fisheries.

Full details of a revision of the estimates of natural mortality for ling are presented in Appendix B below. The current study indicates that the estimate of *M* used in previous assessments of ling (i.e., 0.18 for both sexes) was probably reasonable. No suitable otolith samples are available from an unexploited ling stock, so it is difficult to confidently update the estimate of *M*. It is suggested that 0.16 is the best estimate of *M* for females. Given that the *M* for male ling should probably be slightly higher than that for females, a value of 0.18 is suggested here.

The Middle Depth Species Fisheries Assessment Working Group chose to retain the estimate of *M* used in previous assessments, i.e., 0.18 for both sexes.

11. Publications

Harley, S.J. 1999: Catch per unit effort (CPUE) analysis of the Chatham Rise, Southern Plateau, and Bounty Platform ling (*Genypterus blacodes*) longline fisheries. *N.Z. Fisheries Assessment Research Document 99/31.* 26 p.

12. Data Storage

All age data are stored on the *age* database at NIWA, Greta Point, Wellington.

13. References

Annala, J.H., Sullivan, K.J., O'Brien, C.J., & Iball, S.D. (Comps.) 1998: Report from the Fishery Assessment Plenary, May 1998: stock assessments and yield estimates. 409 p. (Unpublished report held in NIWA library, Wellington.)

Chapman, D.G. & Robson, D.S. 1960: The analysis of a catch curve. *Biometrics 16*: 354–368.

Cordue, P.L. 1993: A Minimised Integrated Average Mean Squared Error Approach to Biomass and Risk Estimation. *N.Z. Fisheries Assessment Research Document 93/1.* 21 p.

Cordue, P.L. 1995: MIAEL estimation of biomass and fishery indicators for the 1995 assessment of hoki stocks. *N.Z. Fisheries Assessment Research Document 95/13.* 38 p.

Cordue, P.L. 1998: Designing optimal estimators for fish stock assessment. *Canadian Journal of Fisheries and Aquatic Sciences 55*: 376–386.

Dunn, A., Francis, R.I.C.C., & Doonan, I.J. 1999: The sensitivity of some catch curve estimators of mortality to stochastic noise, error, and selectivity. *N.Z. Fisheries Assessment Research Document 99/5.* 23 p.

Harley, S.J. 1999: Catch per unit effort (CPUE) analysis of the Chatham Rise, Southern Plateau, and Bounty Platform ling (*Genypterus blacodes*) longline fisheries. *N.Z. Fisheries Assessment Research Document 99/31.* 26 p.

Hoenig, J.M. 1983: Empirical use of longevity data to estimate mortality rates. *Fishery Bulletin 82*: 898–902.

Horn, P.L. 1993a: Assessment of ling (*Genypterus blacodes*) stocks (LIN 3, 4, 5, 6 and 7) off the South Island, New Zealand. *N.Z. Fisheries Assessment Research Document 93/9.* 29 p.

Horn, P.L. 1993b: Growth, age structure, and productivity of ling, *Genypterus blacodes* (Ophidiidae), in New Zealand waters. *N.Z. Journal of Marine and Freshwater Research 27*: 385–397.

Horn, P.L. 1997: An update of stock assessment for ling (*Genypterus blacodes*) stocks LIN 3, 4, 5, and 6 for the 1997–98 fishing year. *N.Z. Fisheries Assessment Research Document 97/11.* 20 p.

Horn, P.L. & Cordue, P.L. 1996: MIAEL estimates of virgin biomass and MCY and an update of stock assessment for ling (*Genypterus blacodes*) for the 1996–97 fishing year. *N.Z. Fisheries Assessment Research Document 96/9.* 15 p.

Horn, P.L. & Ballara, S.L. 1999: Analysis of longline CPUE, and stock assessment of ling (*Genypterus blacodes*) off the northwest coast of the South Island (Fishstock LIN 7). *N.Z. Fisheries Assessment Research Document 99/27.* 31 p.

Pauly, D. 1980: On the interrelationships between natural mortality, growth parameters, and mean environmental temperature in 175 fish stocks. *Journal du Conseil International pour l'Exploration de la Mer 39*: 175–192.

Ricker, W.E. 1975: Computation and interpretation of biological statistics of fish populations. *Bulletin of the Fisheries Research Board, Canada 191.* 382 p.

APPENDIX A

Calculated catch-at-age data

Table A1: Calculated catch at age, by sex, for ling from a series of comparable trawl surveys in the Southern Plateau. Numbers have been scaled to total population in the survey area. Summary statistics show the total number of fish, by sex, that were measured (Meas.mal, Meas.fem) or successfully aged (Aged.mal, Aged.fem), the number of trawl shots that were sampled (Samp.tows), and the mean weighted *c.v.* across all age classes for the catch at age data (Mean CV)

		TAN9204		TAN9304		TAN9605		TAN9805	
	Age	Number	cv	Number	cv	Number	cv	Number	cv
Male	2	0	0.000	9 361	1.211	0	0.000	64 324	0.522
	3	37 335	0.482	86 294	0.546	102 616	0.323	270 431	0.271
	4	116 359	0.267	150 938	0.244	418 378	0.211	722 914	0.185
	5	165 966	0.329	330 585	0.233	372 581	0.261	746 835	0.186
	6	677 661	0.171	599 439	0.199	679 343	0.180	488 161	0.231
	7	712 208	0.206	823 311	0.184	846 483	0.138	608 391	0.222
	8	1470 440	0.139	617 863	0.225	448 474	0.202	620 412	0.220
	9	598 055	0.263	512 400	0.245	411 983	0.203	412 598	0.277
	10	578 405	0.241	530 813	0.246	456 270	0.203	259 363	0.338
	11	370 357	0.325	505 893	0.257	270 257	0.245	446 643	0.268
	12	470 269	0.290	465 582	0.259	268 787	0.242	350 274	0.285
	13	143 532	0.513	198 480	0.418	467 347	0.186	85 830	0.521
	14	267 788	0.315	252 272	0.346	392 279	0.207	198 515	0.358
	15	149 243	0.366	298 846	0.329	256 562	0.252	232 012	0.328
	16	109 050	0.452	97 278	0.549	114 432	0.436	241 599	0.305
	17	84 662	0.590	171 248	0.404	225 839	0.269	206 884	0.370
	18	43 403	0.746	119 106	0.394	125 643	0.387	83 027	0.547
	19	20 809	0.936	102 963	0.577	11 682	1.025	55 350	0.606
	20	188 135	0.446	107 165	0.496	24 703	0.728	60 647	0.686
	21	127 149	0.593	111 550	0.491	36 045	0.601	38 106	0.753
	22	239 322	0.406	22 467	0.719	33 679	0.706	16 151	0.897
	23	49 135	0.702	113 316	0.441	18 597	0.792	8 814	1.487
	24	45 426	0.843	62 032	0.619	50 719	0.522	18 478	1.065
	25	30 214	0.832	0	0.000	0	0.000	0	0.000
	26	2 126	1.287	28 004	1.015	11 896	0.960	17 412	1.036
	27	6 769	1.348	522	1.632	0	0.000	0	0.000
	28	64 655	0.816	0	0.000	0	0.000	7 377	1.156
	29	41 482	0.967	13 700	0.729	0	0.000	0	0.000
	30	19 244	1.000	0	0.000	0	0.000	0	0.000

Table A1: (*continued*)

	Age	TAN9204 Number	cv	TAN9304 Number	cv	TAN9605 Number	cv	TAN9805 Number	cv
Female	2	0	0.000	0	0.000	0	0.000	98 804	0.631
	3	26 138	0.535	43 105	1.052	61 996	0.456	439 282	0.262
	4	131 905	0.276	134 958	0.389	306 839	0.437	634 221	0.215
	5	193 546	0.357	296 532	0.235	529 490	0.252	769 880	0.179
	6	420 317	0.226	429 235	0.198	578 314	0.271	525 512	0.215
	7	636 003	0.194	685 500	0.166	564 309	0.219	525 028	0.218
	8	1075 749	0.153	569 995	0.184	513 220	0.202	508 310	0.232
	9	678 386	0.209	695 147	0.182	456 862	0.229	601 825	0.226
	10	922 289	0.178	430 485	0.234	394 654	0.229	376 171	0.278
	11	597 893	0.217	709 969	0.168	349 263	0.276	322 754	0.297
	12	662 036	0.198	523 093	0.208	321 522	0.272	321 985	0.312
	13	391 850	0.250	464 460	0.214	331 842	0.259	299 375	0.298
	14	211 904	0.336	343 102	0.234	382 997	0.387	229 846	0.337
	15	267 215	0.296	258 856	0.275	361 139	0.254	228 994	0.323
	16	123 048	0.360	128 165	0.375	86 871	0.482	164 562	0.357
	17	109 142	0.539	167 346	0.334	132 423	0.442	207 940	0.330
	18	134 018	0.343	217 817	0.284	76 313	0.510	117 701	0.464
	19	66 685	0.563	115 883	0.379	110 985	0.452	48 843	0.762
	20	81 730	0.530	55 997	0.662	20 606	1.182	20 849	1.216
	21	51 583	0.503	51 351	0.632	34 055	0.517	48 293	0.935
	22	29 822	0.660	28 838	0.735	0	0.000	0	0.000
	23	22 202	0.640	15 781	1.150	0	0.000	12 747	1.396
	24	64 726	0.617	26 976	0.715	0	0.000	12 585	1.347
	25	11 650	0.890	12 528	1.041	0	0.000	0	0.000
	26	0	0.000	34 221	0.826	0	0.000	0	0.000
	27	1 531	9.819	36 596	0.662	0	0.000	0	0.000
	28	0	0.000	9 590	0.933	0	0.000	0	0.000
	29	0	0.000	0	0.000	0	0.000	0	0.000
	30	1 709	1.541	0	0.000	0	0.000	0	0.000
Meas.mal		1570		1353		1149		816	
Meas.fem		1498		1344		906		767	
Aged.mal		216		256		331		271	
Aged.fem		310		370		274		296	
Smp.tows		90		97		88		64	
Mean CV		26.5		26.7		25.7		27.8	

Table A2: **Calculated catch at age, by sex, for ling from a series of comparable trawl surveys on the Chatham Rise. Numbers have been scaled to total population in the survey area. Summary statistics show the total number of fish, by sex, that were measured (Meas.mal, Meas.fem) or successfully aged (Aged.mal, Aged.fem), the number of trawl shots that were sampled (Samp.tows), and the mean weighted *c.v.* across all age classes for the catch at age data (Mean CV)**

		TAN9106		TAN9212		TAN9401		TAN9501		TAN9601		TAN9701		TAN9801		TAN9901	
	Age	Number	cv	Number	cv	Number	cv	Number	cv	Number	cv	Number	cv	Number	cv	Number	cv
Male	2	9 410	0.353	782	1.689	5 099	0.623	0	0.000	0	0.000	5 434	3.010	3 780	0.404	0	0.000
	3	103 233	0.136	34 908	0.361	61 425	0.233	32 923	0.273	10 431	0.991	40 747	0.347	88 611	0.316	268 651	0.152
	4	96 690	0.145	222 491	0.150	220 033	0.168	36 871	0.471	106 174	0.247	118 340	0.234	157 738	0.305	318 130	0.145
	5	80 391	0.129	189 424	0.167	327 585	0.123	89 075	0.303	229 677	0.206	183 441	0.200	174 783	0.265	302 895	0.166
	6	119 877	0.148	118 769	0.233	196 763	0.184	128 255	0.203	117 699	0.282	156 310	0.218	162 807	0.227	118 562	0.336
	7	170 624	0.151	81 124	0.257	130 214	0.215	108 538	0.221	165 897	0.228	155 806	0.236	171 589	0.215	101 855	0.327
	8	121 616	0.202	97 945	0.235	98 960	0.249	100 657	0.224	138 650	0.225	123 105	0.263	122 170	0.255	137 953	0.252
	9	58 261	0.243	110 465	0.219	129 552	0.220	95 302	0.238	96 003	0.246	168 614	0.233	130 115	0.264	112 433	0.321
	10	47 981	0.327	64 481	0.302	110 693	0.239	56 618	0.326	47 995	0.332	113 806	0.244	77 033	0.307	103 482	0.320
	11	120 285	0.216	63 072	0.304	88 576	0.275	41 284	0.373	51 602	0.316	116 300	0.226	101 264	0.324	136 852	0.267
	12	124 427	0.194	60 399	0.300	95 475	0.266	50 751	0.311	44 229	0.354	52 408	0.318	57 943	0.388	84 922	0.330
	13	57 175	0.275	76 912	0.290	34 604	0.462	39 308	0.453	49 031	0.309	69 769	0.274	47 132	0.418	64 229	0.358
	14	77 534	0.249	72 506	0.277	61 243	0.335	47 503	0.358	42 612	0.379	24 074	0.484	41 619	0.448	73 096	0.403
	15	49 128	0.309	70 981	0.292	53 429	0.329	51 294	0.327	40 231	0.333	20 854	0.471	18 376	0.717	53 230	0.533
	16	19 093	0.547	61 124	0.292	45 877	0.341	37 319	0.381	25 805	0.440	37 521	0.335	22 590	0.519	93 711	0.323
	17	14 525	0.380	79 519	0.258	75 261	0.281	26 152	0.453	42 769	0.345	41 624	0.335	14 052	0.833	51 421	0.357
	18	4 814	0.473	49 571	0.309	36 631	0.396	26 092	0.490	42 159	0.360	54 403	0.317	18 691	0.534	28 447	0.420
	19	8 521	0.409	26 444	0.543	56 264	0.280	35 154	0.375	68 466	0.263	20 223	0.493	23 523	0.669	27 277	0.382
	20	8 259	0.384	12 606	0.496	35 736	0.409	26 508	0.511	24 499	0.527	17 327	0.521	15 622	0.606	2 209	3.350
	21	2 865	0.967	10 160	1.033	30 178	0.434	35 177	0.376	20 911	0.438	14 091	0.560	27 600	0.546	23 795	0.642
	22	0	0.000	5 414	0.619	2 718	1.098	2 662	1.198	12 348	0.561	21 582	0.466	0	0.000	56 424	0.643
	23	4 802	0.474	1 627	2.617	11 658	0.720	0	0.000	9 814	0.872	12 862	0.540	12 581	0.649	14 405	0.612
	24	11 484	0.643	4 902	0.928	8 263	0.948	2 449	1.223	4 470	0.796	4 326	1.728	20 021	0.620	15 094	0.726
	25	1 520	1.016	6 647	0.496	12 787	0.568	1 974	1.001	1 062	1.374	4 405	1.720	0	0.000	9 187	0.587
	26	0	0.000	2 794	1.194	4 076	0.474	0	0.000	0	0.000	5 922	0.646	1 185	0.544	3 446	0.849
	27	8 802	0.350	0	0.000	795	1.159	731	1.974	4 513	1.146	0	0.000	0	0.000	7 103	1.277
	28	0	0.000	0	0.000	0	0.000	3 825	1.031	1 143	0.383	0	0.000	6 274	1.030	1 321	1.531
	29	0	0.000	2 131	0.945	0	0.000	0	0.000	0	0.000	0	0.000	0	0.000	0	0.000
	30	2 047	0.808	0	0.000	0	0.000	0	0.000	3 803	0.714	2 352	1.179	0	0.000	0	0.000
	31	0	0.000	0	0.000	0	0.000	0	0.000	7 440	0.389	1 200	1.582	0	0.000	0	0.000
	32	0	0.000	0	0.000	0	0.000	665	2.169	0	0.000	1 642	1.588	0	0.000	0	0.000
	33	1 336	1.051	0	0.000	2 663	1.547	1 974	1.001	0	0.000	4 812	0.956	0	0.000	0	0.000
	34	0	0.000	0	0.000	3 559	1.169	0	0.000	0	0.000	0	0.000	0	0.000	2 358	0.582
	35	0	0.000	0	0.000	0	0.000	2 294	1.214	0	0.000	0	0.000	2 489	0.218	0	0.000
	36	0	0.000	0	0.000	0	0.000	0	0.000	0	0.000	1 200	1.582	0	0.000	0	0.000
	37	0	0.000	0	0.000	0	0.000	1 353	1.430	0	0.000	3 263	0.916	0	0.000	0	0.000
	38	0	0.000	1 859	1.377	0	0.000	0	0.000	0	0.000	0	0.000	0	0.000	0	0.000
	39	0	0.000	0	0.000	0	0.000	0	0.000	0	0.000	0	0.000	0	0.000	0	0.000
	40	0	0.000	3 662	1.083	0	0.000	0	0.000	0	0.000	0	0.000	0	0.000	0	0.000

Table A2: (*continued*)

	Age	TAN9106 Number	cv	TAN9212 Number	cv	TAN9401 Number	cv	TAN9501 Number	cv	TAN9601 Number	cv	TAN9701 Number	cv	TAN9801 Number	cv	TAN9901 Number	cv
Female	2	8 426	0.387	1 886	2.280	0	0.000	0	0.000	0	0.000	0	0.000	0	0.000	7 333	0.966
	3	118 415	0.123	36 757	0.297	40 017	0.301	26 510	0.437	26 337	0.390	47 322	0.298	79 388	0.313	219 770	0.151
	4	76 667	0.180	221 816	0.113	218 461	0.144	118 848	0.188	87 189	0.256	96 529	0.218	107 024	0.220	304 700	0.178
	5	90 980	0.133	97 900	0.217	207 011	0.177	62 023	0.259	206 033	0.259	73 591	0.352	125 264	0.297	163 194	0.198
	6	63 938	0.176	86 982	0.225	185 690	0.180	200 199	0.201	153 207	0.253	132 974	0.254	99 764	0.212	126 716	0.236
	7	92 946	0.175	33 319	0.383	129 738	0.264	91 627	0.262	156 843	0.254	166 883	0.174	120 237	0.184	133 639	0.238
	8	114 922	0.161	54 356	0.293	94 413	0.285	42 817	0.356	159 055	0.235	138 716	0.204	102 646	0.208	138 714	0.219
	9	112 871	0.156	74 706	0.224	63 061	0.251	71 459	0.261	94 320	0.246	94 757	0.267	58 501	0.298	106 371	0.269
	10	65 230	0.199	70 978	0.232	76 079	0.240	56 394	0.349	78 921	0.280	56 072	0.316	74 301	0.270	136 134	0.227
	11	16 647	0.472	38 622	0.323	47 876	0.319	67 417	0.335	31 030	0.430	33 626	0.355	77 997	0.265	97 249	0.255
	12	44 021	0.259	69 750	0.240	64 209	0.284	79 778	0.260	48 096	0.337	49 289	0.298	18 529	0.530	75 874	0.301
	13	67 787	0.205	63 907	0.267	42 833	0.343	4 965	1.030	26 963	0.395	25 466	0.715	36 083	0.483	49 682	0.355
	14	87 724	0.169	84 407	0.219	67 765	0.270	37 599	0.287	18 107	0.584	32 086	0.549	34 587	0.428	30 444	0.433
	15	46 691	0.229	30 145	0.347	49 773	0.275	28 931	0.386	27 224	0.469	25 597	0.449	25 788	0.438	26 046	0.429
	16	65 448	0.222	64 077	0.258	38 938	0.289	23 858	0.405	34 556	0.446	2 115	1.436	10 349	0.417	19 015	0.579
	17	43 512	0.238	46 747	0.305	54 462	0.321	26 545	0.319	38 602	0.475	10 270	0.947	6 646	1.312	17 375	0.427
	18	18 854	0.320	50 281	0.316	16 431	0.485	21 816	0.538	42 771	0.393	22 060	0.426	17 627	0.619	21 860	0.460
	19	30 995	0.262	27 837	0.390	35 778	0.324	19 379	0.430	21 859	0.763	19 892	0.468	8 818	0.581	16 218	1.522
	20	9 652	0.485	21 476	0.419	31 632	0.365	26 466	0.432	2 664	0.917	12 657	0.523	8 043	0.324	16 171	0.697
	21	9 985	0.441	4 984	0.581	18 259	0.439	27 982	0.548	12 160	1.087	23 763	0.588	4 506	0.905	1 588	1.209
	22	19 924	0.350	1 953	0.955	11 501	0.681	7 596	1.147	17 116	0.740	0	0.000	7 143	0.653	5 516	0.764
	23	10 208	0.367	10 400	0.490	7 270	0.547	16 258	0.436	9 116	0.861	9 634	1.001	15 946	0.640	1 496	1.128
	24	6 063	0.697	14 540	0.302	4 907	0.715	10 642	0.844	13 317	0.772	8 693	1.099	2 593	0.509	2 619	1.734
	25	8 047	0.389	11 894	0.462	3 543	0.929	1 618	1.554	8 743	0.815	7 541	0.538	3 014	2.717	9 185	0.625
	26	3 029	0.675	4 033	0.718	6 243	0.521	1 418	3.897	2 888	1.832	3 468	0.738	6 635	1.363	9 773	0.690
	27	11 750	0.326	2 336	1.057	2 644	0.953	8 853	1.242	0	0.000	0	0.000	1 849	0.907	0	0.000
	28	0	0.000	7 246	0.689	2 241	0.805	0	0.000	1 332	0.971	0	0.000	0	0.000	3 666	1.230
	29	5 673	0.436	1 701	0.715	5 174	0.720	0	0.000	0	0.000	1 675	0.980	2 041	1.209	0	0.000
	30	1 509	1.018	2 351	2.116	0	0.000	0	0.000	0	0.000	2 774	2.007	0	0.000	3 030	6.927
	31	0	0.000	2 038	1.485	0	0.000	0	0.000	2 003	0.746	0	0.000	0	0.000	0	0.000
	32	0	0.000	0	0.000	3 247	0.854	0	0.000	1 696	1.235	0	0.000	0	0.000	0	0.000
	33	0	0.000	1 295	1.104	0	0.000	0	0.000	0	0.000	6 850	0.603	0	0.000	2 711	0.964
	34	1 899	0.962	0	0.000	0	0.000	3 243	1.022	1 062	1.026	0	0.000	0	0.000	0	0.000
	35	0	0.000	0	0.000	0	0.000	0	0.000	0	0.000	0	0.000	0	0.000	0	0.000
	36	0	0.000	0	0.000	0	0.000	0	0.000	0	0.000	0	0.000	0	0.000	0	0.000
	37	0	0.000	0	0.000	0	0.000	2 294	1.490	0	0.000	0	0.000	0	0.000	0	0.000
Meas.mal		1 214		1 237		1 541		583		556		837		681		1 079	
Meas.fem		1 198		1 114		1 349		578		509		601		500		851	
Aged.mal		246		280		297		229		297		317		349		333	
Aged.fem		311		310		299		195		273		248		281		317	
Smp.tows		174		169		157		114		79		98		92		113	
Mean CV		21.0		26.4		24.9		32.5		31.4		30.7		32.3		28.2	

Table A3: **Calculated catch-at-age, by sex, for comparable samples of ling caught by commercial longline and research trawl in LIN 5&6 (April–May 1998) and LIN 3&4 (January 1999). Numbers have been scaled to total population in the survey area (for trawl surveys), or to total sampled catch (for commercial longline). Summary statistics show the total number of fish, by sex, that were measured (Meas.mal, Meas.fem) or successfully aged (Aged.mal, Aged.fem), the number of longline sets or trawl shots that were sampled (Samp.sets/tows), and the mean weighted *c.v.* across all age classes for the catch at age data (Mean CV)**

		LIN 3 & 4				LIN 5 & 6			
		Longline		TAN9901		Longline		TAN9805	
	Age	Number	cv	Number	cv	Number	cv	Number	cv
Male	2	0	0.000	0	0.000	0	0.000	64 324	0.522
	3	0	0.000	268 651	0.152	0	0.000	270 431	0.271
	4	0	0.000	318 130	0.145	12	0.695	722 914	0.185
	5	4	2.286	302 895	0.166	112	0.259	746 835	0.186
	6	16	0.713	118 562	0.336	135	0.229	488 161	0.231
	7	39	0.612	101 855	0.327	174	0.277	608 391	0.222
	8	147	0.276	137 953	0.252	161	0.403	620 412	0.220
	9	231	0.229	112 433	0.321	84	0.512	412 598	0.277
	10	161	0.254	103 482	0.320	0	0.000	259 363	0.338
	11	187	0.227	136 852	0.267	21	0.951	446 643	0.268
	12	210	0.225	84 922	0.330	77	0.583	350 274	0.285
	13	123	0.281	64 229	0.358	90	0.266	85 830	0.521
	14	80	0.331	73 096	0.403	48	0.660	198 515	0.358
	15	67	0.430	53 230	0.533	170	0.278	232 012	0.328
	16	53	0.480	93 711	0.323	186	0.222	241 599	0.305
	17	23	0.564	51 421	0.357	147	0.278	206 884	0.370
	18	16	0.642	28 447	0.420	45	0.771	83 027	0.547
	19	45	0.520	27 277	0.382	59	0.564	55 350	0.606
	20	10	1.076	2 209	3.350	183	0.255	60 647	0.686
	21	30	0.652	23 795	0.642	96	0.415	38 106	0.753
	22	37	0.444	56 424	0.643	0	0.000	16 151	0.897
	23	13	0.782	14 405	0.612	0	0.000	8 814	1.487
	24	27	0.706	15 094	0.726	102	0.296	18 478	1.065
	25	28	0.606	9 187	0.587	18	0.878	0	0.000
	26	13	0.931	3 446	0.849	29	0.728	17 412	1.036
	27	15	0.930	7 103	1.277	0	0.000	0	0.000
	28	22	0.689	1 321	1.531	22	0.739	7 377	1.156
	29	0	0.000	0	0.000	27	0.916	0	0.000
	30	0	0.000	0	0.000	0	0.000	0	0.000
	31	0	0.000	0	0.000	0	0.000	0	0.000
	32	0	0.000	0	0.000	0	0.000	0	0.000
	33	3	2.054	0	0.000	0	0.000	0	0.000
	34	0	0.000	2 358	0.582	0	0.000	0	0.000
	35	7	1.680	0	0.000	0	0.000	0	0.000

Table A3: (*continued*)

		LIN 3 & 4				LIN 5 & 6			
		Longline		TAN9901		Longline		TAN9805	
	Age	Number	cv	Number	cv	Number	cv	Number	cv
Female	2	0	0.000	7 333	0.966	0	0.000	98 804	0.631
	3	0	0.000	219 770	0.151	0	0.000	439 282	0.262
	4	0	0.000	304 700	0.178	5	1.221	634 221	0.215
	5	22	0.598	163 194	0.198	81	0.376	769 880	0.179
	6	80	0.296	126 716	0.236	301	0.231	525 512	0.215
	7	176	0.230	133 639	0.238	215	0.330	525 028	0.218
	8	530	0.180	138 714	0.219	500	0.186	508 310	0.232
	9	856	0.139	106 371	0.269	479	0.222	601 825	0.226
	10	919	0.137	136 134	0.227	700	0.190	376 171	0.278
	11	959	0.130	97 249	0.255	676	0.192	322 754	0.297
	12	689	0.153	75 874	0.301	817	0.178	321 985	0.312
	13	674	0.146	49 682	0.355	551	0.204	299 375	0.298
	14	484	0.173	30 444	0.433	791	0.178	229 846	0.337
	15	420	0.181	26 046	0.429	1 281	0.138	228 994	0.323
	16	190	0.260	19 015	0.579	687	0.184	164 562	0.357
	17	132	0.304	17 375	0.427	618	0.200	207 940	0.330
	18	153	0.276	21 860	0.460	569	0.208	117 701	0.464
	19	67	0.434	16 218	1.522	373	0.251	48 843	0.762
	20	71	0.422	16 171	0.697	230	0.289	20 849	1.216
	21	25	0.573	1 588	1.209	391	0.230	48 293	0.935
	22	70	0.410	5 516	0.764	122	0.388	0	0.000
	23	43	0.536	1 496	1.128	93	0.522	12 747	1.396
	24	21	0.710	2 619	1.734	34	0.966	12 585	1.347
	25	23	0.780	9 185	0.625	22	0.924	0	0.000
	26	11	0.856	9 773	0.690	87	0.410	0	0.000
	27	28	0.598	0	0.000	71	0.381	0	0.000
	28	11	0.856	3 666	1.230	0	0.000	0	0.000
	29	5	1.519	0	0.000	48	0.756	0	0.000
	30	9	1.118	3 030	6.927	52	0.497	0	0.000
	31	0	0.000	0	0.000	0	0.000	0	0.000
	32	7	1.167	0	0.000	0	0.000	0	0.000
	33	7	1.101	2 711	0.964	0	0.000	0	0.000
Meas.mal		410		1 079		608		816	
Meas.fem		1 590		851		2 763		767	
Aged.mal		117		333		82		271	
Aged.fem		416		317		404		296	
Smp.sets/tows		69		113		34		64	
Mean CV		22.3		28.2		24.1		27.8	

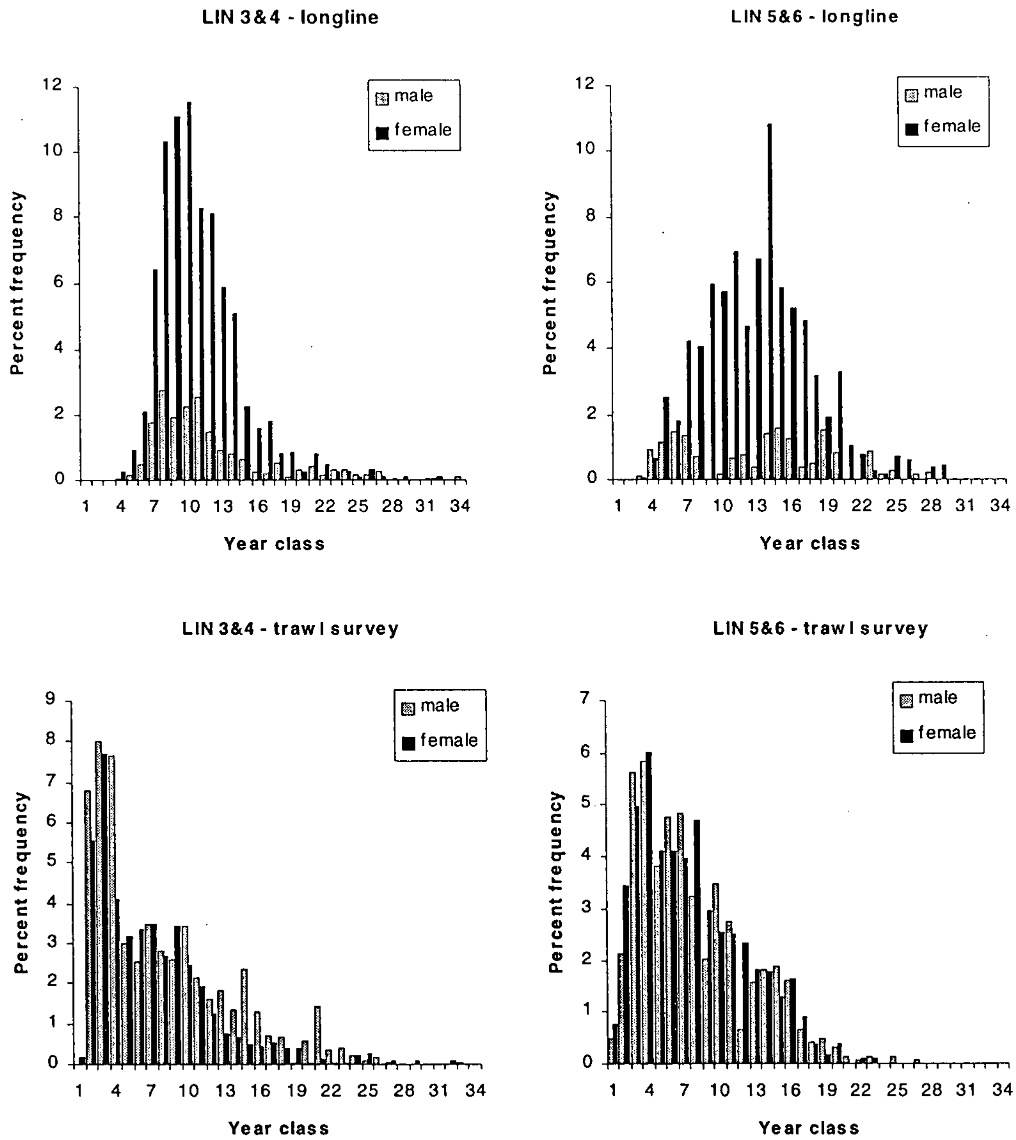

Figure A1: Calculated proportion-at-age, by sex, for comparable samples of ling caught by commercial longline and research trawl in LIN 5&6 (April–May 1998) and LIN 3&4 (January 1999)

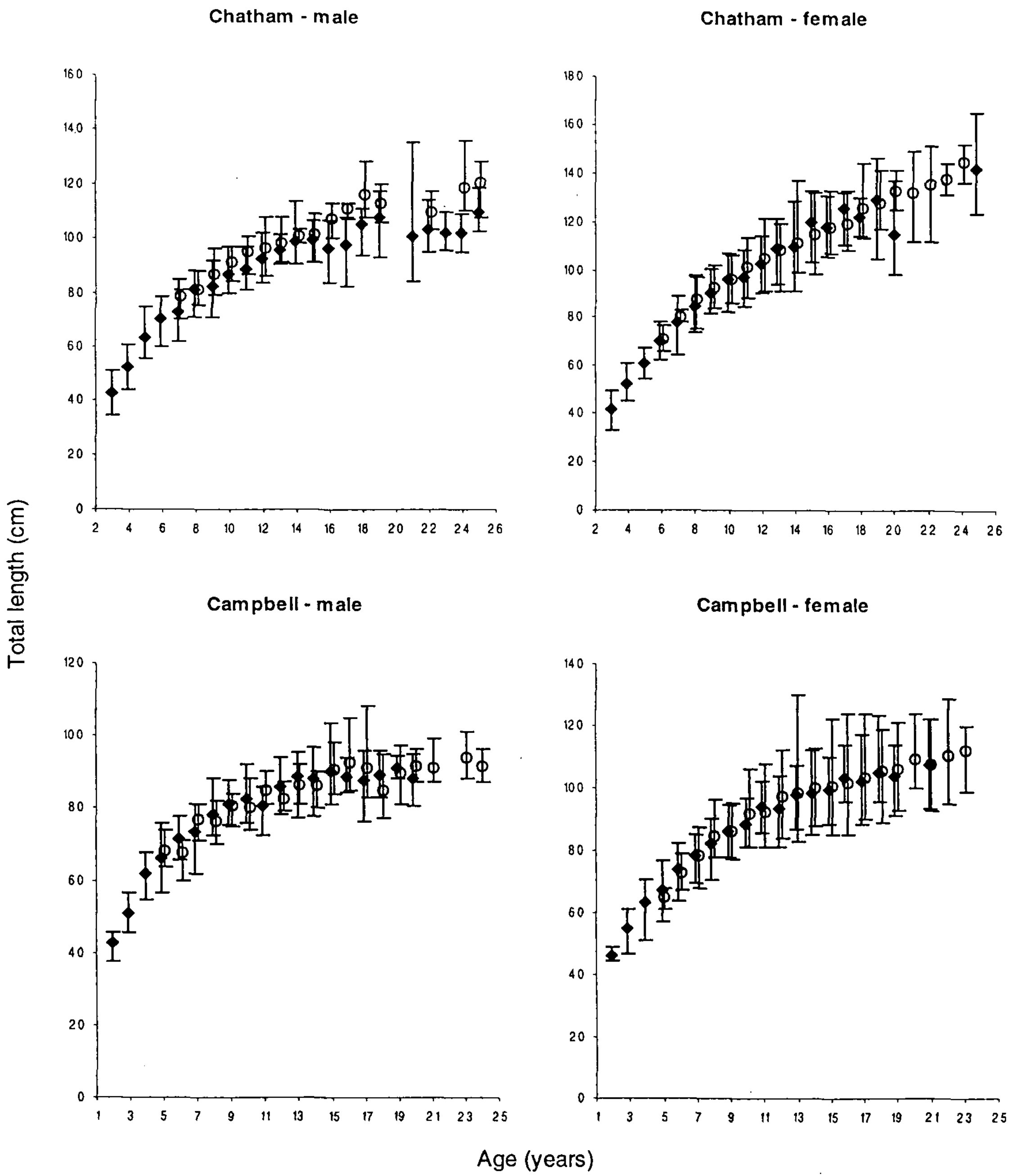

Figure A2: **Mean lengths at age, separately by sex, for ling caught by commercial longline (open circles) and by research trawl (closed diamonds), on the Chatham Rise in January 1999 and the Campbell Plateau in April-May 1998. Means were calculated only where $n \geq 3$. Bars show range of size at age**

APPENDIX B

A review of the estimate of natural mortality for ling

Objective 5 of Project MID9801 required the estimate of natural mortality (*M*) for ling to be reviewed, and revised if possible. A report of this investigation follows, and concludes that the best estimates of *M* for ling are 0.18 for males and 0.16 for females.

1. Methods

Numerous sets of age data, represented as catch-at-age distributions, were available for ling from various areas and years. They comprise samples from trawl surveys of the Chatham Rise from 1989 to 1999, trawl surveys of the Southern Plateau from 1989 to 1998, and the commercial trawl catch off the west coast of the South Island (WCSI) in 1991, 1997, and 1998. Data were also available from two samples from the commercial longline catch on the Southern Plateau (1998) and the Chatham Rise (1999).

Available sets of catch-at-age data were collated by biological stock (as defined by Horn & Cordue 1996), sex, and sampling method, but split into groups of samples collected before or after February 1993. Numbers at age of all samples within each group were then summed across each age class to produce a single distribution for each sex in each stock, by sampling method. Where several years of data are combined in this way it has the effect of smoothing the data and reducing the influence of any particularly weak or strong year classes.

Estimates of instantaneous natural mortality (*M*) were derived using the three following methods.

1. $$M = -\frac{\log_e(p)}{A}$$

   where *p* is the proportion of the population that reaches age *A* or older (Hoenig 1983). Values of *p* of 0.01 and 0.05 were used here. In an unexploited population, a *p* of 0.01 is usually used. This method assumes that all age classes in the population are fully vulnerable to the sampling technique. This assumption does not hold for ling; in all samples, some of the younger age classes are not fully recruited. To correct for this, an age at recruitment *R* was chosen, the proportion *p* of the fully recruited population (i.e., aged *R* or older) that reaches age *A* or older is calculated, and the denominator in Hoenig's equation is replace by *A*–*R*+1. This is subsequently referred to as the A_{max} estimator.

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

   where *a* is the mean age above recruitment age and *n* is the sample size (Chapman & Robson 1960). For this estimator, age at recruitment (*R*) should be the age at which 100% of fish are vulnerable to the sampling method (rather than the often used age at 50% recruitment). This is subsequently referred to as the CR estimator. A 95% confidence interval around this estimator is $\pm 2*\sqrt{var}$, where var $= (1-e^{-CR})^2/(ne^{-CR})$.

3. M is minus the slope of the right hand limb (i.e., points where age is R or older) of the relationship between age and the natural logarithm of the frequency of fish in that age class (Ricker 1975). The regression model defined as R1 by Dunn *et al.* (1999) was used here, i.e., reject all fish of ages greater than i_{max}, where i_{max} is the greatest age for which $N_i \geq 1$ for all $i \leq i_{max}$. This is subsequently referred to as the R1 estimator. A 95% confidence interval around this estimator was taken as ± 2*SE of the slope.

All three methods estimate instantaneous total mortality (Z), rather than M. However, if it can be assumed for any particular sample that exploitation (i.e., instantaneous fishing mortality, F) has been negligible, then Z will approximate M.

All three estimators require the initial determination of an age at full recruitment (R). It was not possible to use a single, consistent age at full recruitment for all samples from all areas, owing to differences in sampling methods (i.e., research trawl with 60 mm mesh codend, commercial trawl with 100 mm mesh codend, and commercial longline). However, for valid comparisons between estimates from an individual sample, it is important to use the same age at recruitment in all estimators.

2. Results

Details of the sets of samples used in this analysis, and the chosen ages at recruitment (R), are given in Table B1. There was considerable uncertainty about the age at recruitment for the fish from the Chatham Rise (LIN 3 & 4) and the Southern Plateau (LIN 5 & 6). Some samples indicated that ling as young as 4 or 5 years old may be fully recruited. However, because the results of all estimators are sensitive to the chosen R, it was considered prudent to select higher values, thereby increasing the likelihood that only fully recruited year classes are used in the estimations. The values chosen here vary between stocks, but were the lowest age that appeared to be fully recruited in all samples from a particular stock.

Catch curve plots, and calculated regression lines of the right hand limbs of these distributions, are presented in Figures B1, B2, B3, and B4. Estimates of Z using the three estimators are summarised in Table B1. The estimates have a reasonably wide range, both within and between samples and estimation methods.

For LIN 3 & 4 (Chatham Rise), there were relatively small differences in trawl survey estimates of Z from the earlier and later periods of exploitation, but any differences did indicate that the earlier period had the greater rate of total mortality. The catch curves (Figure B1) also exhibit only minor difference in shape between periods. There is some indication that the trawl survey catch curves could be better represented by 'broken stick' regressions, with points of discontinuity at about 15 years in the earlier period and 20 years in the later period (Figure B5). Estimates of Z from the single Chatham Rise commercial longline sample (Figure B2) are higher for females than those derived from the trawl surveys, but lower for males. However, the longline fishery may not comprehensively sample males; females comprised more than 70% of the catch.

Estimates of Z for LIN 5 & 6 (Southern Plateau) derived from research trawl surveys also exhibit relatively small differences between comparable estimates from the earlier and later periods of exploitation. The catch curves from the two periods are also similar (Figure B3). As in the case of Chatham Rise fish, the trawl survey catch curves from the Southern Plateau could be represented by 'broken stick' regressions, particularly for females. The estimates of Z from the single 1998 commercial longline sample (Figure B2) are consistently lower than those from the research samples taken from 1993–98. As on the Chatham Rise, the longline fishery catches relatively few males.

The commercial trawl samples from LIN 7 (Figure B4) produce estimates of Z which are lower in 1991 than in the latter part of the 1990s.

Comparisons between sexes of estimates of Z derived from the same data set and estimation method exhibit some trends. For all the LIN 7 samples, there is a consistent trend for Z to be greater for males, relative to females. The LIN 3 & 4 research samples exhibit a similar trend; however, from research surveys of LIN 5 & 6, comparable estimates are generally higher for females. Both commercial longline samples produce estimates of Z which are generally higher for females (although males in both areas are poorly sampled by this method).

3. Discussion

Dunn *et al.* (1999) compared the merits of estimating M using the CR estimator and various regression methods (including R1). They concluded that CR was the most accurate estimator, with R1 being the best of the regression estimators. They did not examine any A_{max} estimators. The values of variance reported here for the CR and R1 estimators are likely to be underestimates because their calculation assumes no ageing error, constant recruitment, a constant M, and little sampling variability. None of these assumptions are likely to be true.

Clearly, estimates derived using all three methods can vary (sometimes quite markedly) given uncertainties in some parameters. The CR estimator is sensitive to the chosen age at recruitment. The R1 estimate can be influenced by where the right limb of the catch curve is started (i.e., the chosen age at recruitment), or by a single outlying point in the data series. To demonstrate the dependence of Z on the selected age at recruitment, results using the CR and R1 estimation methods are presented for several data sets (Figure B6). Both estimators should become asymptotic, assuming that M and F are constant for all fish older than the age of recruitment (A. Dunn, NIWA, pers. comm.). The shapes of the curves in Figure B6 vary considerably, and few exhibit a clear asymptote. If there is a trend in curve shape it is for an initial increase in Z, followed by a period where the curve flattens (or even declines), then another period of increase (sometimes followed by a relatively steep decline). The data presented in Figures B5 and B6 raise the possibility that M and/or F are not constant after recruitment, or have changed markedly during the period covered by the samples.

There is some indication from the Chatham Rise trawl samples in Figure B6 that the CR and R1 estimates of *Z* are approaching asymptotes between about 0.16 and 0.22 over the sections where age at recruitment is assumed to be in the range of 6 to 13 years. This characteristic is particularly apparent for females. The CR estimates are lower than those derived using the R1 estimator, and indicate an asymptote at about 0.18.

It was considered possible that the 'broken stick' nature of the catch curve regressions for the Chatham Rise samples could be a result of heavy exploitation in 1976–77 when about 45,000 t of ling was believed to have been taken from this region (Horn 1997) primarily by foreign longliners (Annala *et al.* 1998). However, assuming that fish from about age 9 and older were heavily exploited by this method (as indicated for recent longlining, *see* Figure B2), then the 'break' in the regression should occur at about age 23 in the 1989–93 plot, and about age 28 in the 1994–99 plot. From Figure B5, it is apparent that the breaks occur somewhere in the range of 14–18 years in 1989–93, and 19–22 years in 1994–99. For the fishery to be responsible for the apparent change in *Z*, age classes as young as 1–3 years would have to have been heavily exploited by longline operations. This is considered unlikely. As the position of the break shifts by about 5 years between the two samples, and the mean difference between the two sampling periods is also 5 years, it is likely that the change in *Z* at this point is a true characteristic of the population, rather than an effect related to fishing selectivity.

The regression lines in Figure B5 for fish aged from 5 to about 15–20 years indicate a *Z* of about 0.06 for males and 0.15 for females. These values (particularly that for male ling) are considered to be too low. There are numerous possible explanations for these relatively flat curves. Two of the more likely ones are that the younger fish in the range are not fully sampled by the trawl gear, or that there are some relatively strong year classes in the latter part of the range.

The catch curves from trawl surveys of the Southern Plateau could also be fitted using a 'broken stick' regression, with the break somewhere in the range of 14 to 18 years. It is unlikely that heavy exploitation prior to the 1990s could be responsible for this effect; estimated annual landings were generally in the order of 2000 to 3000 t, with a peak in 1979 of about 6400 t (Horn 1997).

All estimates of *Z* based on the samples examined here are likely to comprise a non-trivial component of *F*. However, samples from LIN 5, 6, and 7 collected before 1993 should be the least influenced in this regard because landings from these areas were relatively low (Annala *et al.* 1998). Estimates of *Z* from these samples using the CR and R1 methods range from 0.20 to 0.34. Using the A_{max} method and a *p* of 0.05 gave a range of 0.21 to 0.30. While the A_{max} estimate may be a better estimate of *M* than those from CR and R1 because it does account for some component of fishing mortality, the true extent of *F* is unknown, so the chosen *p* may be inappropriate.

Results from the current study suggest that the longevity of female ling is greater than that for males in LIN 3, 4, and 7, but that male ling tend to live longer in LIN 5 and 6. Differing levels of *M* for fish of the same sex, living in such close proximity, would not be expected. Differences in *M* between sexes of a species are relatively common when there are marked sexual differences in growth rate, and where there is an apparent difference in *M*, it appears almost universal that the value for females will be lower than that for males, i.e., the longevity of females is greater (Pauly 1980). Ling exhibit significant differences in growth rates between sexes (Horn 1993b). Comparisons of Z between sexes from individual data sets from LIN 3, 4, and 7 suggest that for males it is about 0.01 to 0.05 higher than for females.

Previous estimates of M for ling were calculated by Horn (1993a), using the A_{max} estimator, and slopes of the right hand limb of catch curves from five samples of otoliths collected from 1989 to 1992. (These otolith samples were incorporated in the current study.) Estimates of Z from catch curve regressions ranged from 0.18 to 0.27, but these were not R1 estimates as they included all non-zero age classes (i.e., they were the RG estimator of Dunn *et al.* 1999). The A_{max} estimates used a p of 0.01 and did not correct for the age classes that are not fully recruited into the sampled fishery. An estimate of M of 0.18 for both sexes was suggested, and has been used in all ling stock assessments since then.

There is little in the current study that can be used to confidently update the estimate of M for ling. No otolith samples are available from an unexploited stock. The estimates that are available vary widely depending on the chosen age at recruitment, and appear to be confounded either by changes in M or F over time, or by uncertainties about the selectivities of some age classes. The CR estimates from the Chatham Rise trawl survey samples (calculated assuming an age at recruitment between 6 and 13 years) suggest a likely Z for females of 0.18. The assessment of the LIN 3 and 4 stock indicated a virgin biomass of about 150,000 t on the Chatham Rise, and a mean F over the period 1975–92 of 0.02 (Horn 1997). Subtracting the estimated value of F from the Z value for females, suggests that 0.16 is the best value for M. Given the conclusion above that M for male ling should probably be slightly higher than that for females, a value of 0.18 is suggested here.

Table B1: Details of samples of catch-at-age data, by Fishstock and sampling period, and estimates of *Z* from these samples. Method: RT, research trawl; CT, commercial trawl; LL, commercial longline. *N*, number of samples. *R*, age at recruitment. For the CR and R1 estimators, 95% confidence intervals are plus or minus the value in brackets. For the A_{max} estimator, two values of *p* (0.01, 0.05) were used. –, not calculated

Fishstock	Method	Period	*N*	*R*	*Z* (male)						*Z* (female)					
					CR		R1		A_{max}		CR		R1		A_{max}	
									0.01	0.05					0.01	0.05
LIN 3 & 4	RT	1989–93	3	12	0.26	(0.02)	0.26	(0.04)	0.27	0.27	0.21	(0.01)	0.22	(0.03)	0.27	0.23
(Chatham Rise)	RT	1994–99	6	12	0.19	(0.01)	0.22	(0.04)	0.23	0.25	0.19	(0.01)	0.21	(0.03)	0.23	0.23
	LL	1998	1	12	0.20	(0.04)	0.13	(0.06)	0.21	0.19	0.29	(0.03)	0.26	(0.03)	0.27	0.25
LIN 5 & 6	RT	1989–92	4	15	0.20	(0.01)	0.21	(0.10)	0.29	0.21	0.30	(0.02)	0.34	(0.06)	0.35	0.30
(Southern Plateau)	RT	1993–98	3	15	0.29	(0.02)	0.22	(0.08)	0.38	0.30	0.35	(0.02)	0.32	(0.07)	0.35	0.33
	LL	1998	1	15	0.22	(0.05)	–	–	0.31	0.25	0.29	(0.03)	0.29	(0.08)	0.29	0.25
LIN 7	CT	1991	1	12	0.31	(0.04)	0.30	(0.10)	0.31	0.25	0.25	(0.03)	0.24	(0.05)	0.29	0.21
(WCSI)	CT	1997–98	2	12	0.39	(0.03)	0.49	(0.12)	0.42	0.33	0.30	(0.03)	0.34	(0.06)	0.29	0.33

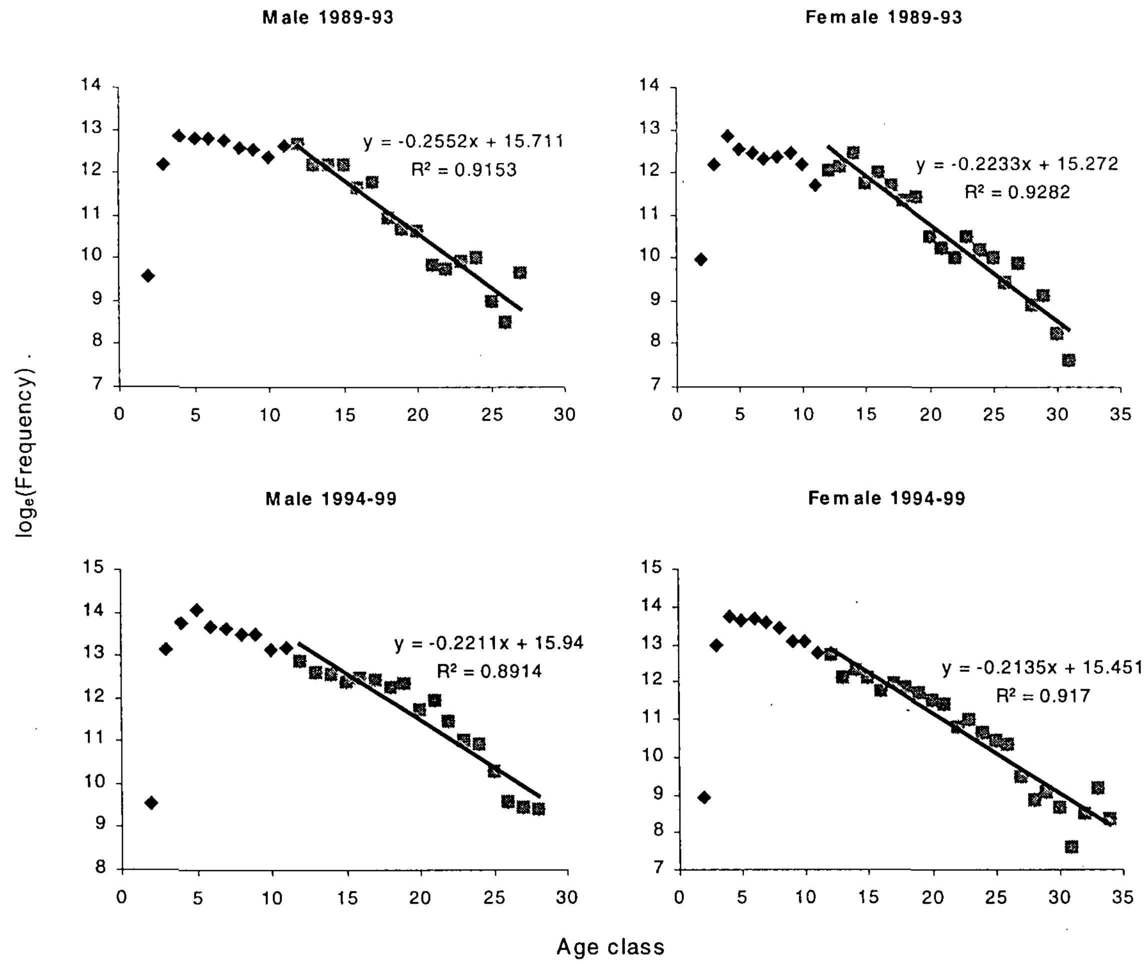

Figure B1: **Estimated catch-at-age, by sex, for samples of ling taken in trawl surveys of the Chatham Rise, from 1989 to 1999. Lines are the least squares linear regressions fitted to the data points represented by shaded squares.**

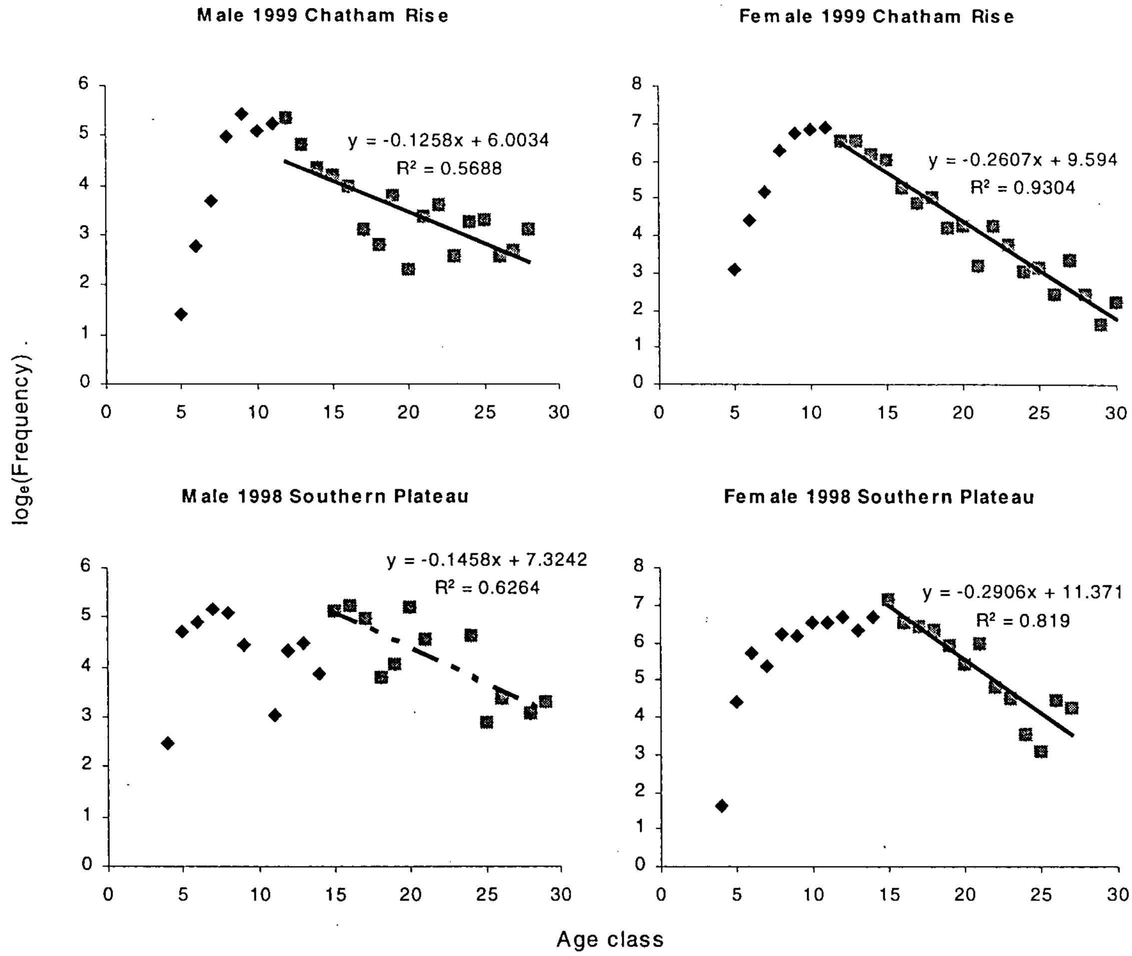

Figure B2: Estimated catch-at-age, by sex, for samples of ling taken by commercial longline vessels on the Chatham Rise and Southern Plateau. Lines are the least squares linear regressions fitted to the data points represented by shaded squares. (The slope of the regression for the Southern Plateau male sample is not the R1 estimate of *Z* because some age classes in the regressed range have zero fish.)

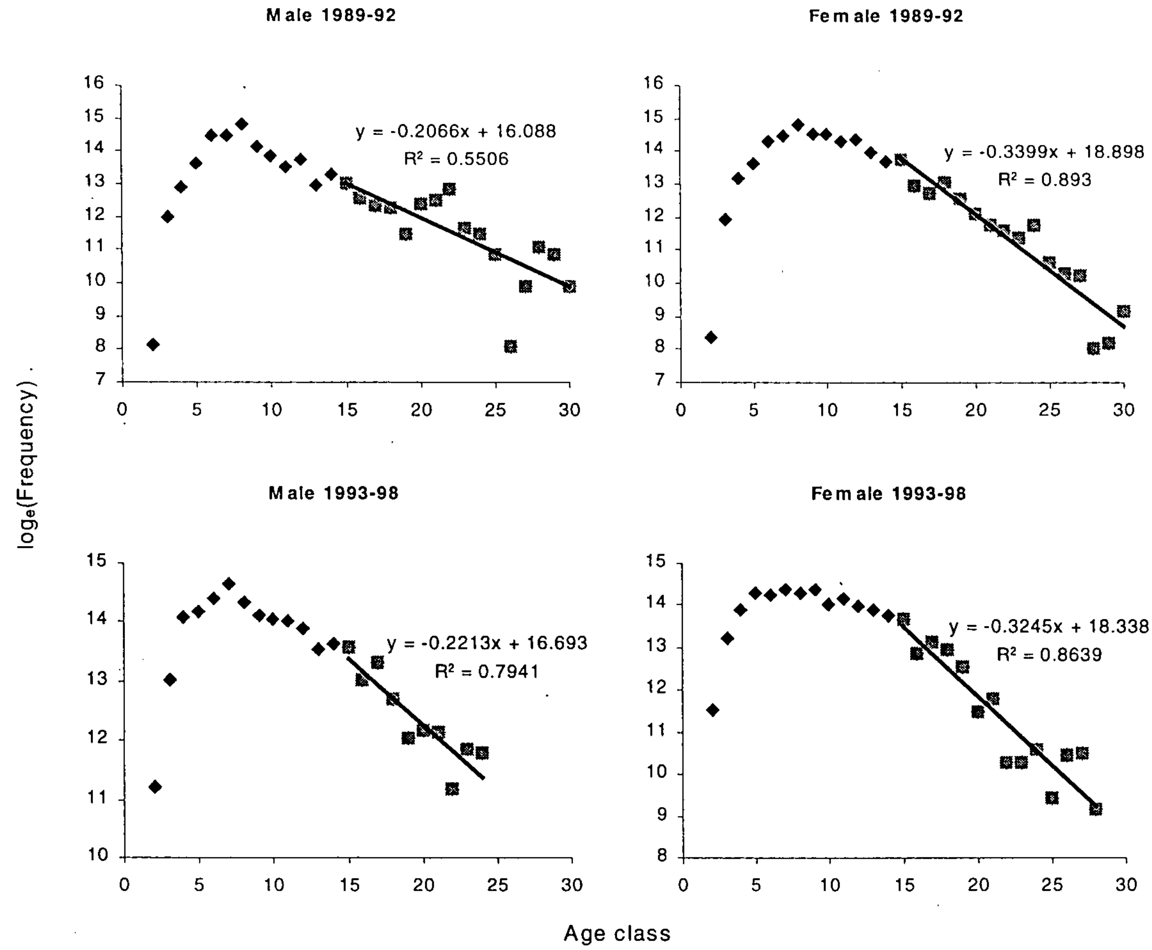

Figure B3: Estimated catch-at-age, by sex, for a sample of ling taken in trawl surveys of the Southern Plateau, from 1989 to 1998. Lines are the least squares linear regressions fitted to the data points represented by shaded squares.

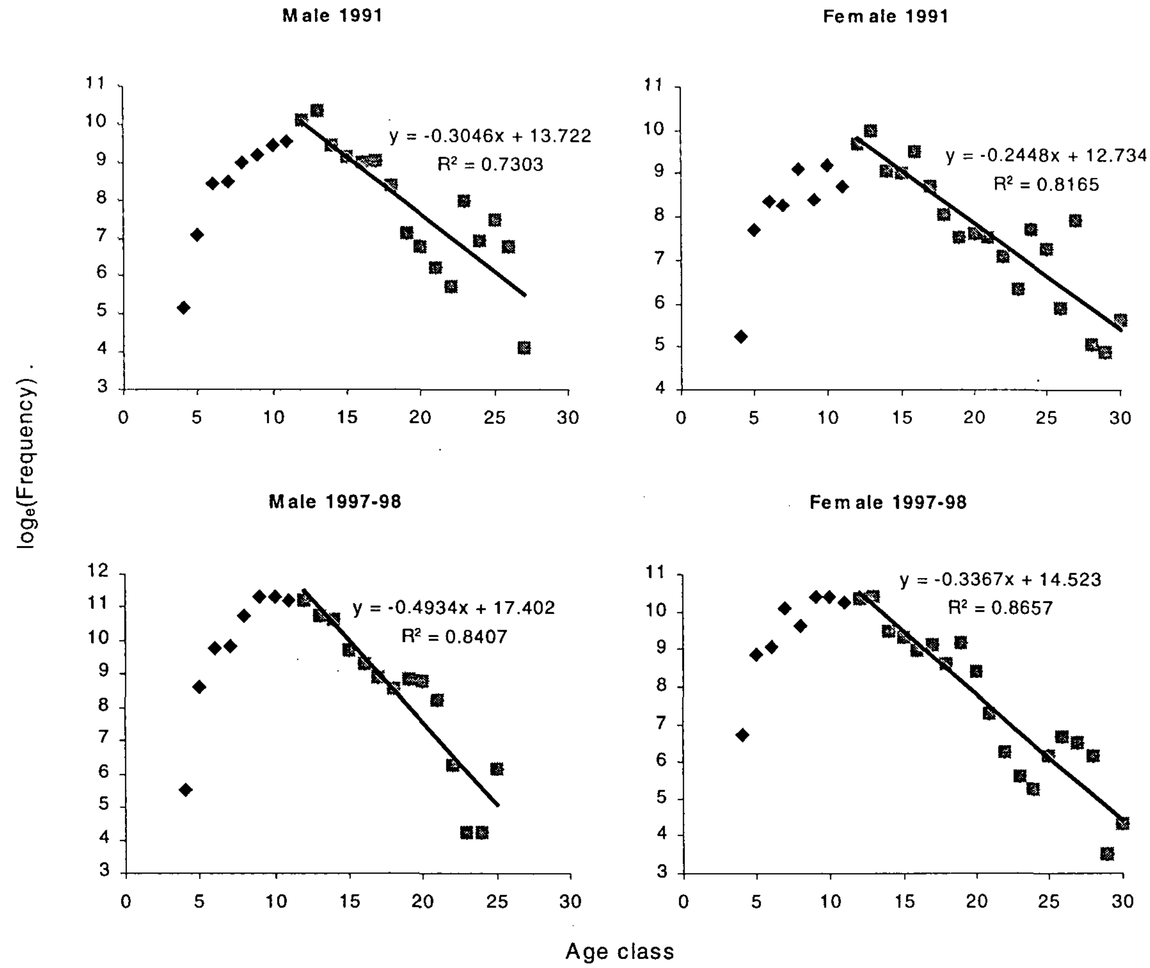

Figure B4: Estimated catch-at-age, by sex, for a sample of ling taken by commercial trawlers off the west coast of the South Island, from 1991 to 1998. Lines are the least squares linear regressions fitted to the data points represented by shaded squares.

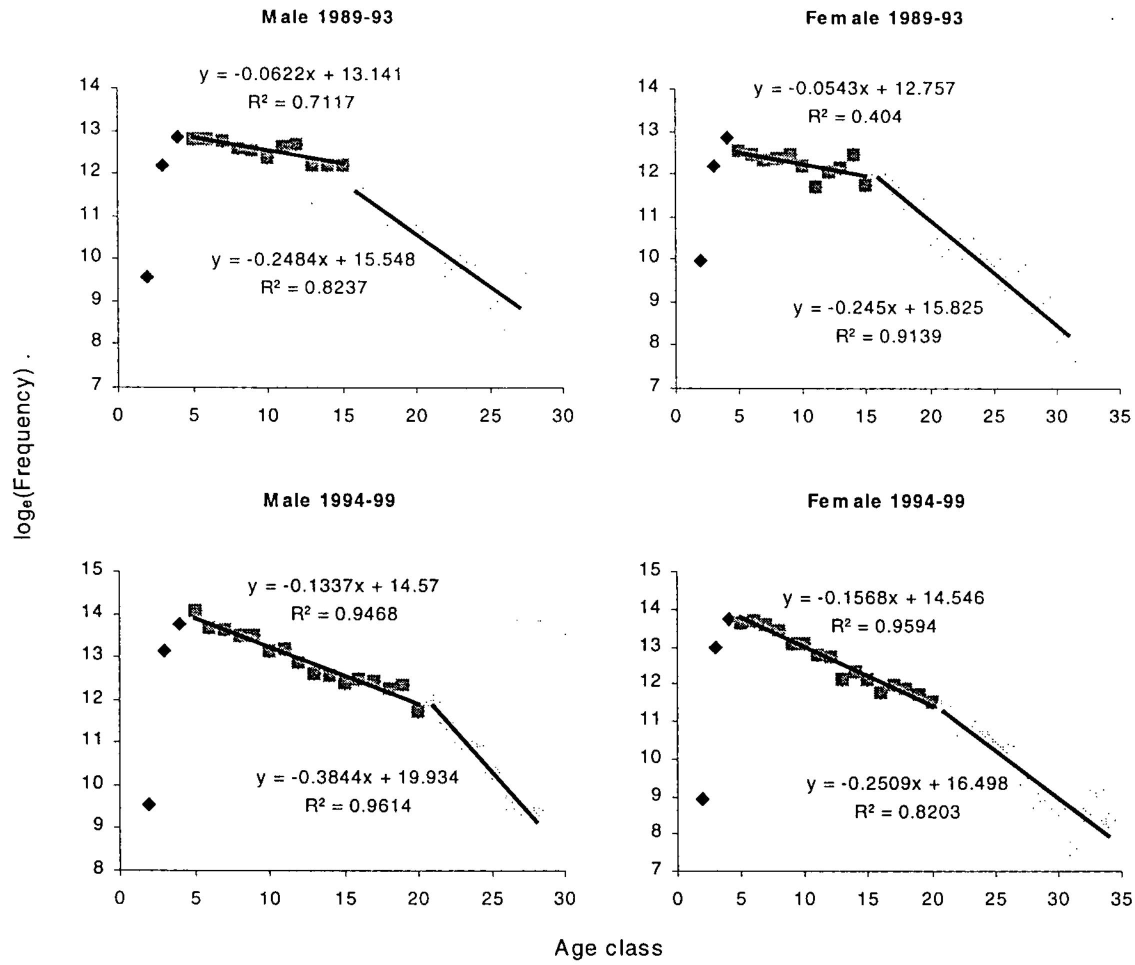

Figure B5: Estimated catch-at-age, by sex, for samples of ling taken in trawl surveys of the Chatham Rise (as shown in Figure B1), but with two least squares regression lines fitted separately to each data set.

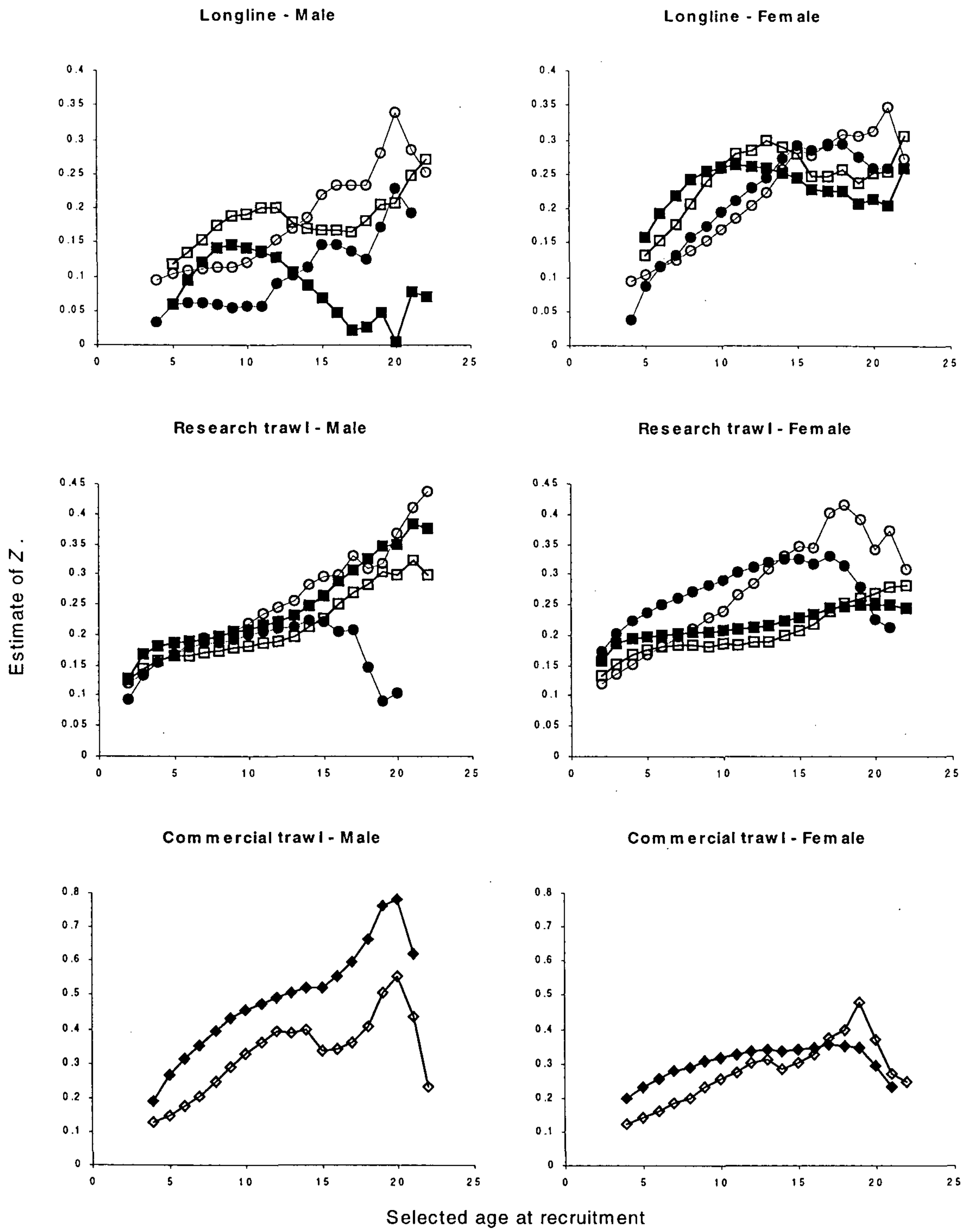

Figure B6: **Estimates of *Z* using the CR (empty symbols) and R1 (filled symbols) estimation methods and a range of ages at recruitment, for several of the data sets and all sampling methods. Different Fishstocks are represented by different shaped symbols: square, LIN 3 and 4; circle, LIN 5 and 6; diamond, LIN 7.**