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EXECUTIVE SUMMARY

Dunn, A.; Ballara, S.L.; Phillips, N.L. (2006). Stock assessment of hake (*Merluccius australis*) in HAK 1 & 4 for the 2004–05 fishing year.

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This report summarises the stock assessment of hake in the Quota Management Areas (QMAs) HAK 1 and HAK 4, for the sub-Antarctic and Chatham Rise stocks for the 2004–05 fishing year. The report presents an analysis of the stock assessment of hake that includes data up to the end of the 2003–04 fishing year. Catch-at-age estimates from resource surveys and scientific observer data, collected from commercial tows of hake in HAK 1 and 4 are revised and updated. Revised landings data for the three hake stocks (sub-Antarctic, Chatham Rise, and west coast South Island) are presented, and literature published since the previous stock assessment for hake is summarised.

The stock assessments of hake in the sub-Antarctic and on the Chatham Rise have been presented as a Bayesian assessment of two stocks of hake, the sub-Antarctic stock and the Chatham Rise stock, implemented as a two stock model using the general-purpose stock assessment program CASAL v2.06.

The model estimates of the state of the sub-Antarctic stock suggest that there has been a relatively small decline in the stock size since the early 1990s. However, results from biomass surveys were inconclusive with respect to the absolute size of the stock. Model fits to the most recent sub-Antarctic resource surveys were poor, and were unable to mirror the recent observed small decline since 2001. In general, the lack of contrast in abundance indices collected since 1991 suggests that, although the status of the sub-Antarctic stock is probably similar to that in the early 1990s, the absolute level of current biomass is difficult to determine.

In contrast, information about the stock status of hake on the Chatham Rise appears reasonably strong. Biomass estimates from the Chatham Rise research series suggest strong evidence of a uniform decline in biomass, with biomass in 2005 at about 35% the level of that in the early 1990s. If the model assumptions are correct, and the recent estimated relative year class strengths are as weak as have been estimated, then current catch levels will continue to reduce the size of the Chatham Rise stock in the immediate future. Sensitivity analyses, with only minor changes in assumptions as the base case, gave similar results.

Projections for the Chatham Rise stock estimated the risk of reducing the stock below 20% B_0 in 2009 to be 88% with catches of 3616 t, and 28% with catches of 1800 t.

1. INTRODUCTION

This report outlines the stock assessment of hake in the hake Quota Management Areas (QMAs) HAK 1 and HAK 4, for the sub-Antarctic and Chatham Rise hake stocks with the inclusion of data up to the end of the 2003–04 fishing year. Catch-at-age estimates from resource surveys, and scientific observer data collected from commercial tows of hake in HAK 1 and 4 were also revised and updated.

The current stock hypothesis for hake suggests that there are three separate hake stocks (Colman 1998); the west coast South Island stock (the area of HAK 7 on the west coast South Island), the sub-Antarctic stock (the area of HAK 1 that encompasses the Southern Plateau), and the Chatham Rise stock (HAK 4 and the area of HAK 1 on the western Chatham Rise).

The stock assessment of hake in HAK 1 and HAK 4 is presented as a Bayesian assessment of two stocks of hake, the sub-Antarctic stock and Chatham Rise stock, implemented as a two stock model using the general-purpose stock assessment program CASAL (Bull et al. 2004). The stock assessment for the Chatham Rise and the sub-Antarctic is described, and estimates of the current stock status and projected stock status for each stock are provided.

This report fulfils Objective 2 of Project HAK2003/01 "To update the stock assessment of hake, including biomass estimates and sustainable yields".

1.1 Description of the fishery

Hake are widely distributed through the middle depths of the New Zealand Exclusive Economic Zone (EEZ) mostly south of latitude 40° S (Anderson et al. 1998). Adults are mainly distributed in depths from 250 to 800 m although some have been found as deep as 1200 m, while juveniles (0+) are found in shallower inshore regions under 250 m (Hurst et al. 2000). Hake are taken by large trawlers — often as bycatch in fisheries targeting other species such as hoki and southern blue whiting, although target fisheries also exist (Phillips & Livingston 2004). Present management practices divide the fishery into three main fish stocks: (a) the Challenger QMA (HAK 7), (b) the southeast (Chatham Rise) QMA (HAK 4), and (c) the remainder of the EEZ comprising the Auckland, Central, southeast (Coast), Southland, and sub-Antarctic QMAs (HAK 1). An administrative fish stock exists in the Kermadec QMA (HAK 10) although there are no recorded landings from this area. The hake QMAs are shown in Figure 1.

The largest fishery has been off the west coast of the South Island (HAK 7) with the highest catch (17 000 t) recorded in 1977, immediately before the establishment of the EEZ. The TACC for HAK 7 is the largest, at 6855 t out of a total for the EEZ of 13 997 t. The west coast South Island hake fishery has generally consisted of bycatch in the much larger hoki fishery, but it has undergone a number of changes during the last decade. These include changes to the TACCs of both hake and hoki, and also changes in fishing practices such as gear used, tow duration, and strategies to limit hake bycatch. In some years, notably in 1992 and 1993, there has been a hake target fishery in September after the peak of the hoki fishery is over; more than 2000 t of hake were taken in this target fishery during September 1993. Bycatch levels of hake early in the fishing season in the years 1994–95, 1995–96, and 1997–89 to 2000–01 were relatively high.

On the Chatham Rise and in the sub-Antarctic, hake have been caught mainly as bycatch by trawlers targeting hoki (Phillips & Livingston 2004). However, in both areas significant targeting for hake occurs, particularly in Statistical Area 404 (HAK 4), and east of the

Solander Trough between the Snares and Auckland Islands in the sub-Antarctic (Phillips & Livingston 2004). Increases in TACCs from 2610 t to 3632 t in HAK 1 and from 1000 t to 3500 t in HAK 4, from the 1991–92 fishing year allowed the fleet to increase their reported landings of hake from these fish stocks. Reported catches have since risen to the levels of the new TACCs and remained close to these values up to 2001–02. In 2002–03, reported catches from HAK 4 dropped markedly (to about two-thirds of previous values), but were again high in 2003–04.

Dunn (2003a) found that area misreporting between the west coast South Island and the Chatham Rise fisheries occurred from 1994–95 to 2000–01. He estimated that between 16 and 23% (700–1000 t annually) of landings were misreported, predominantly in the months of June, July, and September. Levels of misreporting before 1994–95 and after 2000–01, and between the west coast South Island and sub-Antarctic, were estimated as negligible, and there is no evidence of similar misreporting since 2001–02 (N.L. Phillips, NIWA, unpublished results).

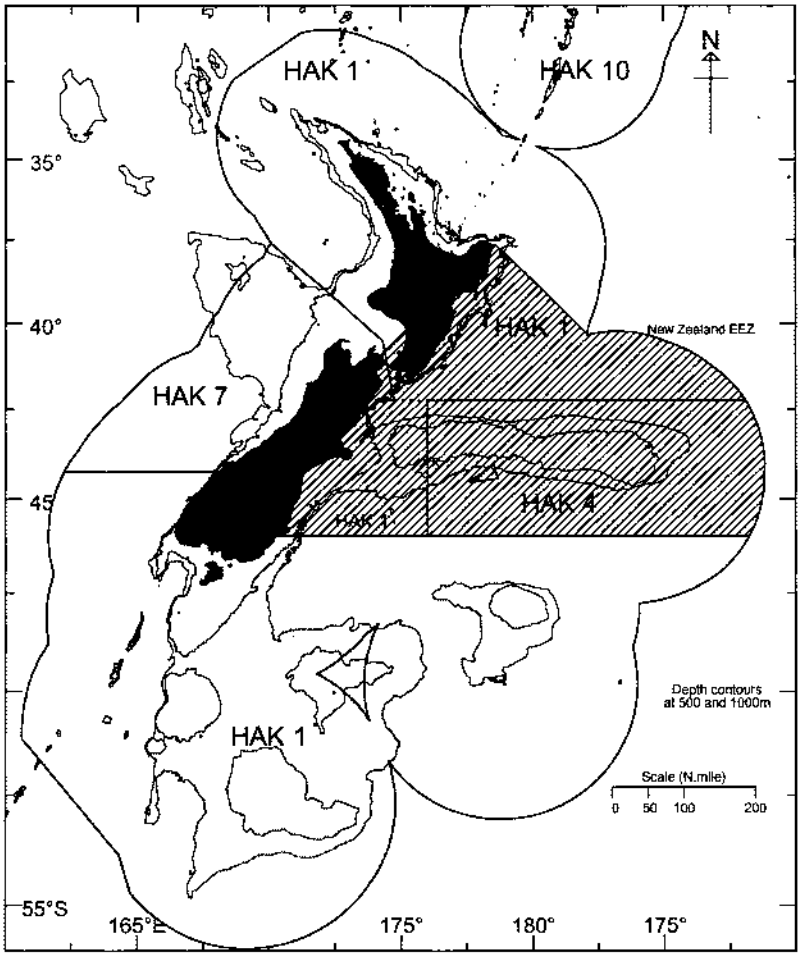

Figure 1: Quota Management Areas (QMAs) HAK 1, 4, 7, & 10; and the west coast South Island (light shading), Chatham Rise (dark shading), and sub-Antarctic (medium shading) hake stock boundaries assumed in this report.

1.2 Literature review

Previous assessments of hake include those by Colman et al. (1991) for the 1991–92 fishing year, Colman & Vignaux (1992) for the 1992–93 fishing year, Colman (1997) for the 1997–98 fishing year, and Dunn (1998), Dunn et al. (2000) and Dunn (2001, 2003b, 2004) for the 1998–99, 1999–00, 2000–01, 2002–03, 2003–04 fishing years respectively. The two most recent of these assessments were two-stock Bayesian assessments using CASAL (Bull et al. 2003).

Since 1991, resource surveys have been carried out from R.V. *Tangaroa* in the sub-Antarctic in November and December 1991, 1992, 1993, 2000, 2001, 2002, 2003, and 2004 (Chatterton & Hanchet 1994, Ingerson & Hanchet 1995, Ingerson et al. 1995, O'Driscoll et al. 2002, O'Driscoll & Bagley 2003a, 2003b, 2004, 2005), September–October 1992 (Schofield & Livingston 1994b), and April–June 1992, 1993, 1996, 1998, (Schofield & Livingston 1994a, 1994c, Colman 1996, Bagley & McMillan 1999).

On the Chatham Rise, a consistent time series of resource surveys from *Tangaroa* has been in January 1992 to 2005 (Horn 1994a, 1994b, Schofield & Horn 1994, Schofield & Livingston 1995, 1996, 1997, Bagley & Hurst 1998, Bagley & Livingston 2000, Stevens et al. 2001, 2002, Stevens & Livingston 2003, Livingston et al. 2004, Livingston & Stevens 2005, Stevens & O'Driscoll 2005).

Standardised CPUE indices for the sub-Antarctic and Chatham Rise stocks were updated for the period up to the 2002–03 fishing year (N.L. Phillips, NIWA, unpublished results). These update the indices estimated by Phillips & Livingston (2004), Kendrick (1998), and Dunn et al. (2000).

2. REVIEW OF THE FISHERY

2.1 TACCs, catch, landings, and effort data

Reported catches from 1975 to 1987–88 are shown in Table 1, and reported landings for each QMA since 1983–84 and TACs since 1986–87 are shown in Table 2. Revised estimates of landings by QMA and by stock for 1974–75 to 2003–04 are provided in Tables 3 and 4 respectively.

West coast South Island revised estimates for 1989–90 and 1990–91 are taken from Colman & Vignaux (1992) who corrected for under-reporting in 1989–90 and 1990–91 using estimates of landings from vessel trips with Ministry of Fisheries observers to correct catches from vessel trips that did not carry Ministry of Fisheries observers, and not from revised estimates of landings based on area misreporting.

2.2 Recreational and Maori customary fisheries

The recreational fishery for hake is believed to be negligible. The amount of hake caught by Maori is not known, but is believed to be negligible.

Table 1: Reported hake catches (t) from 1975 to 1987–88. Data from 1975 to 1983 from Ministry of Agriculture & Fisheries (Fisheries); data from 1983–84 to 1985–86 from Fisheries Statistics Unit; data from 1986–87 to 1987–88 from Quota Management System.

	New Zealand vessels			Foreign licensed vessels				
Fishing year	Domestic	Chartered	Total	Japan	Korea	USSR	Total	Total
1975 [1]	0	0	0	382	0	0	382	382
1976 [1]	0	0	0	5 474	0	300	5 774	5 774
1977 [1]	0	0	0	12 482	5 784	1 200	19 466	19 466
1978–79 [2]	0	3	3	398	308	585	1 291	1 294
1979–80 [2]	0	5 283	5 283	293	0	134	427	5 710
1980–81 [2]				No data available				
1981–82 [2]	0	3 513	3 513	268	9	44	321	3 834
1982–83 [2]	38	2 107	2 145	203	53	0	255	2 400
1983 [3]	2	1 006	1 008	382	67	2	451	1 459
1983–84 [4]	196	1 212	1 408	522	76	5	603	2 011
1984–85 [4]	265	1 318	1 583	400	35	16	451	2 034
1985–86 [4]	241	2 104	2 345	465	52	13	530	2 875
1986–87 [4]	229	3 666	3 895	234	1	1	236	4 131
1987–88 [4]	122	4 334	4 456	231	1	1	233	4 689

1. Calendar year
2. 1 April to 31 March
3. 1 April to 30 September
4. 1 October to 30 September

Table 2: Reported landings (t) of hake by QMA from 1983–84 to 2003–04 and actual TACs (t) for 1986–87 to 2003–04. Data from 1983–84 to 1985–86 from Fisheries Statistics Unit; data from 1986–87 to 2003–04 from Quota Management System (– indicates that the data are unavailable).

QMA	HAK 1		HAK 4		HAK 7		HAK 10		Total	
	Landings	TAC	Landings	TAC	Landings	TAC	Landings	TAC	Landings	TAC
1983–84	886	–	180	–	945	–	0	–	2 011	–
1984–85	670	–	399	–	965	–	0	–	2 034	–
1985–86	1 047	–	133	–	1 695	–	0	–	2 875	–
1986–87	1 022	2 500	200	1 000	2 909	3 000	0	10	4 131	6 510
1987–88	1 381	2 500	288	1 000	3 019	3 000	0	10	4 689	6 510
1988–89	1 487	2 513	554	1 000	6 835	3 004	0	10	8 876	6 527
1989–90	2 115	2 610	763	1 000	4 903	3 310	0	10	7 783	6 930
1990–91	2 635	2 610	743	1 000	6 189	3 310	0	10	9 567	6 930
1991–92	3 156	3 500	2 013	3 500	3 027	6 770	0	10	8 196	13 780
1992–93	3 525	3 501	2 545	3 500	7 154	6 835	0	10	13 224	13 846
1993–94	1 803	3 501	2 587	3 500	2 973	6 835	0	10	7 363	13 847
1994–95	2 572	3 632	3 369	3 500	8 840	6 855	0	10	14 781	13 997
1995–96	3 956	3 632	3 466	3 500	8 660	6 855	0	10	16 082	13 997
1996–97	3 534	3 632	3 524	3 500	6 118	6 855	0	10	13 176	13 997
1997–98	3 810	3 632	3 523	3 500	7 416	6 855	0	10	14 749	13 997
1998–99	3 845	3 632	3 324	3 500	8 165	6 855	0	10	15 333	13 997
1999–00	3 899	3 632	2 803	3 500	6 898	6 855	0	10	13 600	13 997
2000–01	3 628	3 632	2 784	3 500	7 698	6 855	0	10	14 110	13 997
2001–02	2 870	3 632	1 424	3 500	7 519	6 855	0	10	11 813	13 997
2002–03	3 336	3 632	811	3 500	7 433	6 855	0	10	11 581	13 997
2003–04	3 466	3 632	2 275	3 500	7 944	6 855	–	10	13 684	13 997

Table 3: Revised landings (t) by QMA 1989–90 to 2000–01 from Dunn (2003a).

Fishing Year	QMA HAK 1	HAK 4	HAK 7	Total
1989–90	2 115	763	4 903	7 781
1990–91	2 592	703	6 199	9 494
1991–92	3 156	2 013	3 027	8 196
1992–93	3 525	2 504	7 196	13 224
1993–94	1 787	2 587	2 990	7 364
1994–95	2 319	2 922	9 537	14 779
1995–96	3 782	2 894	9 581	16 257
1996–97	3 229	2 752	7 030	13 011
1997–98	3 728	2 892	8 118	14 738
1998–99	3 645	2 511	9 170	15 326
1999–00	3 663	2 307	7 621	13 591
2000–01	3 402	2 318	8 383	14 103

Table 4: Previously assumed landings (Prev.) (Dunn 2001), landings assuming no misreporting (None), and revised landings 1974–75 to 2003–04 (t) (Rev.) for the west coast South Island, sub-Antarctic and Chatham Rise stocks.

Fishing	West coast S.I.			Sub-Antarctic			Chatham Rise		
Year	Prev.	None	Rev.	Prev.	None	Rev.	Prev.	None	Rev.
1974–75	71	71	71	120	120	120	191	191	191
1975–76	5 005	5 005	5 005	281	281	281	488	488	488
1976–77	17 806	17 806	17 806	372	372	372	1 288	1 288	1 288
1977–78	498	498	498	762	762	762	34	34	34
1978–79	4 737	4 737	4 737	364	364	364	609	609	609
1979–80	3 600	3 600	3 600	350	350	350	750	750	750
1980–81	2 565	2 565	2 565	272	272	272	997	997	997
1981–82	1 625	1 625	1 625	179	179	179	596	596	596
1982–83	745	745	745	448	448	448	302	302	302
1983–84	945	945	945	722	722	722	344	344	344
1984–85	965	965	965	525	525	525	544	544	544
1985–86	1 918	1 918	1 918	818	818	818	362	362	362
1986–87	3 755	3 755	3 755	713	713	713	509	509	509
1987–88	3 009	3 009	3 009	1 095	1 095	1 095	574	574	574
1988–89	8 696	8 696	8 696	1 237	1 237	1 237	804	804	804
1989–90	8 741	4 886	8 741	1 522	1 923	1 928	977	950	950
1990–91	8 546	6 116	8 246	1 756	2 370	2 388	991	959	907
1991–92	3 027	3 001	3 027	2 464	2 743	2 752	2 454	2 415	2 417
1992–93	7 154	7 014	7 154	3 206	3 263	3 271	2 775	2 798	2 801
1993–94	2 973	2 920	2 974	1 586	1 448	1 455	2 898	2 948	2 933
1994–95	8 840	8 807	9 537	2 019	1 844	1 856	4 094	4 081	3 386
1995–96	8 660	8 606	9 433	2 479	2 820	2 902	4 760	4 501	3 919
1996–97	6 119	6 006	7 008	2 293	2 282	2 276	4 761	4 768	3 728
1997–98	–	7 310	8 118	2 566	2 626	2 626	4 673	4 650	3 949
1998–99	–	8 002	9 117	2 645	2 787	2 803	4 524	4 385	3 390
1999–00	–	6 719	7 617	2 699	3 008	3 028	4 003	3 670	2 945
2000–01	–	7 581	8 761	–	2 939	2 856	–	3 456	2 491
2001–02	–	7 520	7 519	–	2 523	2 516	–	1 782	1 778
2002–03	–	7 432	7 432	–	2 523	2 729	–	1 418	1 418
2003–04	–	–	–	–	–	2 729[2]	–	–	3 012[2]

1. West coast South Island revised estimates for 1989–90 and 1990–91 are taken from Colman & Vignaux (1992) who corrected for underreporting in 1989–90 and 1990–91, and not from Dunn (2003a) who ignored such underreporting.
2. Catches assumed for 2003–04, for (a) the Chatham Rise, being the sum of the HAK 4 landings in 2003–04 plus the HAK 1 landings from the Chatham Rise in 2002–03, and (b) the sub-Antarctic, being the HAK 1 landings from the sub-Antarctic in 2002–03

2.3 Other sources of fishing mortality

Colman & Vignaux (1992) suggested, in a comparison of hoki and hake catches from vessels carrying Ministry of Fisheries scientific observers with those not carrying observers, that catches of hake were not always fully reported in HAK 7 between 1988–89 and 1990–91. They concluded that the actual catch of hake was significantly under-reported in HAK 7 in some years, and they estimated the actual hake catch in HAK 7 by multiplying the total hoki catch (which was assumed to be correctly reported by vessels both with and without observers) by the ratio of hake to hoki in the catch of vessels carrying observers. Reported and estimated catches for 1988–89 were respectively 6835 t and 8696 t; for 1989–90, 4903 t reported and 8741 t estimated; and for 1990–91, 6189 t reported and 8246 t estimated. More recently, the level of such misreporting has not been estimated and is not known.

Dunn (2003a) revised the estimates of the total landings by stock, accounting for are misreporting between 1994–95 and 2000–01. He estimated that the level of hake over-reporting on the Chatham Rise (and hence under-reporting on the west coast South Island) had been between 16 and 23% (700–1000 t annually) of landings between 1994–95 and 2000–01, predominantly in the months of June, July, and September. Probable levels of misreporting before 1994–95 and between the west coast South Island and sub-Antarctic were probably negligible. There is no evidence of such misreporting since 2001–02 (N.L. Phillips, NIWA, unpublished results).

There is likely to be some mortality associated with escapement from trawl nets, but the level is not known and is assumed to be negligible.

3. BIOLOGY, STOCK STRUCTURE, AND RESOURCE SURVEYS

3.1 Biology

Data collected by observers on commercial trawlers and from resource surveys suggest that there are at least three main spawning areas for hake (Colman 1998). The best known area is off the west coast of the South Island, where the season can extend from June to October, possibly with a peak in September. Spawning also occurs to the west of the Chatham Islands during a prolonged period from at least September to January. Spawning on the Campbell Plateau, primarily to the northeast of the Auckland Islands, may occur from September to February with a peak in September–October. Spawning fish have also been recorded occasionally on the Puysegur Bank, with a seasonality that appears similar to that on the Campbell Plateau (Colman 1998).

Horn (1997) validated the use of otoliths to age hake. Readings of otoliths from hake have been used to develop age-length keys to scale length frequency distributions for hake collected on resource surveys and from commercial fisheries on the Chatham Rise, sub-Antarctic, and west coast South Island. The resulting age frequency distributions and numbers of measurements are given in Appendix A. The relative observed proportions-at-age data from resource surveys and the observer data for the sub-Antarctic and Chatham Rise stocks are also shown in Figure 2 and Figure 3 respectively.

New Zealand hake reach a maximum age of at least 25 years. Males, which rarely exceed 100 cm total length, do not grow as large as females, which can grow to 120 cm total length or more. Length frequency plots from resource surveys and observer data are given in Appendix A.

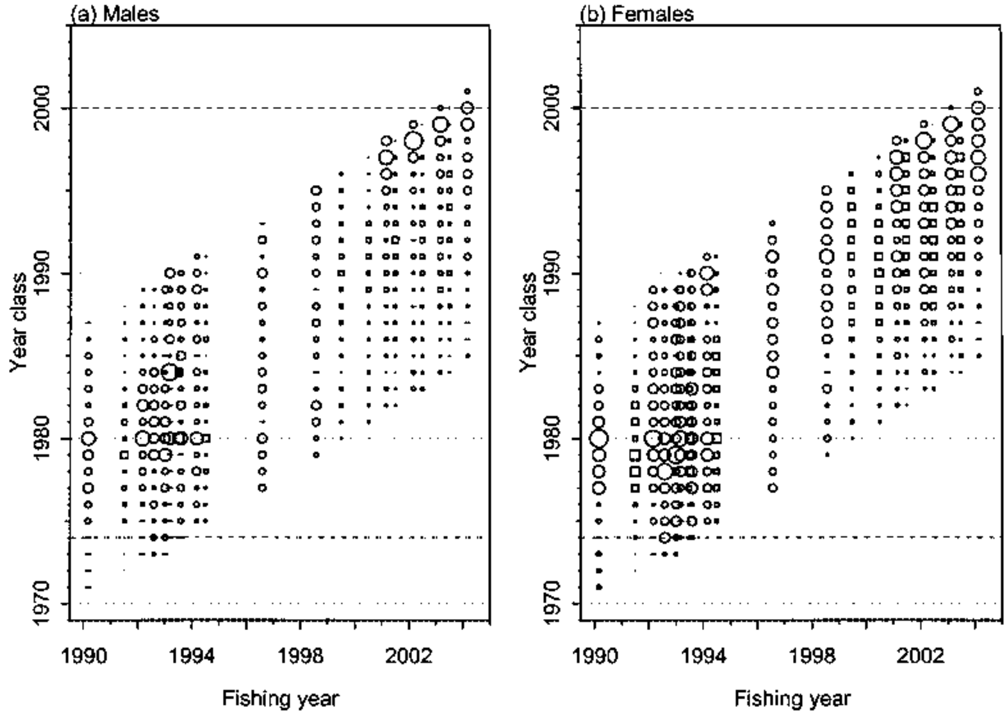

Figure 2: Age frequencies (ages 3 to 20+) by year class and year (symbol area proportional to the proportions-at-age within sampling event) in the sub-Antarctic for (a) resource surveys (circles) and (b) commercial catch-at-age data (squares). Zero values are represented by a dash, and horizontal lines indicate the earliest (1974) and latest (2000) year class strengths estimated within the stock assessment model.

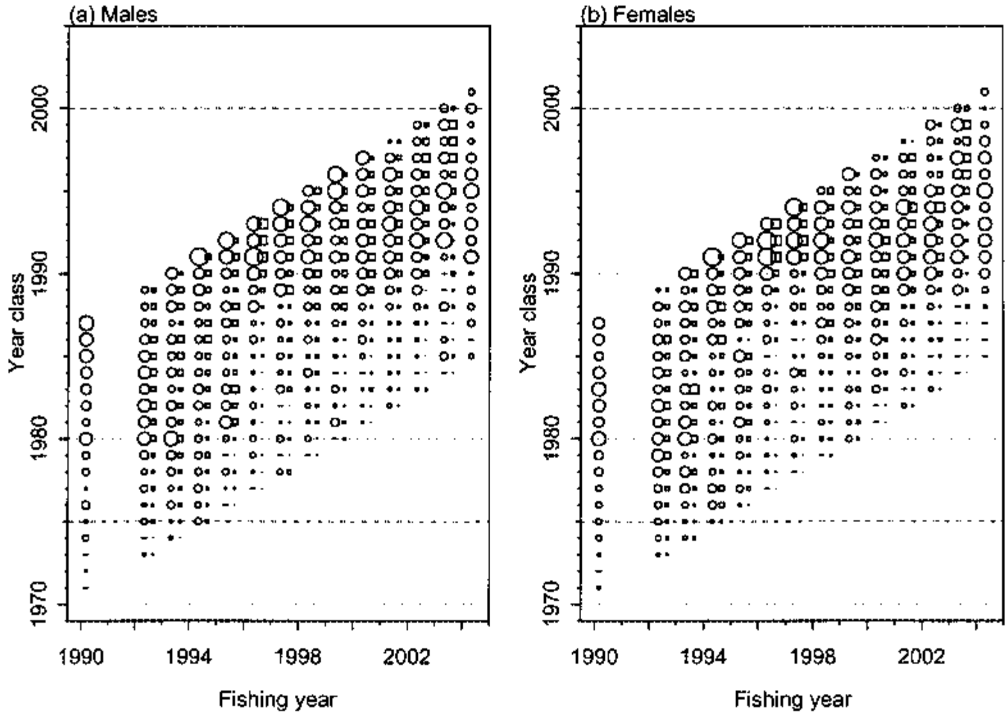

Figure 3: Age frequencies (ages 3 to 20+) by year class and year (symbol area proportional to the proportions-at-age within sampling event) on the Chatham Rise for (a) resource surveys (circles) and (b) commercial catch-at-age data (squares). Zero values are represented by a dash, and horizontal lines indicate the earliest (1975) and latest (2000) year class strengths estimated within the stock assessment model.

Colman (1988) found that hake reach sexual maturity between 6 and 10 years of age, at total lengths of about 67–75 cm (males) and 75–85 cm (females); he concluded that hake reached 50% maturity at between 6 and 8 years in HAK 1, and 7–8 years in HAK 4. In previous assessments, the maturity ogive for the Chatham Rise and sub-Antarctic was assumed from a combination of the estimates of Colman (1988) and model fits presented by Dunn (1998) to the west coast South Island stock. Here, we fit the maturity ogive for the Chatham Rise and sub-Antarctic within the assessment model to data derived from resource survey samples with information on the gonosomatic index, gonad stage, and age.

Individual hake were classified as either immature or mature at sex and age, where maturity was determined from the gonad stage and gonosomatic index (GSI, the ratio of the gonad weight to body weight). Fish identified as stage 1 were classified as immature. Stage 2 fish were classified as immature or mature depending on the GSI index, using the definitions defined by Colman (1988) — i.e., classified as immature if GSI < 0.005 (males) or GSI < 0.015 (females), or mature if GSI ≥0.005 (males) or GSI ≥0.015 (females). Fish identified as stages 3–7 were classified as mature. The available data are shown in Table 5, and the aggregated observed proportions mature from all resource survey data in the months of September–March for the years 1990, 1992–2003 are plotted in Figure 4 (sub-Antarctic) and Figure 5 (Chatham Rise). Empirical estimates from these data suggest that Chatham Rise hake reach 50% maturity at about 6 years for males and 7.5 years for females; and sub-Antarctic hake reach 50% maturity at 6 years for males and 7 years for females.

Estimated von Bertalanffy parameters (Horn 1998) are given in Table 6. Juvenile hake have been taken in coastal waters on both sides of the South Island and on the Campbell Plateau. They reach a total length of about 15–20 cm at 1 year old, and about 35 cm total length at 2 years (Colman 1998).

Table 5: Numbers of samples by area and year (N), number aged (Aged), number where maturity status could be categorised (Avail), and percent of all samples with maturity assigned (%) for the sub-Antarctic, Chatham Rise, and west coast South Island from 1986–2004.

Year	Sub-Antarctic				Chatham Rise				West coast South Island			
	N	Aged	Avail	%	N	Aged	Avail	%	N	Aged	Avail	%
1986	–	–	–	–	120	0	0	0	17	0		
1988	1	0	0	0	–	–	–	–	52	0		
1990	332	89	88	27	524	319	308	59	911	289		
1991	322	0	0	0	–	–	0	–	7	0		
1992	495	402	214	43	523	453	453	87	–	–		
1993	667	599	428	64	420	400	400	95	55	0		
1994	443	266	263	59	449	396	395	88	48	0		
1995	90	0	0	0	375	354	354	94	–	–		
1996	293	203	88	30	338	269	177	52	–	–		
1997	–	–	–	–	301	291	241	80	–	–		
1998	280	275	0	0	419	270	189	45	–	–		
1999	–	–	–	–	284	260	191	67	1 780	0		
2000	–	–	–	–	363	350	340	94	1 264	0		
2001	738	590	346	47	275	262	193	70	–	–		
2002	582	561	440	76	385	347	221	57	–	–		
2003	842	568	430	51	105	105	76	72	–	–		
2004	424	0	0	0	204	0	0	0	–	–		
Total	5 509	3 553	2297	42	5 085	4 076	3538	70	4 134	289		

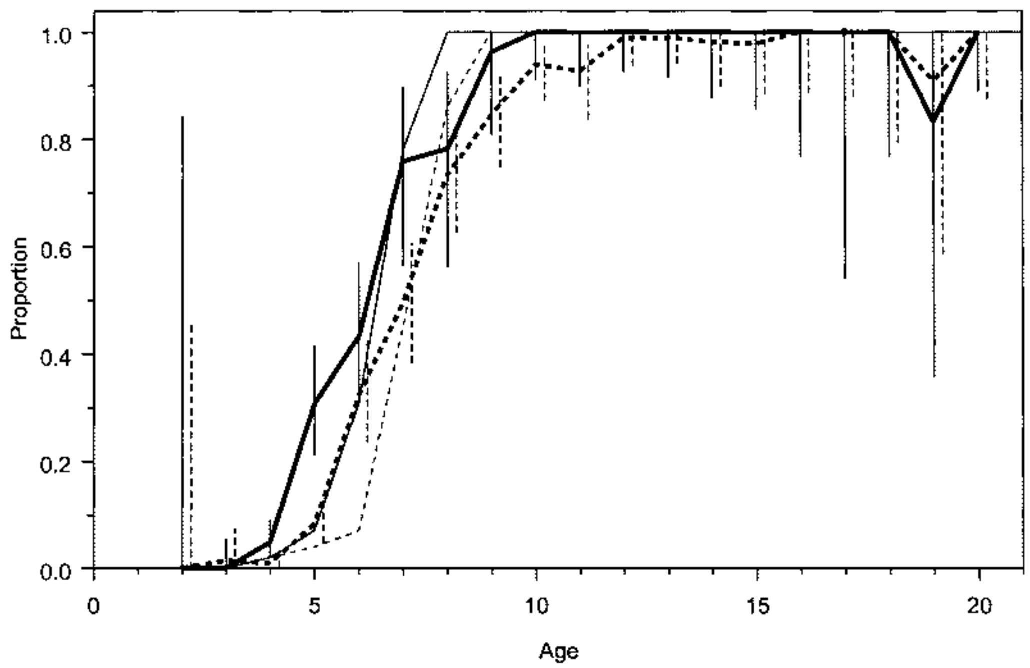

Figure 4: Observed proportions mature by age for sub-Antarctic male (solid line) and female (dashed line) hake from resource surveys (all years combined) in the years 1990, 1992–94, 1996, and 2001–03. Vertical lines indicate exact 95% confidence intervals (female C.I.s offset by 0.2 years). Previously assumed ogives are given for males (solid grey line) and females (dashed grey line).

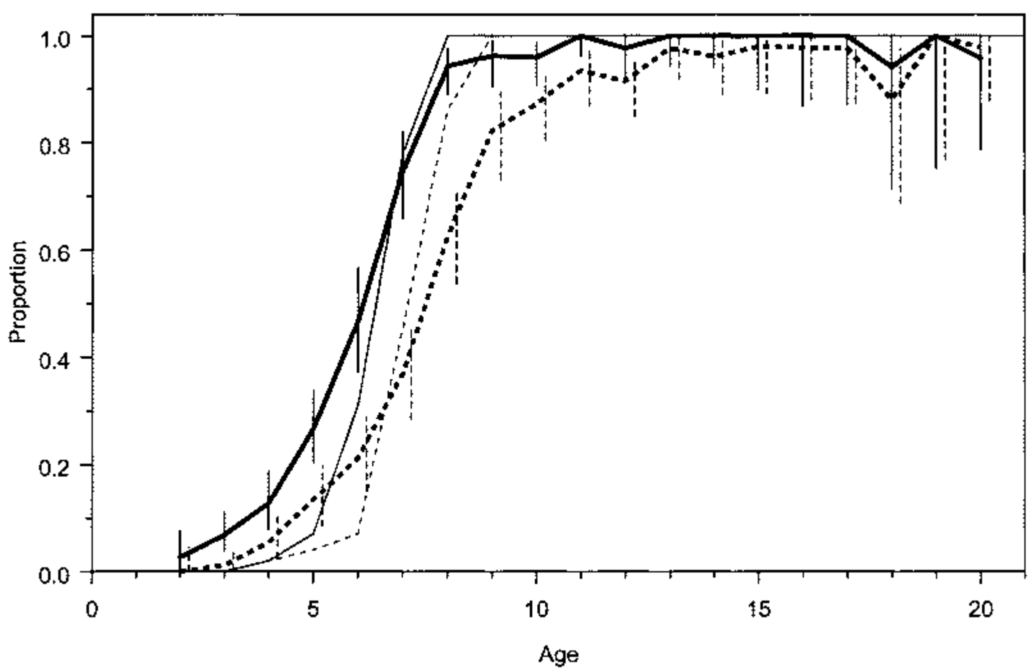

Figure 5: Observed proportions mature by age for Chatham Rise male (solid line) and female (dashed line) hake from resource surveys (all years combined) in the years 1990 and 1992–2003. Vertical lines indicate exact 95% confidence intervals (female C.I.s offset by 0.2 years). Previously assumed ogives are given for males (solid grey line) and females (dashed grey line).

Estimates of natural mortality (M) and the associated methodology were given by Dunn et al. (2000); M was estimated as 0.18 y^{-1} for females and 0.20 y^{-1} for males. Colman et al. (1991) estimated M as 0.20 y^{-1} for females and 0.22 y^{-1} for males using the maximum age method of Hoenig (1983) (where they defined the maximum ages at which 1% of the population survives in an unexploited stock as 23 years for females and 21 years for males). These are similar to the values proposed by Horn (1997), who determined the age of hake by counting zones in sectioned otoliths and concluded from that study that it was likely that M was in the range 0.20–0.25 y^{-1}.

Table 6: Estimates of biological parameters for the Chatham Rise and sub-Antarctic stocks.

				Estimate	Source
Natural mortality					
Males	$M = 0.20$				(Dunn et al. 2000)
Females	$M = 0.18$				(Dunn et al. 2000)
Weight = a·(length)^b (Weight in t, length in cm)					
Sub-Antarctic					
Males	$a = 3.95 \times 10^{-9}$	$b = 3.130$			(Horn 1998)
Females	$a = 1.86 \times 10^{-9}$	$b = 3.313$			(Horn 1998)
Chatham Rise					
Males	$a = 2.49 \times 10^{-9}$	$b = 3.234$			(Horn 1998)
Females	$a = 1.70 \times 10^{-9}$	$b = 3.328$			(Horn 1998)
von Bertalanffy growth parameters					
Sub-Antarctic					
Males	$k = 0.263$	$t_0 = -0.06$	$L_\infty = 90.8$		(Horn 1998)
Females	$k = 0.188$	$t_0 = -0.13$	$L_\infty = 115.0$		(Horn 1998)
Chatham Rise					
Males	$k = 0.277$	$t_0 = -0.11$	$L_\infty = 90.3$		(Horn 1998)
Females	$k = 0.202$	$t_0 = -0.20$	$L_\infty = 113.4$		(Horn 1998)

3.2 Stock structure

There are at least three hake spawning areas; off the west coast of the South Island, on the Chatham Rise, and on the Campbell Plateau (Colman 1998). Juvenile hake are found in all three areas, there are differences in size frequency of hake between the west coast and other areas, and differences in growth parameters between all three areas (Horn 1997). There is reason, therefore, to believe that at least three separate stocks may exist in the EEZ.

Analysis of morphometric data (Colman 1998) showed little difference between hake from the Chatham Rise and from the east coast of the North Island, but highly significant differences between these fish and those from the sub-Antarctic, Puysegur, and on the west coast. The Puysegur fish are most similar to those from the west coast South Island, although, depending on which variables are used, they cannot always be distinguished from the sub-Antarctic hake. However, the data are not unequivocal so the stock affinity is uncertain.

For stock assessment models, the Chatham Rise stock was considered to include the whole of the Chatham Rise (HAK 4 and the western end of the Chatham Rise that forms part of the HAK 1 management area). The sub-Antarctic stock was considered to contain hake in the remaining Puysegur, Southland, and sub-Antarctic regions of the HAK 1 management area. The stock areas assumed for this report are shown earlier, in Figure 1.

3.3 Resource surveys

In the sub-Antarctic, three resource surveys were carried out by *Tangaroa* with the same gear and similar survey designs in November–December 1991, 1992, and 1993; but the series was then terminated as there was evidence that hake, in particular, might be aggregated for spawning at that time of the year and that spawning aggregations had a high probability of being missed during a survey. However, research interest in hoki on the sub-Antarctic resulted in a return to the November–December series in 2000, 2001, 2002, 2003, and 2004. Surveys by *Tangaroa* in April 1992, May 1993, April 1996, and April 1998 formed the basis for a second series, with hake appearing to be more evenly distributed through the survey area at that time of year. A single survey in September 1992 by *Tangaroa*, was used in the stock assessments of the sub-Antarctic for the first time, with the assumption that its selectivity was equivalent to the November–December series.

Sub-Antarctic surveys were conducted by *Shinkai Maru* (March–May 1982 and October–November 1983) and *Amaltal Explorer* (October–November 1989, July–August 1990, and November–December 1990). However, these vessels had different performance characteristics and used different gear (Livingston et al. 2002), hence (except for the October–November 1989 *Amaltal Explorer* survey — see later) cannot be used as a part of a consistent time series.

The data inputs to the stock model included biomass and age data from the region of the sub-Antarctic defined by strata with depths of 300–800 m for the April–May and September *Tangaroa* series, with the November-December *Tangaroa* series adding the 800–1000 m depth strata around Puysegur. Other *Tangaroa* surveys (April–May 1996 and 1998; and November–December 2000, 2001, 2002, and 2003) have also surveyed additional deepwater strata (i.e., 800–1000 m strata to the north and to the south of the survey region). The deepwater strata were excluded from the data used in this analysis to maintain consistency in the time series. Data from the most recent *Tangaroa* survey (December 2004) are reported, but were not available for inclusion in the stock assessment model. In some model runs, biomass and age data from the 1989 *Amaltal Explorer* survey (200–800 m) were included in data inputs. The biomass estimates from the sub-Antarctic *Tangaroa* and 1989 *Amaltal Explorer* surveys are shown in Figure 6. The distributions of catches from these surveys are given in Appendix B.

Resource surveys have been carried out at depths of 200–800 m on the Chatham Rise since 1992 by *Tangaroa* with the same gear and similar survey designs (see Appendix B). However, although the survey designs since 1992 have been similar, there was a reduction in the number of stations surveyed between 1996 and 1999, and some strata in the survey design used between 1996 and 1999 were merged (see Bull & Bagley 1999). The most recent surveys in 2000–05 used a revised design — with some strata being split and additional stations added. In addition, the 2000 and 2002 surveys included deepwater strata (i.e., 800–1000 m) on the northern Chatham Rise. The deepwater strata were excluded from the *Tangaroa* data used in this analysis to maintain consistency in the time series. Data from the most recent *Tangaroa* survey (January 2005) are reported, but were not available for inclusion in the stock assessment model.

Chatham Rise surveys were conducted by *Shinkai Maru* (March 1983 and June–July 1986) and *Amaltal Explorer* (November–December 1989). However, these surveys used a range of gear, survey methodologies, and survey designs (Livingston et al. 2002), and (except for the November–December 1989 *Amaltal Explorer* survey — see later) cannot be used as a consistent time series. The biomass estimates from Chatham Rise resource surveys are shown in Figure 7. The distributions of catches from these surveys are given in Appendix B.

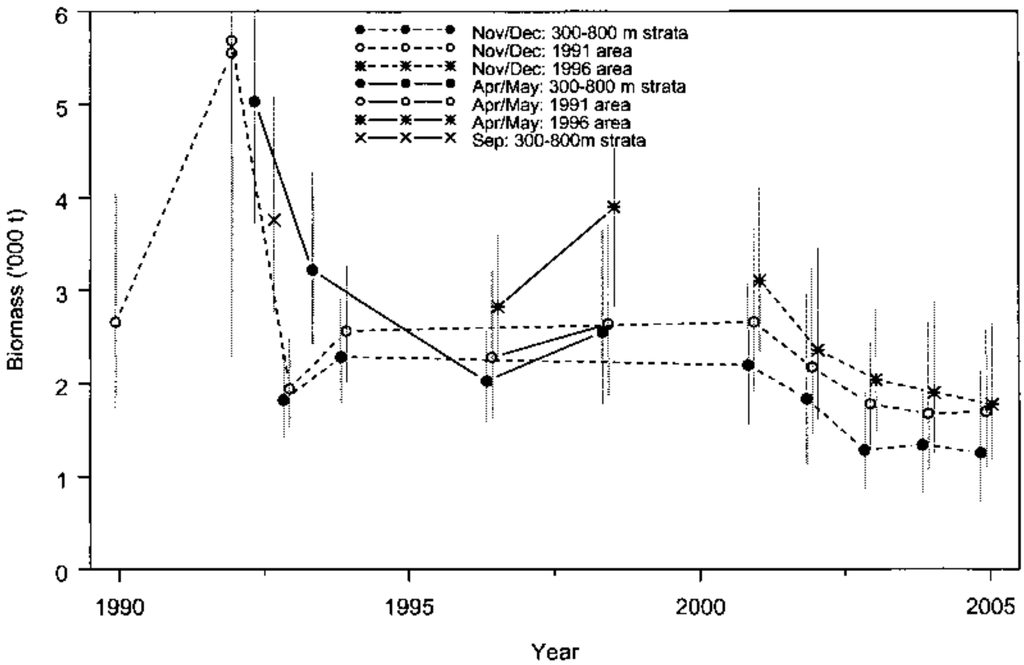

Figure 6: Hake biomass estimates from the *Amaltal Explorer* (October–November 1989) and *Tangaroa* (1992–2004 including the November–December, April–May, and September series) surveys of the sub-Antarctic, with approximate 95% confidence intervals. (See also Appendix B.)

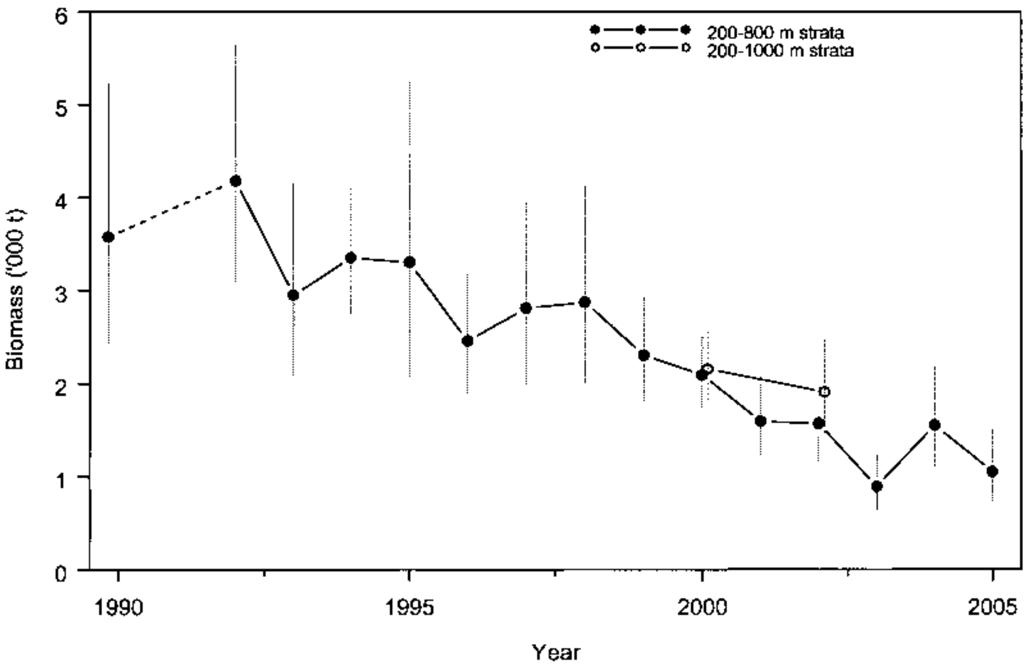

Figure 7: Hake biomass estimates from the *Amaltal Explorer* (November–December 1989) and *Tangaroa* (1992–2005 for the January series), with approximate 95% confidence intervals. (See also Appendix B.)

3.4 CPUE indices

CPUE indices were calculated for daily processed summary data up the end of the 2002–03 fishing season for the Chatham Rise and the sub-Antarctic fisheries (N.L Phillips, NIWA, pers. comm.). CPUE indices for the Chatham Rise, Statistical Area 404 of the Chatham Rise, and the sub-Antarctic are given in Table 7.

Table 7: Hake CPUE indices (and associated c.v.s) for the Chatham Rise, Statistical Area 404, and the sub-Antarctic (N.L. Phillips, NIWA, pers. comm.).

Year	Chatham Rise		Statistical Area 404		Sub-Antarctic	
	Index	c.v.	Index	c.v.	Index	c.v.
1989–90	1.96	0.085			1.27	0.073
1990–91	1.09	0.086			1.05	0.063
1991–92	1.30	0.069	4.85	0.193	1.00	–
1992–93	0.95	0.059	2.54	0.150	0.75	0.057
1993–94	1.27	0.068	1.68	0.165	0.75	0.072
1994–95	1.15	0.047	3.27	0.180	0.67	0.075
1995–96	1.52	0.054	3.20	0.180	0.66	0.078
1996–97	1.30	0.044	2.78	0.192	0.61	0.067
1997–98	1.07	0.036	2.42	0.176	0.47	0.070
1998–99	1.00	–	2.25	0.147	0.41	0.081
1999–00	1.04	0.038	1.73	0.204	0.50	0.071
2000–01	0.98	0.039	1.13	0.173	0.51	0.075
2001–02	1.03	0.037	1.00	–	0.44	0.077
2002–03	0.84	0.038	0.92	0.142	0.43	0.075

4. MODEL STRUCTURE, INPUTS, AND ESTIMATION

4.1 Model structure

The stock assessment model partitioned the sub-Antarctic and Chatham Rise populations into two sexes and age groups 1–30, with the last age class considered a plus group. Each stock was considered to reside in a single area (sub-Antarctic and Chatham Rise), with no interaction between the stocks. Unlike models before 2002 (Dunn 2003b), the model included both the sub-Antarctic and Chatham Rise stocks, estimated simultaneously, but were considered independent. While this offered no advantage over the use of separate stock models, the structure allowed the option of sensitivity analyses — with some common parameters — to be estimated across both stocks simultaneously.

Due to a constraint within the modelling software in allowing different maturity ogives between stocks when maturity was not a part of the partition, the partition was modified to include maturity (see Bull et al. 2004). Previous models had assumed that a constant proportion of fish at age and sex were mature, and further, that this proportion was constant between stocks. This model assumed that a constant proportion of fish at age and sex *become* mature and that the rates may be different between stocks. While the distinction with the maturity parameterisation makes little difference in this case, the change permits the use of the maturity data for the Chatham Rise and sub-Antarctic stocks within the two-stock model, hence allowed the ogives to be estimated from the data from each stock separately.

The model's annual cycle was based on the fishing year and divided the year into three steps (Table 8). Note that model references to "year" within this document refer to the fishing year, and are labelled as the most recent calendar year, i.e., the fishing year 1998–99 is referred to as "1999".

The model used 10 selectivity ogives; male and female fishing selectivities on the sub-Antarctic and Chatham Rise, male and female survey selectivities for each of the sub-Antarctic *Tangaroa* November–December and April–May resource survey series (with the September 1992 survey assumed to have a selectivity equal to the November–December series), and male and female survey selectivities for the Chatham Rise *Tangaroa* resource survey series. The resource survey and fishing selectivities were initially assumed to be logistic, with female selectivity estimated relative to male selectivity.

The choice of the logistic parameterisation was used as it forces a monotonic increasing curve to selectivities by age, with a minimum number of parameters. Fishing selectivities for hake are unlikely to be exactly logistic shaped, and may even be domed, but the low sample sizes and high variability in the numbers at age data make accurate determination of the shape difficult. The logistic parameterisation of selectivity (for male observations) for each age x was,

$$f(x)=1\Big/\left[1+19^{(a_{50}-x)/a_{to95}}\right]$$

with estimable parameters a_{50} and a_{to95}. This has value 0.5 at $x = a_{50}$ and 0.95 at $x = a_{50} + a_{to95}$. Similarly, the parameterisation for female observations was,

$$f(x)=1\Big/\left[1+19^{(a_{50}-x)/a_{to95}}\right].a_{max}$$

with estimable parameters a_{50}, a_{to95}, and a_{max}. When $a_{max} = 1$, this is identical to the standard logistic parameterisation. This has value $0.5a_{max}$ at $x = a_{50}$ and $0.95a_{max}$ at $x = a_{50} + a_{to95}$. Selectivities were assumed constant over all years in each fishery, and hence there was no allowance for annual changes in selectivity.

In addition to the selectivity ogives, maturity ogives were fitted for males and females for the sub-Antarctic and Chatham Rise stocks separately. These were fitted using a "logistic producing" ogive, i.e., the ogive parameterises the proportions maturing (not the proportions mature), so that the observed proportions mature in any year will tend to follow a logistic curve (or, in the special case with no fishing and equilibrium recruitment, the proportions mature will be exactly logistic). Here, the ogive at age x was,

$$f(x)=\left(\lambda(x)-\lambda(x-1)\right)/\left(1-\lambda(x-1)\right),\ \text{where}\ \lambda(x)=1\Big/\left[1+19^{(a_{50}-x)/a_{to95}}\right]$$

with estimable parameters a_{50} and a_{to95}.

In some model runs, biomass and age data from the two 1989 *Amaltal Explorer* surveys (i.e., one each in the sub-Antarctic and Chatham Rise) were included with data inputs. In these cases, their selectivities were assumed equal to the selectivity for the appropriate *Tangaroa* series (i.e., the January series for the Chatham Rise or the November–December series for the sub-Antarctic).

Maximum exploitation rates for hake are assumed to be 0.7 for both the sub-Antarctic and Chatham Rise 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.

The catch histories assumed in all model runs were the revised estimates of catch for the sub-Antarctic and Chatham Rise reported by Dunn (2003a) and updated for 2002–03, with the assumption that the catch in 2003–04 was the same as that reported for 2002–03 (2729 t in the sub-Antarctic and 1418 t on the Chatham Rise). Five-year projected biomass estimates have assumed that future catches in the sub-Antarctic and Chatham Rise were at either of two values (a) high, the level of the current combined TACC, with about half occurring in the sub-Antarctic (3632 t) and Chatham Rise (3616 t) fisheries respectively, and (b) low, for both the sub-Antarctic (1816 t) and Chatham Rise (1800 t) fisheries

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

					Observations	
Step	Period	Processes	M^1	Age[2]	Description	$\%M^3$
1	Oct–Feb	Fishing,	0.42	0.25		
		recruitment,			Nov./Dec. survey (sub-Antarctic)	50
		& spawning			Jan. survey (Chatham Rise)	100
2	Mar–May	None	0.25	0.50	Apr./May survey (sub-Antarctic)	50
3	Jun–Sep	Increment age	0.33	0.00	Sep. survey (sub-Antarctic)	100

1. M is the proportion of natural mortality that was assumed to have occurred in that time step.
2. Age is the age fraction, used for determining length at age, that was assumed to occur in that time step.
3. $\%M$ is the percentage of the natural mortality in each time step that was assumed to have taken place at the time each observation was made.

4.2 Biological parameters and observations

Estimates of known biological parameters and fixed biological parameters used in the assessments are given in Table 6 and Table 10 respectively. A Beverton-Holt stock-recruitment relationship, with steepness 0.9, was assumed. Variability was assumed in the von Bertalanffy age-length relationship, with variability assumed to be lognormal with a constant c.v. (coefficient of variation) of 0.1. The proportion of males at recruitment was assumed to be 0.5 of all recruits, as there is no external data from which to estimate this value.

Catch-at-age observations were available for each survey on the sub-Antarctic and Chatham Rise, and from commercial observer data for the two fisheries (see Figure 2 and Figure 3 earlier). Multinomial errors, with estimated sample sizes, were assumed for the proportions-at-age observations. Ageing error was assumed to occur for the observed proportions-at-age data, by assuming a discrete normally distributed error with c.v. 0.08 (P. Horn, NIWA, pers. Comm.).

Biomass estimates from the resource surveys were used as relative biomass indices, with associated c.v.s estimated from the survey analysis. Catchability constants (qs) were assumed to be constant and estimated independently for the Chatham Rise *Tangaroa* survey series, sub-Antarctic November–December and September *Tangaroa* series combined, and the sub-Antarctic April–May *Tangaroa* series respectively.

Where model runs included the two 1989 *Amaltal Explorer* surveys, their catchability constants were assumed to differ from that of the *Tangaroa* survey series but were constrained so that the ratio of the qs from the Chatham Rise and the November–December sub-Antarctic *Tangaroa* surveys was equal to the ratio of the catchability constants from the Chatham Rise and sub-Antarctic *Amaltal Explorer* surveys. The constraint was imposed in the form of a prior on the ratio and is described in more detail later.

The effective sample sizes (in the case of observations fitted with multinomial likelihoods) or c.v.s (for observations fitted with lognormal likelihoods) are assumed to have allowed for sampling error only. Additional variance, assumed to arise from differences between model simplifications and real world variation, was added to the sampling variance for al observations in all model runs.

The additional variance, termed process error, was estimated in MPD runs of the each model, and the total error assumed in each run for each observation was calculated by adding process error and observation error.

Estimates of the sample size for the proportions-at-age observations were made via a two-step process; (a) first, the sample sizes were derived by assuming the relationship between the observed proportions, E_i, and estimated c.v.s, c_i, followed that for a multinomial distribution with unknown sample size N_j. The estimated sample size was then derived using a robust non-linear least squares fit of $\log(c_i) \sim \log(P_i)$, and (b) by estimating an effective sample size, N_j', by adding additional process error, N_{PE}, to the sample size calculated in (a) above, where,

$$N_j' = 1 \Big/ \left(1/N_j + 1/N_{PE} \right)$$

i.e., from an initial MPD model fit, an estimate of the additional process error was made by solving the following equation for N_{PE},

$$n = \sum_{ij} \frac{\left(O_{ij} - E_{ij}\right)^2}{E_{ij}\left(1 - E_{ij}\right)\left(1/N_j + 1/N_{PE} \right)}$$

where n was the number of multinomial cells, O_{ij} was the observed proportions for age class i in year j, E_{ij} was the expected proportions, N_j was the effective sample size estimated in (a) above, and N_{PE} was the associated process error for that class of observations.

Estimates of the effective c.v. for biomass observations were made by fitting the process error within each model run, where the effective c.v. c_i' was determined from the process error c_{PE} and the observed c.v.s c_i by,

$$c_i' = \sqrt{c_i^2 + c_{PE}^2}\ .$$

Estimated observation error and additional process errors for the base case and CPUE models are summarised in Table 9.

Table 9: Minimum and maximum of the observation error (c.v.s for lognormal and *n*'s for multinomial likelihoods), and the effective error assumed after the addition of process error for the base case and sensitivity case, by stock and observation type.

Stock	Data series	Likelihood	Observation		Base case		CPUE case	
			Min	Max	Min	Max	Min	Max
Chatham Rise	Survey biomass	Lognormal	0.09	0.23	0.09	0.23	–	–
	Survey age	Multinomial	49	223	49	223	–	–
	Catch-at-age	Multinomial	152	417	97	163	97	163
	Catch-at-age -additional	Multinomial	67	447	47	116	47	116
	Catch-at-length-additional	Multinomial	28	956	25	191	25	191
	CPUE	Lognormal	0.14	0.2	–	–	0.24	0.28
Sub-Antarctic	Survey biomass (Nov)	Lognormal	0.12	0.43	0.12	0.43	–	–
	Survey age (Nov)	Multinomial	75	189	60	118	–	–
	Survey biomass (Apr)	Lognormal	0.12	0.18	0.12	0.18	–	–
	Survey age (Apr)	Multinomial	56	88	56	88	–	–
	Survey biomass (Sep)	Lognormal	0.15	0.15	0.15	0.15	–	–
	Survey age (Sep)	Multinomial	85	85	76	76	–	–
	Catch-at-age	Multinomial	178	522	115	201	115	201
	Catch-at-age -additional	Multinomial	105	176	14	15	14	15
	Catch-at-length-additional	Multinomial	12	388	9	42	9	42
	CPUE	Lognormal	0.06	0.08	–	–	0.21	0.22

Table 10: Fixed biological parameters assumed for the sub-Antarctic and Chatham Rise stock assessment model.

Parameter	Value
Steepness (Beverton & Holt stock- recruitment relationship)	0.90
Proportion spawning	1.0
Proportion of recruits that are male	0.5
Spawning season length	0
Natural mortality (*M* male, female)	0.20 y^{-1}, 0.18 y^{-1}
Maximum exploitation rate (U_{max})	0.5

4.3 Model estimation

Model parameters were estimated using Bayesian estimation implemented using the CASAL software. (Full details of the CASAL algorithms, software, and methods are detailed in Bull et al. 2004.) 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 Monte Carlo Markov Chain (MCMC) methods, based on the Metropolis-Hastings algorithm.

Year class strengths were assumed known (and equal to one) for years prior to 1974 (sub-Antarctic stock) and 1975 (Chatham Rise stock), and after 2000, when inadequate or no catch-at-age data were available. Otherwise year class strengths were estimated under the assumption that the estimates from the model must average one. However, in the projections, the assumption that the relative year class strengths were equal to one was relaxed. Here, relative year class strengths from 2001 were assumed to be 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. Note that Dunn (2004) parameterised year class multipliers using the Haist parameterisation, whereas here, we employ the Francis parameterisation (see Bull et al. 2004 for detail). The main differences between these parameterisations are that the priors on the year class strength apply directly to the estimated values; that a penalty to encourage the mean of the year class strengths to equal one is no longer required; and that B_0 is parameter derived from the model estimate of B_{mean} multiplied by the mean recruitment.

MCMCs were estimated using a burn-in length of 1×10^6 iterations, with every 5000^{th} sample taken from the next 5×10^6 iterations (i.e., a final sample of length 1000 was taken from the Bayesian posterior). Autocorrelations, and 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 Output Analysis software (Smith, B.J., 2001. Bayesian output analysis program. Version 1.01 user's manual. Unpublished manuscript. 45 p. University of Iowa College of Public Health. http://www.public-health.uiowa.edu/boa).

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 survey qs and the ratio of catchability constants for the *Amaltal Explorer* surveys (when used).

The priors for survey qs were estimated by assuming that the catchability constant was the product of areal availability, vertical availability, and vulnerability. A simple simulation was conducted that estimated a distribution of possible values for the catchability constant by assuming that each of these factors was uniformly distributed. A prior was then determined by assuming that the resulting, sampled, distribution was lognormally distributed. Values assumed for the parameters were; areal availability (0.50–1.00), vertical availability (0.50–1.00), and vulnerability (0.01–0.50). The resulting (approximate lognormal) distribution had mean 0.16 and c.v. 0.79, with bounds assumed to be (0.01–0.40). The assumed distributions for the survey catchability constants are shown in Figure 8. Selectivity priors, for all parameters, were assumed to be uniform. Note that the values of survey catchability constants are dependant on the selectivity parameters, and the absolute catchability can be determined by the product of the selectivity by age and sex, and the catchability constant q.

As described earlier, the catchability constants for the *Amaltal Explorer* surveys were constrained so that the ratio of the qs from the Chatham Rise and the November–December sub-Antarctic *Tangaroa* surveys was equal to the ratio of the catchability constants from the Chatham Rise and sub-Antarctic *Amaltal Explorer* surveys. The constraint was imposed in the form of a lognormal prior on the relative ratio, r, with mean 1.0 and c.v. 0.05 (Figure 8), where the r was defined as;

$$r = \frac{q_{\text{Chatham Rise}(\textit{Tangaroa})}}{q_{\text{Sub-Antarctic}(\textit{Tangaroa})}} \bigg/ \frac{q_{\text{Chatham Rise}(\textit{Amaltal Explorer})}}{q_{\text{Sub-Antarctic}(\textit{Amaltal Explorer})}}$$

A penalty function was used to constrain the model so that any combination of parameters that did not allow the historical catch to be taken was strongly penalised.

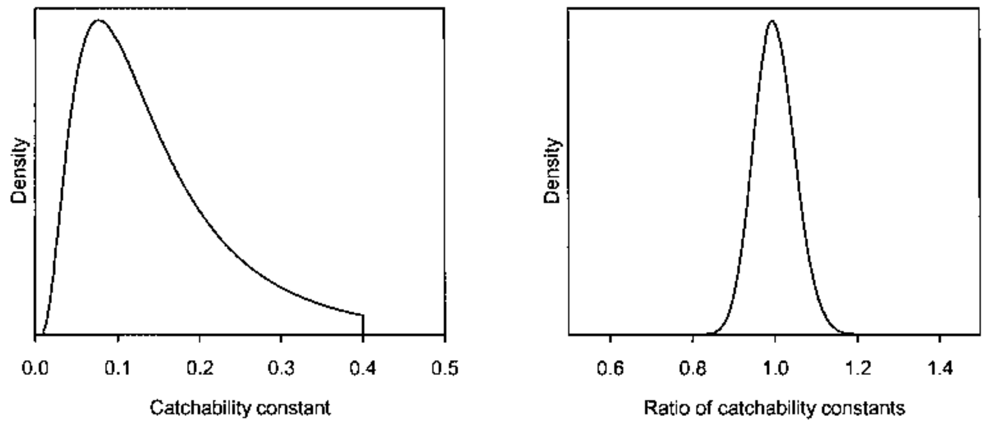

Figure 8: The prior distribution for (left figure) survey catchability constants (*qs*), lognormal where μ=0.16, c.v.=0.79, and bounds (0.01,0.40), and (right figure) the prior distribution for ratio of the *Tangaroa* survey catchability constants (*qs*) to the *Amaltal Explorer* survey catchability constants, lognormal where μ=1.0, c.v.=0.05.

Table 11: The assumed priors assumed for key distributions (when estimated). The parameters are mean (in natural space) and c.v. for lognormal; and mean and s.d. for normal.

Stock	Parameter	Distribution	Parameters		Bounds	
Chatham Rise	B_{mean}	Uniform-log	–	–	2 500	250 000
	Survey q	Lognormal	0.16	0.79	0.01	0.40
	CPUE q	Uniform-log	–	–	1e-20	1.0
	YCS	Lognormal	1.0	1.1	0.01	100
Sub-Antarctic	B_{mean}	Uniform-log	–	–	2 500	250 000
	Survey q	Lognormal	0.16	0.79	0.01	0.40
	YCS	Lognormal	1.0	1.1	0.01	100
	CPUE q	Uniform-log	–	–	1e-20	1.0

5. MODEL ESTIMATES

Initial case estimates of biomass were estimated using the biological parameters (Table 6) and model input parameters described earlier, but excluding *Amaltal Explorer* data. Only one sensitivity ("CPUE") was investigated to MCMC. Here, the CPUE indices were substituted for the survey biomass indices for both stocks. Other runs evaluated to MPD included the inclusion of the *Amaltal Explorer* survey data ("AEX"), estimation of natural mortality ("Estimate M"), adding additional process error to the biomass indices ("C.v.s") — effectively changing the relative data weightings of the observations within the model, and the exclusion of the November trawl survey series from the sub-Antarctic model ("November"). Table 12 summarises the names and descriptions of the model runs.

For each model run, MPD fits were obtained and qualitatively evaluated. Objective function values (negative log-likelihood) for each model run are shown in Table 13. MCMC estimates of the posterior distribution were obtained for two model runs (the base case and the CPUE sensitivity), and are presented below. In addition, MCMC estimates of the median posterior and 95% percentile credible intervals are reported for the key output parameters. Summary plots of the base case MPD model fits are given in Appendix C.

The Geweke (1992), Heidelberger & Welch (1983) stationarity test, and the Heidelberger & Welch (1983) half width tests were used to investigate evidence of MCMC convergence. No evidence of lack of convergence was found in the estimates of B_0, although some estimates of selectivity parameters and YCS showed evidence of lack of convergence, particularly for the sub-Antarctic model (Table 14). The constraint of YCS having average 1 contributed to large correlations between some parameters, resulting in a lack of possible convergence. Trace diagnostics of key parameters for the sub-Antarctic and Chatham Rise stock models are shown in Figure 9 and Figure 10.

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 are 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.

Table 12: Model run labels and descriptions for the initial case and sensitivity model runs.

Model run	Description
Base case	Base case model
CPUE	Same as the base case, but excluding survey data and including CPUE indices
AEX	Same as the base case model, with the inclusion of *Amaltal Explorer* data
Estimate M	Same as the base case, but also estimating natural mortality (M)
Cvs	Same as the base case, but with the addition of process error (20%) on survey abundance indices
November	Same as the base case, but excluding the November sub-Antarctic survey series

Table 13: Objective function values (negative log-likelihood) for MPD fits to observations, priors, and catch limit penalties and the total objective function (negative log-likelihood) value.

Stock	Likelihood component	Base	CPUE	AEX	M	Cvs	Nov.
Chatham Rise	chatAEXage	–	–	75	–	–	–
	chatAEXbiomass	–	–	-2	–	–	–
	chatCPUE	–	-10	–	–	–	–
	chatOBS	412	397	416	407	412	412
	chatOBS-additional	366	370	365	353	365	366
	chatOBS-additional-LF	87	87	87	87	87	87
	chatTANage	881	–	885	861	881	882
	chatTANbiomass	-15	–	-15	-12	-14	-14
	chatTANmaturity	452	450	452	453	452	452
Sub-Antarctic	subaAEXage	–	–	44	–	–	–
	subaAEXbiomass	–	–	-2	–	–	–
	subaCPUE	–	-17	–	–	–	–
	subaOBS	412	399	410	399	412	404
	subaOBS-additional	75	77	75	74	75	78
	subaOBS-additional-LF	173	169	174	175	173	171
	subaTANageAPR	234	–	236	223	234	232
	subaTANageNOV	439	–	441	429	438	–
	subaTANageSEP	62	–	65	60	62	61
	subaTANbiomassAPR	-2	–	-3	-4	-4	-2
	subaTANbiomassNOV	-5	–	-4	-2	-6	–
	subaTANbiomassSEP	-2	–	-2	-2	-2	-2
	subaTANmaturity	212	212	212	211	212	203
Penalties		0	0	0	0	0	0
Priors		-16	-29	-20	-13	-16	-14
Total		3 766	2 106	3 889	3 700	3 763	3 315

Table 14: Percentage of derived parameters that passed the Geweke and Heidelberger & Welch convergence diagnostics for selected derived parameters from the base case MCMC chain for the sub-Antarctic and Chatham Rise stock models (% refers to the percentage of derived parameters that passed each test).

Stock	Parameter	N	Geweke	Heidelberger & Welch	
				Stationarity	Half width test
Sub-Antarctic	B_0	1	100.0 %	Passed	Passed
	Selectivity	180	57.2 %	66.1 %	98.9 %
	YCS	30	80.0 %	86.7 %	96.7 %
Chatham Rise	B_0	1	100.0 %	Passed	Passed
	Selectivity	120	67.5 %	100.0 %	100.0 %
	YCS	29	86.2 %	100.0 %	100.0 %

5.1 Sub-Antarctic results

The estimated MCMC marginal posterior distributions for selected parameters for the sub-Antarctic stock are shown in Figure 11–Figure 18. Resource survey selectivities for males and females diverged, with males less selected that females at older ages in both the November–December and the April–May survey series. Nevertheless, the posterior density estimates of selectivities indicated considerable uncertainty in the estimates of selectivity by age and sex. Fishing selectivities were again poorly estimated, with strong evidence that the selectivity of male fish was considerably higher at age than for females (Figure 13). There is no information outside the model that allows the shape of the estimated selectivity ogives to be verified. Year class strength estimates were poorly estimated for years where only older fish were available to determine age class strength (i.e., before the mid-1980s), and the most recent year class strength (1999) was also poorly determined (Figure 14).

The base case assessment relied on biomass data from the sub-Antarctic trawl survey series. In this model run, estimated trawl survey relativity constants were very low (about 1–10%) and were constrained by the lower bound on the prior for q, suggesting that the absolute catchability of the sub-Antarctic trawl survey series was extremely low. It is not known if the catchability of the sub-Antarctic trawl survey series is as low as estimated by the stock model, but we note that higher estimates of the relativity constant q (although confounded with selectivity) would likely result in lower current and virgin biomass estimates. A plausible explanation for the estimated values is that there is little contrast in the biomass indices from the sub-Antarctic trawl survey series, and that the model has little information on which to determine an appropriate "scale" of biomass estimates.

Sensitivity runs did not suggest any great departure from the base case estimates of current biomass (approximate ranges over all sensitivities was 60–75% B_0). The most optimistic MPD run ("estimate M") was when natural mortality was estimated within the model — although this resulted in unlikely estimates of natural mortality (i.e., 0.28 y^{-1} and 0.29 y^{-1} for females and males respectively). MPD model estimates that excluded the November–December trawl survey series ("November") suggested lower estimates of B_0, although this model also indicated above average year class strengths in the early 1980s. For this model, estimated (MPD) estimates of biomass in 2004 were about 63% B_0.

The estimates suggested that the sub-Antarctic stock was characterised by a group of moderate or strong year classes in the late 1970s, followed by a period of slightly less than average recruitment. Consequently, biomass estimates for the stock have declined, in particular since the early 1990s (Figure 15). However, biomass estimates for the stock appear relatively healthy, with estimated current biomass at about 70% of B_0 (95% credible intervals 59–83%). (See Figure 16 and Table 15.) Exploitation rates (Figure 17) for the sub-Antarctic were estimated to be low, and were a consequence of the high estimated stock size in relationship to the level of relative catches.

Projections with either "high" or "low" catches (3612 and 1816 t respectively) had little effect on the projected stock size to 2009 (Table 16 and Table 17). The lack of contrast in abundance indices since 1991 indicate that while the status of the sub-Antarctic stock is probably similar to that in the early 1990s, the absolute level of current biomass is difficult to determine, and further, we note that the relative biomass estimate from the most recent survey in December 2004 (1694 t) was similar to the estimate for the previous year (1672 t).

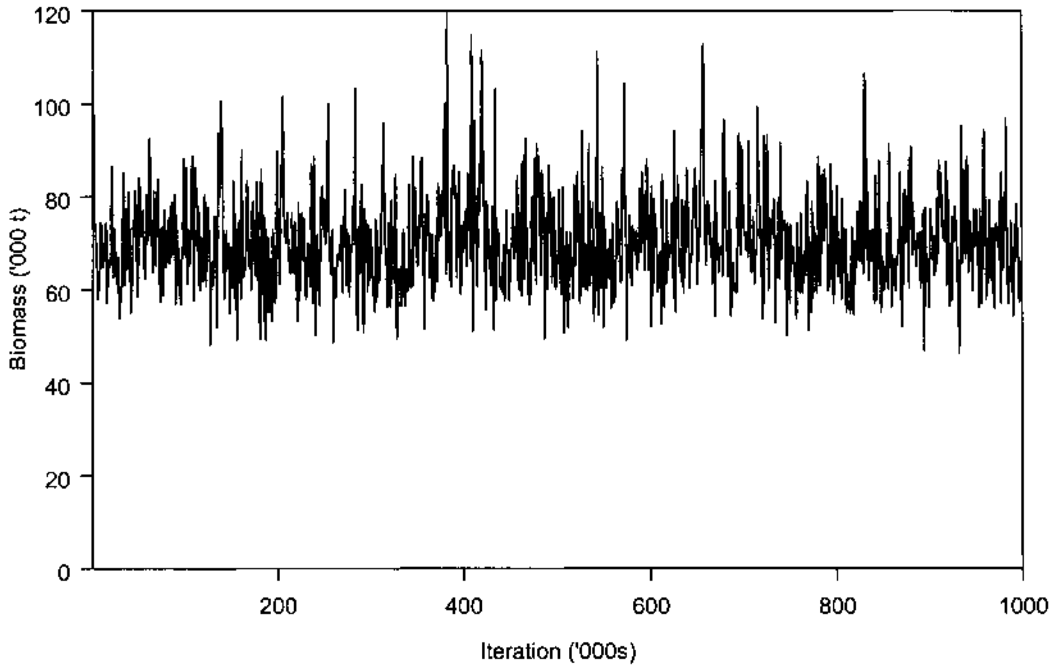

Figure 9: Trace diagnostic plot for base case MCMC chain for estimates of B_0 for the sub-Antarctic stock model.

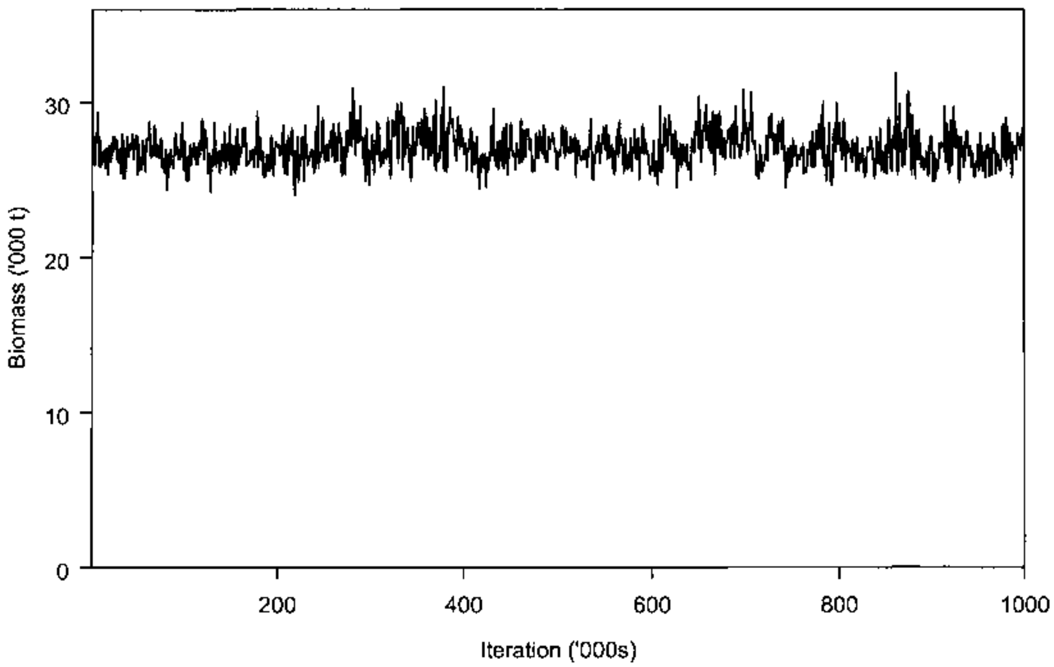

Figure 10: Trace diagnostic plot for base case MCMC chain for estimates of B_0 for the Chatham Rise stock model.

Table 15: Bayesian median and 95% credible intervals of B_0, B_{2004}, and B_{2004} as a percentage of B_0 for the sub-Antarctic base and sensitivity cases.

Model run	B_0	B_{2004}	B_{2004} (%B_0)
Base case	68 810 (52 620–94 270)	45 410 (29 050–70 100)	65.7 (54.1–75.3)
CPUE	81 750 (53 260–202 500)	57 510 (33 210–168 590)	70.7 (54.5–88.7)

Table 16: Bayesian median and 95% credible intervals of projected B_{2009}, B_{2009} as a percentage of B_0, and B_{2008}/B_{2004} (%) for the sub-Antarctic base and sensitivity cases where future catches are assumed equal to the TACC or current levels.

Future catch	Model run	B_{2008}	B_{2008} (%B_0)	B_{2008}/B_{2003} (%)
High (3 632 t)	Base case	42 930 (23 110–77 060)	62.0 (42.1–90.2)	93.6 (72.4–129.8)
	CPUE	43 460 (16 690–143 130)	52.8 (30.0–82.8)	73.7 (51.3–105.2)
Low (1 816 t)	Base case	48 860 (30 130–79 230)	69.9 (53.0–91.7)	106.7 (88.0–136.6)
	CPUE	49 220 (22 240–152 250)	59.4 (39.0–87.6)	82.7 (64.2–119.9)

Table 17: Estimates of stock risk for the sub-Antarctic for 2005–2009, i.e., the probability that the stock will fall below 20% B_0, for the base and sensitivity case where future catches are assumed to be 3632 t and 1816 t.

Future catch	Model run					Year
		2005	2006	2007	2008	2009
High (3 632 t)	Base case	0.00	0.00	0.00	0.00	0.00
	CPUE	0.00	0.00	0.00	0.00	0.00
Low (1 816 t)	Base case	0.00	0.00	0.00	0.00	0.00
	CPUE	0.00	0.00	0.00	0.00	0.00

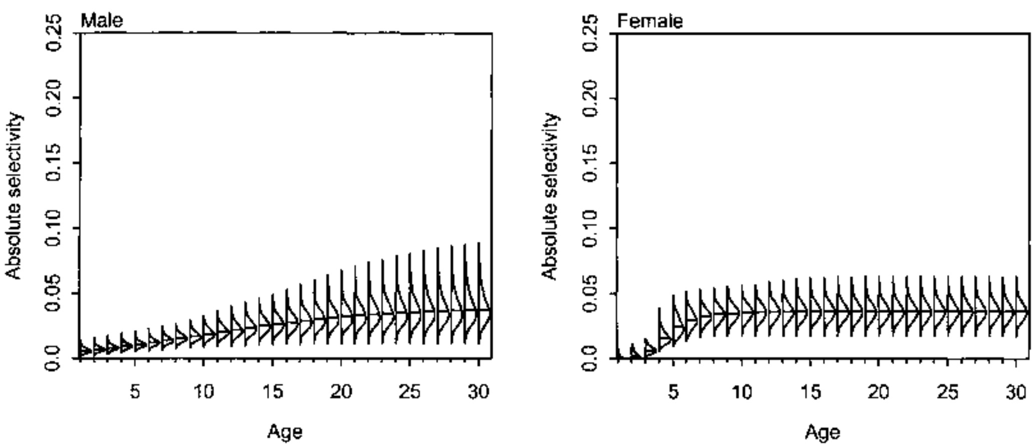

Figure 11: Estimated posterior distributions of absolute selectivity by age and sex, for the base case for the sub-Antarctic November–December resource survey proportions-at-age. Individual distributions show the marginal posterior distribution, with horizontal lines indicating the median.

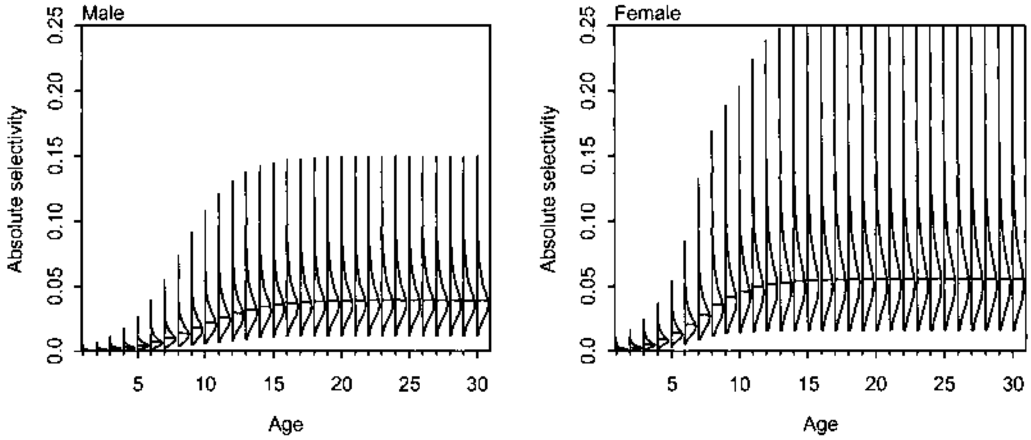

Figure 12: Estimated posterior distributions of absolute selectivity by age and sex, for the base case for the sub-Antarctic April–May resource survey proportions-at-age. Individual distributions show the marginal posterior distribution, with horizontal lines indicating the median.

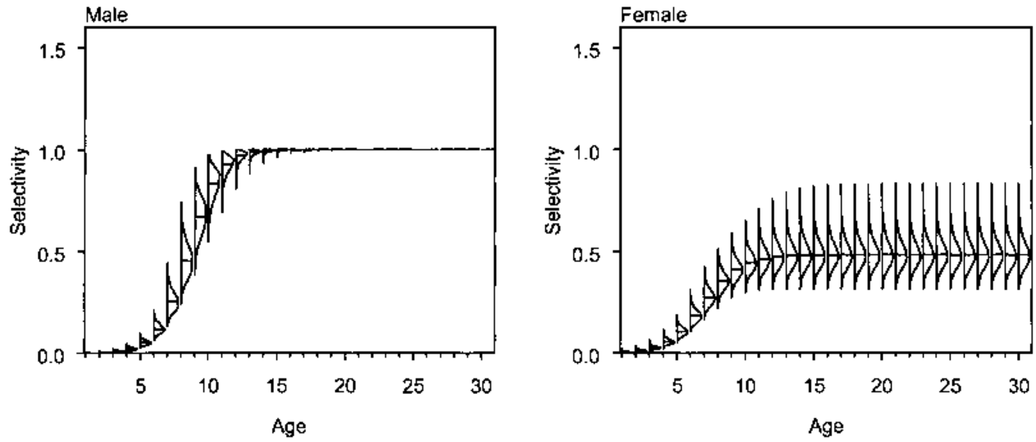

Figure 13: Estimated posterior distributions of relative selectivity by age and sex, for the base case for the sub-Antarctic fishery proportions-at-age. Individual distributions show the marginal posterior distribution, with horizontal lines indicating the median.

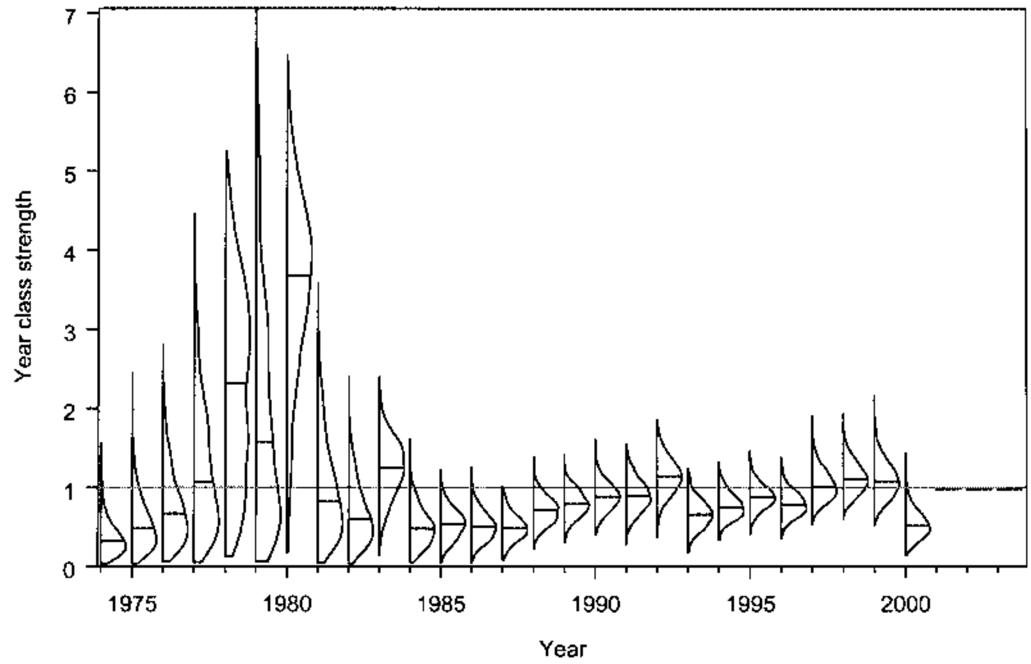

Figure 14: Estimated posterior distributions of year class strengths for the base case for the sub-Antarctic stock. The grey horizontal line indicated the year class strength of one. Individual distributions show the marginal posterior distribution, with horizontal lines indicating the median.

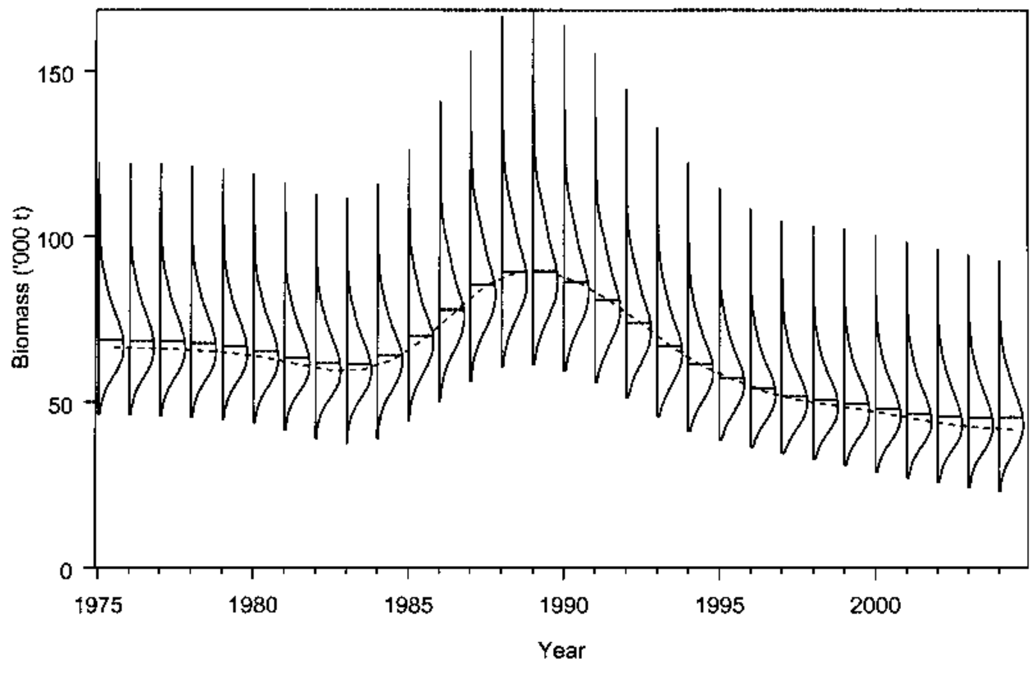

Figure 15: Estimated posterior distributions of biomass trajectories for the base case for the sub-Antarctic stock. Individual distributions show the marginal posterior distribution, with horizontal lines indicating the median. The MPD trajectory is shown as a dashed line.

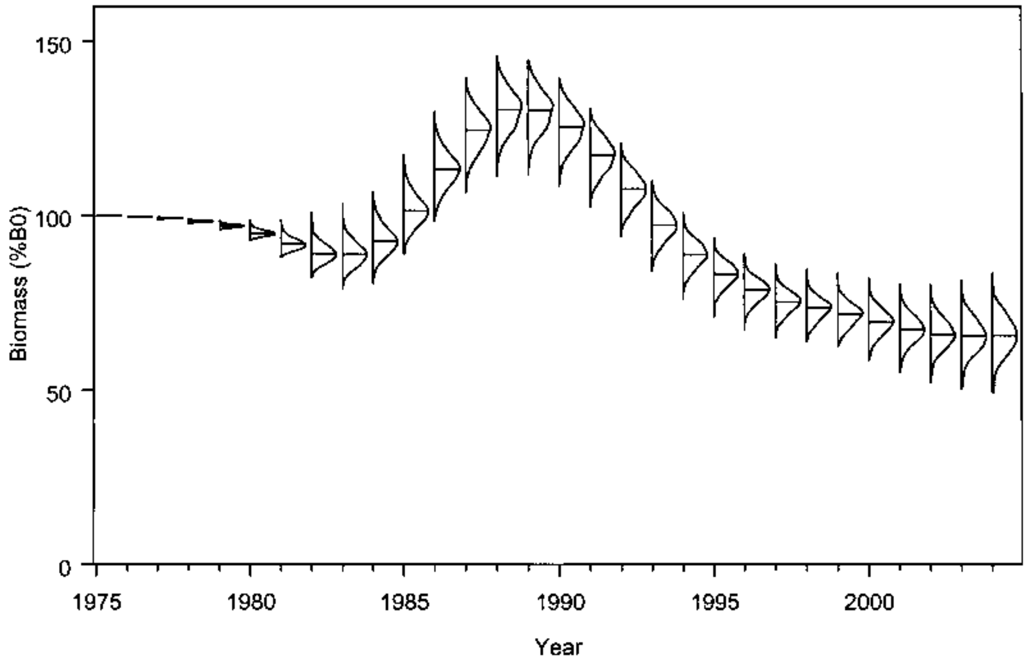

Figure 16: Estimated posterior distributions of biomass trajectories (%B_0) for the base case for the sub-Antarctic stock, projected to 2008. Individual distributions show the marginal posterior distribution, with horizontal lines indicating the median.

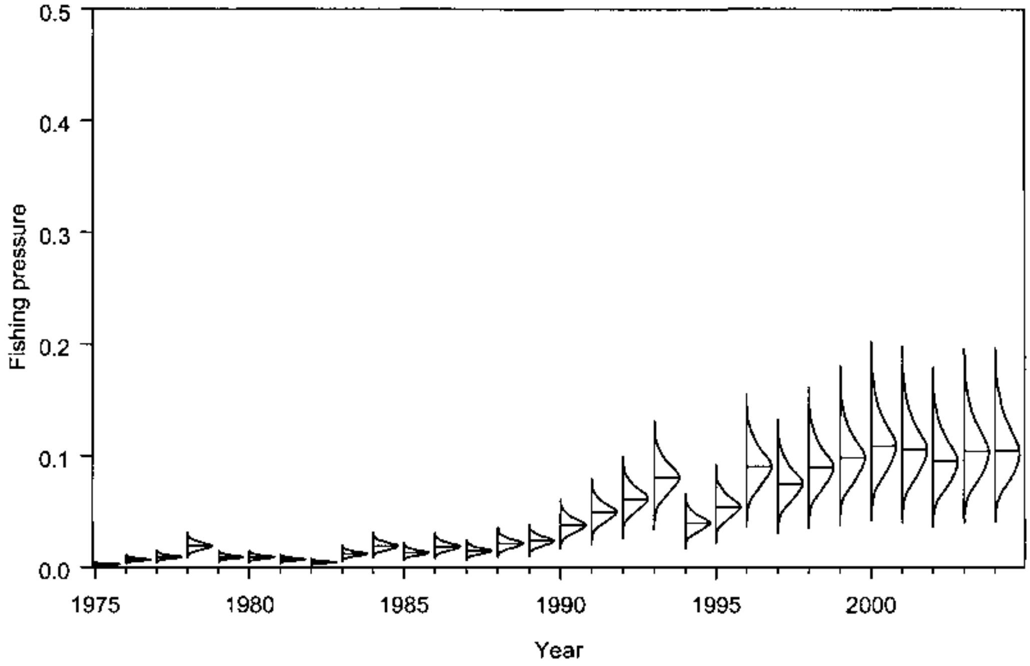

Figure 17: Estimated posterior distributions of exploitation rates for the base case for the sub-Antarctic stock. Individual distributions show the marginal posterior distribution, with horizontal lines indicating the median.

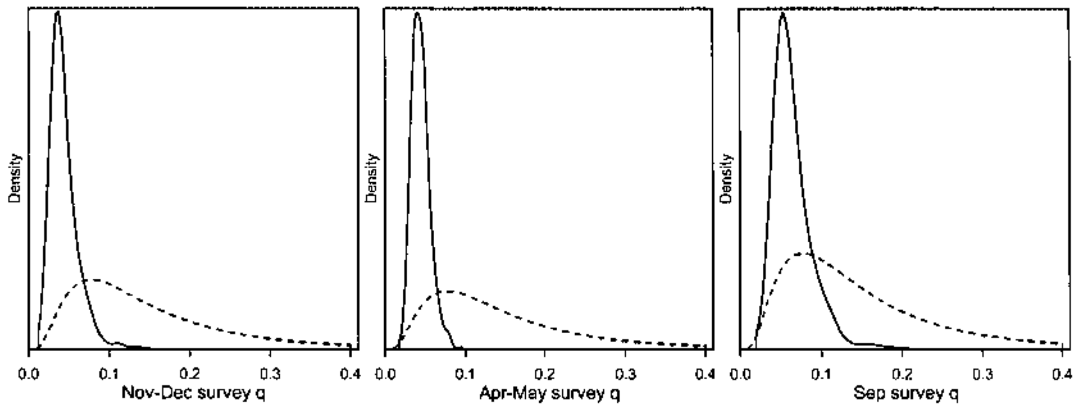

Figure 18: Estimated posterior distributions (solid lines) and priors (dashed line) of survey catchability constants for the base case for the sub-Antarctic November–December, April–May, and September resource survey series.

5.2 Chatham Rise results

The estimated MCMC marginal posterior distributions for selected parameters for the Chatham Rise stock are shown in Figure 19–Figure 25. As with the sub-Antarctic resource survey selectivity estimates, selectivities for males and females were divergent with the selectivities for males lower than that for females in the resource surveys at older ages (15+). Both the male and female selectivities suggested that males and females were not fully selected by the research gear until aged at least 14+. However, the posterior density estimates of selectivities indicated considerable uncertainty in the estimates of selectivity by age and sex (see Figure 19). Fishing selectivities were again poorly estimated, with roughly equivalent male and female fishing selectivity (Figure 20). There is no information outside the model that allows the shape of the estimated selectivity ogives to be verified.

Year class strength estimates were poorly estimated for years where only older fish were available to determine age class strength (i.e., before the mid-1980s). More recent year class strengths appear well estimated, although the signal in the very recent year class strengths is unlikely to be as strong as indicated by the model estimates (Figure 22). The year class strength estimates suggested that the Chatham Rise stock is characterised by a group of strong year classes in the late 1970s and 1980s, with strong recruitment in the early 1990s, followed by a period of rapidly declining recruitment. Consequently, biomass estimates for the stock have declined (Figure 23). Biomass estimates for the stock appear to be low, at about 36% of B_0 (95% credible intervals 28–46%). (See Figure 24 and Table 18.) Exploitation rates (catch over vulnerable biomass) for the Chatham Rise appear to be increasing, with upper estimates approaching 0.7 in the most recent year.

Base case model projections with “high” catches (3616 t) suggested that biomass will decline to about 6–26% B_0 by 2009 (Table 19). At “low” catches (1800 t), projections suggested that biomass will decline more slowly (12–43 % B_0). Risks that the stock will fall below 20%B_0 are given in Table 20. Under both catch scenarios, the risks to the stock increase with time — reaching about 95% in 2009 at higher catch levels and 56% at current catch levels.

The CPUE sensitivity run did not suggest any great departure from the base case estimate of biomass (Table 18). All sensitivity runs showed a similar pattern of reducing recruitment in recent years, and rapidly declining stock status.. The most optimistic run was when natural mortality was estimated within the model — although this resulted in unlikely estimates of natural mortality (i.e., 0.28 y^{-1} and 0.29 y^{-1} for females and males respectively).

Table 18: Bayesian median and 95% credible intervals of B_0, B_{2003}, and B_{2003} as a percentage of B_0 for the Chatham Rise base and sensitivity cases.

Model run	B_0	B_{2003}	B_{2003} (% B_0)
Base case	26 920 (25 040–29 500)	9 410 (7 460–12 020)	35.0 (29.2–41.4)
CPUE	24 200 (22 050–28 230)	6 220 (3 900–10 350)	25.7 (17.5–37.5)

Table 19: Bayesian median and 95% credible intervals of projected B_{2008}, B_{2008} as a percentage of B_0, and B_{2008}/B_{2003} (%) for the Chatham Rise base and sensitivity cases where future catches are assumed equal to the TACC or current levels.

Future catch	Model run	B_{2008}	B_{2008} (% B_0)	B_{2008}/B_{2003} (%)
High (3 616 t)	Base case	3 430 (1 640–7 230)	12.8 (6.1–25.9)	36.7 (18.1–70.6)
	CPUE	2 430 (1 250–5 100)	9.9 (5.3–19.8)	38.5 (22.0–70.1)
Low (1 800 t)	Base case	6 360 (3 230–11 820)	23.6 (12.3–43.0)	66.9 (38.9–117.2)
	CPUE	4 410 (1 380–10 040)	17.9 (5.9–37.2)	68.7 (29.8–126.0)

Table 20: Estimates of stock risk, i.e., the probability that the stock will fall below 20% B_0, for the Chatham Rise base and sensitivity cases where future catches are assumed equal to the TACC or current levels.

						Year
Future catch	Model run	2005	2006	2007	2008	2009
High (3 616 t)	Base case	0.01	0.47	0.82	0.88	0.88
	CPUE	0.60	0.91	0.97	0.98	0.98
Low (1 800 t)	Base case	0.00	0.04	0.18	0.28	0.28
	CPUE	0.45	0.60	0.64	0.62	0.59

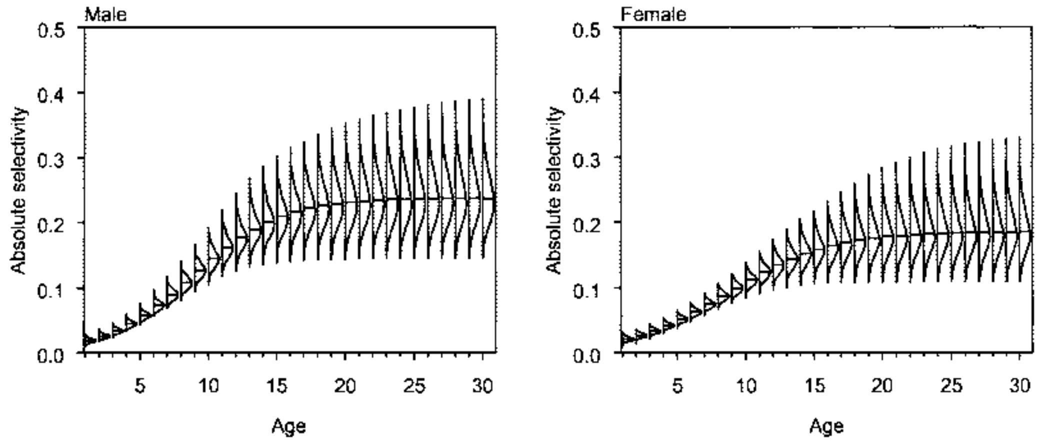

Figure 19: Estimated posterior distributions of absolute selectivity by age and sex, for the base case for the Chatham Rise January resource survey proportions-at-age. Individual distributions show the marginal posterior distribution, with horizontal lines indicating the median.

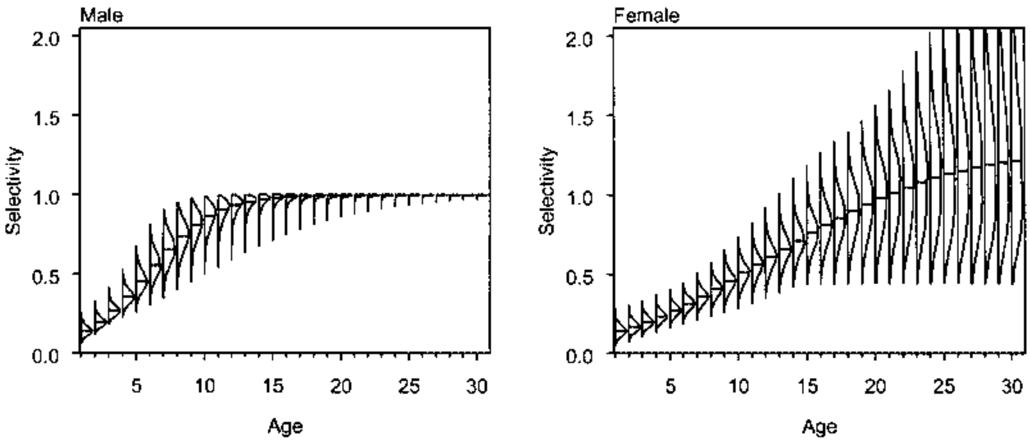

Figure 20: Estimated posterior distributions of relative selectivity by age and sex, for the base case for the Chatham Rise fishery proportions-at-age. Individual distributions show the marginal posterior distribution, with horizontal lines indicating the median.

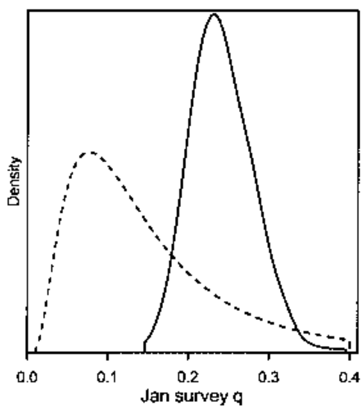

Figure 21: Estimated posterior distribution (solid line) and prior (dashed line) of survey catchability constant for the base case for the Chatham Rise January resource survey series.

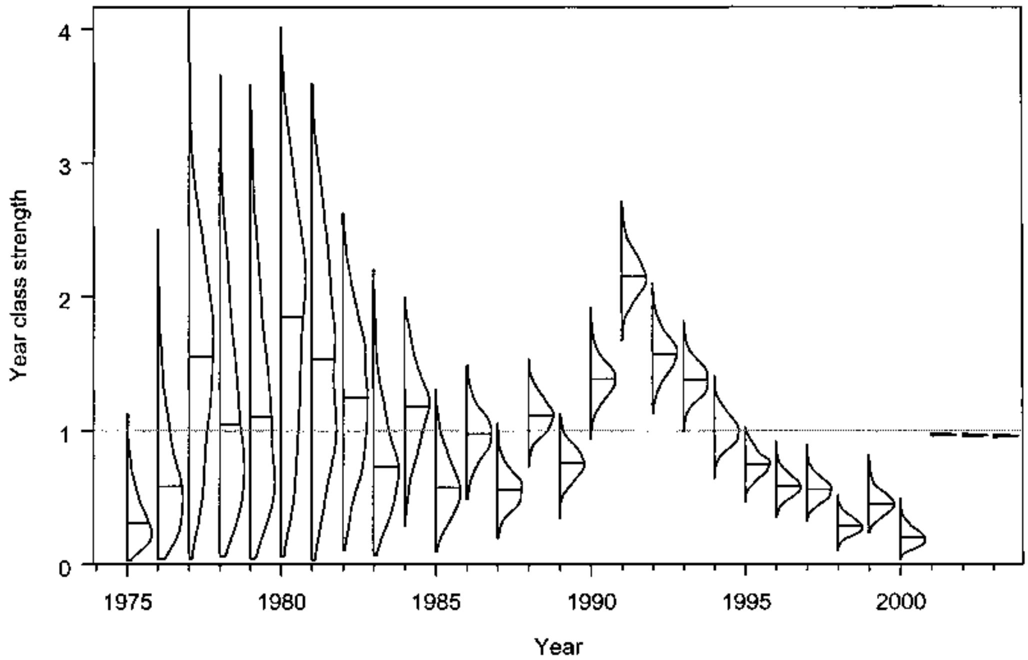

Figure 22: Estimated posterior distributions of year class strengths for the base case for the Chatham Rise stock. The grey horizontal line indicated the year class strength of one. Individual distributions show the marginal posterior distribution, with horizontal lines indicating the median.

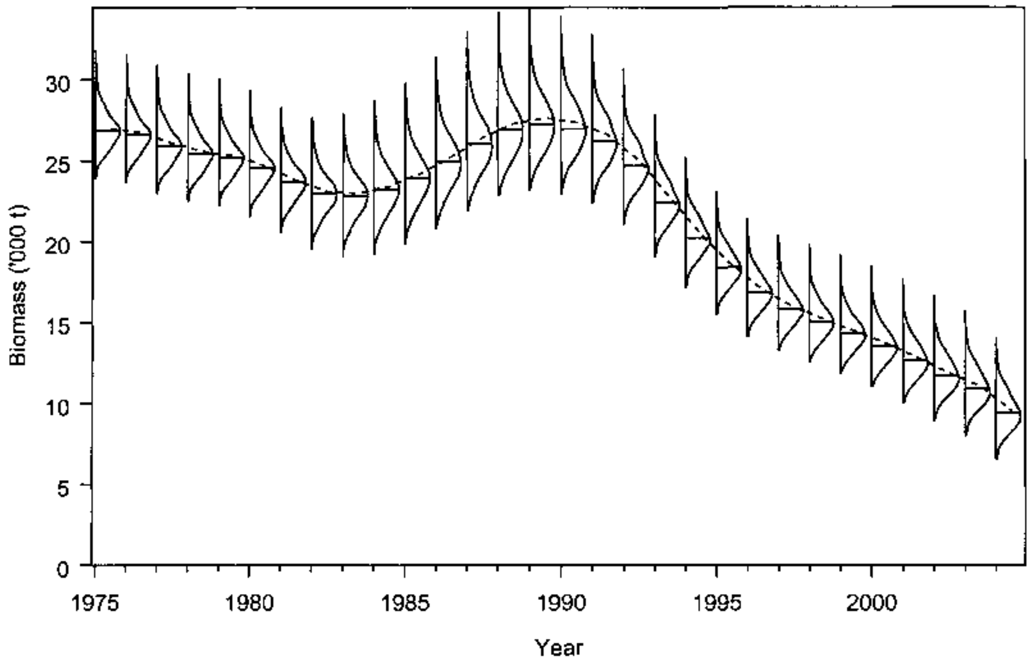

Figure 23: Estimated posterior distributions of biomass trajectories for the base case for the Chatham Rise stock. Individual distributions show the marginal posterior distribution, with horizontal lines indicating the median. The MPD trajectory is shown as a dashed line.

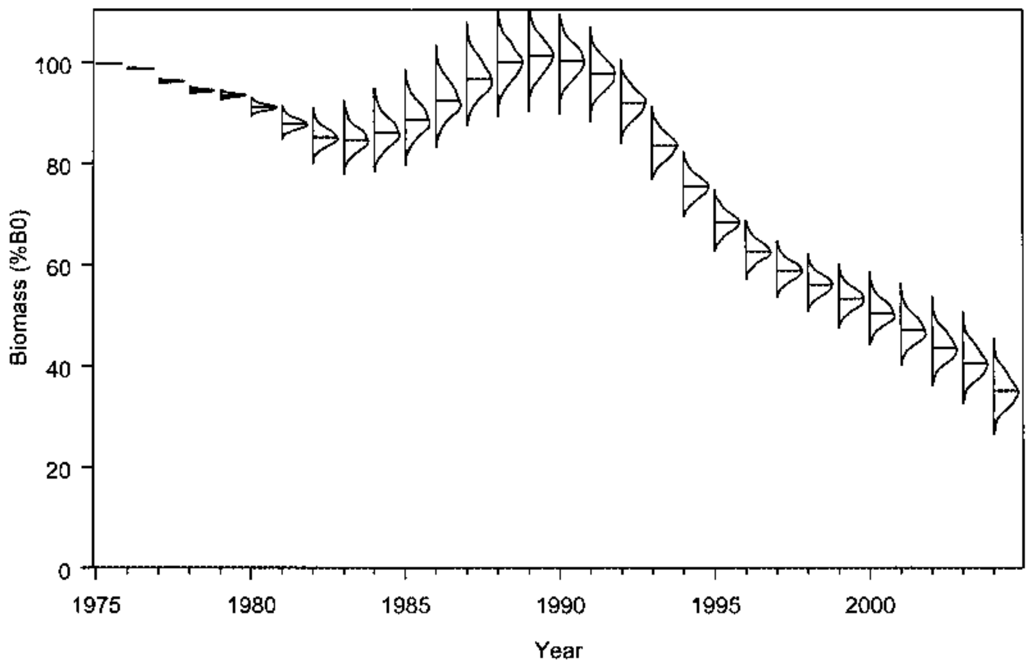

Figure 24: Estimated posterior distributions of biomass trajectories (%B_0) for the base case for the Chatham Rise stock, projected to 2008 with future catches assumed equal to the TACC. Individual distributions show the marginal posterior distribution, with horizontal lines indicating the median.

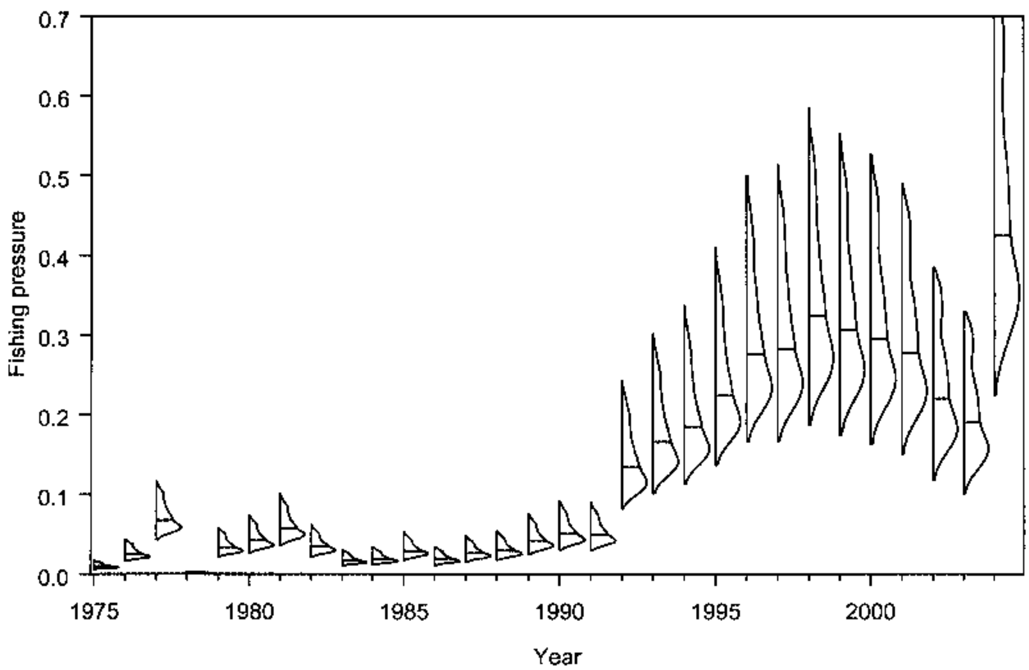

Figure 25: Estimated posterior distributions of exploitation rates for the base case for the Chatham Rise stock. Individual distributions show the marginal posterior distribution, with horizontal lines indicating the median.

5.3 Estimates of sustainable yields

Estimates of sustainable yields were carried out for both the Chatham Rise and sub-Antarctic stocks. CAY yield estimates were based on the 1000 samples from the Bayesian posterior for each stock with stochastic simulations run over 100 years (Francis 1992), and is such that yields were maximised subject to the constraint that spawning stock biomass should not fall below 20% of B_0 more than 10% of the time.

For the sub-Antarctic, the base case model estimates of MAY and CAY were 6300 t and 13 800 t respectively (B_{MAY} = 19 810 t). For the Chatham Rise, base case model estimates of MAY and CAY were 2230 t and 2330 t respectively (B_{MAY} = 7500 t) (Table 21).

Table 21: Yield estimates (MCY, MAY, and CAY) and associated parameters for the Chatham Rise and sub-Antarctic stocks.

Stock	Model	B_{MAY} (t)	MAY (t)	CAY (t)
Chatham Rise	Base case	7 500	2 230	2 330
Sub-Antarctic	Base case	19 810	6 300	13 800

6. DISCUSSION

Both the sub-Antarctic and Chatham Rise stock models gave similar estimates of the current state as that estimated by Dunn (2004).

The model estimates of the state of the sub-Antarctic stock suggest that there was a relatively small decline in the stock status since the early 1990s. However, biomass surveys were inconclusive with respect to changes in stock status. Model fits to the most recent sub-Antarctic resource surveys were poor and, except for cases where the *Amaltal Explorer* data were included, were unable to mirror the small observed decline since 2001. In general, the lack of contrast in abundance indices collected since 1991 suggested that, while the status of the sub-Antarctic stock was probably similar to that in the early 1990s, the absolute level of current biomass was difficult to determine. The selectivity patterns fitted in the model may be a result of the observer sampling of the fishery rather than representing real selectivity differences between the sexes.

Estimates of resource survey catchability constants (qs) appear low for the sub-Antarctic stock — although no information is available that would allow these estimates to be verified. The low estimated catchability constants are of some concern, as higher values for these constants result in lower biomass estimates.

Model estimates of the state of the sub-Antarctic stock suggested that there had been only a small reduction in the available biomass since the mid-1990s. Minor changes to the model structure and assumptions from the previous assessment resulted in lower estimates of current biomass that reflect the recent small decline in the survey abundance estimates, but were still estimated to be at relatively high levels. The lack of contrast in abundance indices collected since 1991 suggests that while the status of the sub-Antarctic stock is probably similar to that in the early 1990s, the absolute level of current biomass may difficult to determine. Although estimates of current and reference spawning stock biomass may not be reliable, it is likely that the current catch can be continued to be taken without undue risk that the stock will decline below 20% B_0.

In contrast, information about the stock status of hake on the Chatham Rise appears reasonably strong. Biomass estimates from the Chatham Rise research series suggests strong evidence of a uniform decline in biomass, with biomass in 2005 at about 35% the level of in the early 1990s. Estimates of recruitment on the Chatham Rise suggest strong evidence of lower than average recruitment in recent years. While there is some suggestion in the resource survey proportions-at-age data that the relative numbers of younger fish has declined, there is stronger evidence from the commercial catch proportions-at-age data. This continues the trend noted in previous assessments (Dunn 2003b, 2004). Sensitivity analyses, while making similar assumptions as for the base case, gave similar results.

While the year class strengths from 1995 to 2000 were estimated to be weaker than average, survey data suggested that the 2002 year class could be above average. For projections, average year class strength were assumed after 2000, possibly leading to a conservative estimate of risk Projections for the Chatham Rise stock estimated the risk of reducing the stock below 20% B_0 in 2009 to be 88% with catches of 3616 t, and 28% with catches of 1800 t.

In 2004–05, large catches were taken on the Mernoo Bank of the Chatham Rise at the start of the fishing year. This is not included in the model results shown here and represents a change in the fishery in the last year from the historical fishing pattern. With the current maximum bound on the exploitation rates, the model may suggest that these catches were implausible, which would indicate that the model estimates of biomass are too low.

The estimates of stock size and projected stock status, for both stocks, rely on the estimated shape of the selectivity ogives. Both stock models suggest that maximum selectivity (for both research and fishing selectivities) appears to occur at ages about 12–15. These ages are higher than may be expected given the age at maturity, growth rates, and the maximum age of hake. Length based ogives suggest a pattern that is more consistent with that expected by the age at maturity, growth rates, and the maximum age of hake. However, sensitivity analyses with alternative selectivity patterns suggest that the conclusions of current and future stock status for both stocks are reasonably robust to alternative selectivity parameterisations.

In both the Chatham Rise and sub-Antarctic models, poor fits to the observer proportions-at-age suggest that better estimates of commercial catch-at-age may be beneficial. Neither model was able to adequately explain the commercial proportions-at-age data without assuming relatively high variability. In addition, while evidence that strong and weak year classes track between resource survey observations of proportions-at-age, there is little evidence that such patterns can be observed in the commercial proportions-at-age data. Annual changes in selectivity are possible in the hake fishery, especially as hake are taken predominantly as a bycatch species. It is possible that the lack of observed pattern in the observer proportions-at-age may reflect this. Annual changes in selectivity have not been modelled here, as the data are probably not adequate to allow sensible estimation of additional selectivity parameters.

For both models, the model structural assumptions are likely to lead to the Bayesian posteriors of current stock status under-estimating the true level of uncertainty. The projected stock status relies on adequate estimation of recent recruitment. With small sample size age data from resource surveys on the sub-Antarctic and inconclusive commercial catch proportions-at-age data, the projections of future stock status are likely to underestimate the true level of uncertainty.

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8. REFERENCES

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

Bagley, N.W.; Hurst, R.J. (1998). Trawl survey of hoki and middle depth species on the Chatham Rise January 1998 (TAN9801). *NIWA Technical Report 44*. 54 p.

Bagley, N.W.; Livingston, M.E. (2000). Trawl survey of hoki and middle depth species on the Chatham Rise January 1999 (TAN9901). *NIWA Technical Report 81*. 52 p.

Bagley, N.W.; McMillan, P.J. (1999). Trawl survey of hake and middle depth species in the Southland and sub-Antarctic areas, April–May 1998 (TAN9805). *NIWA Technical Report 52*. 48 p.

Bull, B.; Bagley, N.W. (1999). The effects of the 1995–96 Chatham Rise survey design on abundance estimates for hake age groups. New Zealand Fisheries Assessment Research Document. 99/36. 26 p. Ministry of Fisheries. (Unpublished report held in NIWA library, Wellington.)

Bull, B.; Francis, R.I.C.C.; Dunn, A.; McKenzie, A.; Gilbert, D.J.; Smith, M.H. (2003). CASAL (C++ algorithmic stock assessment laboratory): CASAL user manual v2.01-2003/08/01. *NIWA Technical Report 124*. 223 p.

Bull, B.; Francis, R.I.C.C.; Dunn, A.; McKenzie, A.; Gilbert, D.J.; Smith, M.H. (2004). CASAL (C++ algorithmic stock assessment laboratory): CASAL user manual v2.06-2004/19/26. *NIWA Technical Report 126*. 261 p.

Chatterton, T.D.; Hanchet, S.M. (1994). Trawl survey of hoki and associated species in the Southland and sub-Antarctic areas, November–December 1991 (TAN9105). *New Zealand Fisheries Data Report 41*. 55 p.

Colman, J.A. (1988). Hake. New Zealand Fisheries Assessment Research Document. 88/31. 23 p. MAF (Fisheries). (Unpublished report held in NIWA library, Wellington.)

Colman, J.A. (1996). Trawl survey of middle depth species in the Southland and sub-Antarctic areas, March–April 1996 (TAN9605). *New Zealand Fisheries Data Report 83*. 40 p.

Colman, J.A. (1997). Stock assessment of hake (*Merluccius australis*) for the 1997–98 fishing year. New Zealand Fisheries Assessment Research Document. 97/19. 15 p. MAF (Fisheries). (Unpublished report held in NIWA library, Wellington.)

Colman, J.A. (1998). Spawning areas and size and age at maturity of hake (*Merluccius australis*) in the New Zealand Exclusive Economic Zone. New Zealand Fisheries Assessment

Research Document. 98/2. 17 p. MAF (Fisheries). (Unpublished report held in NIWA library, Wellington.)

Colman, J.A.; Stocker, M.; Pikitch, E. (1991). Assessment of hake (*Merluccius australis*) stocks for the 1991–92 fishing year. New Zealand Fisheries Assessment Research Document. 91/14. 29 p. MAF (Fisheries). (Unpublished report held in NIWA library, Wellington.)

Colman, J.A.; Vignaux, M. (1992). Assessment of New Zealand hake (*Merluccius australis*) stocks for the 1992–93 fishing year. New Zealand Fisheries Assessment Research Document. 92/17. 23 p. MAF (Fisheries). (Unpublished report held in NIWA library, Wellington.)

Dunn, A. (1998). Stock assessment of hake (*Merluccius australis*) for the 1998–99 fishing year. New Zealand Fisheries Assessment Research Document. 98/30. 19 p. Ministry of Fisheries. (Unpublished report held in NIWA library, Wellington.)

Dunn, A. (2001). Stock assessment of hake (*Merluccius australis*) for the 2000–01 fishing year. *New Zealand Fisheries Assessment Report 2001/22*. 31 p.

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

Dunn, A. (2003b). Stock assessment of hake (*Merluccius australis*) for the 2002–03 fishing year. *New Zealand Fisheries Assessment Report 2003/38*. 57 p.

Dunn, A. (2004). Stock assessment of hake (*Merluccius australis*) for the 2003–04 fishing year. *New Zealand Fisheries Assessment Report 2004/34*. 62 p.

Dunn, A.; Horn, P.L.; Cordue, P.L.; Kendrick, T.H. (2000). Stock assessment of hake (*Merluccius australis*) for the 1999–2000 fishing year. *New Zealand Fisheries Assessment Report 2000/50*. 50 p.

Francis, R.I.C.C. (1992). Recommendations concerning the calculation of Maximum Constant Yield (MCY) and Current Annual Yield (CAY). New Zealand Fisheries Assessment Research Document. 92/8. 23 p. MAF (Fisheries). (Unpublished report held in NIWA library, Wellington.)

Geweke, J. (1992). Evaluating the accuracy of sampling-based approaches to calculating posterior moments. *In*: Bayesian Statistics, 4. Bernardo, J.M.; Berger, J.O.; Dawid, A.P.; Smith, A.F.M. (eds.). Clarendon Press, Oxford. pp 169–194.

Heidelberger, P.; Welch, P. (1983). Simulation run length control in the presence of an initial transient. *Operations Research 31*: 1109–1144.

Hoenig, J.M. (1983). Empirical use of longevity data to estimate mortality rates. *Fisheries Bulletin 81*: 899–903.

Horn, P.L. (1994a). Trawl survey of hoki and middle depth species on the Chatham Rise, December 1991–January 1992 (TAN9106). *New Zealand Fisheries Data Report 43*. 38 p.

Horn, P.L. (1994b). Trawl survey of hoki and middle depth species on the Chatham Rise, December 1992–January 1993 (TAN9212). *New Zealand Fisheries Data Report 44*. 43 p.

Horn, P.L. (1997). An ageing methodology, growth parameters, and estimates of mortality for hake (*Merluccius australis*) from around the South Island, New Zealand. *Marine and Freshwater Research 48(3)*: 201–209.

Horn, P.L. (1998). The stock affinity of hake (*Merluccius australis*) from Puysegur Bank, and catch-at-age data and revised productivity parameters for hake stocks HAK 1, 4, and 7. New Zealand Fisheries Assessment Research Document. 98/34. 18 p. Ministry of Fisheries. (Unpublished report held in NIWA library, Wellington.)

Hurst, R.J.; Bagley, N.W.; Anderson, O.F.; Francis, M.P.; Griggs, L.H.; Clark, M.R.; Paul, L.J.; Taylor, P.R. (2000). Atlas of juvenile and adult fish and squid distributions from bottom and midwater trawls and tuna longlines in New Zealand waters. *NIWA Technical Report 84*. 162 p.

Hurst, R.J.; Schofield, K.A. (1995). Winter and summer trawl surveys of hoki and associated species in the Southland and sub-Antarctic areas 1990. *New Zealand Fisheries Technical Report 43*. 55 p.

Ingerson, J.K.V.; Hanchet, S.M. (1995). Trawl survey of hoki and associated species in the Southland and sub-Antarctic areas, November–December 1993 (TAN9310). *New Zealand Fisheries Data Report 67*. 44 p.

Ingerson, J.K.V.; Hanchet, S.M.; Chatterton, T.D. (1995). Trawl survey of hoki and associated species in the Southland and sub-Antarctic areas, November–December 1992 (TAN9211). *New Zealand Fisheries Data Report 66*. 43 p.

Kendrick, T.H. (1998). Feasibility of using CPUE as an index of stock abundance for hake. New Zealand Fisheries Assessment Research Document. 98/27. 22 p. Ministry of Fisheries. (Unpublished report held in NIWA library, Wellington.)

Kerstan, M.; Sahrhage, D. (1980). Biological investigations on fish stocks in the waters off New Zealand. *Mitteilungen aus dem Institut für Seefischerei der Bundesforschungsanstalt für Fischerei, Hamburg. No. 29*. 287 p.

Livingston, M.E.; Bull, B.; Stevens, D.W.; Bagley, N.W. (2002). A review of hoki and middle depths trawl surveys of the Chatham Rise, January 1992-2001. *New Zealand Fisheries Assessment Report 2002/48*. 69 p.

Livingston, M.E.; Schofield, K.A. (1993). Trawl survey of hoki and associated species south of New Zealand, October–November 1989. *New Zealand Fisheries Technical Report 36*. 39 p.

Livingston, M.E.; Stevens, D.W. (2005). Trawl survey of hoki and middle depth species on the Chatham Rise, January 2004 (TAN0401). *New Zealand Fisheries Assessment Report 2005/21*. 62 p.

Livingston, M.E.; Stevens, D.W.; O'Driscoll, R.L.; Francis, R.I.C.C. (2004). Trawl survey of hoki and middle depth species on the Chatham Rise, January 2003 (TAN0301). *New Zealand Fisheries Assessment Report 2004/16*. 71 p.

O'Driscoll, R.L.; Bagley, N.W. (2001). Review of summer and autumn trawl survey time series from the Southland and sub-Antarctic areas, 1991–98. *NIWA Technical Report 102*. 115 p.

O'Driscoll, R.L.; Bagley, N.W. (2003a). Trawl survey of middle depth species in the Southland and sub-Antarctic areas, November–December 2001 (TAN0118). *New Zealand Fisheries Assessment Report 2003/01.* 53 p.

O'Driscoll, R.L.; Bagley, N.W. (2003b). Trawl survey of middle depth species in the Southland and sub-Antarctic areas, November–December 2002 (TAN0219). *New Zealand Fisheries Assessment Report 2003/46.* 57 p.

O'Driscoll, R.L.; Bagley, N.W. (2004). Trawl survey of middle depth species in the Southland and sub-Antarctic areas, November–December 2003 (TAN0317). *New Zealand Fisheries Assessment Report 2004/49.* 58 p.

O'Driscoll, R.L.; Bagley, N.W. (2005). Trawl survey of middle depth species in the Southland and sub-Antarctic areas, November–December 2004 (TAN0414). *New Zealand Fisheries Assessment Report xx.* xx p.

O'Driscoll, R.L.; Bagley, N.W.; Bull, B. (2002). Trawl survey of middle depth species in the Southland and sub-Antarctic areas, November–December 2000 (TAN0012). *NIWA Technical Report 110.* 78 p.

Phillips, N.L.; Livingston, M.E. (2004). Catch-per-unit-effort (CPUE) analysis of hake (*Merluccius australis*) for the Chatham Rise and sub-Antarctic from 1989–90 to 2000–01. *New Zealand Fisheries Assessment Report 2004/19.* 39 p.

Schofield, K.A.; Horn, P.L. (1994). Trawl survey of hoki and middle depth species on the Chatham Rise, January 1994 (TAN9401). *New Zealand Fisheries Data Report 53.* 54 p.

Schofield, K.A.; Livingston, M.E. (1994a). Trawl survey of hoki and associated species in the Southland and sub-Antarctic areas, April–May 1992 (TAN9204). *New Zealand Fisheries Data Report 45.* 38 p.

Schofield, K.A.; Livingston, M.E. (1994b). Trawl survey of hoki and associated species in the Southland and sub-Antarctic areas, September–October 1992 (TAN9209). *New Zealand Fisheries Data Report 46.* 43 p.

Schofield, K.A.; Livingston, M.E. (1994c). Trawl survey of hoki and associated species in the Southland and sub-Antarctic areas, May–June 1993 (TAN9304). *New Zealand Fisheries Data Report 47.* 39 p.

Schofield, K.A.; Livingston, M.E. (1995). Trawl survey of hoki and middle depth species on the Chatham Rise, January 1995 (TAN9501). *New Zealand Fisheries Data Report 59.* 53 p.

Schofield, K.A.; Livingston, M.E. (1996). Trawl survey of hoki and middle depth species on the Chatham Rise, January 1996 (TAN9601). *New Zealand Fisheries Data Report 71.* 50 p.

Schofield, K.A.; Livingston, M.E. (1997). Trawl survey of hoki and middle depth species on the Chatham Rise, January 1997 (TAN9701). *NIWA Technical Report 6.* 50 p.

Stevens, D.W.; Livingston, M.E. (2003). Trawl survey of hoki and middle depth species on the Chatham Rise, January 2002 (TAN0201). *New Zealand Fisheries Assessment Report 2003/19.* 57 p.

Stevens, D.W.; Livingston, M.E.; Bagley, N.W. (2001). Trawl survey of hoki and middle depth species on the Chatham Rise, January 2000 (TAN0001). *NIWA Technical Report 104.* 55 p.

Stevens, D.W.; Livingston, M.E.; Bagley, N.W. (2002). Trawl survey of hoki and middle depth species on the Chatham Rise, January 2001 (TAN0101). *NIWA Technical Report 116.* 61 p.

Stevens, D.W.; O'Driscoll, R.L. (2005). Trawl survey of hoki and middle depth species on the Chatham Rise, January 2005 (TAN0501). *New Zealand Fisheries Assessment Report xx.* xx p.

APPENDIX A: Summaries of the proportions-at-age data from resource surveys and trawl fishery observer sampling in the sub-Antarctic and Chatham Rise fisheries.

Table A1: Numbers of measured and aged fish by data source for male and female hake, and the number of sampled tows and estimated mean weighted c.v. (%) by age for the sub-Antarctic.

	Males		Females			Mean c.v.
Source	Measured	Aged	Measured	Aged	Tows	
AEX8902	45	43	76	66	34	52.7
TAN9105	337	117	332	217	61	65.1
TAN9204	60	58	113	107	48	46.8
TAN9209	76	68	141	113	44	43.8
TAN9211	14	46	133	168	48	48.6
TAN9304	36	36	124	122	54	49.5
TAN9310	57	93	181	182	59	47.2
TAN9605	32	86	93	137	45	61.9
TAN9805	49	94	146	189	31	52.0
TAN0012	348	239	392	352	56	37.3
TAN0118	219	212	351	349	44	35.6
TAN0219	331	191	490	377	38	36.1
TAN0317	126	186	175	220	30	41.0
Commercial catch 1998–99	408	190	969	406	189	24.4
Commercial catch 1999–00	3 112	250	2 868	389	415	23.0
Commercial catch 2000–01	568	183	2 227	392	353	29.7
Commercial catch 2001–02	834	140	1221	427	189	29.1
Commercial catch 2002–03	190	156	614	417	146	57.1

Table A2: Numbers of measured and aged fish by data source for male and female hake, and the number of sampled tows and estimated mean weighted c.v. (%) by age for the Chatham Rise.

	Males		Females			Mean c.v.
Source	Measured	Aged	Measured	Aged	Tows	
AEX8903	220	154	212	179	63	39.5
TAN9106	322	233	305	230	122	30.0
TAN9212	243	200	275	225	121	32.7
TAN9401	293	181	355	217	123	33.1
TAN9501	201	170	229	191	87	38.7
TAN9601	149	113	200	165	56	36.4
TAN9701	149	145	159	149	77	36.1
TAN9801	137	135	142	139	55	39.0
TAN9901	94	103	142	157	62	44.1
TAN0001	177	177	178	177	72	35.9
TAN0101	104	112	148	150	66	37.3
TAN0201	104	177	121	172	61	36.4
TAN0301	33	34	69	71	46	61.4
TAN0401	94	82	110	105	53	49.4
Commercial catch 1997–98	3 512	264	3 442	258	543	17.9
Commercial catch 1998–99	1 013	190	1 698	285	297	23.1
Commercial catch 1999–00	1 157	269	1 124	323	314	19.2
Commercial catch 2000–01	1 893	205	1 576	276	363	22.0
Commercial catch 2001–02	522	278	481	247	119	21.6
Commercial catch 2002–03	282	222	370	274	121	35.4

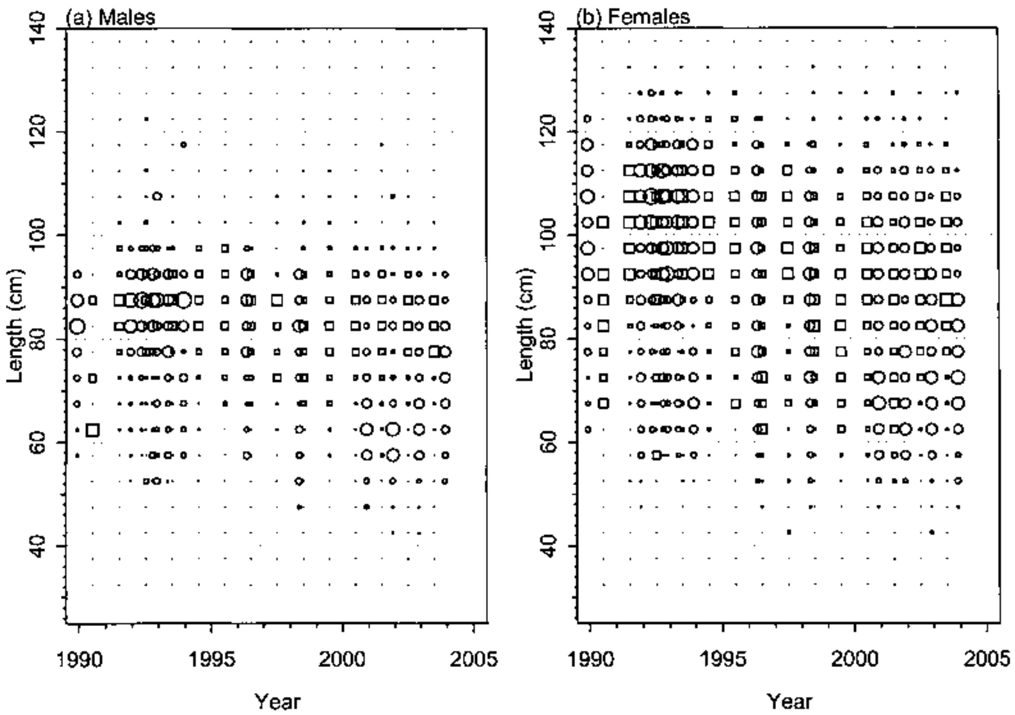

Figure A1: Length frequencies by year (symbol area proportional to the proportions-at-length within sampling event) in the sub-Antarctic for (a) resource surveys (circles) and (b) commercial catch-at-age data (squares). Zero values are represented by a dash.

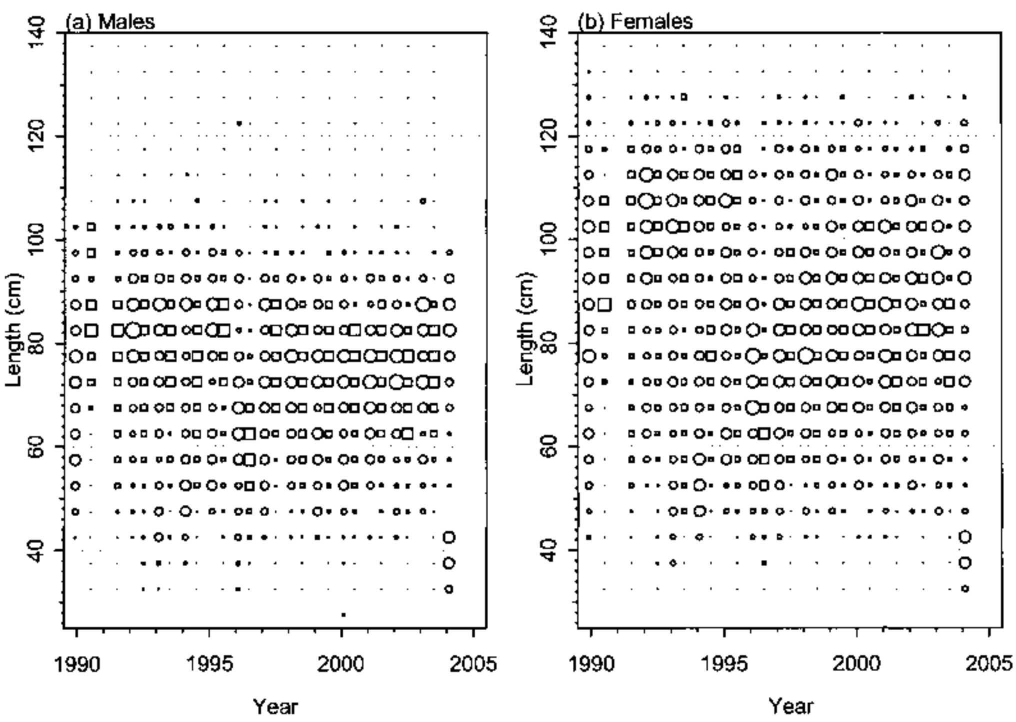

Figure A2: Length frequencies by year (symbol area proportional to the proportions-at-length within sampling event) on the Chatham Rise for (a) resource surveys (circles) and (b) commercial catch-at-age data (squares). Zero values are represented by a dash.

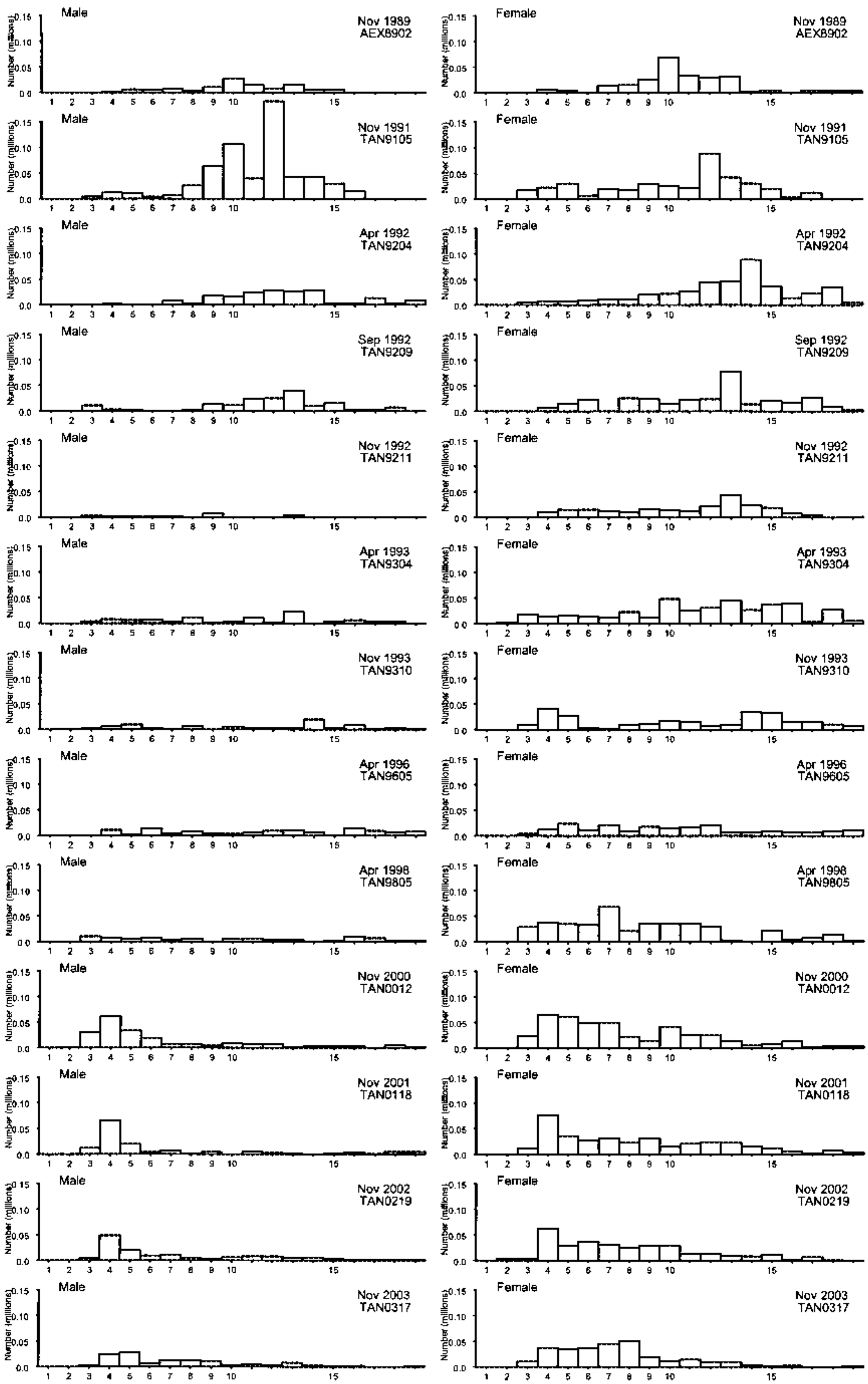

Figure A3: Age frequencies of hake (ages 1 to 19) from resource surveys in the sub-Antarctic, 1988-89 to 2002–03.

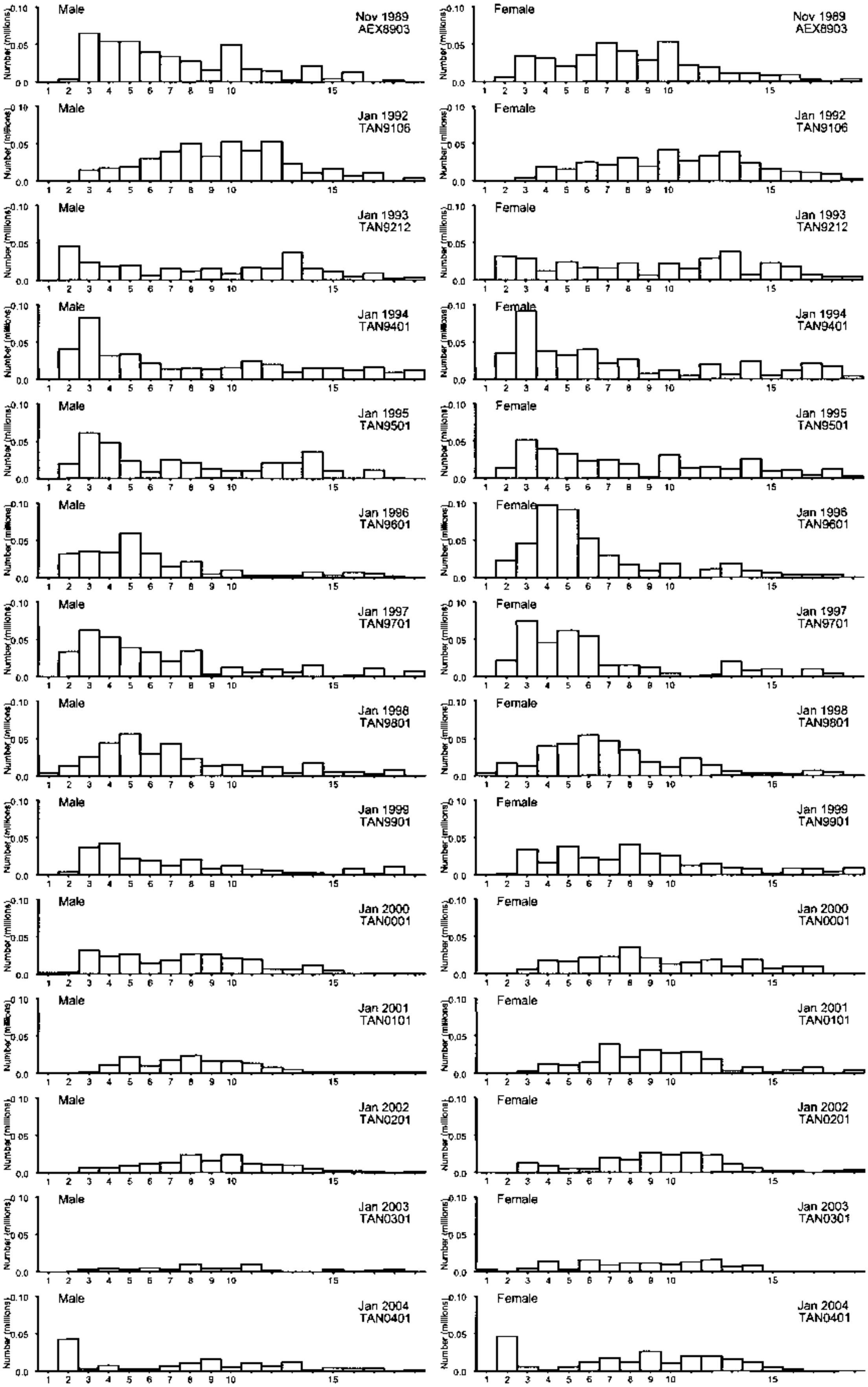

Figure A4: Age frequencies of hake (ages 1 to 19) from resource surveys in the Chatham Rise, 1989–90 to 2003–04.

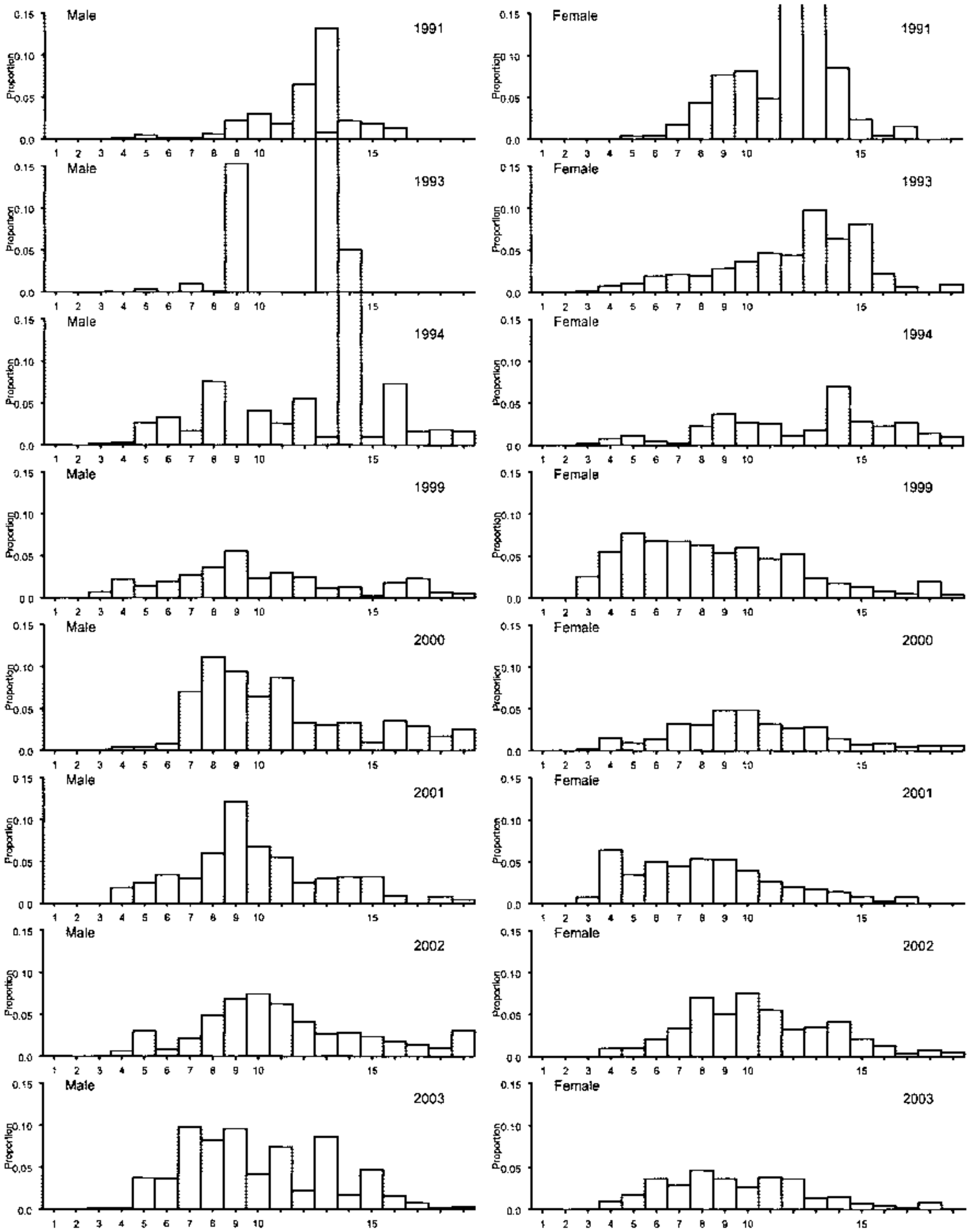

Figure A5: Age frequencies of hake (ages 1 to 19) from commercial catch-at-age data in the sub-Antarctic trawl fishery, 1998–99 to 2002–03.

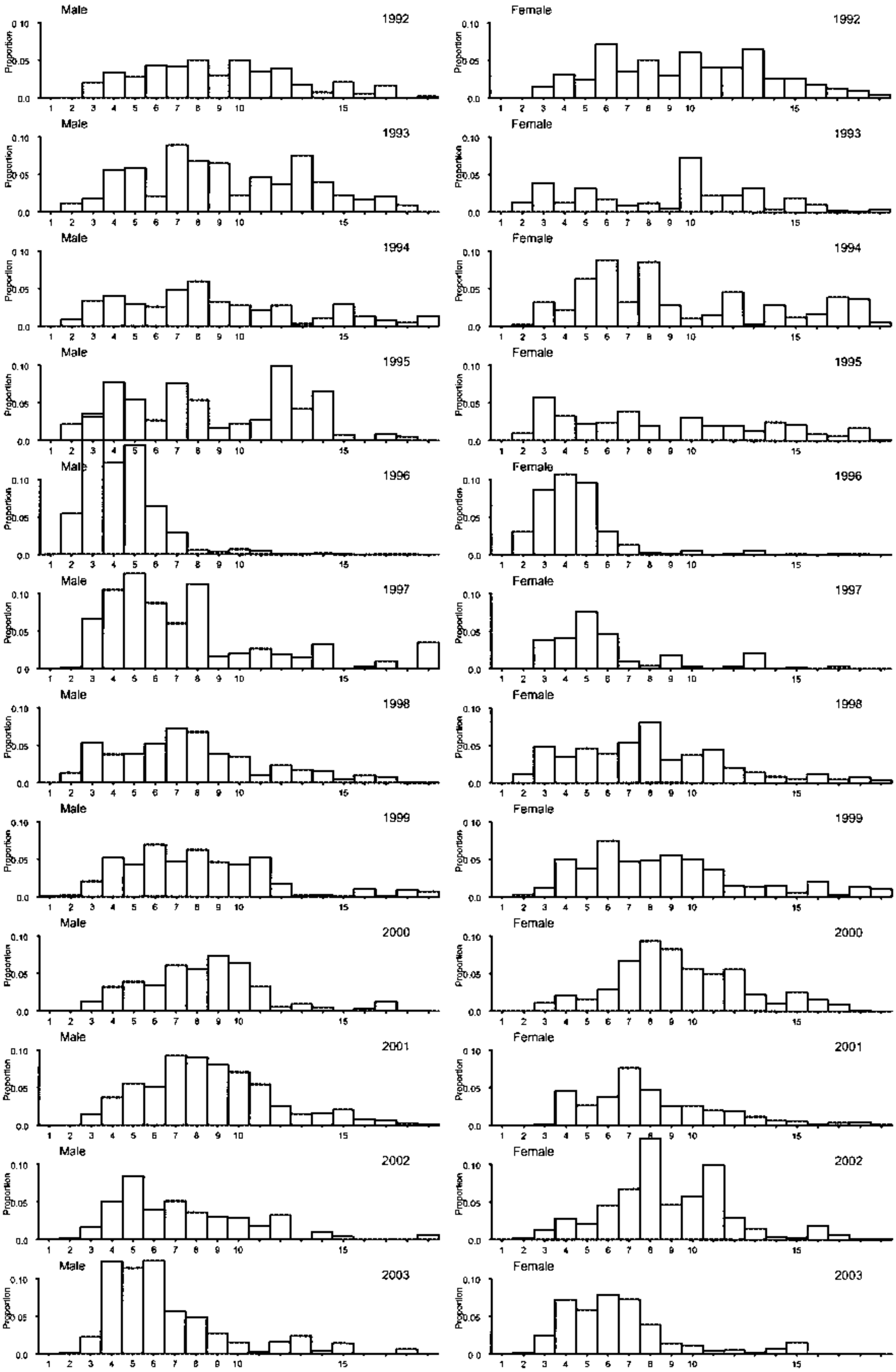

Figure A6: Age frequencies of hake (ages 1 to 19) from commercial catch-at-age data in the Chatham Rise trawl fishery, 1997–98 to 2002–03.

APPENDIX B: Resource survey biomass indices for hake in HAK 1 and 4

Table B1: Biomass indices (t) and coefficients of variation (c.v.) for hake from resource surveys of the sub-Antarctic. (These estimates assume that the areal availability, vertical availability, and vulnerability are equal to one.)

Vessel	Date	Trip code	Depth	Biomass	c.v.	Reference
Wesermünde	Mar–May 1979		– [1]	–	–	(Kerstan & Sahrhage 1980)
Wesermünde	Oct–Dec 1979		– [1]	–	–	(Kerstan & Sahrhage 1980)
Shinkai Maru	Mar–Apr 1982	SHI8201	200–800	6 045	0.15	N.W. Bagley, NIWA, pers. comm.
Shinkai Maru	Oct–Nov 1983	SHI8303	200–800	11 282	0.22	N.W. Bagley, NIWA, pers. comm.
Amaltal Explorer	Oct–Nov 1989	AEX8902	200–800	2 660	0.21	(Livingston & Schofield 1993)
Amaltal Explorer	Jul–Aug 1990	AEX9001	300–800	4 343	0.19	(Hurst & Schofield 1995)
Amaltal Explorer	Nov–Dec 1991	AEX9002	300–800	2 460	0.16	N.W. Bagley, NIWA, pers. comm.
Tangaroa	Nov–Dec 1991	TAN9105	Reported [2]	5 686	0.43	(Chatterton & Hanchet 1994)
			300–800 [3]	5 553	0.44	(O'Driscoll & Bagley 2001)
			1991 area [4]	5 686	0.43	(O'Driscoll & Bagley 2001)
			1996 area [5]	–	–	
Tangaroa	Apr–May 1992	TAN9204	Reported [2]	5 028	0.15	(Schofield & Livingston 1994a)
			300–800 [3]	5 028	0.15	(O'Driscoll & Bagley 2001)
			1991 area [4]	–	–	
			1996 area [5]	–	–	
Tangaroa	Sep–Oct 1992	TAN9209	Reported [2]	3 762	0.15	(Schofield & Livingston 1994b)
			300–800 [3, 7]	3 760	0.15	(O'Driscoll & Bagley 2001)
			1991 area [4]	–	–	
			1996 area [5]	–	–	
Tangaroa	Nov–Dec 1992	TAN9211	Reported [2]	1 944	0.12	(Ingerson et al. 1995)
			300–800 [3]	1 822	0.12	(O'Driscoll & Bagley 2001)
			1991 area [4]	1 944	0.12	(O'Driscoll & Bagley 2001)
			1996 area [5]	–	–	
Tangaroa	May–Jun 1993	TAN9304 [6]	Reported [2]	3 602	0.14	(Schofield & Livingston 1994c)
			300–800 [3]	3 221	0.14	(O'Driscoll & Bagley 2001)
			1991 area [4]	–	–	
			1996 area [5]	–	–	
Tangaroa	Nov–Dec 1993	TAN9310	Reported [2]	2 572	0.12	(Ingerson & Hanchet 1995)
			300–800 [3]	2 286	0.12	(O'Driscoll & Bagley 2001)
			1991 area [4]	2 567	0.12	(O'Driscoll & Bagley 2001)
			1996 area [5]	–	–	

Table B1: (Continued...)

Vessel	Date	Trip code	Depth		Biomass	c.v.	Reference
Tangaroa	Mar–Apr 1996	TAN9605	Reported	[2]	3 946	0.16	(Colman 1996)
			300–800	[3]	2 026	0.12	(O'Driscoll & Bagley 2001)
			1991 area	[4]	2 281	0.17	(O'Driscoll & Bagley 2001)
			1996 area	[5]	2 825	0.12	(O'Driscoll & Bagley 2001)
Tangaroa	Apr–May 1998	TAN9805	Reported	[2]	2 554	0.18	(Bagley & McMillan 1999)
			300–800	[3]	2 554	0.18	(O'Driscoll & Bagley 2001)
			1991 area	[4]	2 643	0.17	(O'Driscoll & Bagley 2001)
			1996 area	[5]	3 898	0.16	(O'Driscoll & Bagley 2001)
Tangaroa	Nov–Dec 2000	TAN0012	300–800	[3]	2 194	0.17	(O'Driscoll et al. 2002)
			1991 area	[4]	2 657	0.16	(O'Driscoll et al. 2002)
			1996 area	[5]	3 103	0.14	(O'Driscoll et al. 2002)
Tangaroa	Nov–Dec 2001	TAN0118	300–800	[3]	1 831	0.24	(O'Driscoll & Bagley 2003a)
			1991 area	[4]	2 170	0.20	(O'Driscoll & Bagley 2003a)
			1996 area	[5]	2 360	0.19	(O'Driscoll & Bagley 2003a)
Tangaroa	Nov–Dec 2002	TAN0219	300–800	[3]	1 283	0.20	(O'Driscoll & Bagley 2003b)
			1991 area	[4]	1 777	0.16	(O'Driscoll & Bagley 2003b)
			1996 area	[5]	2 037	0.16	(O'Driscoll & Bagley 2003b)
Tangaroa	Nov–Dec 2003	TAN0317	300–800	[3]	1 335	0.24	(O'Driscoll & Bagley 2004)
			1991 area	[4]	1 672	0.23	(O'Driscoll & Bagley 2004)
			1996 area	[7]	1 898	0.21	(O'Driscoll & Bagley 2004)
Tangaroa	Nov–Dec 2004	TAN0414	300–800	[3]	1 250	0.27	(O'Driscoll & Bagley 2005)
			1991 area	[4]	1 694	0.21	(O'Driscoll & Bagley 2005)
			1996 area	[7]	1 774	0.20	(O'Driscoll & Bagley 2005)

1. While surveys by the *Wesermünde* were carried out on the Sub-Antarctic in 1979, biomass estimates for hake were not calculated.
2. The depth range, biomass and c.v. reported by the original report
3. The biomass and c.v. calculated from source records using the equivalent 1991 region, but excluding both the 800–1000 m strata in Puysegur region and the Bounty Platform strata.
4. The biomass and c.v. calculated from source records using the equivalent 1991 region, which includes the 800–1000 m strata in Puysegur region but excludes the Bounty Platform strata.
5. The biomass and c.v. calculated from source records using the equivalent 1996 region, which includes the 800–1000 m strata in Puysegur region but excludes the Bounty Platform strata. (The 1996 region added additional 800–1000 m strata to the north and to the south of the sub-Antarctic to the 1991 region).
6. Doorspread data not recorded for this survey. Analysis of source data with average of all other survey doorspread estimates resulted in a new estimate of biomass.
7. The biomass and c.v. calculated from source records using the equivalent 1996 region, which includes the 800–1000 m strata in Puysegur region but excludes the Bounty Platform strata. (The 1996 region added additional 800–1000 m strata to the north and to the south of the sub-Antarctic to the 1991 region). However, in 2003, stratum 26 (the most southern 800–1000m strata) was not surveyed. In previous years this stratum yielded either a very low or zero hake biomass. The yield in 2003 from stratum 26 was assumed to be zero.

Table B2: Biomass indices (t) and coefficients of variation (c.v.) for hake from resource surveys of the Chatham Rise. (These estimates assume that the areal availability, vertical availability, and vulnerability are equal to one.)

Vessel	Date	Trip code	Depth	Biomass	c.v.	Reference
Wesermünde	Mar–May 1979		– [1]	–	–	(Kerstan & Sahrhage 1980)
Wesermünde	Oct Dec 1979		– [1]	–	–	(Kerstan & Sahrhage 1980)
Shinkai Maru	Mar 1983	SHI8301	200–800	11 327	0.12	N.W. Bagley, NIWA, pers. comm.
Shinkai Maru	Nov–Dec 1983	SHI8304	200–800[2]	8 160	0.12	N.W. Bagley, NIWA, pers. comm.
Shinkai Maru	Jul 1986	SHI8602	200–800	7 630	0.13	N.W. Bagley, NIWA, pers. comm.
Amaltal Explorer	Nov–Dec 1989	AEX8903	200–800	3 576	0.19	N.W. Bagley, NIWA, pers. comm.
Tangaroa	Jan 1992	TAN9106	200–800	4 180	0.15	(Horn 1994a)
Tangaroa	Jan 1993	TAN9212	200–800	2 950	0.17	(Horn 1994b)
Tangaroa	Jan 1994	TAN9401	200–800	3 353	0.10	(Schofield & Horn 1994)
Tangaroa	Jan 1995	TAN9501	200–800	3 303	0.23	(Schofield & Livingston 1995)
Tangaroa	Jan 1996	TAN9601	200–800	2 457	0.13	(Schofield & Livingston 1996)
Tangaroa	Jan 1997	TAN9701	200–800	2 811	0.17	(Schofield & Livingston 1997)
Tangaroa	Jan 1998	TAN9801	200–800	2 873	0.18	(Bagley & Hurst 1998)
Tangaroa	Jan 1999	TAN9901	200–800	2 302	0.12	(Bagley & Livingston 2000)
Tangaroa	Jan 2000	TAN0001	200–800	2 090	0.09	(Stevens et al. 2001)
			200–1000	2 152	0.09	(Stevens et al. 2001)
Tangaroa	Jan 2001	TAN0101	200–800	1 589	0.13	(Stevens et al. 2002)
Tangaroa	Jan 2002	TAN0201	200–800	1 567	0.15	(Stevens & Livingston 2003)
			200–1000	1 905	0.13	(Stevens & Livingston 2003)
Tangaroa	Jan 2003	TAN0301	200–800	890	0.16	(Livingston et al. 2004)
Tangaroa	Jan 2004	TAN0401	200–800	1 547	0.17	(Livingston & Stevens 2005)
Tangaroa	Jan 2005	TAN0501	200–800	1 049	0.18	(Stevens & O'Driscoll 2005)

1. While surveys by the *Wesermünde* were carried out on the Chatham Rise in 1979, biomass estimates for hake were not calculated.
2. East of 176° E only.

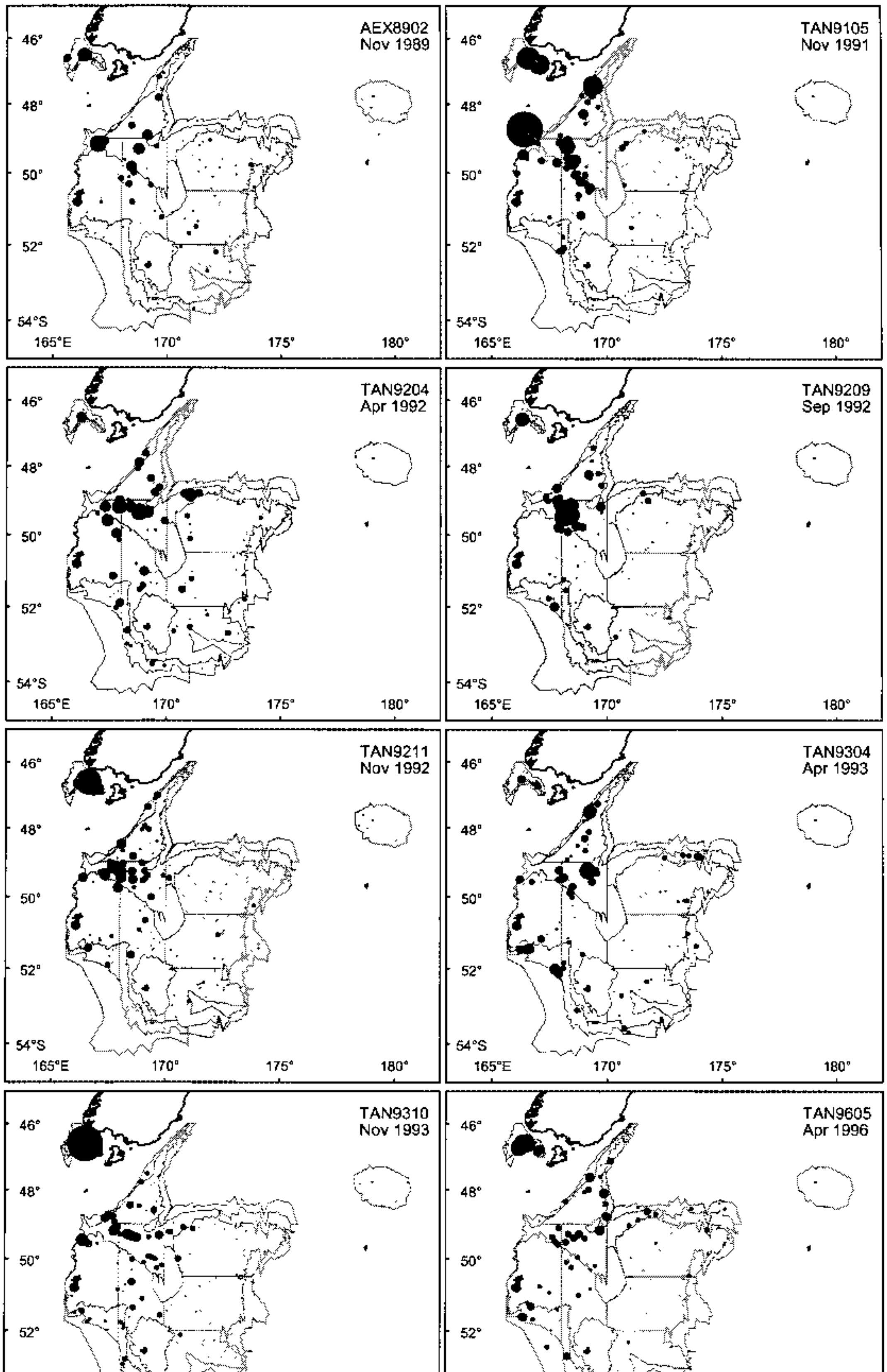

Figure B1: Density of hake by location from the 1989–2003 sub-Antarctic resource surveys. Tow density (kg/km^2) proportional to symbol area, zero values indicated in grey.

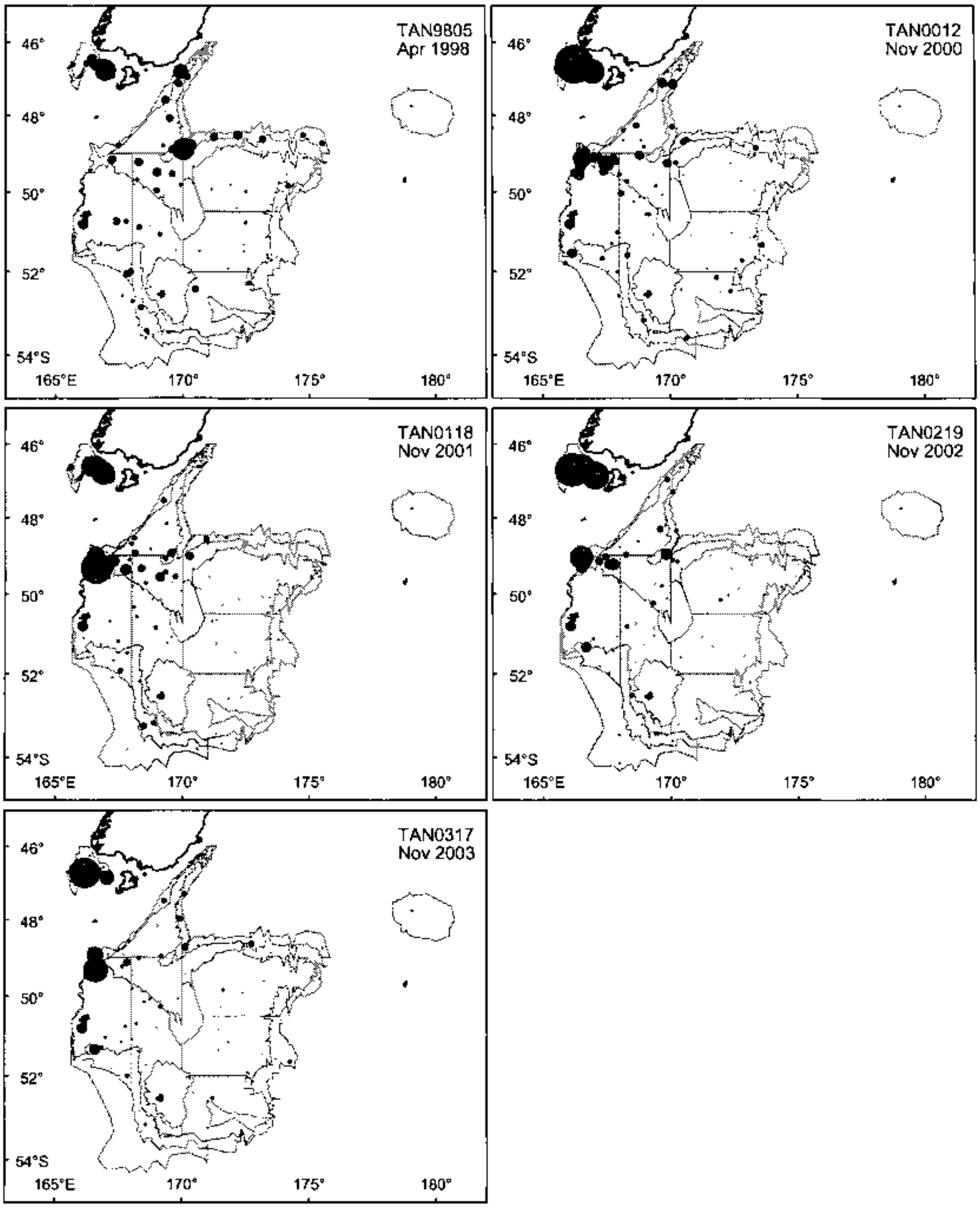

Figure B1: (Continued...) Density of hake by location from the 1989–2003 sub-Antarctic resource surveys. Tow density (kg/km^2) proportional to symbol area, zero values indicated in grey.

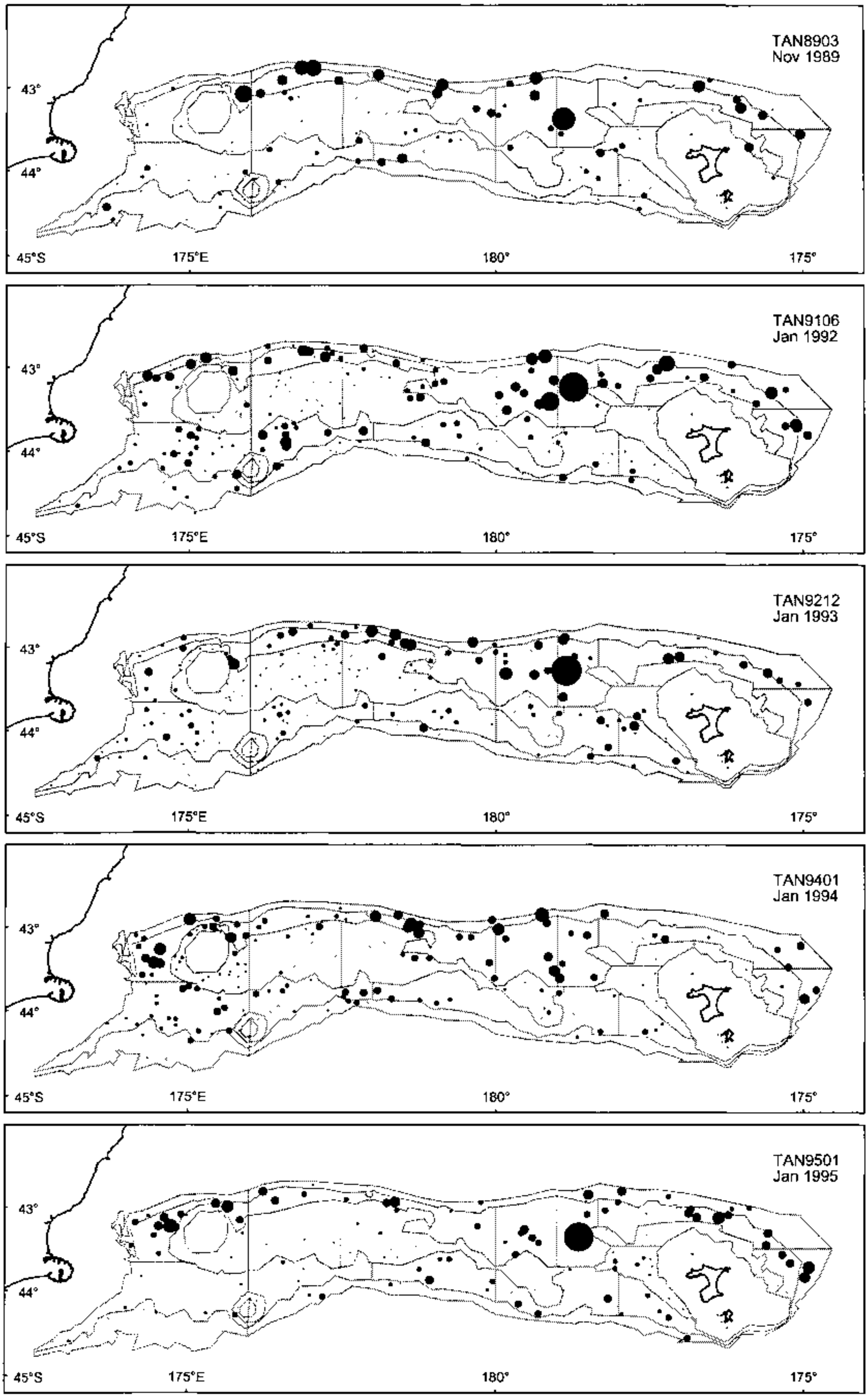

Figure B2: Density of hake by location from the 1989 to 2004 Chatham Rise resource surveys. Tow density (kg/km^2) proportional to symbol area, zero values indicated in grey.

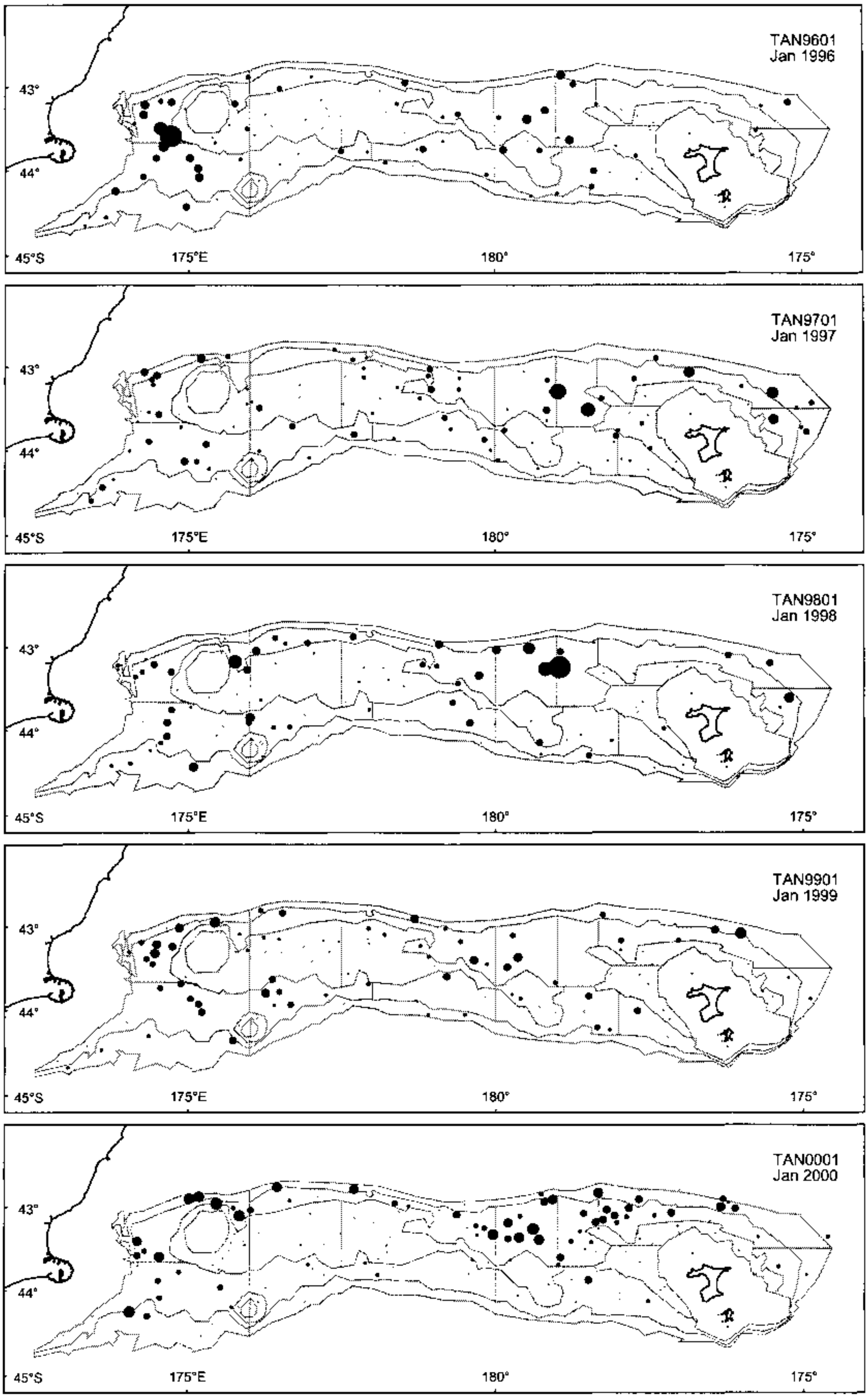

Figure B2: (Continued...) Density of hake by location from the 1989 to 2004 Chatham Rise resource surveys. Tow density (kg/km^2) proportional to symbol area, zero values indicated in grey.

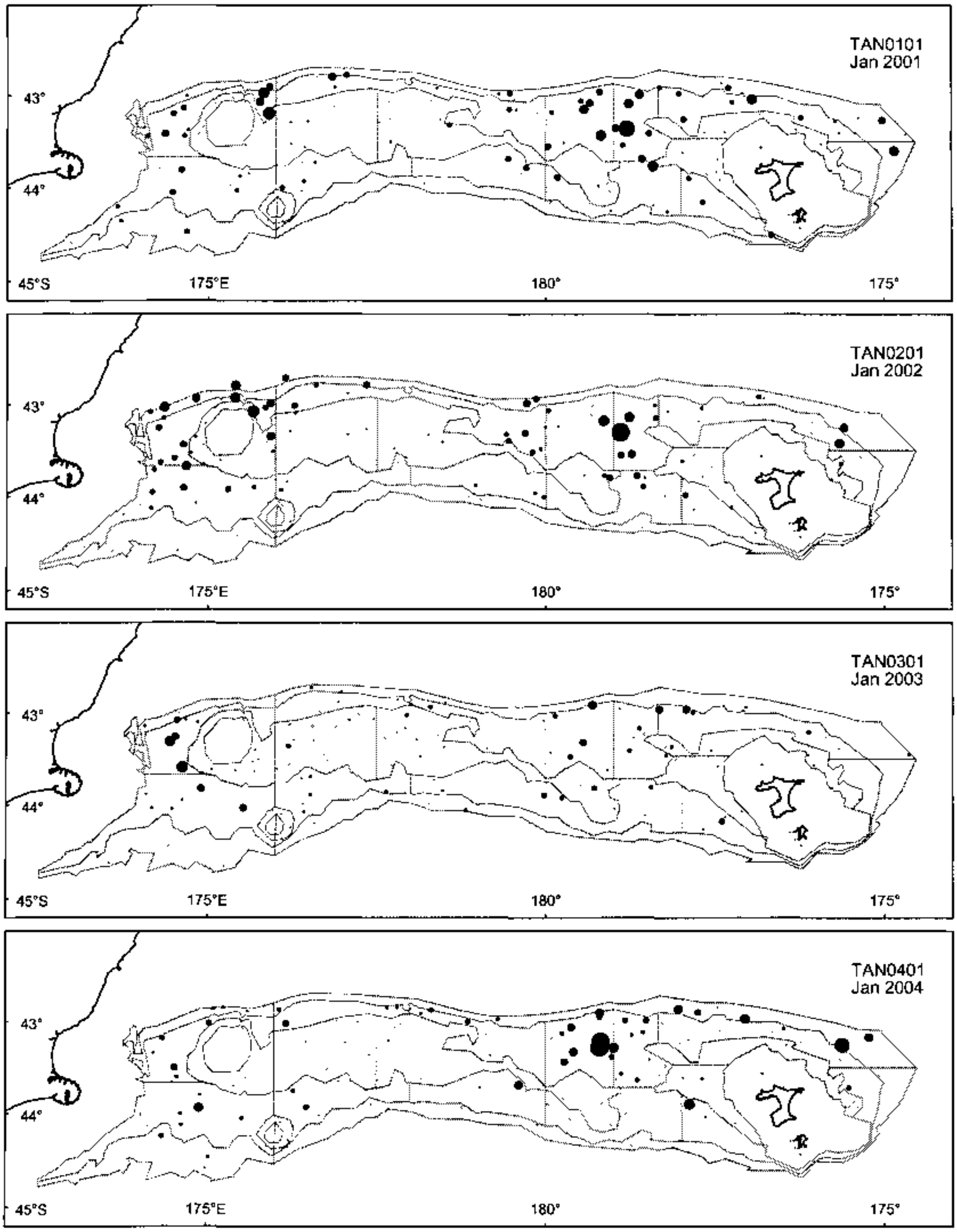

Figure B2: (Continued...) Density of hake by location from the 1989 to 2004 Chatham Rise resource surveys. Tow density (kg/km^2) proportional to symbol area, zero values indicated in grey.

APPENDIX C: Summary MPD (base case) model fits

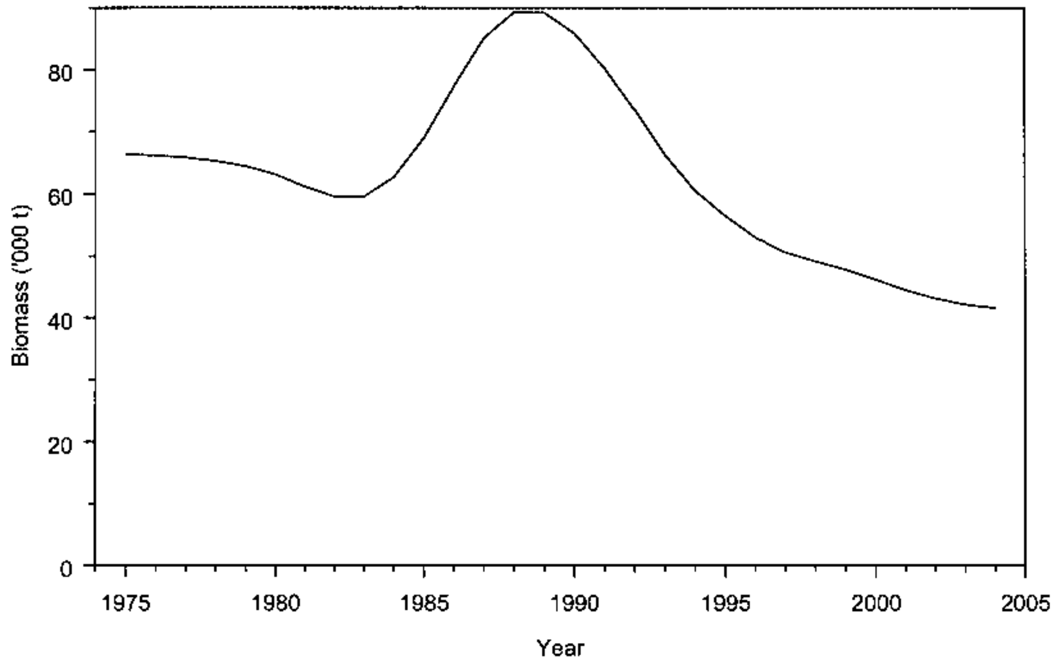

Figure C1: Estimated MPD biomass trajectory for the sub-Antarctic stock.

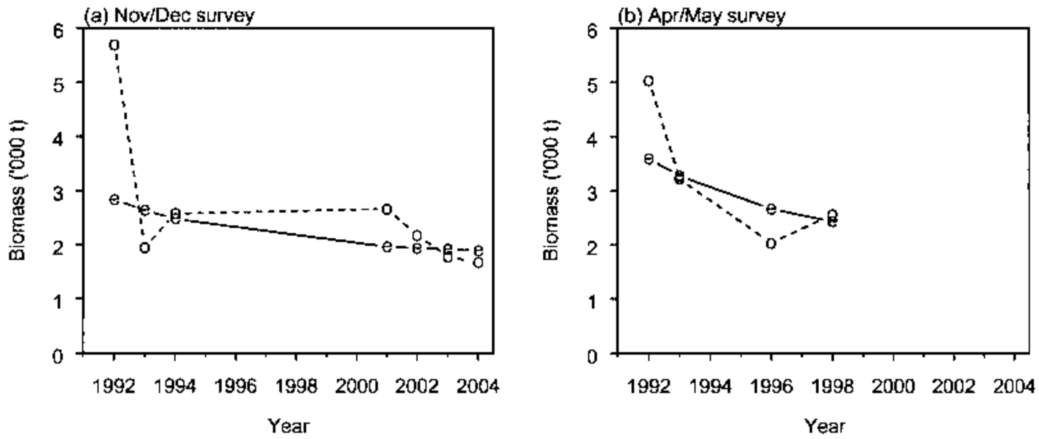

Figure C2: MPD (base case) fits to the (a) Nov–Dec resource survey biomass index, and (b) Apr–May resource survey biomass index, where 'o' indicated the observed value and 'e' indicated the fitted (expected) value.

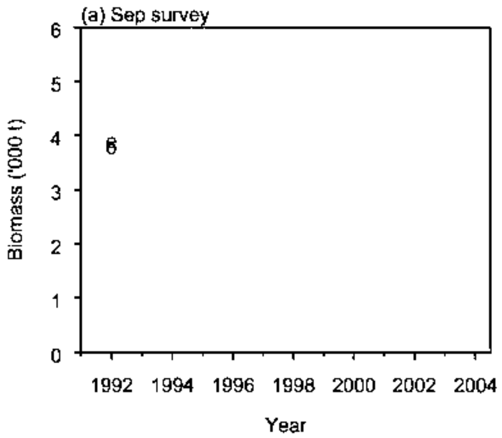

Figure C3: MPD (base case) fits to the (a) Sep resource survey biomass index, and (b) the sub-Antarctic CPUE series, where 'o' indicated the observed value and 'e' indicated the fitted (expected) value.

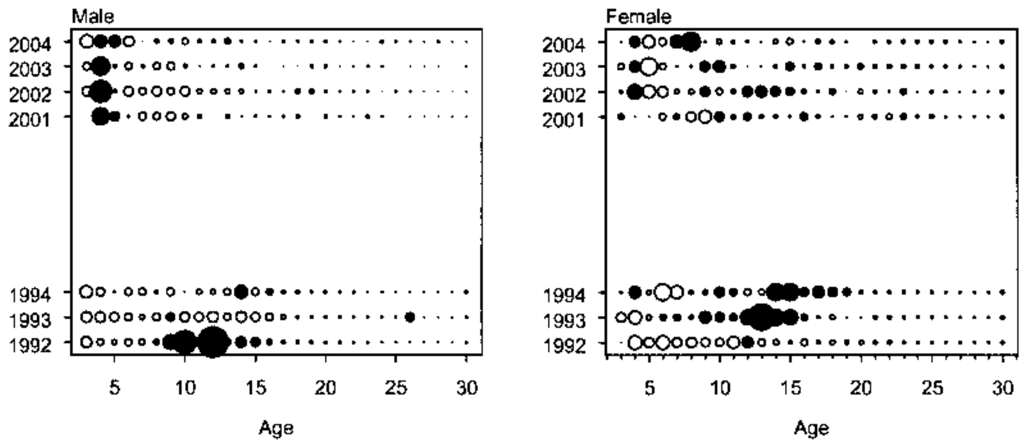

Figure C4: MPD (base case) residual values for the proportions-at-age data for the sub-Antarctic Nov–Dec resource survey series. Symbol area is proportional to the absolute value of the residual, with filled circles indicating positive residuals and open circles indicating negative residuals.

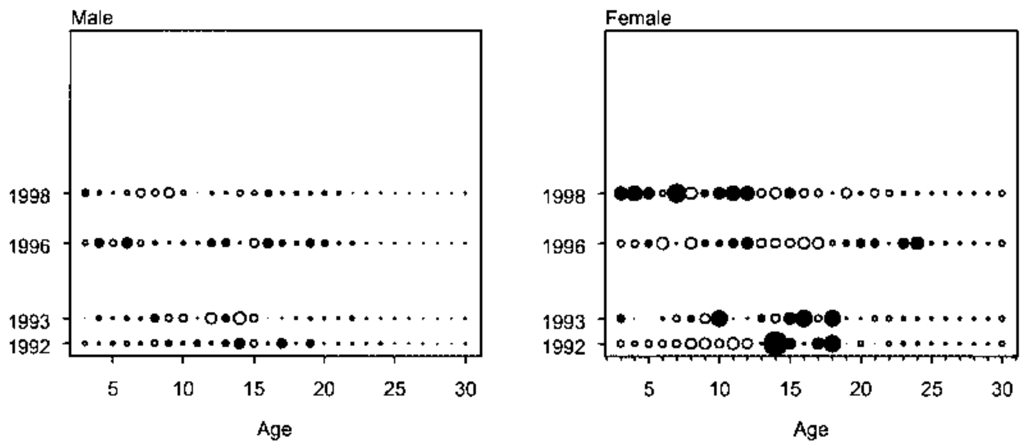

Figure C5: MPD (base case) residual values for the proportions-at-age data for the sub-Antarctic Apr–May resource survey series. Symbol area is proportional to the absolute value of the residual, with filled circles indicating positive residuals and open circles indicating negative residuals.

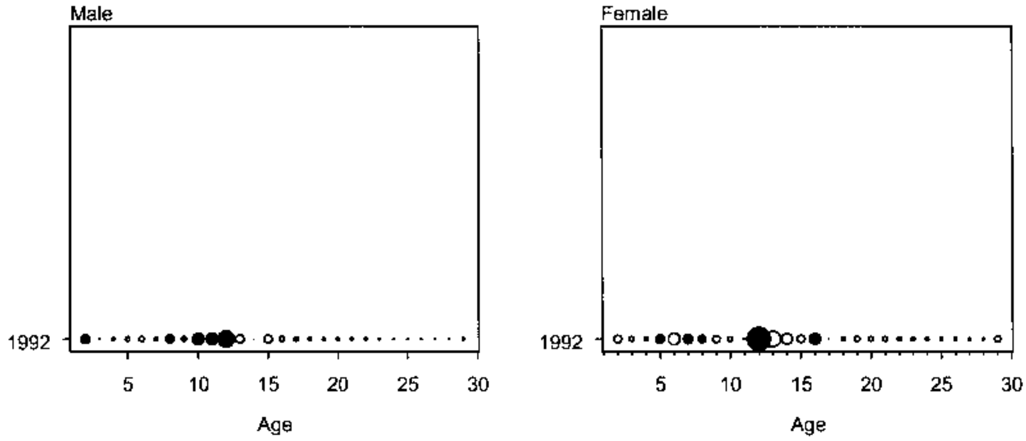

Figure C6: MPD (base case) residual values for the proportions-at-age data for the sub-Antarctic Sep resource survey series. Symbol area is proportional to the absolute value of the residual, with filled circles indicating positive residuals and open circles indicating negative residuals.

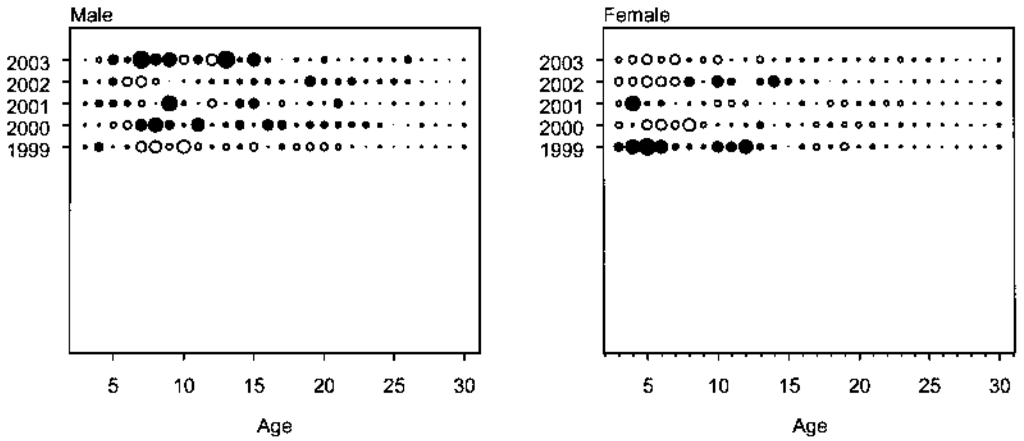

Figure C7: MPD (base case) residual values for the proportions-at-age data for the sub-Antarctic trawl fishery observer sampling series. Symbol area is proportional to the absolute value of the residual, with filled circles indicating positive residuals and open circles indicating negative residuals.

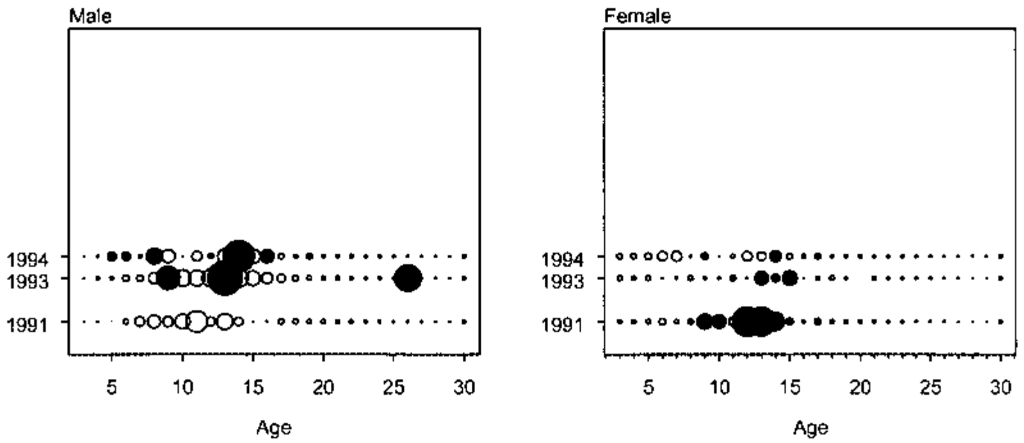

Figure C8: MPD (base case) residual values for the proportions-at-age data for the sub-Antarctic trawl fishery observer sampling series. Symbol area is proportional to the absolute value of the residual, with filled circles indicating positive residuals and open circles indicating negative residuals.

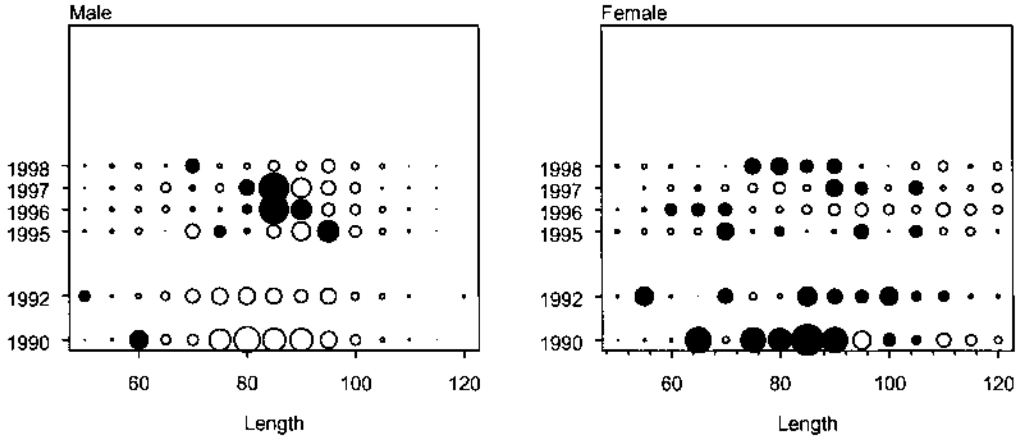

Figure C9: MPD (base case) residual values for the proportions-at-length data for the sub-Antarctic trawl fishery observer sampling series. Symbol area is proportional to the absolute value of the residual, with filled circles indicating positive residuals and open circles indicating negative residuals.

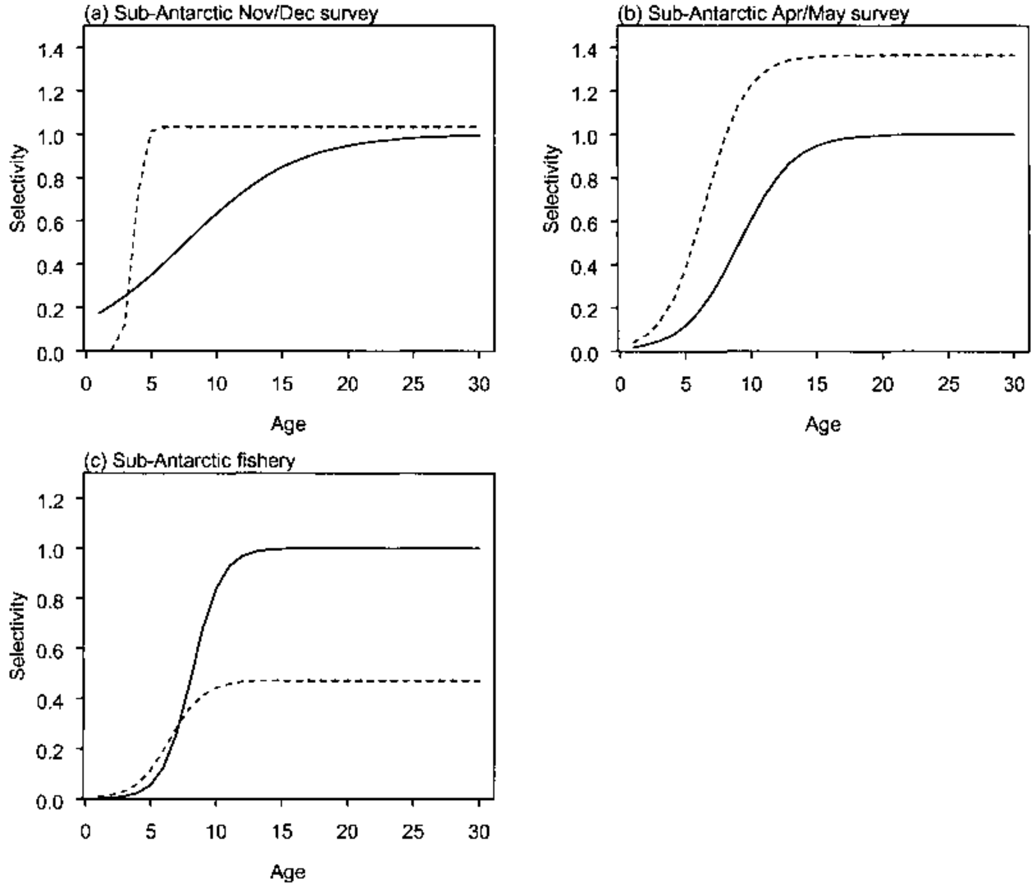

Figure C10: MPD (base case) estimated selectivities for the sub-Antarctic (a) Nov–Dec resource survey proportions at age, (b) Apr–May resource survey proportions at age, and (c) fishery proportions at age (solid lines for males and dashed lines for females).

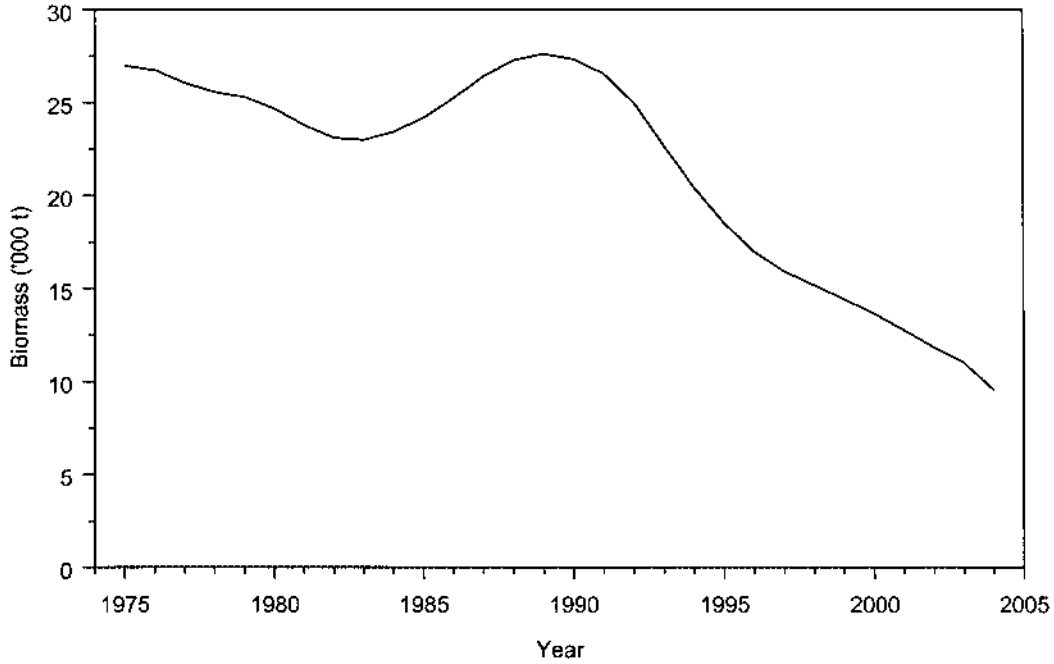

Figure C11: Estimated MPD biomass trajectory for the Chatham Rise stock.

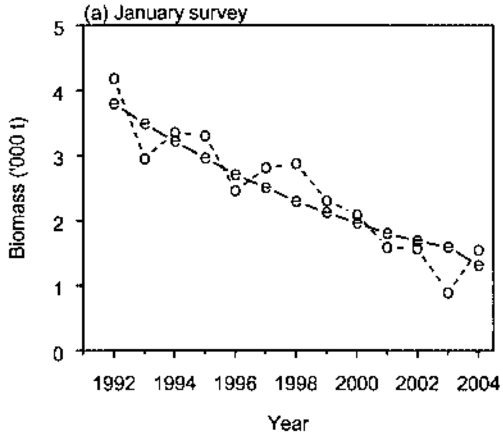

Figure C12: MPD (base case) fits to the (a) January resource survey biomass index and (b) Chatham Rise CPUE series, where 'o' indicated the observed value and 'e' indicated the fitted (expected) value.

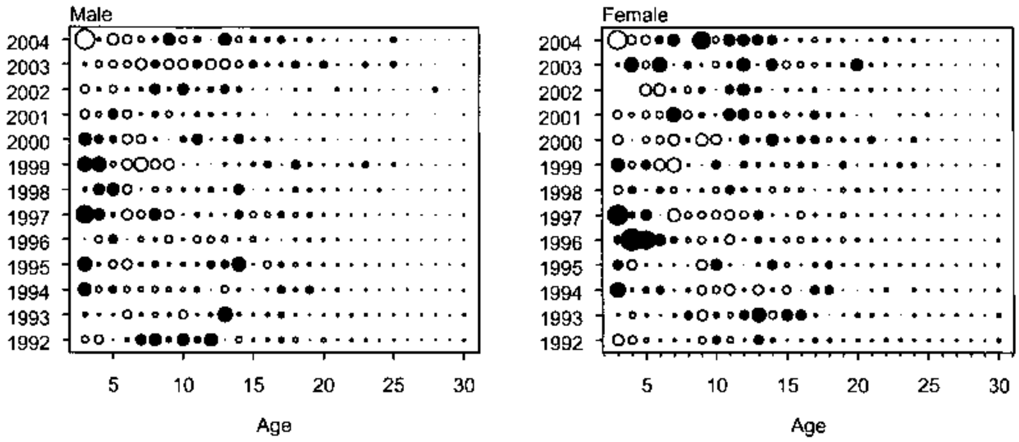

Figure C13: MPD (base case) residual values for the proportions-at-age data for the Chatham Rise January resource survey series. Symbol area is proportional to the absolute value of the residual, with filled circles indicating positive residuals and open circles indicating negative residuals.

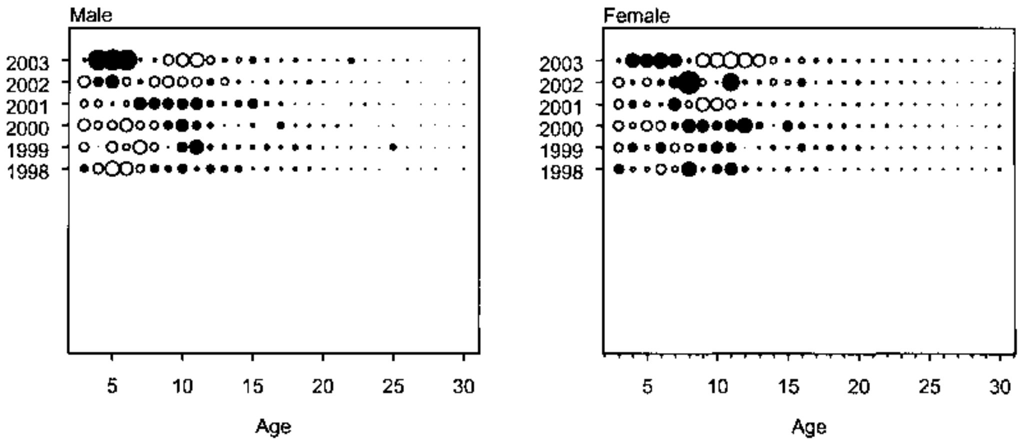

Figure C14: MPD (base case) residual values for the proportions-at-age data for the Chatham Rise trawl fishery observer sampling series. Symbol area is proportional to the absolute value of the residual, with filled circles indicating positive residuals and open circles indicating negative residuals.

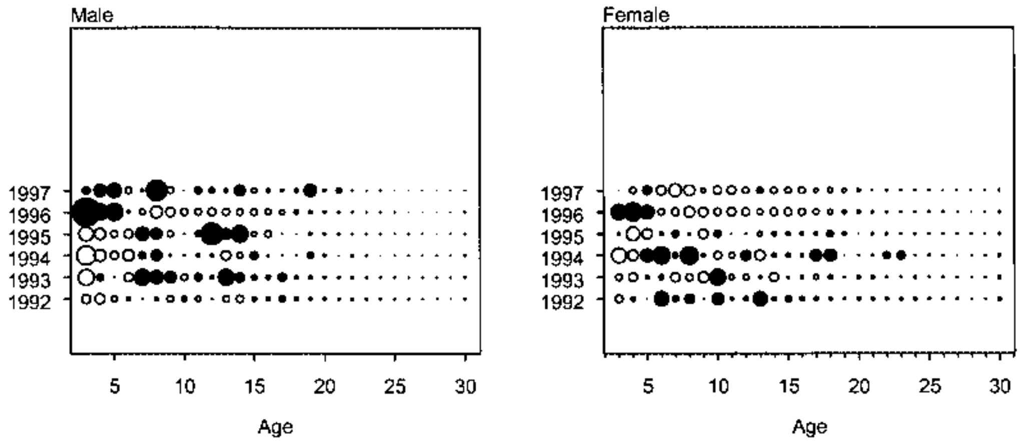

Figure C15: MPD (base case) residual values for the proportions-at-age data for the Chatham Rise trawl fishery observer sampling series. Symbol area is proportional to the absolute value of the residual, with filled circles indicating positive residuals and open circles indicating negative residuals.

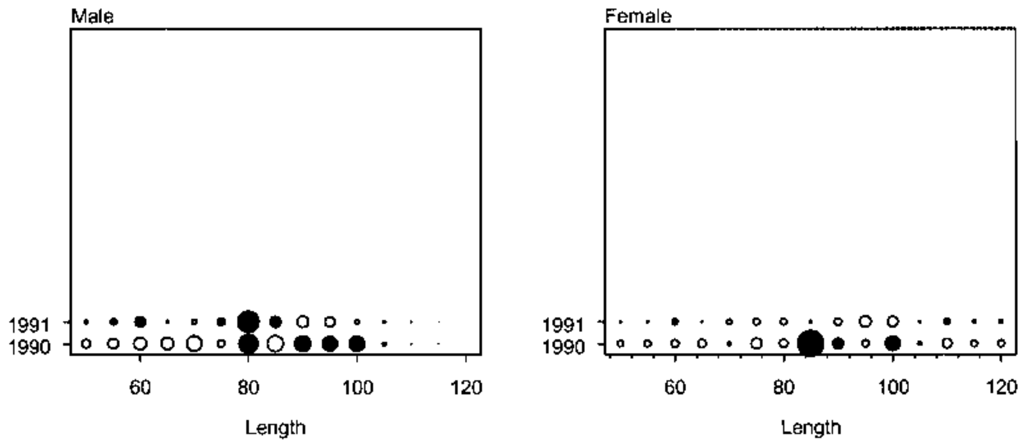

Figure C16: MPD (base case) residual values for the proportions-at-length data for the Chatham Rise trawl fishery observer sampling series. Symbol area is proportional to the absolute value of the residual, with filled circles indicating positive residuals and open circles indicating negative residuals.

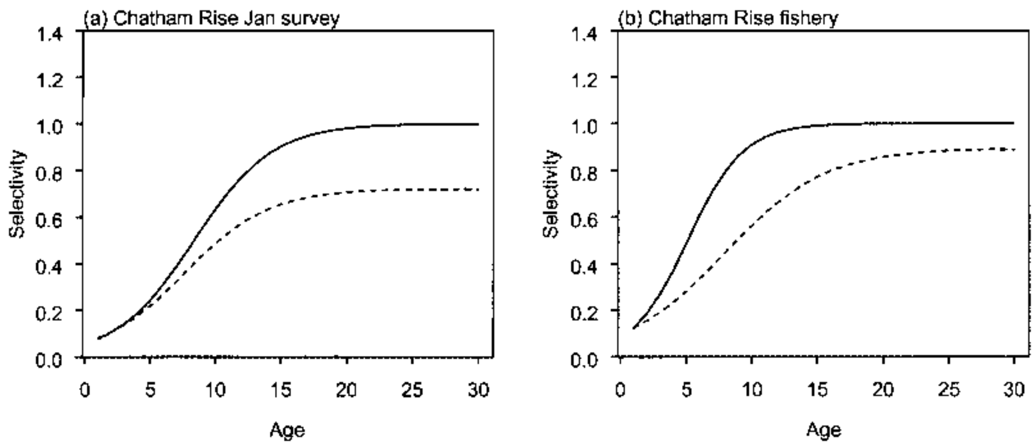

Figure C17: MPD (base case) estimated selectivities for the Chatham Rise (a) January resource survey proportions at age, and (b) fishery proportions at age (solid lines for males and dashed lines for females).