Stock assessment of hake (*Merluccius australis*) on the Chatham Rise for the 2009–10 fishing year

P. L. Horn
R. I. C. C. Francis

NIWA
Private Bag 14901
Wellington 6241

New Zealand Fisheries Assessment Report 2010/14
June 2010

Published by Ministry of Fisheries
Wellington
2010

ISSN 1175-1584 (print)
ISSN 1179-5352 (online)

Horn, P.L.; Francis, R.I.C.C. (2010).
Stock assessment of hake (*Merluccius australis*) on the Chatham Rise
for the 2009–10 fishing year.
New Zealand Fisheries Assessment Report 2010/14.

This series continues the informal
New Zealand Fisheries Assessment Research Document series
which ceased at the end of 1999.

EXECUTIVE SUMMARY

Horn, P.L.; Francis, R.I.C.C. (2010). Stock assessment of hake (*Merluccius australis*) on the Chatham Rise for the 2009–10 fishing year.

New Zealand Fisheries Assessment Report 2010/14.

This report summarises the stock assessment of hake in the Quota Management Areas (QMAs) HAK 4 and part of HAK 1, for the Chatham Rise stock for the 2009–10 fishing year. The report presents an analysis of the stock assessment of hake that includes fishery data up to the end of the 2007–08 fishing year, plus research survey data from January 2009. 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.

Initial investigations of the available data indicated that the widely fluctuating and sometimes very high estimates of year class strengths throughout the late 1970s were driven by the error structure applied to the age data acting on sparse data sets. Subsequently, the 1975 to 1983 year class strengths were smoothed. It was also apparent that the sex ratios in the at-age data were inconsistent. Consequently, a revised base case model structure was developed, excluding sex from the partition, and incorporating two commercial trawl fisheries (east and west, separated at 178.1° E) each with their own age based selectivity ogive. (Previous models included sex in the partition, and had either a single fishery or four fisheries.) The new model (called the 'Single sex' model) was also encouraged to fit the research survey biomass series well by not adding any process error to this series.

An additional 'Two sex' model was run as a sensitivity analysis. It was the same as the 'Single sex' model except that sex was included in the partition and 'at-age' data were provided by sex.

The stock assessment of hake on the Chatham Rise has been presented as a Bayesian assessment implemented as a single stock model using the general-purpose stock assessment program CASAL v2.21. The stock status of hake on the Chatham Rise appears to be relatively clear. The stock has been steadily fished down throughout the 1990s, but median B_{2009} is still estimated to be 47% of B_0. Strong recruitment in 2002 (in contrast to generally poor recruitment in other years from 1995 to 2006) has resulted in a slight stock upturn. However, it is likely that an annual catch of about 1150 t over the next five years will still result in a further stock decline. The stock is probably being well monitored by the January trawl survey series, which showed evidence of a uniform decline in biomass since 1992, with biomass in 2006 at about one-third of the original level. The sensitivity analysis gave a slightly more optimistic estimate of stock status (B_{2009} was 56% of B_0), but still indicated that stock status would decline over five years with an annual catch of 1150 t.

1. INTRODUCTION

This report outlines the stock assessment of hake in Quota Management Areas (QMAs) HAK 4 and part of HAK 1, for the Chatham Rise hake stock, with the inclusion of data up to the end of the 2007–08 fishing year. The current stock hypothesis for hake suggests that there are three separate hake stocks (Colman 1998); the west coast South Island stock (WCSI, 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 on the Chatham Rise is presented as a Bayesian assessment implemented as a single stock model using the general-purpose stock assessment program CASAL (Bull et al. 2008). Estimates of the current stock status and projected stock status are provided.

This report fulfils Objective 3 of Project HAK2007-01 "To update the stock assessment of hake, including biomass estimates and sustainable yields", funded by the Ministry of Fisheries.

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 (Devine 2009). 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 7700 t out of a total for the EEZ of 13 211 t. The WCSI 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 (Devine 2009). 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, 1993, and 2006 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 1995, 1996, 1999, 2001, 2004, and 2005 were relatively high.

On the Chatham Rise and in the Sub-Antarctic, hake have been caught mainly as bycatch by trawlers targeting hoki (Devine 2009). However, significant targeting for hake occurs in both areas, particularly in Statistical Area 404 (HAK 4), and around the Norwegian Hole between the Snares and Auckland Islands in the Sub-Antarctic. 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 the reported landings of hake from these fish stocks. Reported catches rose over a number of years to the levels of the new TACCs in both HAK 1 and HAK 4, with catches in HAK 1 remaining relatively steady since. Landings from HAK 4 steadily declined from 1998–99 to a low of 811 t in 2002–03, but increased to 2275 t in 2003–04. However, from 2004–05, the TACC for HAK 4 was reduced from 3500 t to 1800 t. Annual landings have been markedly lower than the new TACC since then. From 1 October 2005 the TACC for HAK 7 was increased to 7700 t within an overall TAC of 7777 t. This new catch limit was set equal to average annual catches over the previous 12 years, a catch level that is believed to be sustainable in the short term.

Dunn (2003a) found that area misreporting between the WCSI 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 June, July, and September. Levels of misreporting before 1994–95 and after 2000–01, and between WCSI and Sub-Antarctic, were estimated as negligible, and there is no evidence of significant misreporting since 2001–02 (Devine 2009).

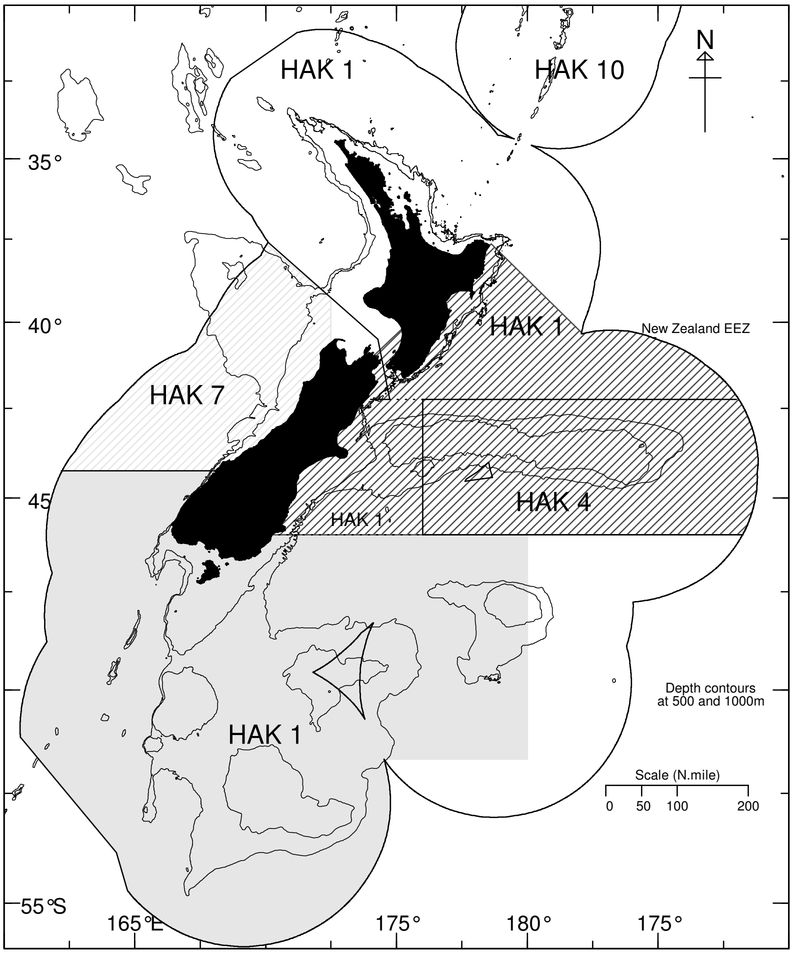


Figure 1: Quota Management Areas (QMAs) HAK 1, 4, 7, & 10; and the west coast South Island (light shading), Chatham Rise (dark shading), and Sub-Antarctic (medium shading) hake stock boundaries assumed in this report.

1.2 Literature review

Previous assessments of hake, by fishing year, are as follows: 1991–92 (Colman et al. 1991), 1992–93 (Colman & Vignaux 1992), 1997–98 (Colman 1997), 1998–99 (Dunn 1998), 1999–2000 (Dunn et al. 2000), 2000–01 (Dunn 2001), 2002–03 (Dunn 2003b), 2003–04 (Dunn 2004), 2004–05 (Dunn et al. 2006), 2005–06 (Dunn 2006), and 2006–07 (Horn & Dunn 2007). The Bayesian stock assessment software CASAL (Bull et al. 2008) has been used for all assessments since 2002–03. The most recent assessments by stock are: Chatham Rise (Horn & Dunn 2007), Sub-Antarctic (Horn 2008), and WCSI (Dunn 1998).

Since 1991, resource surveys have been carried out from R.V. *Tangaroa* in the Sub-Antarctic in November–December 1991–1993 and 2000–2006 (Chatterton & Hanchet 1994, Ingerson & Hanchet 1995, Ingerson et al. 1995, O'Driscoll et al. 2002, O'Driscoll & Bagley 2003a, 2003b, 2004, 2006a, 2006b, 2008, 2009, Bagley et al. 2009), 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 carried out in January 1992–2007 (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 2006, 2007, Stevens et al. 2009a, 2009b).

Standardised CPUE indices for the Sub-Antarctic and Chatham Rise stocks were updated for the period up to the 2007–08 fishing year (Devine 2010). These update the indices estimated by Phillips & Livingston (2004), Kendrick (1998), Dunn et al. (2000), Dunn & Phillips (2006), and Devine & Dunn (2008). A descriptive analysis of all New Zealand's hake fisheries up to the 2005–06 fishing year was prepared by Devine (2009).

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 2007–08 are provided in Tables 3 and 4 respectively.

West coast South Island revised estimates for 1989–90 and 1990–91 (see Table 4) 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.

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 2008–09 and actual TACs (t) for 1986–87 to 2008–09. Data from 1983–84 to 1985–86 from Fisheries Statistics Unit; data from 1986–87 to 2008–09 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	2 603	2 610	743	1 000	6 148	3 310	0	10	9 567	6 930
1991–92	3 156	3 500	2 013	3 500	3 026	6 770	0	10	8 196	13 780
1992–93	3 525	3 501	2 546	3 500	7 154	6 835	0	10	13 224	13 846
1993–94	1 803	3 501	2 587	3 500	2 974	6 835	0	10	7 363	13 847
1994–95	2 572	3 632	3 369	3 500	8 841	6 855	0	10	14 781	13 997
1995–96	3 956	3 632	3 465	3 500	8 678	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	3 809	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	3 504	3 632	2 472	3 500	8 134	6 855	0	10	14 110	13 997
2001–02	2 870	3 701	1 424	3 500	7 519	6 855	0	10	11 813	14 066
2002–03	3 336	3 701	811	3 500	7 433	6 855	0	10	11 581	14 066
2003–04	3 461	3 701	2 272	3 500	7 943	6 855	0	10	13 686	14 066
2004–05	4 797	3 701	1 266	1 800	7 316	6 855	0	10	13 377	12 366
2005–06	2 743	3 701	305	1 800	6 906	7 700	0	10	9 955	13 211
2006–07	2 025	3 701	900	1 800	7 668	7 700	0	10	10 592	13 211
2007–08	2 445	3 701	865	1 800	2 620	7 700	0	10	5 930	13 211
2008–09	3 415	3 701	856	1 800	5 954	7 700	0	10	10 226	13 211

Table 3: Revised landings (t) by QMA 1989–90 to 2007–08 from Devine (2010).

Fishing			QMA	Total
Year	HAK 1	HAK 4	HAK 7	
1989–90	2 110	763	4 886	7 759
1990–91	2 574	700	6 169	9 443
1991–92	3 147	2 012	3 001	8 160
1992–93	3 517	2 543	7 014	13 074
1993–94	1 780	2 584	2 952	7 316
1994–95	2 309	2 921	9 499	14 729
1995–96	3 685	3 020	9 248	15 953
1996–97	3 223	2 694	6 960	12 877
1997–98	3 663	2 973	7 889	14 525
1998–99	3 604	2 529	8 936	15 069
1999–00	3 648	2 313	7 423	13 384
2000–01	3 275	2 064	8 623	13 962
2001–02	2 856	1 415	7 404	11 675
2002–03	3 319	809	7 360	11 488
2003–04	3 454	2 279	8 550	14 283
2004–05	5 255	1 266	7 280	13 801
2005–06	2 240	207	6 423	8 870
2006–07	2 001	899	7 656	10 556
2007–08	2 449	865	2 618	5 932

Table 4: Revised landings from 1974–75 to 2007–08 (t) for the Sub-Antarctic (Sub-A), Chatham Rise (Chat), and west coast South Island (WCSI) stocks.

Fishing year	Sub-A	Chat	WCSI
1974–75	120	191	71
1975–76	281	488	5 005
1976–77	372	1 288	17 806
1977–78	762	34	498
1978–79	364	609	4 737
1979–80	350	750	3 600
1980–81	272	997	2 565
1981–82	179	596	1 625
1982–83	448	302	745
1983–84	722	344	945
1984–85	525	544	965
1985–86	818	362	1 918
1986–87	713	509	3 755
1987–88	1 095	574	3 009
1988–89	1 237	804	8 696
1989–90	1 917	957	8 741
1990–91	2 370	905	8 246
1991–92	2 743	2 414	3 007
1992–93	3 252	2 808	7 047
1993–94	1 446	2 933	2 935
1994–95	1 844	3 386	9 498
1995–96	2 794	3 913	9 241
1996–97	2 266	3 661	6 952
1997–98	2 615	3 983	7 883
1998–99	2 783	3 372	8 899
1999–00	3 019	2 943	7 420
2000–01	2 839	2 504	8 620
2001–02	2 502	1 769	7 404
2002–03	2 715	1 414	7 360
2003–04	3 244	2 492	8 547
2004–05	2 772	3 753	7 276
2005–06	2 089	359	6 423
2006–07	1 814	1 081	7 631
2007–08	2 214	1 098	2 610

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.

2.3 Other sources of fishing mortality

Colman & Vignaux (1992) compared hoki and hake catches from vessels carrying Ministry of Fisheries observers with those not carrying observers, and suggested that the catch of hake was 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 area 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 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 significant misreporting since 2001–02 (Devine 2009).

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 fish have also been recorded occasionally near the Mernoo Bank. 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. 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. 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 were reported by Horn & Sutton (2009). The relative observed proportions-at-age data from resource surveys of the Sub-Antarctic and Chatham Rise stocks are also shown in Figures 2 and 3 respectively.

Colman (1998) 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 assessments before 2005, the maturity ogive for the Chatham Rise and Sub-Antarctic was assumed from a combination of the estimates of Colman (1998) and model fits presented by Dunn (1998) to the west coast South Island stock.

From 2005 to 2007, maturity ogives for the Chatham Rise and Sub-Antarctic stocks were fitted within the assessment model to data derived from resource survey samples with information on the gonosomatic index, gonad stage, and age (Horn & Dunn 2007, Horn 2008). 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 of Colman (1998) — i.e., classified as immature if $GSI < 0.005$ (males) or $GSI < 0.015$ (females), or mature if $GSI \geq 0.005$ (males) or $GSI \geq 0.015$ (females). Fish identified as stages 3–7 were classified as mature. Model fits indicated that Chatham Rise hake reach 50% maturity at about 6 years for males and 7 years for females, and Sub-Antarctic hake reach 50% maturity at 6 years for males and 7.5 years for females (Figure 4). From 2009, fixed ogives (derived from the fitted curves in Figure 4) were used in the assessment models, with values listed in Table 5.

Von Bertalanffy parameters were previously estimated using data up to 1997 (Horn 1998). The parameters for all three stocks were updated using all data available at February 2007 (Horn 2008). Plots of the fitted curves on the raw data indicated that the von Bertalanffy model tended to underestimate the age of large fish (Figure 5). Consequently, the growth model of Schnute (1981) was fitted to the data sets (Table 5). This model appeared to better describe the growth of larger hake (Figure 5), and the resulting parameters can be used in the CASAL stock assessment software. Most aged hake have been 3 years or older. However, juvenile hake have been taken in coastal waters on both sides of the South Island and on the Campbell Plateau. It is known that they reach a total length of about 15–20 cm at 1 year old, and about 35 cm total length at 2 years (Horn 1997).

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}.

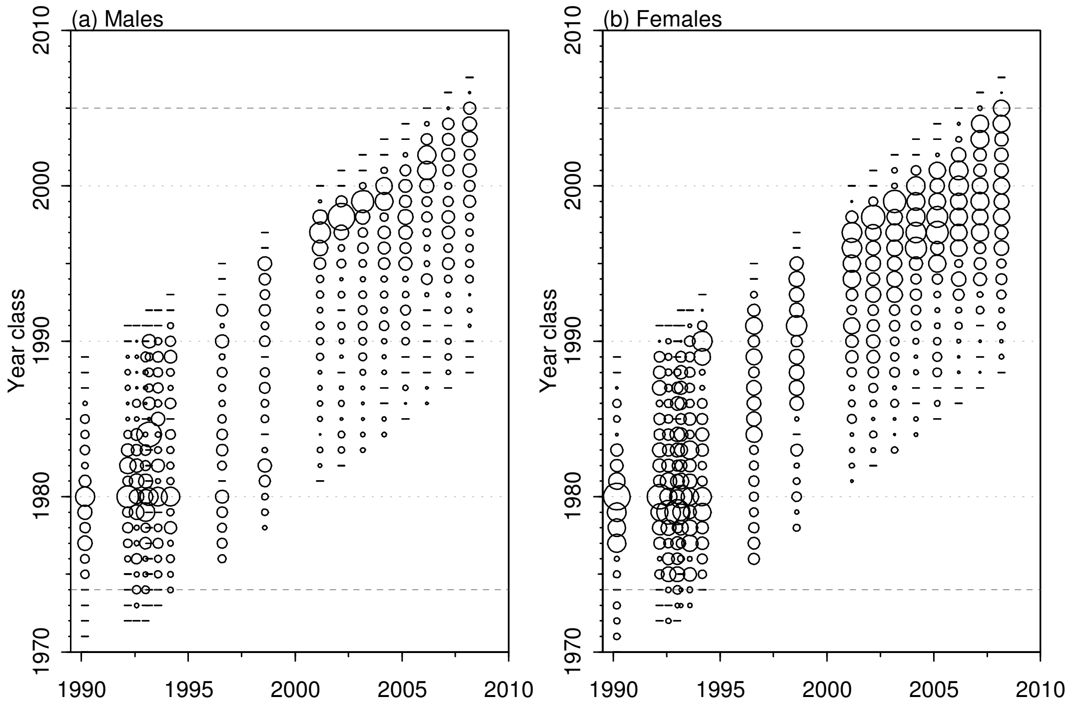


Figure 2: Age frequencies (ages 1 to 20+) by year class and year (symbol area proportional to the proportions-at-age within sampling event) in the Sub-Antarctic resource surveys, 300–800 m strata. Zero values are represented by a dash, and horizontal broken lines indicate the earliest (1974) and latest (2005) year class strengths that would be estimated within the stock assessment model.

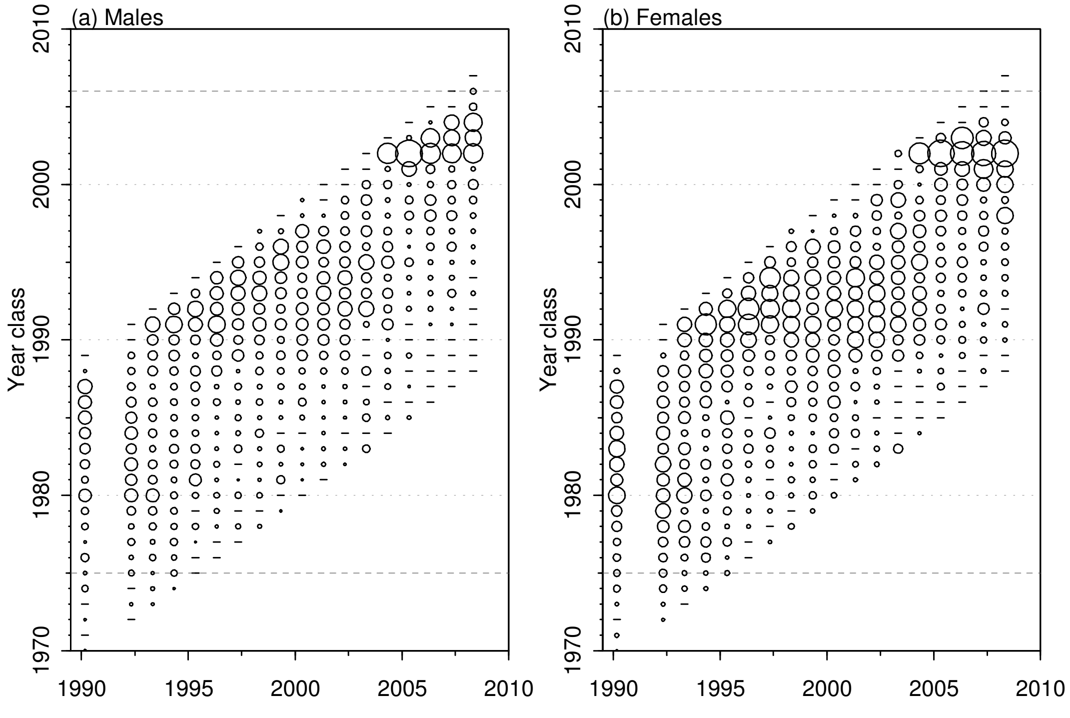


Figure 3: Age frequencies (ages 1 to 20+) by year class and year (symbol area proportional to the proportions-at-age within sampling event) on the Chatham Rise resource surveys, 200–800 m strata. Zero values are represented by a dash, and horizontal broken lines indicate the earliest (1975) and latest (2006) year class strengths estimated within the stock assessment model.

Table 5: Estimates of biological parameters for the three hake stocks.

		Estimate				Source
Natural mortality						
	Males	$M = 0.20$				(Dunn et al. 2000)
	Females	$M = 0.18$				(Dunn et al. 2000)
	Both sexes	$M = 0.19$				(Current study)
Weight = $a \cdot (length)^b$ *(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)
	Both sexes	$a = 2.12 \times 10^{-9}$	$b = 3.275$			(Current study)
von Bertalanffy growth parameters						
Sub-Antarctic						
	Males	$k = 0.295$	$t_0 = 0.06$	$L_\infty = 88.8$		(Horn 2008)
	Females	$k = 0.220$	$t_0 = 0.01$	$L_\infty = 107.3$		(Horn 2008)
Chatham Rise						
	Males	$k = 0.330$	$t_0 = 0.09$	$L_\infty = 85.3$		(Horn 2008)
	Females	$k = 0.229$	$t_0 = 0.01$	$L_\infty = 106.5$		(Horn 2008)
WCSI						
	Males	$k = 0.357$	$t_0 = 0.11$	$L_\infty = 82.3$		(Horn 2008)
	Females	$k = 0.280$	$t_0 = 0.08$	$L_\infty = 99.6$		(Horn 2008)
Schnute growth parameters ($\tau_1 = 1$ and $\tau_2 = 20$ for all stocks)						
Sub-Antarctic						
	Males	$y_1 = 22.3$	$y_2 = 89.8$	$a = 0.249$	$b = 1.243$	(Horn 2008)
	Females	$y_1 = 22.9$	$y_2 = 109.9$	$a = 0.147$	$b = 1.457$	(Horn 2008)
Chatham Rise						
	Males	$y_1 = 24.6$	$y_2 = 90.1$	$a = 0.184$	$b = 1.742$	(Horn 2008)
	Females	$y_1 = 24.4$	$y_2 = 114.5$	$a = 0.098$	$b = 1.764$	(Horn 2008)
	Both sexes	$y_1 = 24.5$	$y_2 = 104.8$	$a = 0.131$	$b = 1.700$	(Current study)
WCSI						
	Males	$y_1 = 23.7$	$y_2 = 83.9$	$a = 0.278$	$b = 1.380$	(Horn 2008)
	Females	$y_1 = 24.5$	$y_2 = 103.6$	$a = 0.182$	$b = 1.510$	(Horn 2008)

Maturity ogives (proportion mature at age)

Age	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Sub-Antarctic														
Males	0.01	0.03	0.09	0.22	0.46	0.71	0.88	0.96	0.98	0.99	1.00	1.00	1.00	1.00
Females	0.01	0.02	0.05	0.11	0.23	0.43	0.64	0.81	0.91	0.96	0.98	0.99	1.00	1.00
Chatham Rise														
Males	0.02	0.06	0.15	0.32	0.55	0.77	0.90	0.96	0.98	0.99	1.00	1.00	1.00	1.00
Females	0.04	0.07	0.13	0.22	0.34	0.49	0.64	0.77	0.86	0.92	0.95	0.98	0.99	1.00
Both	0.03	0.06	0.14	0.27	0.45	0.63	0.77	0.86	0.92	0.96	0.98	0.99	1.00	1.00

Miscellaneous parameters

Steepness (Beverton & Holt stock-recruitment relationship)	0.90
Proportion spawning	1.0
Proportion of recruits that are male	0.5
Ageing error c.v.	0.08
Maximum exploitation rate (U_{max})	0.7

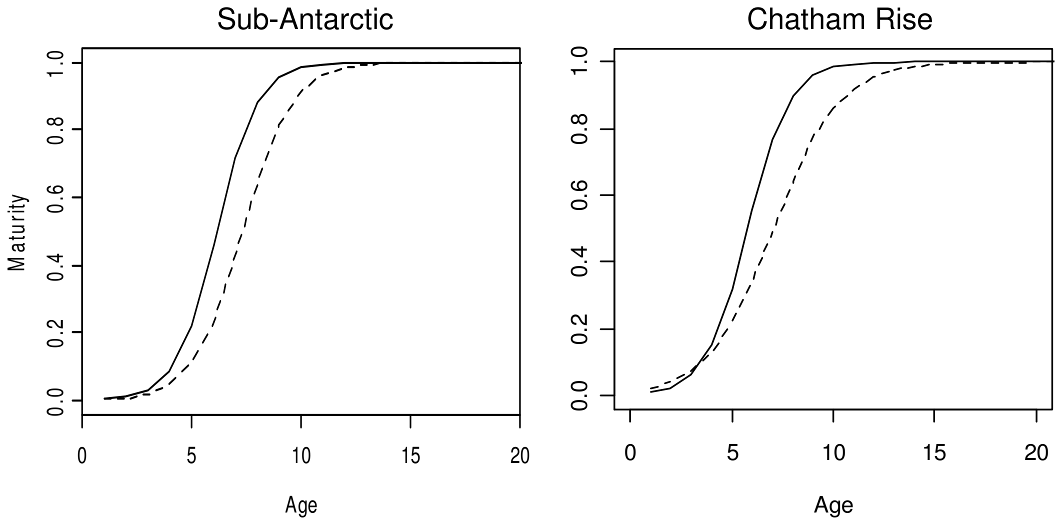


Figure 4: Estimated ogives of proportions mature by age for Sub-Antarctic and Chatham Rise hake males (solid lines) and females (broken lines).

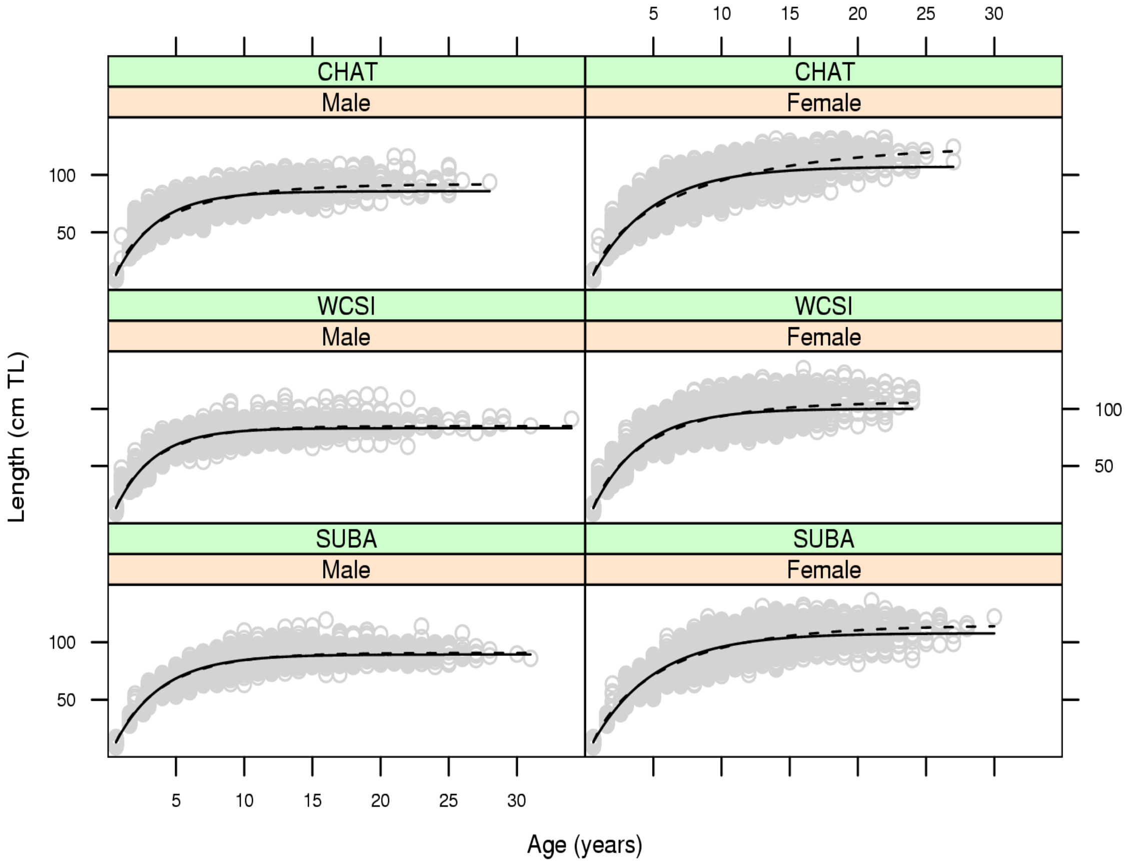


Figure 5: Raw age-length data, by sex, for hake from Chatham Rise (CHAT), west coast South Island (WCSI), and Sub-Antarctic (SUBA), with fitted von Bertalanffy curves (solid lines) and Schnute curves (broken lines).

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 (J.A. Colman, NIWA, unpublished data) 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 in the Sub-Antarctic resulted in a return to the November–December survey annually since 2000. 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 also completed. 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 A.

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 used different gear and had different performance characteristics (Livingston et al. 2002), so cannot be used as a part of a consistent time series.

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 A). While 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 surveys since 2000 used a revised design, with some strata being split and additional stations added. In addition, four surveys (2000, 2002, 2007, and 2008) 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.

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 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 A.

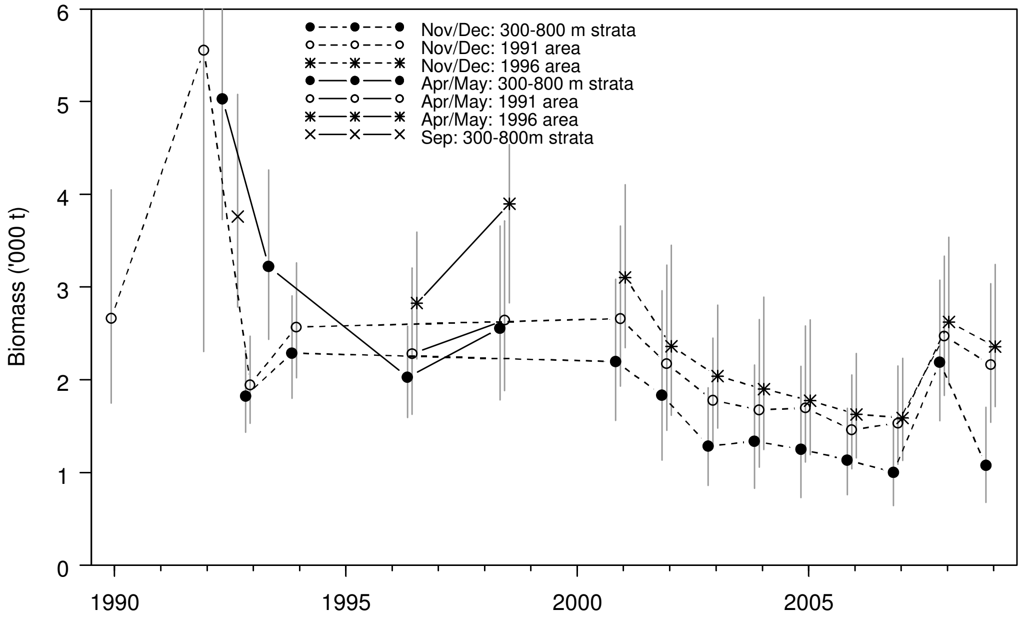


Figure 6: Hake biomass estimates from the *Amaltal Explorer* (October–November 1989) and *Tangaroa* (1991–2008 including the November–December, April–May, and September series) surveys of the Sub-Antarctic, with approximate 95% confidence intervals. (See also Appendix A.)

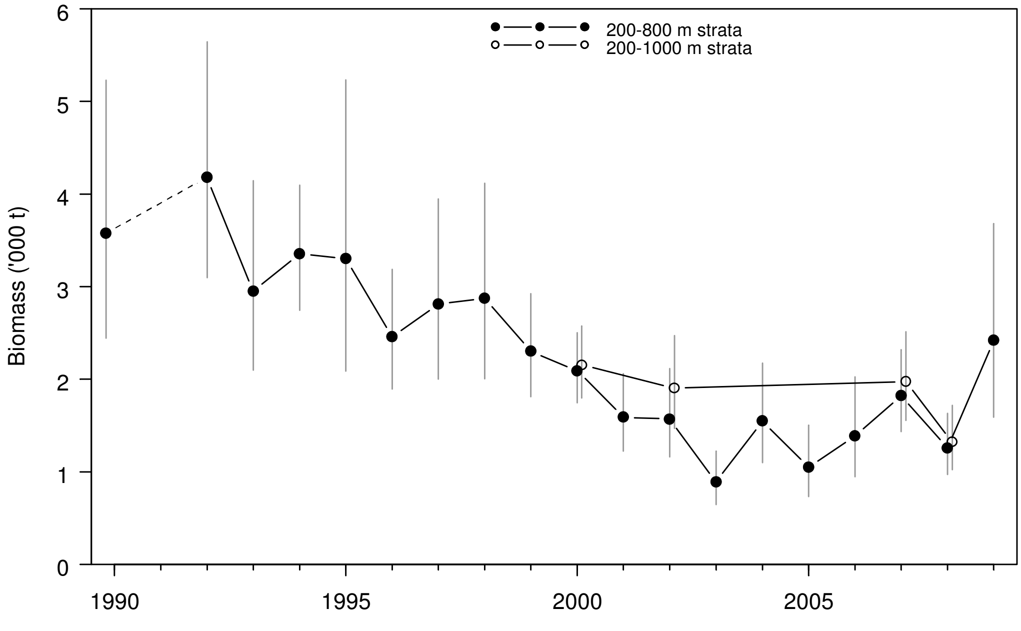


Figure 7: Hake biomass estimates from the *Amaltal Explorer* (November–December 1989) and *Tangaroa* (1992–2009 for the January series) of the Chatham Rise, with approximate 95% confidence intervals. (See also Appendix A.)

3.4 Observer length and age data

3.4.1 Chatham Rise

The fishery on the Chatham Rise was stratified using a tree-based regression on mean lengths of hake in tows where observers had measured five or more hake (Horn & Dunn 2007). The defined strata are shown in Figure 8. Mean fish length tends to increase from west to east, and with increasing depth. Area 404 is a known spawning ground. Because landings and intensity of observer effort varied markedly over the four fisheries between years it was considered necessary to model the Chatham Rise stock with four separate fisheries, each with its own selectivity ogives. Consequently, catch-at-length and catch-at-age series were developed separately for each fishery in the last assessment of this stock (Horn & Dunn 2007).

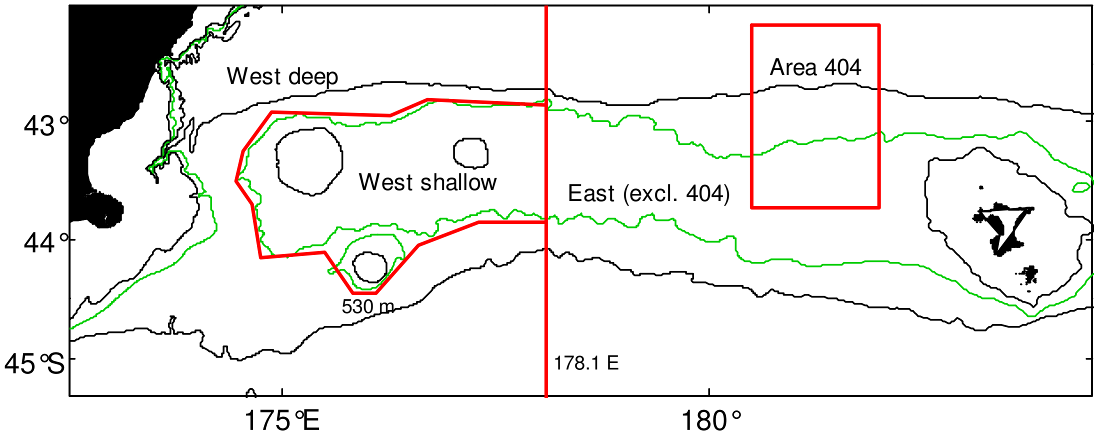


Figure 8: Fishery strata defined for the Chatham Rise hake fishery. The stratum boundary defined by depth (530 m) is shown only approximately. Isobaths at 1000, 500, and 250 m are also shown.

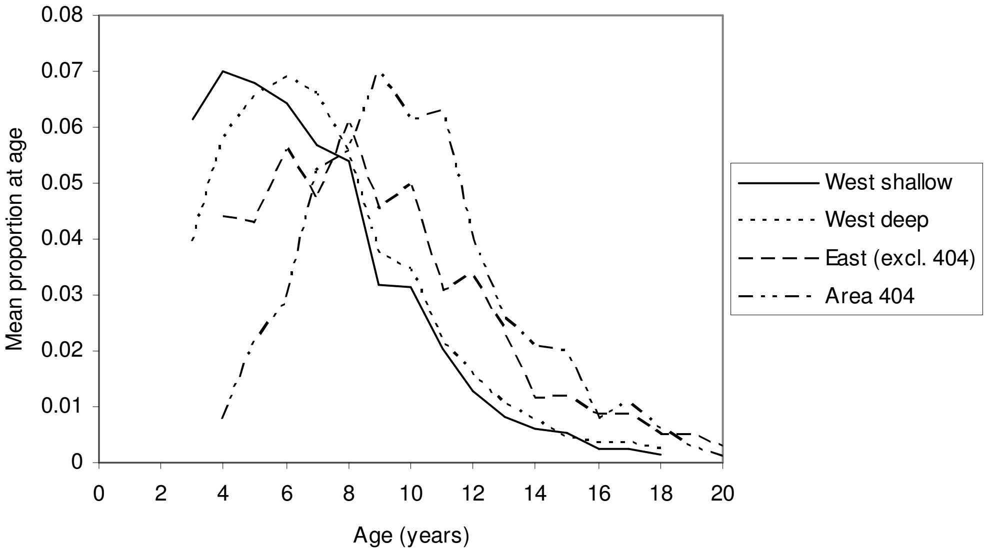


Figure 9: Age-frequency distributions, by fishery, combining data from all years. See Figure 8 for definitions of the fishery areas.

However, it was apparent that the two western fisheries have quite similar age-frequency distributions (Figure 9). Hake caught in the eastern fisheries are, on average, older than those from the west. Although the age-frequency distributions from the eastern fisheries are different (i.e., Area 404 fish tend to be older), these series are data poor. It was possible to calculate sufficiently precise catch-at-age distributions for the Area 404 fishery in only two years, and only three years for East (excl. 404) fishery (Horn & Sutton 2009). This compared to eight and nine years of data for the West shallow and West deep fisheries, respectively. We considered that 2–3 years of data were insufficient to characterise the eastern fishery age distributions, and that these fisheries should be combined. We also considered it was worth investigating the effects of combining the two western fisheries because their catch-at-age distributions were so similar.

Observer data from each fishery stratum were converted into catch-at-age distributions if there were at least 400 length measurements (from western strata) or 320 length measurements (from eastern strata), and the mean weighted c.v. over all age classes was less than 30%. Table 6 summarises the quantities of available data. The two western fisheries have been generally well sampled, but both eastern fisheries (and particularly the Area 404 fishery) have been poorly sampled.

Although the observer length data from each year were partitioned into fisheries, the age data from each year were not (i.e., a single age-length key was constructed for each year and applied to all available sets of length data from that year). Horn & Dunn (2007) showed that mean age at length did not differ between fisheries, so the use of a single age-length key per year has probably not biased the age distributions.

Table 6: Numbers of measured hake available for analyses of catch-at-age, by fishery on the Chatham Rise (i.e., after removal of data from tows where fewer than five hake were measured). –, insufficient data to calculate catch-at-age. "West combined" is a combination of data from the West deep and West shallow fisheries. "East" is a combination of data from the "East (excl. 404)" and "Area 404" fisheries.

	Fishery			
Year	West shallow	West deep	West combined	East
1992	1 917	2 831	4 748	417
1993	–	–	–	–
1994	–	–	807	–
1995	752	–	921	322
1996	1 037	682	1719	–
1997	–	–	587	410
1998	3 916	2 291	6 207	364
1999	1 362	629	1 991	–
2000	535	1 173	1 708	–
2001	1 029	936	1 965	1 300
2002	542	–	878	–
2003	–	–	450	–
2004	–	631	1 035	470
2005	–	914	1 333	–
2006	–	–	564	–
2007	–	–	–	687
2008	–	401	556	–

3.4.2 Sub-Antarctic

The Sub-Antarctic hake observer data were found to be best stratified into the four areas shown in Figure 10 (Horn 2008). Most of the hake target fishing, and most of the catch (average 94% per year), is associated with the Snares-Pukaki area. Puysegur is the next most important area with about 3% of the catch. Available observer data are also concentrated in the Snares-Pukaki region, but it is clear that the smaller fisheries (particularly the Campbell Island area) can often be over-sampled in most years. Consequently, the Sub-Antarctic observer data are analysed as one major and three very minor fisheries, with a single fishery ogive. However, because of clear differences in mean fish length between the fisheries (Horn 2008), it is important to use the four fishery strata when calculating catch-at-age distributions. Without stratification, the frequent over-sampling in the minor fisheries could strongly bias the catch-at-age distributions. However, it is satisfactory to apply a single age-length key to the scaled length-frequency distributions for each fishery to produce the catch-at-age data. Catch-at-age distributions from the Sub-Antarctic trawl fishery are available from all but three years from 1989–90 to 2007–08 (Horn & Sutton 2009).

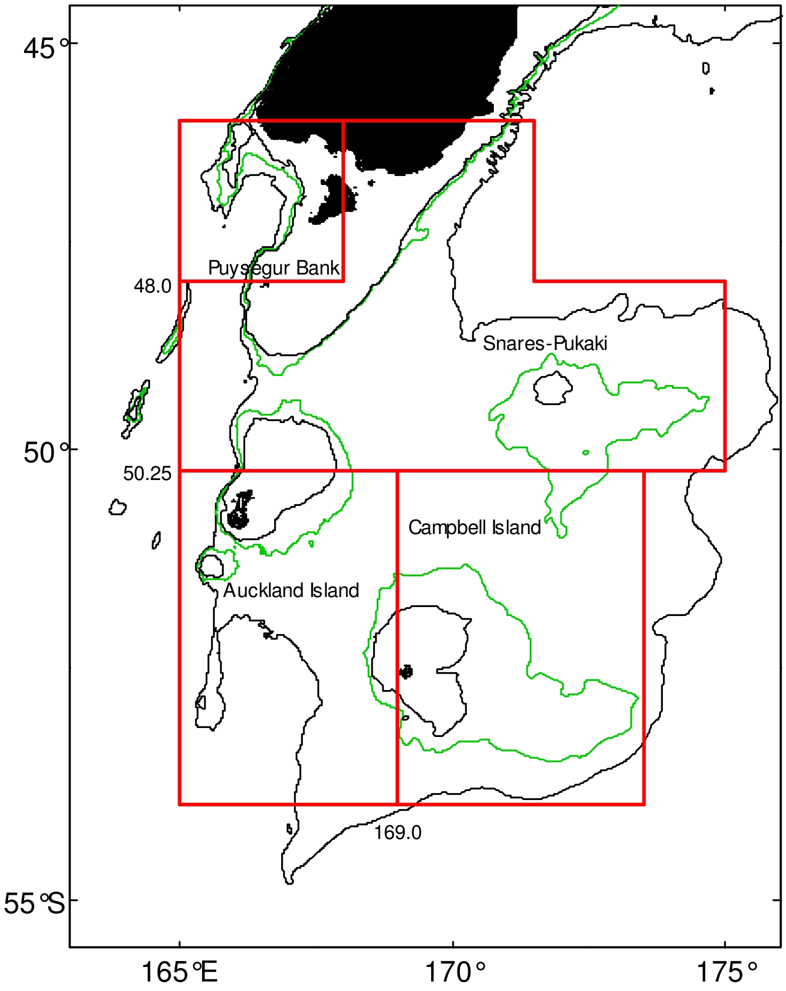


Figure 10: Fishery strata defined for the Sub-Antarctic hake fishery. Numbers show latitudes or longitudes of fishery boundaries. Isobaths at 1000, 500, and 250 m are also shown.

3.5 CPUE indices

Standardised CPUE indices were calculated by Devine (2010) from daily processed summary data up the end of the 2007–08 fishing season. Series were produced for each of the four separate fisheries on the Chatham Rise, for the two eastern Chatham Rise fisheries combined, and for the entire Sub-Antarctic fishery (Table 7).

Table 7: Hake CPUE indices (and associated c.v.s) for the four fisheries on the Chatham Rise, the two Chatham Rise eastern fisheries combined, and the Sub-Antarctic.

	Chatham Rise							
	West shallow		West deep		East (excl. 404)		Area 404	
Year	Index	c.v.	Index	c.v.	Index	c.v.	Index	c.v.
1989–90	0.87	0.11	–	–	–	–	–	–
1990–91	0.36	0.10	–	–	1.71	0.07	–	–
1991–92	0.69	0.08	–	–	1.2	0.08	2.48	0.15
1992–93	0.46	0.08	0.72	0.07	1.22	0.07	1.59	0.09
1993–94	0.68	0.10	0.96	0.09	1.18	0.07	1.28	0.11
1994–95	1.44	0.06	0.98	0.05	0.82	0.05	1.77	0.11
1995–96	1.60	0.05	1.49	0.05	0.88	0.07	1.97	0.10
1996–97	1.19	0.05	1.39	0.04	1.03	0.05	1.51	0.11
1997–98	1.16	0.04	1.24	0.03	0.98	0.04	1.70	0.10
1998–99	1.17	0.04	0.96	0.04	0.89	0.03	1.63	0.08
1999–00	1.05	0.04	1.13	0.04	1.18	0.04	1.19	0.11
2000–01	1.07	0.04	1.21	0.04	1.10	0.04	0.92	0.09
2001–02	1.07	0.04	1.18	0.04	1.12	0.04	0.95	0.08
2002–03	1.09	0.04	1.00	0.04	0.93	0.04	0.66	0.10
2003–04	0.90	0.05	0.74	0.03	0.76	0.04	0.69	0.06
2004–05	0.95	0.05	0.64	0.05	0.49	0.04	0.62	0.08
2005–06	1.13	0.05	0.78	0.05	0.51	0.06	0.21	0.24
2006–07	0.97	0.05	0.69	0.05	0.85	0.05	0.47	0.10
2007–08	1.16	0.06	0.91	0.04	1.12	0.05	0.46	0.11

	Chatham Rise		Sub-Antarctic	
	East combined		All areas	
Year	Index	c.v.	Index	c.v.
1989–90	–	–	1.35	0.07
1990–91	1.50	0.08	1.10	0.06
1991–92	2.22	0.09	1.45	0.05
1992–93	1.47	0.07	1.16	0.05
1993–94	1.33	0.07	1.22	0.06
1994–95	1.26	0.06	0.97	0.06
1995–96	1.43	0.07	1.05	0.05
1996–97	1.07	0.06	0.88	0.04
1997–98	0.99	0.06	0.84	0.04
1998–99	0.91	0.05	0.91	0.04
1999–00	0.84	0.07	0.93	0.04
2000–01	0.74	0.06	0.99	0.04
2001–02	0.72	0.06	0.92	0.04
2002–03	0.68	0.07	0.79	0.04
2003–04	0.82	0.05	1.04	0.04
2004–05	0.47	0.05	0.75	0.05
2005–06	0.43	0.10	1.06	0.07
2006–07	0.55	0.06	0.78	0.07
2007–08	0.57	0.06	0.79	0.06

4. MODEL STRUCTURE, INPUTS, AND ESTIMATION

4.1 Introduction

An updated assessment of the Chatham Rise stock only is presented here. In the most recent previous assessment of this stock (Horn & Dunn 2007) the assessment model partitioned the population into two sexes and age groups 1–30, with the last age class considered a plus group. The partition also included maturity, with ogives being estimated within the model. The model's annual cycle was based on a year beginning on 1 September and divided the year into three steps (Table 8). Note that model references to "year" within this document are labelled as the most recent calendar year, i.e., the year 1 September 1998 to 31 August 1999 is referred to as "1999". Some previous assessments of the Chatham Rise stock have been based on fishing year, i.e., years starting on 1 October. However, landings peaks tend to occur from September to January (Figure 11), so it is logical to include the September catch with landings from the five months immediately following it, rather than with catches taken about seven months previously.

Table 8: Annual cycle of the Chatham Rise 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	$\%Z^3$
1	Sep–Feb	Fishing, recruitment, & spawning	0.42	0.25	January resource survey	100
2	Mar–May	None	0.25	0.50		
3	Jun–Aug	Increment age	0.33	0.00		

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

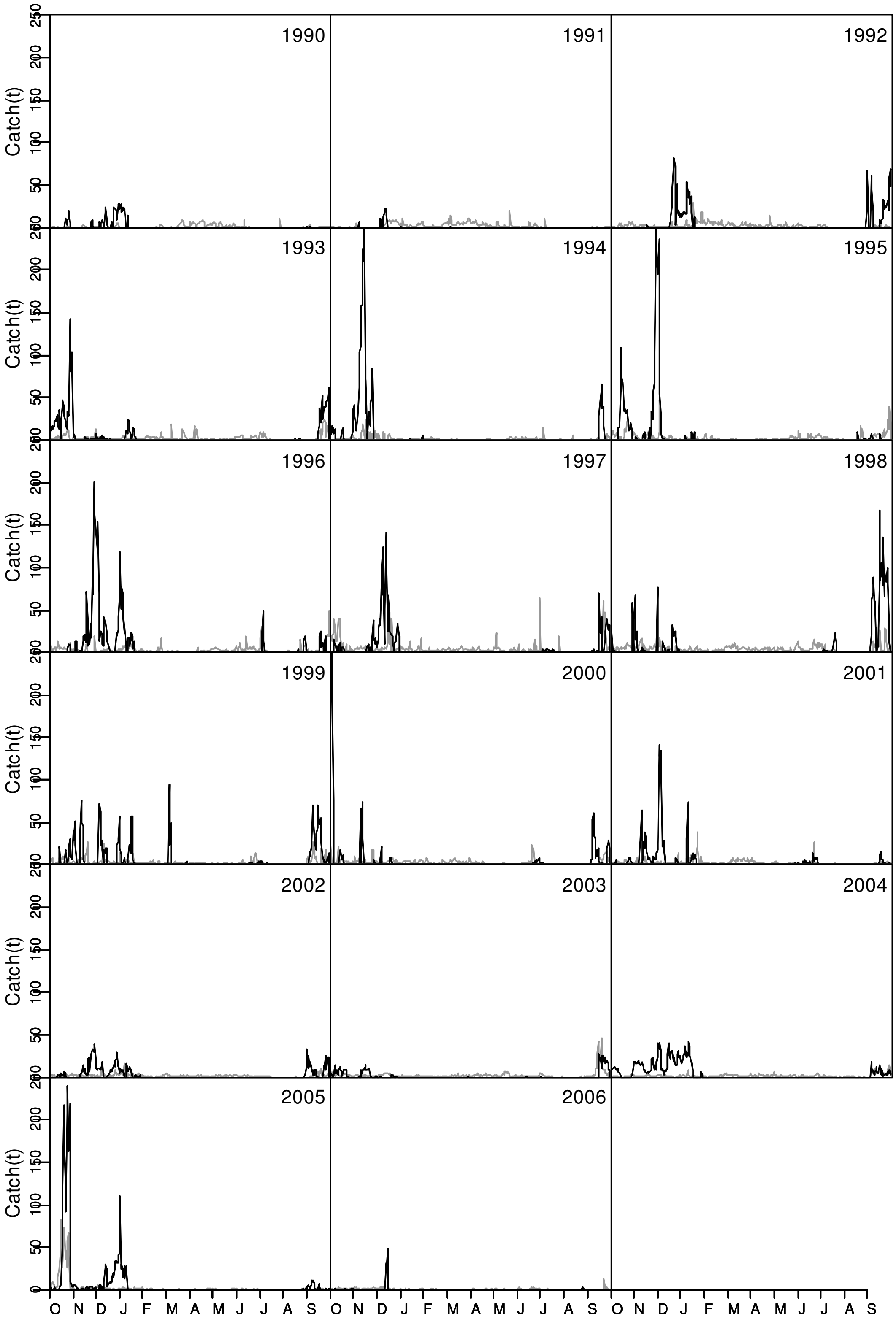


Figure 11: Estimated daily catch (t) of hake on the Chatham Rise by month and target species, 1989–90 to 2005–06, from Devine (2009). Black lines indicate hake targeted tows and grey lines are hoki targeted tows.

For all subsequent models, estimates of fixed biological parameters used in the assessments are given in Table 5. A Beverton-Holt stock-recruitment relationship, with steepness 0.9, was assumed. Variability in the Schnute age-length relationship was assumed to be lognormal with a constant c.v.

of 0.1. The maximum exploitation rate was assumed to be 0.7 for the stock. The choice of the maximum exploitation rate has the effect of determining the minimum possible virgin biomass allowed by the model, given the observed catch history. This value was set relatively high as there was little external information from which to determine it. The model's annual cycle was as described in Table 8.

Biomass estimates from the resource surveys were used as relative biomass indices, with associated c.v.s estimated from the survey analysis. The survey catchability constant (q) was assumed to be constant over all years in the survey series. Catch-at-age observations were available for each research survey (see Figure 3), and from commercial observer data for the fishery. Lognormal errors, with known c.v.s, were assumed for all relative biomass and 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.

The 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 most observations in all model runs. The additional variance, termed process error, was estimated in MPD runs of each model. However, the total error assumed in each run for each observation was not always the sum of process error and observation error (see details for individual models below).

Year class strengths were assumed known (and equal to one) for years before 1975 and after 2005, 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. The Haist parameterisation for year class multipliers is used here (see Bull et al. (2008) for details).

The catch history assumed in all model runs was derived as follows. Using the grooming algorithms of Dunn (2003a), landings of hake reported on TCEPR and CELR forms from 1989–90 to 2007–08 were allocated to month and fishery (based on reported date, location, and depth). Annual totals for each fishery were obtained by summing the monthly totals, but, for reasons described above, using a September to August year. Thus, catch histories for model years 1990 to 2005 were produced. At the same time, catch histories for FMA 3 and FMA 4 were also produced. For each year from 1990 to 2005, the proportions of the FMA 3 catch made up by the 'west shallow' and 'west deep' fisheries were calculated, as were the proportions of the FMA 4 landings made up by the 'east' fishery. Means over all years indicated that the 'west shallow' and 'west deep' fisheries accounted for landings of 99% and 75% respectively of the FMA 3 total, and that the 'east' fishery took landings equivalent to 83% respectively of the FMA 4 total. [Note that the percentages for 'west' and 'east' do not equate to 100% because the western fisheries include an area greater than FMA 3, and the eastern fishery comprises an area smaller than FMA 4.] Dunn et al. (2006) had produced estimates of total Chatham Rise hake catch from 1975 to 1989, and the FMA 4 catch from 1984 to 1989. Estimates of FMA 4 catch before 1984 were obtained primarily from Colman & Livingston (1988). Hence, estimates of hake catch from FMA 3 and FMA 4 from 1975 to 1989 were available or could be derived. To estimate catch by fishery from 1975 to 1989, the percentages presented above were applied to the FMA 3 or FMA 4 landings. The catch in 2008–09 was estimated based largely on patterns of catch from the previous year. Catch histories by fishery are presented in Table 9.

Table 9: Estimated catch (t) by FMA (3 and 4) from the Chatham Rise stock, and total catch, by fishing year, and estimated catch (t) by fishery for the model years. Note that from 1989–90 totals by fishing year and model year differ because the September catch has been shifted from the fishing year into the following model year. Landings from 2008–09 are estimated assuming catch patterns similar to the previous year.

Fishing year	FMA 3	FMA 4	Total	Model year	West shallow	West deep	East	Total
1974–75	50	141	191	1975	46	35	111	191
1975–76	88	400	488	1976	86	65	336	488
1976–77	37	1 251	1 288	1977	42	32	1 214	1 288
1977–78	24	10	34	1978	16	12	6	34
1978–79	55	554	609	1979	59	44	506	609
1979–80	350	400	750	1980	274	207	269	750
1980–81	840	157	997	1981	520	394	83	997
1981–82	290	306	596	1982	224	170	203	596
1982–83	102	200	302	1983	88	66	148	302
1983–84	164	180	344	1984	127	97	120	344
1984–85	145	399	544	1985	132	100	312	544
1985–86	229	133	362	1986	160	122	80	362
1986–87	309	200	509	1987	220	167	122	509
1987–88	286	288	574	1988	219	166	189	574
1988–89	250	554	804	1989	220	166	418	804
1989–90	196	763	959	1990	117	192	689	998
1990–91	207	698	905	1991	131	278	503	912
1991–92	402	2 012	2 414	1992	405	313	1 087	1 805
1992–93	266	2 542	2 808	1993	376	280	1 996	2 652
1993–94	350	2 583	2 933	1994	244	124	2 912	3 280
1994–95	452	2 934	3 386	1995	391	206	2 903	3 500
1995–96	875	3 038	3 913	1996	1 031	323	2 483	3 836
1996–97	924	2 737	3 661	1997	976	499	1 820	3 295
1997–98	1 000	2 983	3 983	1998	835	589	1 124	2 547
1998–99	831	2 541	3 372	1999	729	441	3 339	4 509
1999–00	640	2 302	2 942	2000	771	384	2 130	3 285
2000–01	435	2 069	2 504	2001	731	476	1 700	2 908
2001–02	355	1 414	1 769	2002	200	254	1 058	1 512
2002–03	602	812	1 414	2003	248	249	718	1 215
2003–04	210	2 281	2 491	2004	376	312	1 983	2 671
2004–05	2 485	1 268	3 753	2005	263	2 322	1 434	4 019
2005–06	54	305	359	2006	125	59	255	440
2006–07	181	900	1 081	2007	197	73	683	953
2007–08	233	865	1 098	2008	149	110	901	1 159
2008–09				2009	150	100	890	1 140

4.2 Developing a 'base' model

It was noted above (Section 3.4.1) that some amalgamation of the fisheries defined from the tree regression analysis of the observer catch-at-age data would be desirable, i.e., combining the two western fisheries as one, and combining the two eastern fisheries as one. It was also apparent that the previous Chatham Rise assessment model did not fit the only fishery-independent relative abundance series (i.e., the summer trawl survey series) particularly well (Horn & Dunn 2007). Because this series exhibits a relatively smooth trend over time, and so is probably a reasonable index of relative abundance, we believe that any 'good' assessment model should fit it well. Consequently, some initial investigations were completed to develop a new 'base' model. Model parameters were estimated using Bayesian estimation implemented using the CASAL software. However, only the mode of the joint posterior distribution (MPD) was estimated in these initial runs. (Full details of the CASAL algorithms, software, and methods were detailed by Bull et al. (2008).)

In developing a base model a series of eight models was considered, with each new model typically differing from previous models in only one key assumption (Table 10).

Table 10: Brief description of the assumptions that differed amongst the eight models that were considered in developing a base case model (see text for more detail). For each model, the underlined assumption(s) is the main one that distinguished it from preceding models.

	Model number							
Assumption	1	2	3	4	5[1]	6	7	8[2]
Include process error for survey biomass	Y	N	N	N	N	N	N	N
Double process error for at-age data	N	Y	Y	Y	Y	Y	Y	N
Number of western fisheries	2	2	1	1	1	1	2	1
Ageing error assumed	Y	Y	Y	N	Y	Y	Y	Y
Smooth 1975–83 year-class strengths	N	N	N	N	Y	Y	Y	Y
All selectivities domed	Y	Y	Y	Y	Y	N	Y	Y
CPUE data used	N	N	N	N	N	N	Y	N
Sex in partition and data	Y	Y	Y	Y	Y	Y	Y	N

[1] Referred to in Section 5 as the ‘two sex’ model; [2] Base case model for the assessment

An initial model (model 1) was set up, partitioning the population into two sexes and age groups 1–30, with the last age class considered a plus group. The partition did not include maturity. The model used eight selectivity ogives: male and female survey selectivities for the January *Tangaroa* resource survey series, and male and female survey selectivities for each of the three commercial fisheries (i.e., west shallow, west deep, east). Female selectivity was always estimated relative to male selectivity. Selectivities were assumed constant over all years in the fisheries or the survey series. All selectivity ogives were estimated using the double-normal parameterisation. Process error of 0.2 was added to survey biomass indices following the recommendation of Francis et al. (2003). Process error for all the catch-at-age series was estimated in the model. No catch-at-length data or CPUE series were incorporated.

The MPD fit to this initial model produced the following estimates of process error for the catch-at-age series: research survey, 0.001; west shallow fishery, 0.31; west deep fishery, 0.61; east fishery, 0.19. Stock status in 2009 was estimated to be 61% of B_0. However, the survey biomass series was poorly fitted, with clearly unbalanced residuals (Figure 12). Consequently, this model was not considered to be satisfactory.

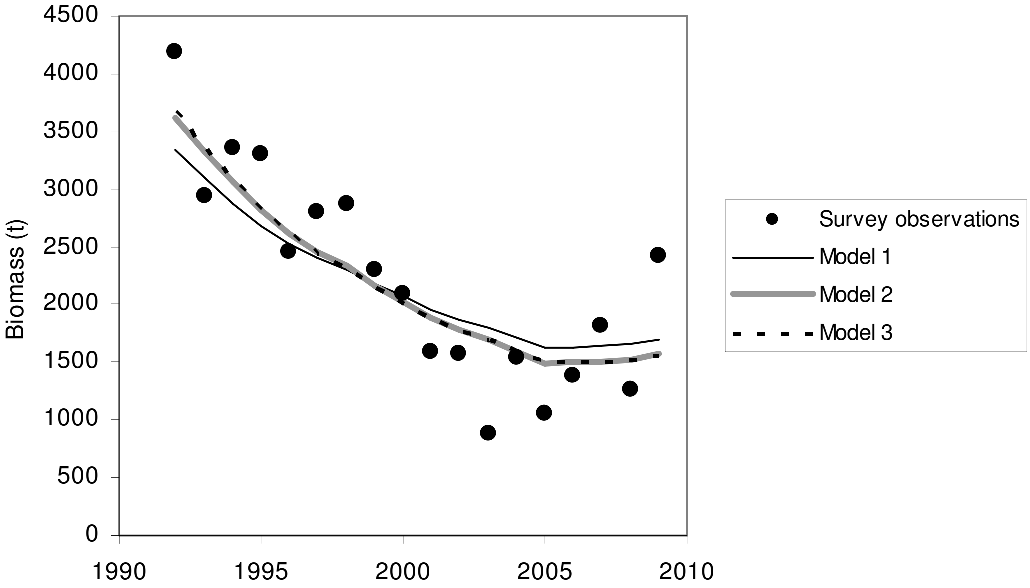


Figure 12: MPD model fits (lines) to the trawl survey biomass indices (dots) for models 1–3.

To encourage a better fit to the biomass indices, model 2 included the survey series with no process error, and approximately doubled the process error for the catch-at-age series, i.e., process errors were: research survey, 0.1; west shallow fishery, 0.6; west deep fishery, 1.2; east fishery, 0.4. This model produced a somewhat better fit to the survey biomass series (Figure 12), and changed the stock status to be 54% of B_0.

Model 3 examined the effect of combining the two western fisheries. It was identical to model 2 except that there was a single catch history, and a single set of catch-at-age distributions, for the previously separate western fisheries. Process error of the western fishery catch-at-age was entered as 1.0, i.e., about twice the estimated value. The results from model 3 run were virtually identical to those from model 2 (see fit to biomass in Figure 12); estimated stock status in 2009 was again 54% of B_0. Because there was little difference between results from models 2 and 3, and because the catch-at-age distributions are so similar for the two western fisheries (see Figure 9), we chose to use a single western fishery in all following models. A striking feature of model 3 is that the spawning biomass was estimated to have increased by 49% in the 1980s, before the survey series started, and this increase was driven primarily by extremely strong year classes in 1977 and 1980 (Figure 13).

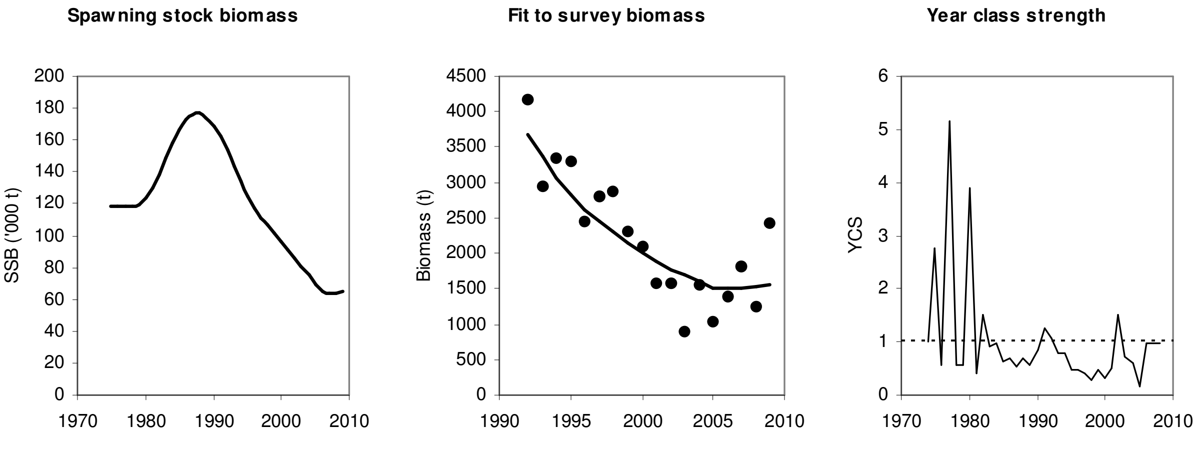


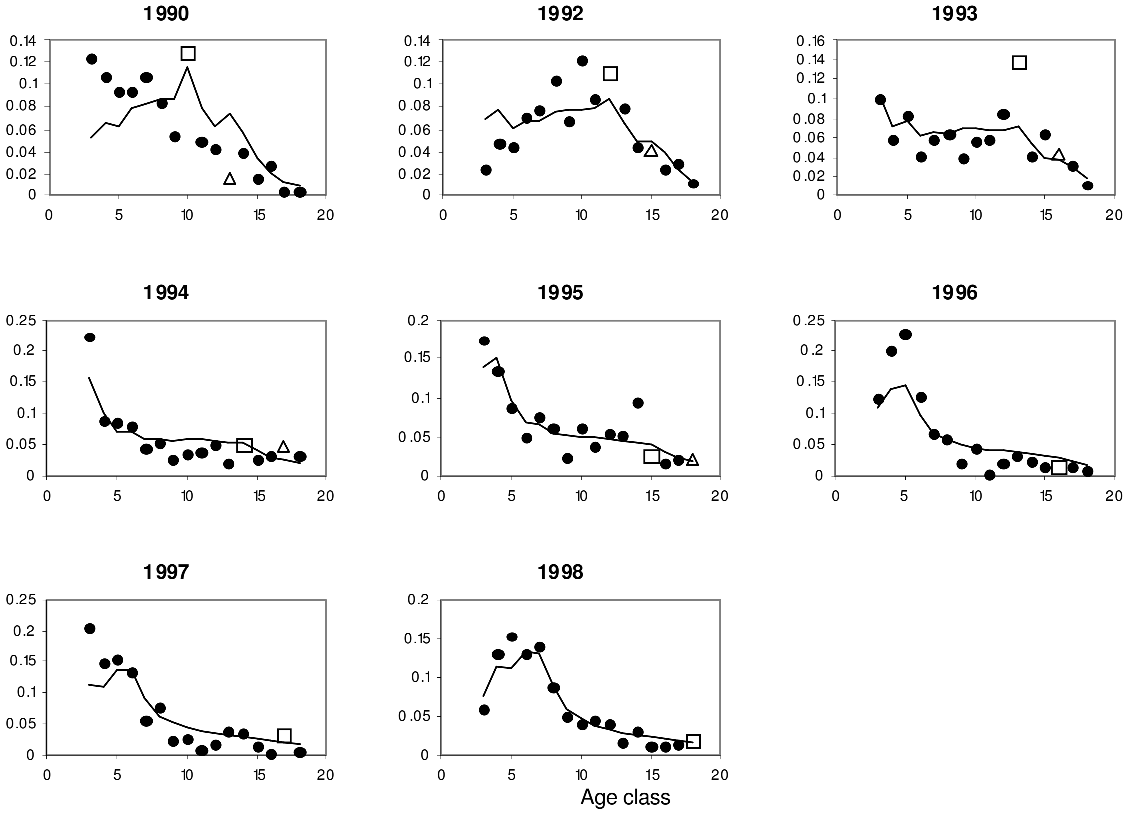
Figure 13: Estimated spawning stock biomass and year class strengths, and fits to the research survey biomass, from model 3.

The age data were examined to see what information existed to indicate that the 1980 and 1977 year classes were particularly strong (Figure 14). There was some indication from the earlier part of the trawl survey series (i.e., the 1990 and 1992–1994 surveys) that the 1980 year class is strong. However, the commercial fishery data seldom indicated that the 1980 year class was exceptional. The 1977 year class seldom appears to be strong in any data set; only the 1994 survey and 1992 fishery distributions suggest that this year class might be stronger than average. It was suspected that these estimated strong year classes were an artefact, the consequence of a tendency for models which assume ageing error to estimate high variability in year-class strength in periods with few data.

Consequently, two additional models were run to investigate year class strength estimation: in model 4, the assumption of ageing error was dropped; model 5 retained this assumption but smoothed the year class strengths from 1975 to 1983.

The new models both produced early year class strength estimates that were markedly different from those of model 3, as well as large changes in estimated spawning stock biomass (Figure 15). It was clear that the extreme estimates of year class strength (both high and low) are artefacts of the application of ageing error to age classes with few data. All three models produced similar patterns of year class strengths from 1984 to 2005, where the data were more abundant. The two new models were similar over their entire range, and they still provided a clear indication of some stronger than average year classes in the late 1970s. However, the magnitude of the pre-survey rise in biomass is markedly reduced in the two new models (from 49% in model 3 to 26% and 32% in models 4 and 5), as are the estimates of B_0 (model 3, 118 740 t; model 4, 67 420 t; model 5, 81 590 t). But stock status (B_{2009} as $\%B_0$) varies little between all three models, i.e., model 3, 54%; model 4, 55%; model 5, 56%.

Trawl survey



Commercial fisheries

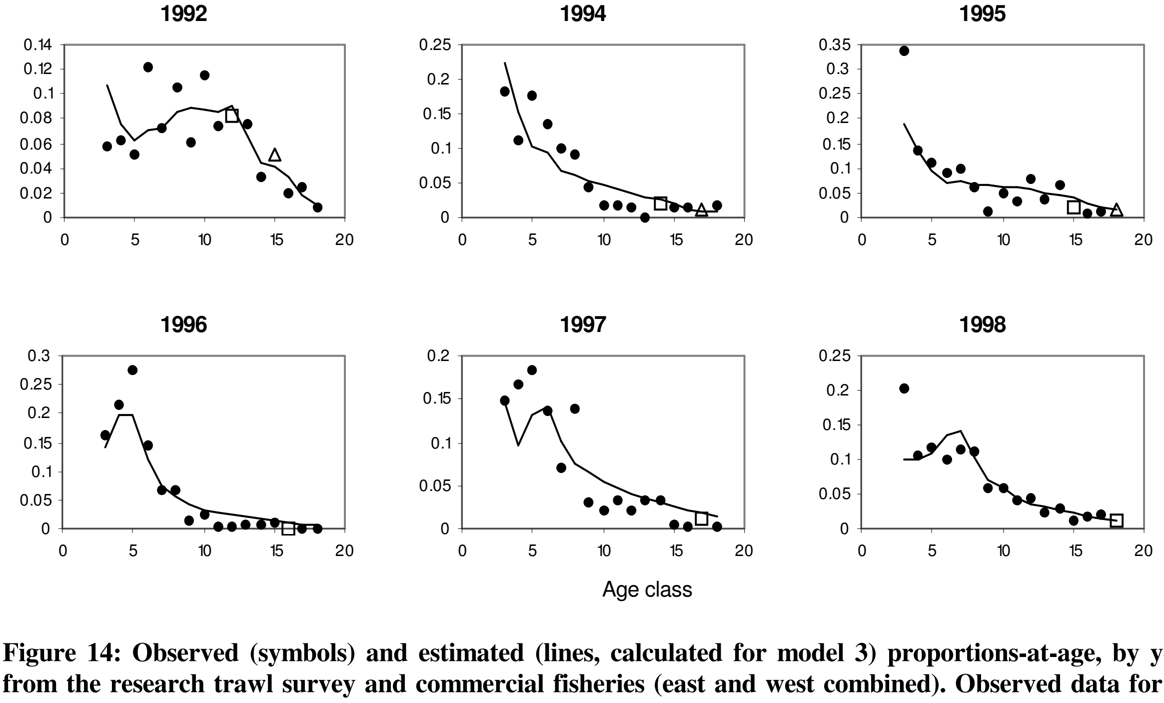


Figure 14: Observed (symbols) and estimated (lines, calculated for model 3) proportions-at-age, by year, from the research trawl survey and commercial fisheries (east and west combined). Observed data for the 1980 year class are represented as open squares, and 1977 year class data are open triangle.

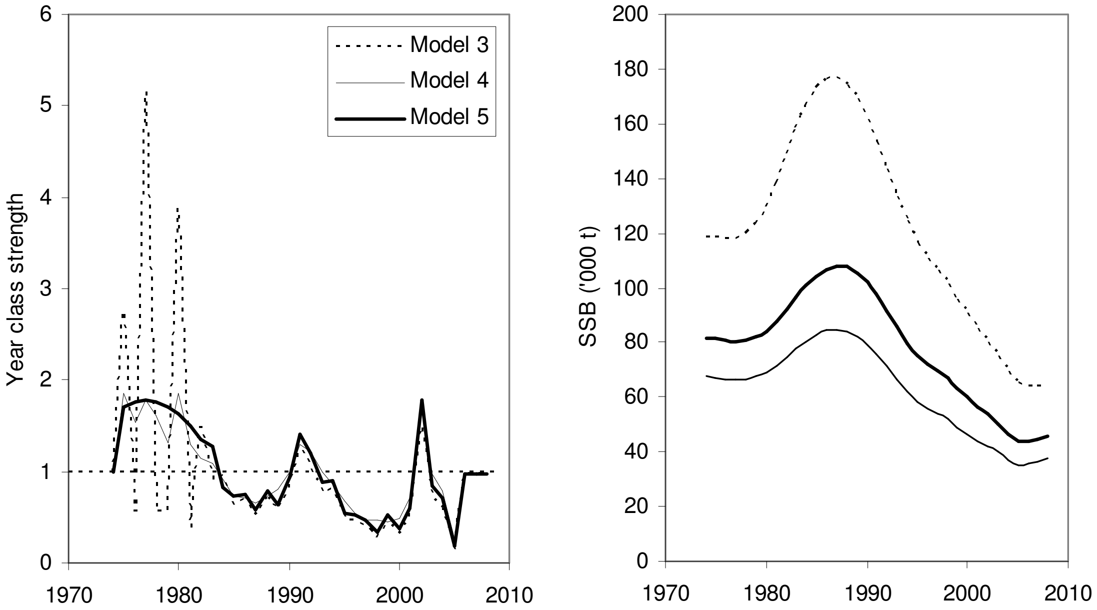


Figure 15: Estimates of year class strength and spawning stock biomass (SSB) from models 3–5.

It was considered desirable to include some ageing error in the assessment model, so the smoothing of early year class strengths was retained for all subsequent models. The effect of including this smoothing was to slightly degrade the fit to all data series (Table 11).

Table 11: Negative log likelihood of all data series for models 3 and 5, showing how the smoothing of early year class strengths in the latter model slightly degraded the fits compared to those in the former.

Data series	Model 3	Model 5	Gain
Survey biomass	-15.1	-13.9	-1.1
Survey age	97.0	98.9	-1.9
West fishery age	216.4	218.6	-2.2
East fishery age	70.2	72.3	-2.1
Priors & penalties	7.7	11.7	-3.9
Total log likelihood	376.4	387.6	-11.2

All models investigated so far had selectivity ogives that had been fitted using the double-normal parameterisation. The effects of forcing logistic selectivity ogives for the research biomass survey and the eastern fishery were examined in model 6, with the underlying assumptions being that the survey comprehensively samples all the adult population, and the eastern fishery exploits all mature fish. However, the overall fit for this model was much worse than for model 5, particularly for the two series where logistic selectivity ogives were applied (Table 12). Consequently, we concluded that given the currently used constant values for natural mortality rate, catch-at-age data from all sources are much better fitted by double-normal, rather than logistic, ogives.

Table 12: Negative log likelihood of all data series from models 5 and 6, showing how forcing ogives for the survey and east fishery to be logistic substantially degraded the fit to the corresponding at-age data.

Data series	Model 5	Model 6	Gain
Survey biomass	-13.9	-14.3	0.4
Survey age	98.9	142.4	-43.5
West fishery age	218.6	210.7	7.9
East fishery age	72.3	114.4	-42.1
Priors & penalties	11.7	6.8	4.9
Total log likelihood	387.6	460.0	-72.4

The usefulness of the available CPUE indices was investigated by including them in model 7, which was like model 2, but with the early year class strengths smoothed. While this model fitted the eastern fishery CPUE reasonably well, the fit to the west deep fishery was poor, and even worse for the west shallow fishery, and the fit to the trawl biomass series was also clearly inadequate (Figure 16). Current stock status was estimated to be 74% of B_0. At this stage we reject the CPUE series as being useful model inputs.

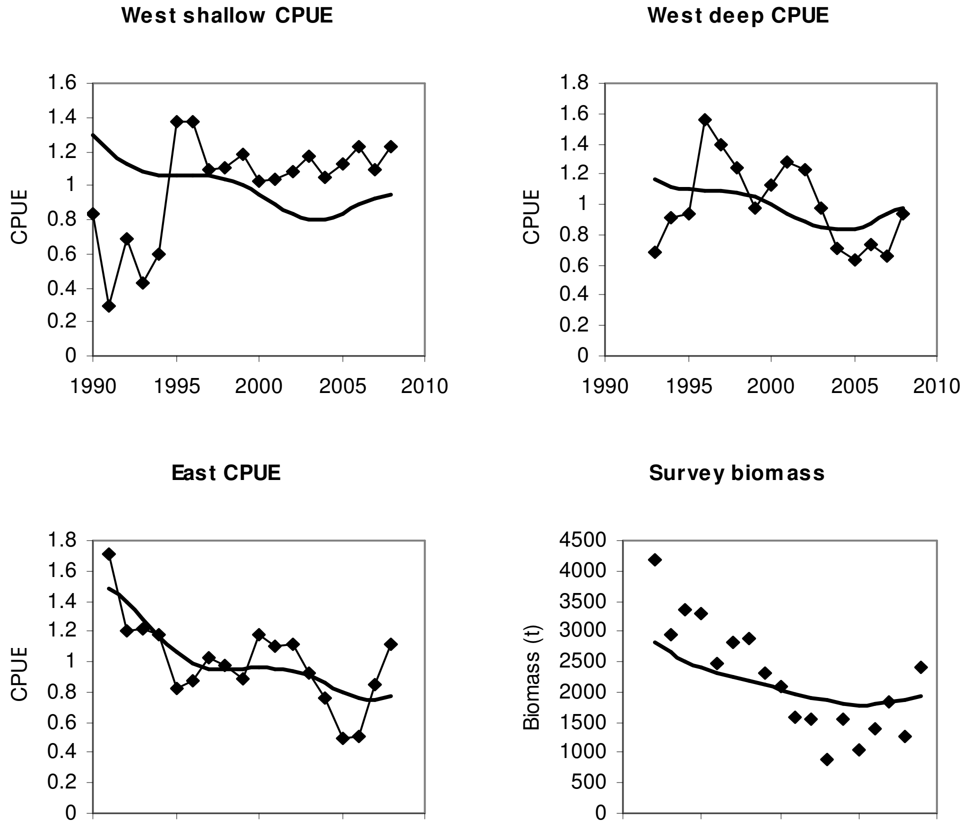


Figure 16: MPD model fits (lines) to observed CPUE and trawl survey biomass indices (dots) for model 7.

A likelihood profile for model 5 showed that the estimated B_0 of about 80 000 t was almost twice that suggested by the trawl survey biomass (44 000 t), and that this was because all the catch-at-age series supported high values of B_0, particularly those from the commercial fisheries (Figure 17). An MPD run forcing B_0 to be 44 000 t did result in a better fit to the biomass series (Figure 18), but, as expected, the fits to the catch-at-age series were worse, particularly for the eastern fishery (Table 13).

Table 13: Negative log likelihood of data series showing the effect on model 5 of forcing B_0 to be 44 000 t.

Data series	Model 5	B_0 = 44 000 t	Gain
Survey biomass	-13.9	-15.9	2.0
Survey age	98.9	104.6	-5.7
West fishery age	218.6	220.8	-2.2
East fishery age	72.3	85.3	-13.0
Priors & penalties	11.7	7.6	4.1
Total log likelihood	387.6	402.4	-14.8

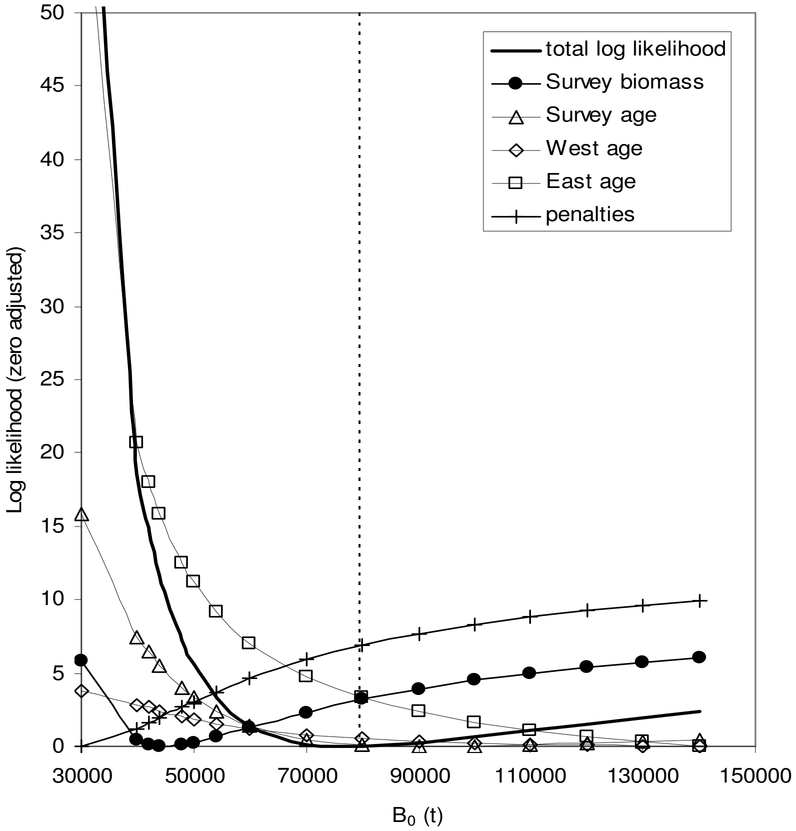


Figure 17: Likelihood profile on B_0 for model 5, showing both the total likelihood (heavy line) and those for individual data series. Vertical dashed line shows the model estimate of B_0.

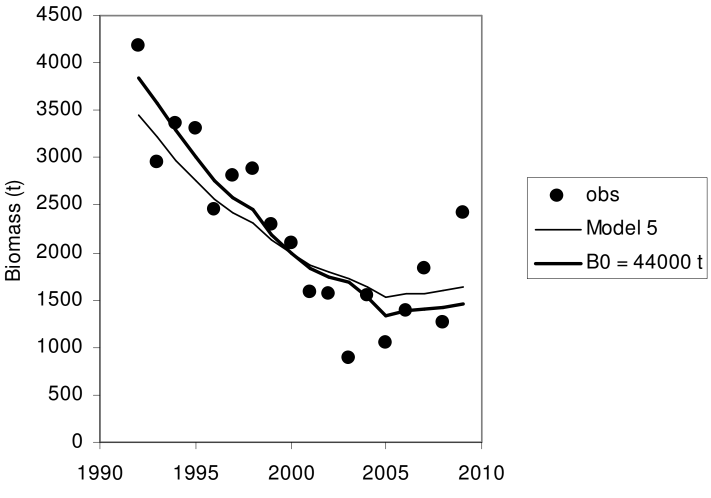


Figure 18: MPD model fits (lines) to the observed trawl survey biomass indices (dots) showing the effect on model 5 of forcing B_0 to be 44 000 t.

The conflict in the signals about stock size from the survey biomass and catch-at-age series was investigated by disaggregating the gains in fit for the at-age data (shown in Table 13) by year, age, and sex. The aim was to determine which parts of these data sets were most strongly in conflict with a B_0 of 44 000 t. There were no trends by year or age that were consistent across all data sets (upper and middle panels, Figure 19), but there was a clear pattern of the male proportions-at-age fitting worse than those for females (lower panels, Figure 19).

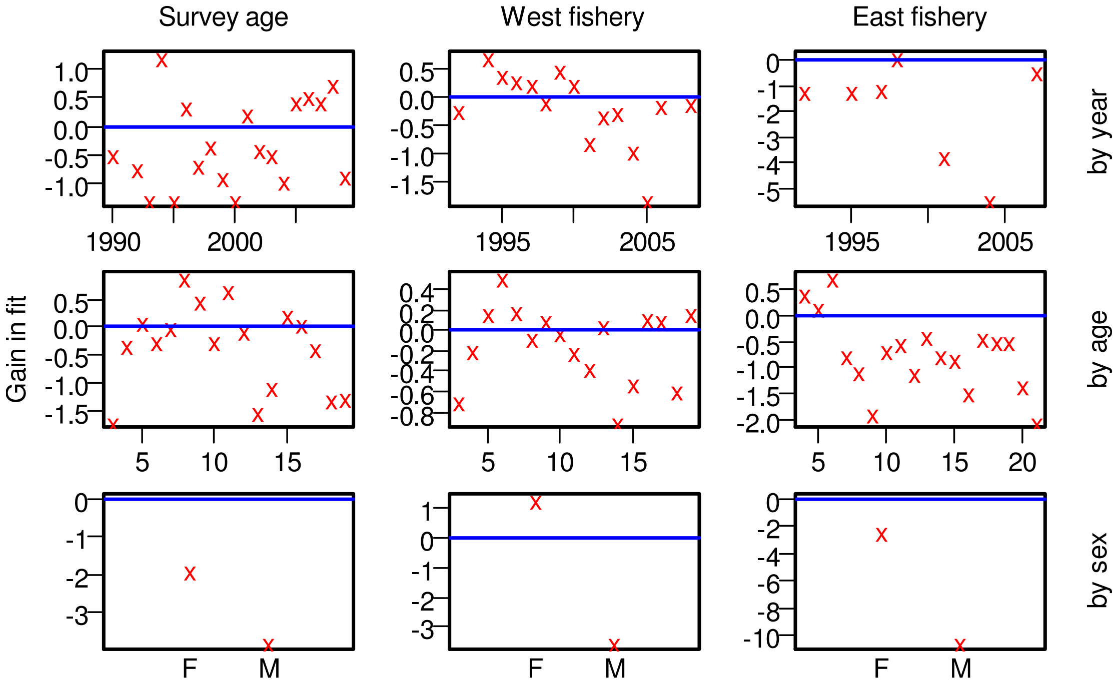


Figure 19: The gains of fit to the three at-age data sets when B_0 is forced to be 44 000 t, disaggregated by year (top panels), age (middle panels), or by sex (bottom panels). Note that the sum of the gains in each panel is as given in Table 13 (e.g., for the east fishery — right-hand panels — the sum of the gains in each panel is always -13.0).

This finding led us to examine the sex ratio data in the model, which were found to be inconsistent, and poorly fitted by the model. The slight downward trend in percentage male in the survey data could be interpreted as a population response to the high percentage male in the eastern fishery, but is inconsistent with the upward trend in the western fishery, with the result that model 5 estimates little or no trend (Figure 20). A closer examination of the fishery data showed strong between-trip variation in percentage male in each year, with the estimated percentage male for each year often being dominated by only one or two trips (Figure 21). Since observer coverage (calculated as total weight of sampled catches in each year as a percentage of the fishery catch) of these fisheries is very low (median annual coverage were 1.4% and 1.7% in the western and eastern fisheries, respectively) the fishery sex ratio data cannot be considered representative. There was also a strong between-trip variation in the mean length of sampled fish in each year (Figure 22), suggesting that catch-at-length (and, therefore, catch-at-age) may also not be representative of the entire fishery.

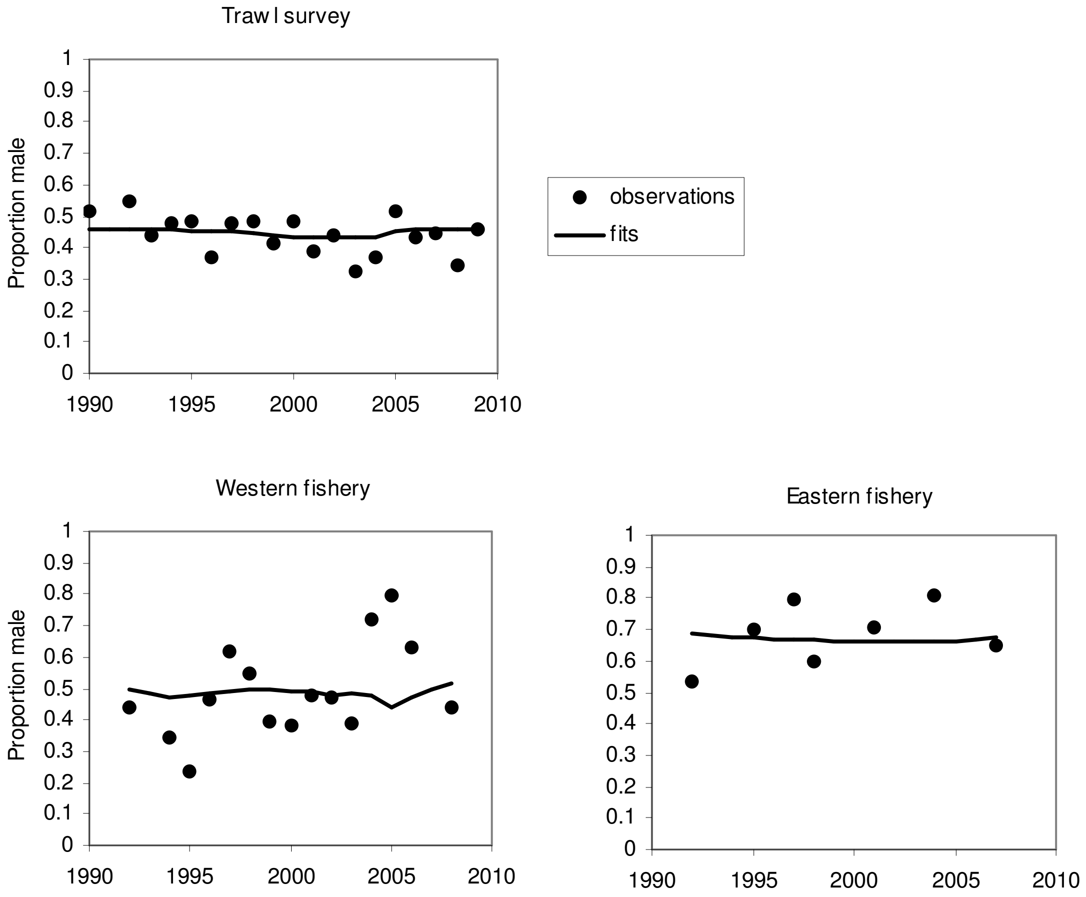


Figure 20: Observed (points) and estimated (lines, from model 5) percentage of male by year from the research trawl survey and fisheries.

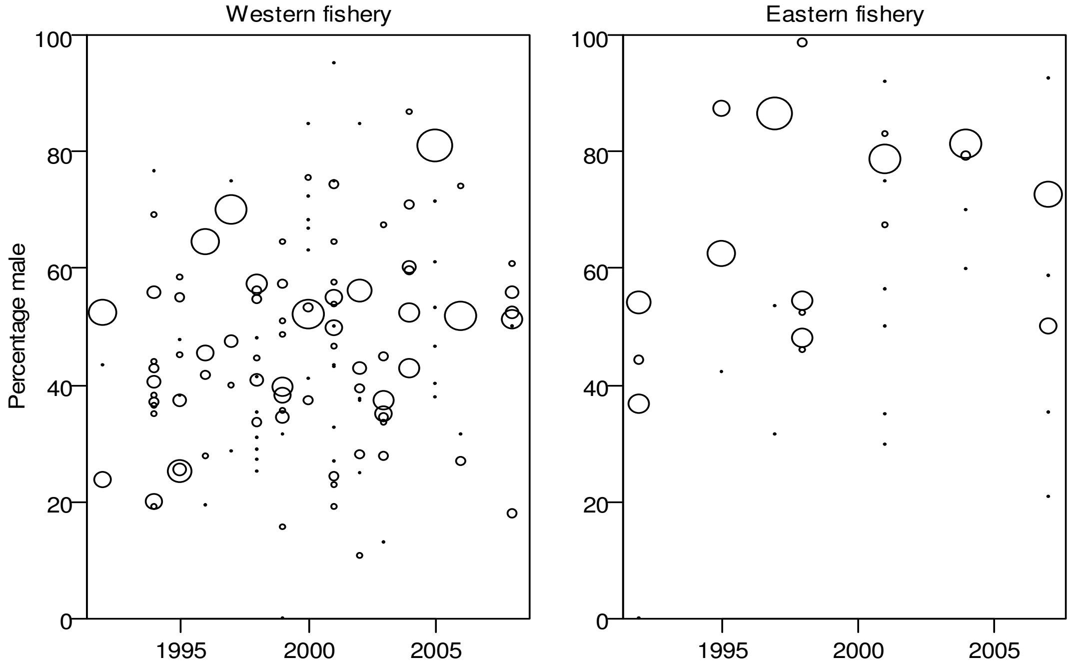


Figure 21: Percentage male by trip and fishery for all fishing trips sampled by observers. Each plotted point shows the weighted average percentage male (weighted by catch weights) for all the sampled tows in one fishing trip that were in the specified fishery. Within each year and fishery, the area of the plotted circle is proportional to the total sampled catch for that trip as a fraction of the total sampled catch for the year. Data for years not included in the catch-at-age data were excluded.

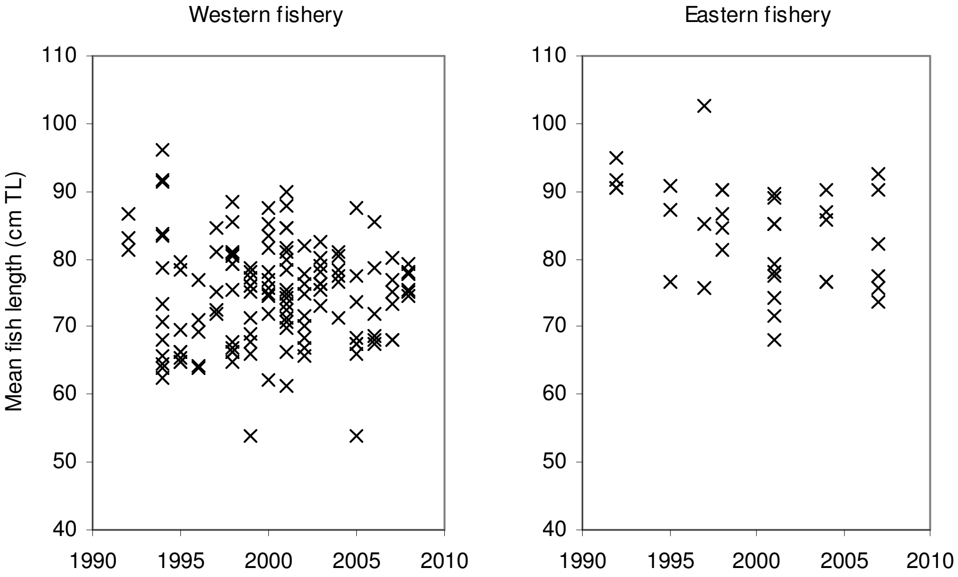


Figure 22: Mean fish length by trip and fishery for all fishing trips sampled by observers. Each plotted point shows the weighted average length (weighted by catch weights) for all the sampled tows in one fishing trip that were in the specified fishery. Data for years not included in the catch-at-age data were excluded.

Consequently, a single-sex model (model 8) was tested. In that model, sex was removed from the partition, length-weight and Schnute growth parameters were calculated for both sexes combined (see Table 5), *M* was set at 0.19 (the average of the male and female values), all catch-at-age data were unsexed, and the 1974–1983 year class strengths were smoothed as before. There were two fisheries (east and west), and all selectivity ogives were estimated using the double-normal parameterisation. The model assumed no process error on the survey biomass indices, but allowed process error on the catch-at-age series as estimated in the model, i.e., research survey, 0.001; west fishery, 0.35; east fishery, 0.001. Note that these process errors were not doubled, as they were in models 2–7.

Removing sex from the model substantially reduced the estimate of B_0 (from 80 000 t to 42 000 t), produced a better fit to the survey biomass indices (the negative log likelihood for this series reduced from -13.9 to -16.2), but had comparatively little effect on the estimated year class strengths (Figure 23). Because of the lower B_0, stock status in 2009 was also lower at 47% of B_0 (compared to 56%B_0 for model 5). Despite the increased pessimism in the single sex model, the fishing pressure in most years is still less than 0.1, and never greater than 0.19. A period of relatively strong recruitment in the late 1970s was still indicated, resulting in a moderate increase in stock biomass during the 1980s before the start of the survey series (see Figure 23). Fishery selectivity ogives are logical, i.e., age at peak selectivity is lower in the western fishery than in the eastern (spawning) fishery (Figure 24).

A major effect of removing sex from the model was to reduce the degree of conflict between the at-age data and the survey biomass series (even though the at-age data were not down-weighted by the doubling of process error c.v.s). MPD model fits to the at-age data are shown in Appendix B. For model 8, the estimated B_0 (42 000 t) was only 14% higher than the value that minimised the negative log likelihood for the biomass data alone (37 000 t, Figure 25), whereas the comparable value for model 5 was 82% (see Figure 17).

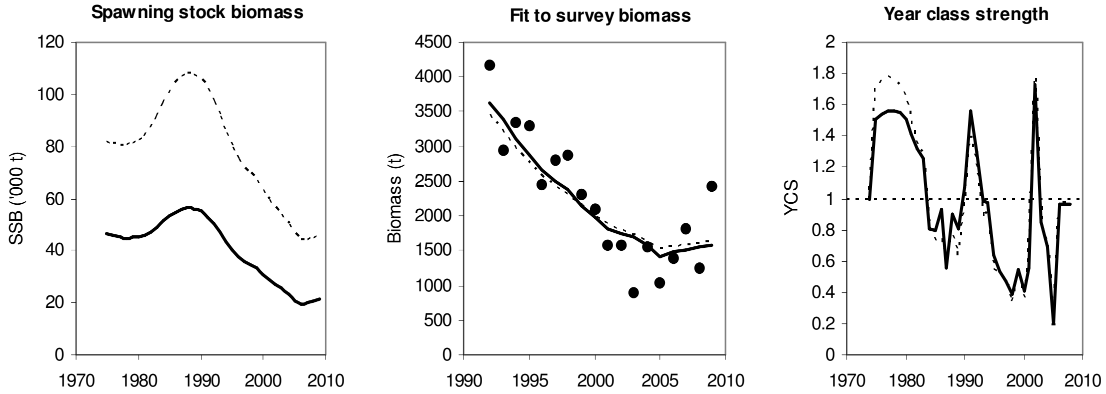


Figure 23: Estimated spawning stock biomass and year class strengths, and fits to the research survey biomass, from model 8 (solid lines). Also shown, for comparison, are estimates from model 5 (broken lines).

Figure 24: Estimated selectivity ogives for the research survey and two commercial fisheries from model 8.

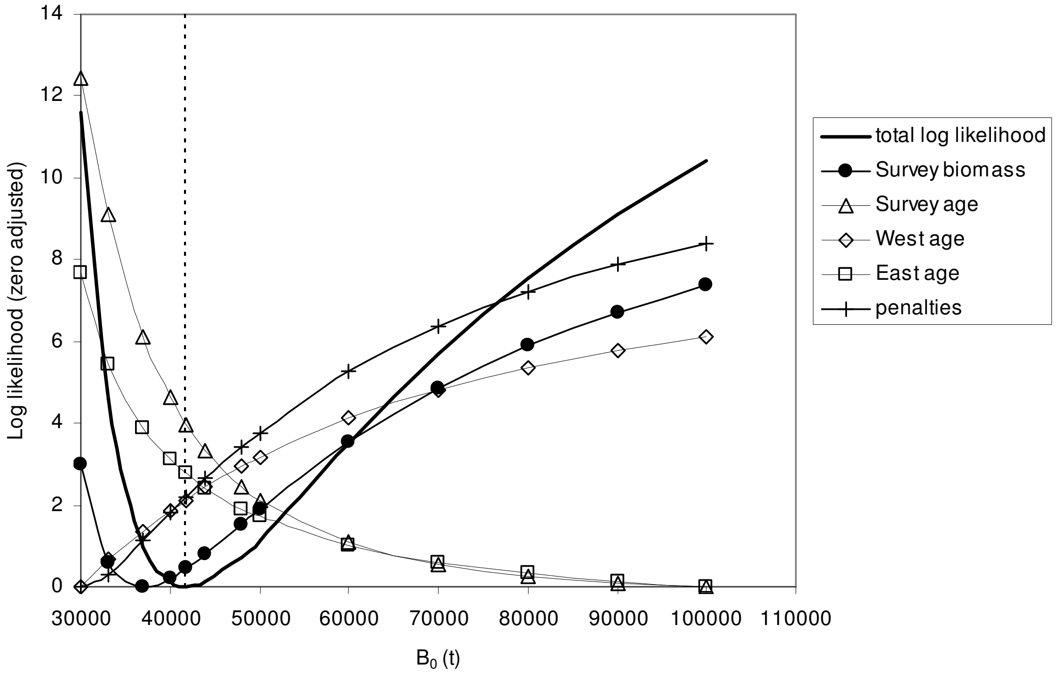


Figure 25: Likelihood profile on B_0 for model 8, showing both the total likelihood (heavy line) and those for individual data series. Vertical dashed line shows the model estimate of B_0.

Following the investigations above with MPD model fits we concluded that the best base case model for MCMC estimation was model 8 (hereafter called the 'single sex' model). The Middle Depth Species Fishery Assessment Working Group requested that model 5 (hereafter called the 'two sex' model) also be fully investigated as a sensitivity to the base case.

4.3 Model estimation using MCMC

Model parameters were estimated using Bayesian estimation implemented using the CASAL software. For final runs, the full posterior distribution was sampled using Monte Carlo Markov Chain (MCMC) methods, based on the Metropolis-Hastings algorithm. MCMCs were estimated using 3×10^6 iterations, a burn-in length of 5×10^5 iterations, and with every 2500th sample kept from the final 2.5×10^6 iterations (i.e., a final sample of length 1000 was taken from the Bayesian posterior). Year class strengths were estimated as in the MPD runs except that values for 2006–08 were no longer fixed at 1.

4.4 Prior distributions and penalty functions

The assumed prior distributions used in the assessment are given in Table 14. The priors for B_0 and year class strengths were intended to be relatively uninformed, and had wide bounds. The prior for the survey *q* was informative and was estimated by assuming that the catchability constant was the product of areal availability, vertical availability, and vulnerability. This same *q* prior was used in the previous Chatham Rise hake assessment (Horn & Dunn 2007). A simple simulation was conducted that estimated a distribution of possible values for the catchability constant by assuming that each of these factors was independent and 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 and 0.40 (Figure 26). Priors for all selectivity parameters were assumed to be uniform. The values of survey catchability constants are dependent 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*.

Penalty functions were used a) to constrain the model so that any combination of parameters that resulted in a stock size that was so low that the historical catch could not have been taken was strongly penalised, b) to ensure that all estimated year class strengths averaged 1, and c) to smooth the year class strengths estimated over the period 1974 to 1983.

Table 14: The assumed priors assumed for key distributions (when estimated). The parameters are mean (in natural space) and c.v.

Stock	Parameter	Distribution	Parameters		Bounds	
Chatham Rise	B_0	Uniform-log	–	–	10 000	250 000
	Survey *q*	Lognormal	0.16	0.79	0.01	0.40
	YCS	Lognormal	1.0	1.1	0.01	100

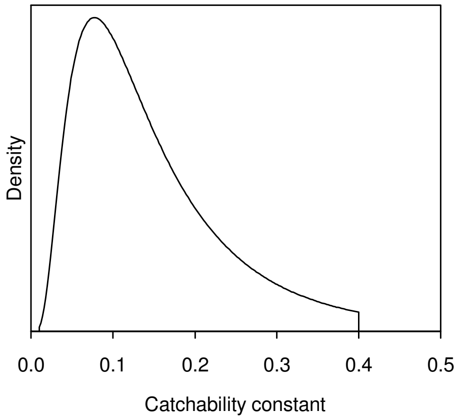


Figure 26: The prior distribution for the survey catchability constant (*q*), lognormal where μ=0.16, c.v.=0.79, and bounds (0.01,0.40).

5. MODEL ESTIMATES

Base case (i.e., single sex model, model 8) estimates of biomass were made using the biological parameters (see Table 5) and model input parameters described earlier. One sensitivity (i.e., two sex model) was investigated. Model characteristics are listed in Table 10.

MCMC estimates of the posterior distribution were obtained for both model runs, and are presented below. In addition, MCMC estimates of the median posterior and 95% percentile credible intervals are reported for the key output parameters. A comparison of the MCMC chains for estimates of B_0 from the two models shows that both are reasonably well converged (Figure 27).

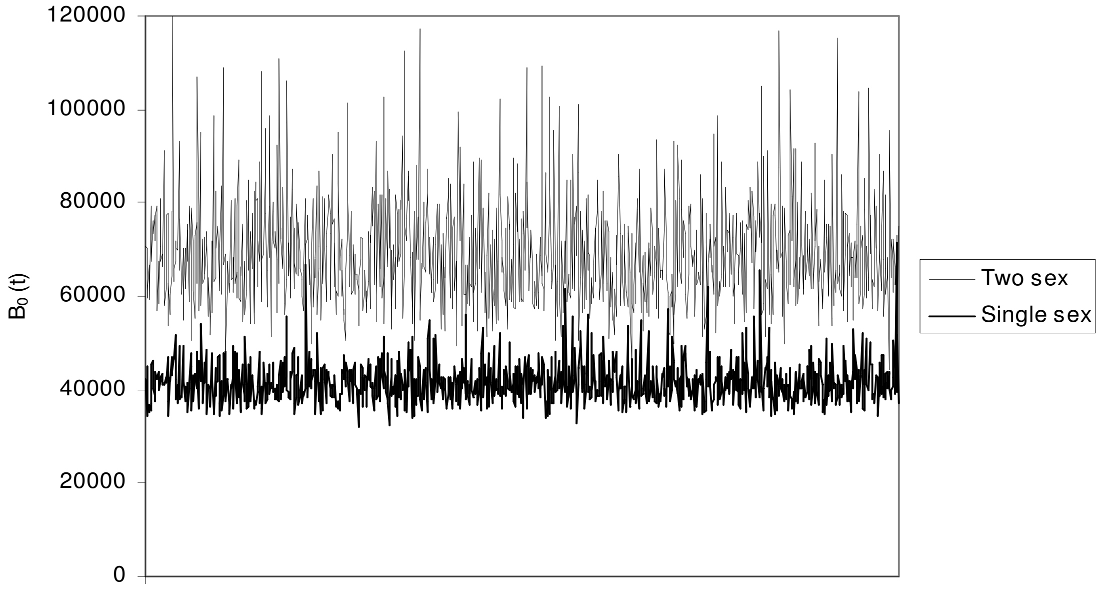


Figure 27: Trace diagnostic plot of the MCMC chains for estimates of B_0 for all the Chatham Rise stock model runs.

The estimated MCMC marginal posterior distributions for selected parameters from the Base case model are shown in Figures 28–32. The estimated research survey catchability constant is estimated to be about 10%, suggesting that the absolute catchability of the survey series is moderately low, though consistent with the prior (Figure 28). The fit to the research series in this model run is reasonably good (Figure 28), but the model was encouraged to fit these indices well by excluding process error from this series. Resource survey and fishery selectivity ogives were relatively tightly defined (Figure 29). The survey ogive suggested that hake were not fully selected by the research gear until about age 16. Fishing selectivities indicated that hake were fully selected in the western fisheries by about age 7 years, compared to age 12 in the eastern fishery; this is logical given that the eastern fishery concentrates more on the spawning (i.e., older) biomass. 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 1984). Consequently, these year class strength estimates were smoothed, and are indicative of a period of generally higher than average recruitment (Figure 30). More recent year class strengths appear well estimated, with strong recruitment in the early 1990s, followed by a period of steadily declining recruitment to 2001. The 2002 year class was strong, but it has been followed by more relatively weak year classes. The strength of the 2002 year class is strongly supported by consistent data from the research survey series (see Figure 3).

Estimated biomass for the Chatham stock increased throughout the 1980s owing to the relatively strong recruitment during the late 1970s (Figure 31). Biomass then steadily declined from 1989 to 2005 owing to higher levels of exploitation and generally poor recruitment. The slight increase since 2005 is a consequence of the growth of the strong 2002 year class. Bounds around the biomass estimates are reasonably tight, with current stock size being about 47% of B_0 (95% credible interval 39–55%) (see Figure 31 and Table 15.) Exploitation rates (catch over vulnerable biomass) were very low up to the early 1990s, then were moderate (0.10–0.25 yr^{-1}) for about 10 years, but low again since 2006 (Figure 32).

Table 15: Bayesian median and 95% credible intervals of B_0, B_{2009}, and B_{2009} as a percentage of B_0 for the Chatham Rise model runs.

Model run	B_0	B_{2009}	B_{2009} (%B_0)
Base case	41 030 (34 910–52 070)	19 160 (14 160–27 810)	46.7 (39.4–54.5)
Two sex	67 600 (52 420–98 560)	37 870 (25 870–62 260)	56.4 (48.6–64.9)

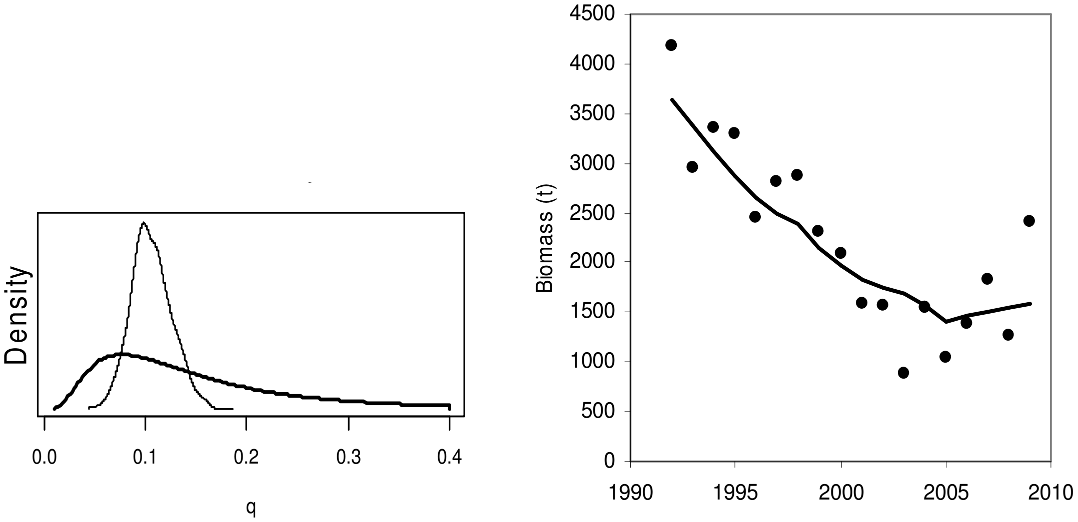


Figure 28: Base case — Estimated posterior distribution (thin line) and prior (thick line) of survey catchability constant *q* for the Chatham Rise January resource survey series, and the MPD fit (thick line) to the observed survey biomass estimates (filled circles).

Figure 29: Base case — Estimated median selectivity ogives (with 95% credible intervals shown as dashed lines) for the trawl survey series, the western fishery and the eastern fishery, for the Chatham Rise stock.

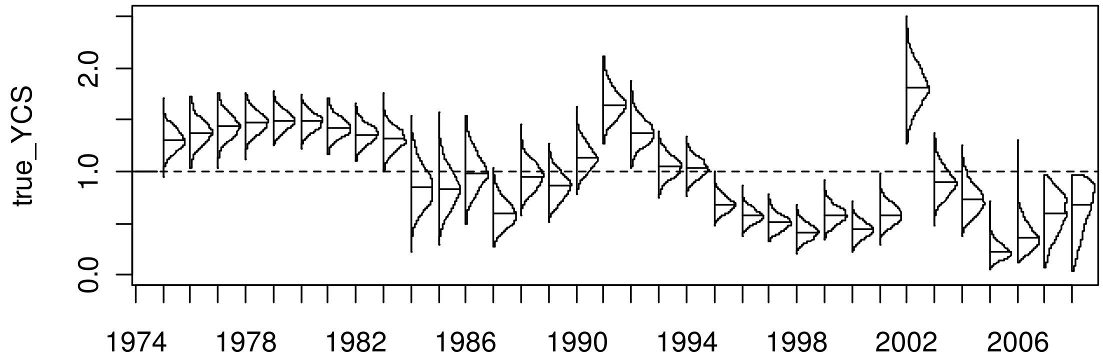


Figure 30: Base case — Estimated posterior distributions of year class strengths for the Chatham Rise stock. The dashed horizontal line indicates the year class strength of one. Individual distributions are the marginal posteriors, with horizontal lines indicating the median.

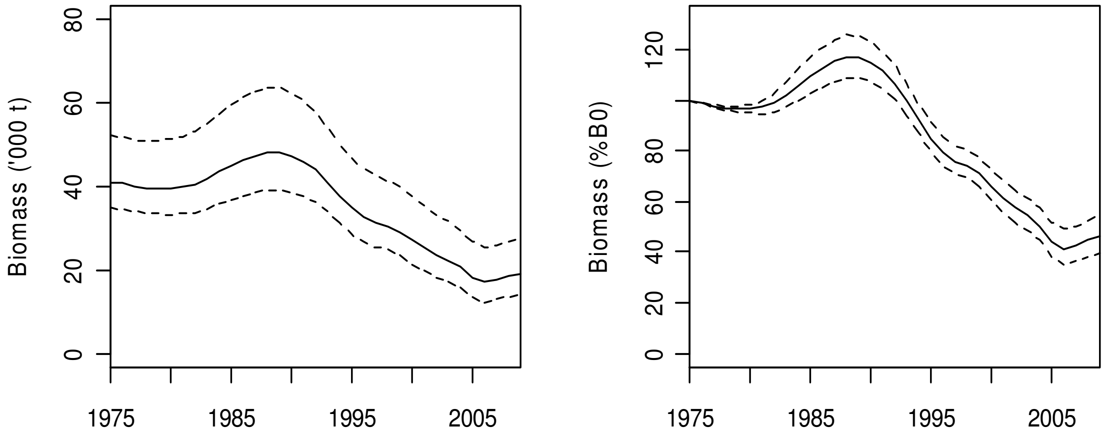


Figure 31: Base case — Estimated median trajectories (with 95% credible intervals shown as dashed lines) for absolute biomass and biomass as a percentage of B_0, for the Chatham Rise stock.

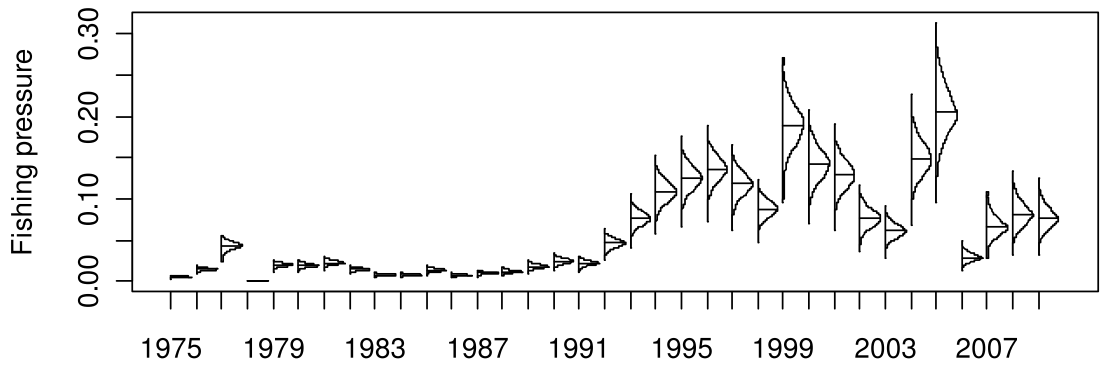


Figure 32: Base case — Estimated posterior distributions of exploitation rates for the Chatham Rise stock. Individual distributions are the marginal posteriors, with horizontal lines indicating the median.

The ‘Two sex’ sensitivity run was identical to the Base case except that sex was included in the partition and the process error applied to the at-age series was approximately double the estimated values. The estimated MCMC marginal posterior distributions for selected parameters from the Two sex model are shown in Figures 33–37. This model indicated higher absolute biomass levels than the Base case. Consequently, the estimated research survey catchability constant of about 4.5% suggests that the absolute catchability of the trawl survey series is quite low (Figure 33). The fit to the research series in this model run is good (Figure 33), but not quite as good as in the Base case model (see Figure 28). Selectivity ogives were relatively tightly defined, but there were some differences between sexes (Figure 34). The survey ogives were similar between sexes, and indicated that hake were not fully selected by the research gear until about ages 13–16. In the western fishery, female hake were fully selected from 1 to 9 years of age, while males were not fully selected until about age 7. In the eastern fishery, age at peak selectivity was similar between sexes (about age 12), but males were almost three times more likely to be caught than females.

There was little difference between the Base case and Two sex models in the estimated pattern or absolute size of year class strengths (Figure 35, compared with Figure 30). The pattern of exploitation rates was also very similar between models, but even in the peak years the rates in the two sex model are unlikely to have exceeded 0.25 yr^{-1} (Figure 36).

Trends in biomass were also very similar between models. However, absolute biomass was greater in the Two sex model, and current stock status (B_{2009} = 56% of B_0) was more optimistic (Figure 37, Table 15).

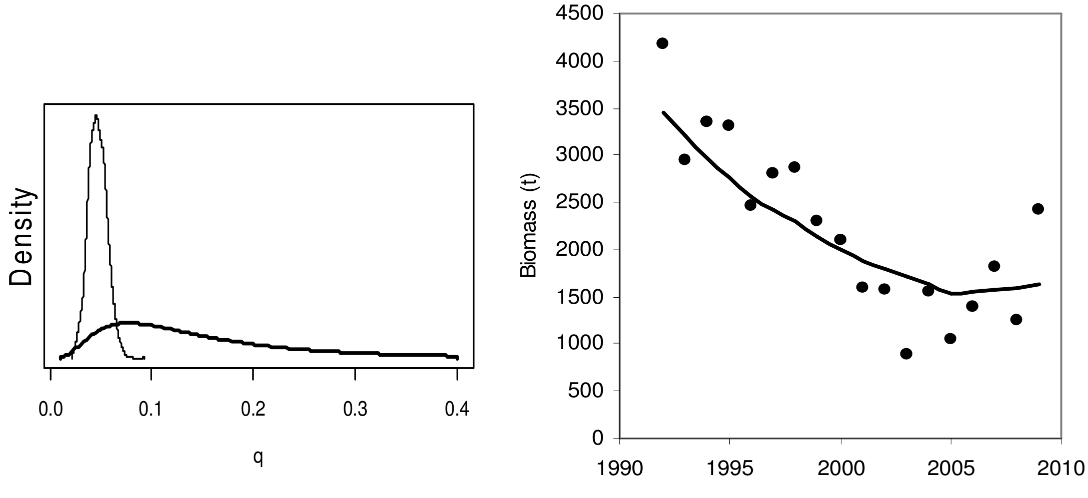


Figure 33: Two sex — Estimated posterior distribution (thin line) and prior (thick line) of survey catchability constant *q* for the Chatham Rise January resource survey series, and the MPD fit (thick line) to the observed survey biomass estimates (filled circles).

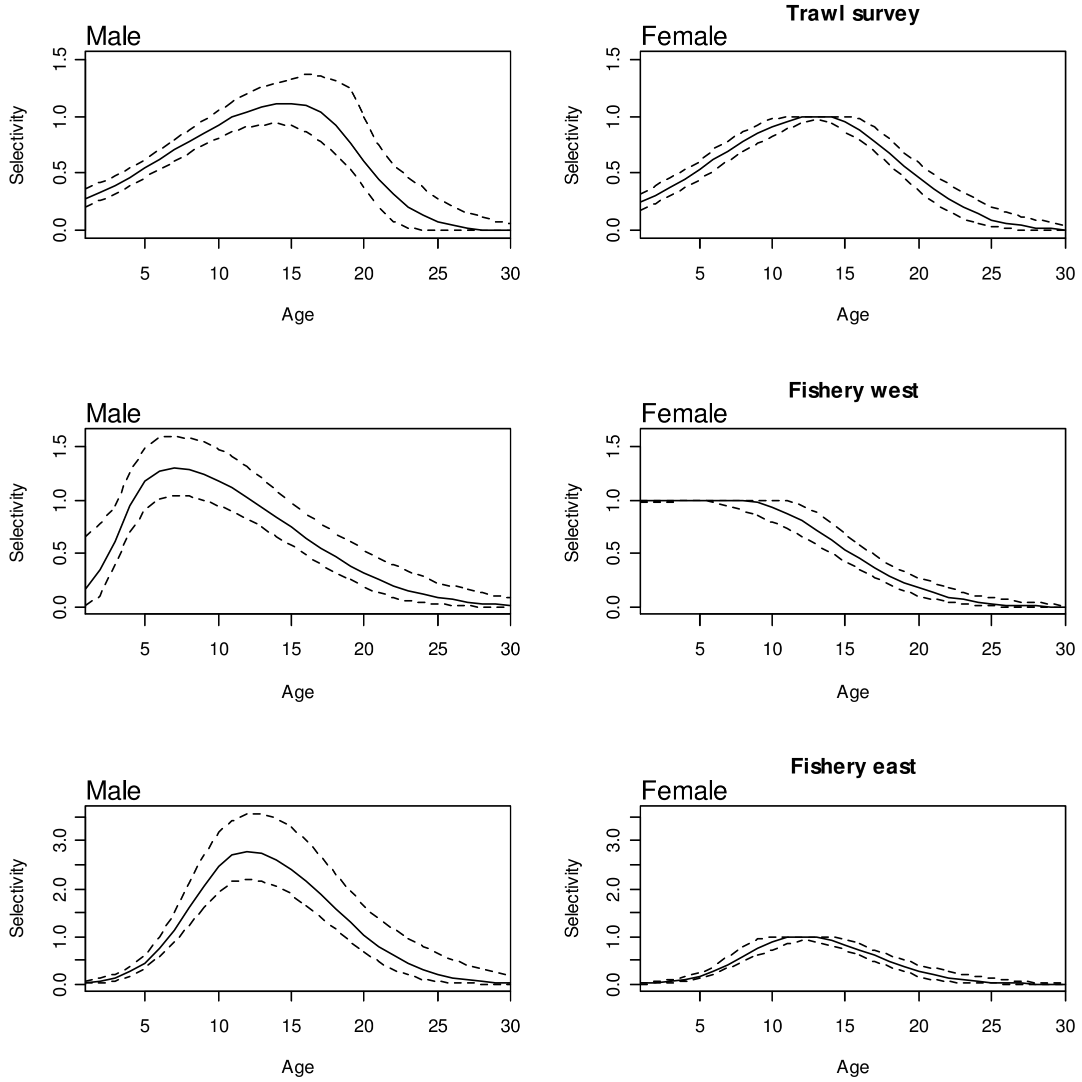


Figure 34: Two sex — Estimated median selectivity ogives (with 95% credible intervals shown as dashed lines) for the trawl survey series, the western fishery and the eastern fishery.

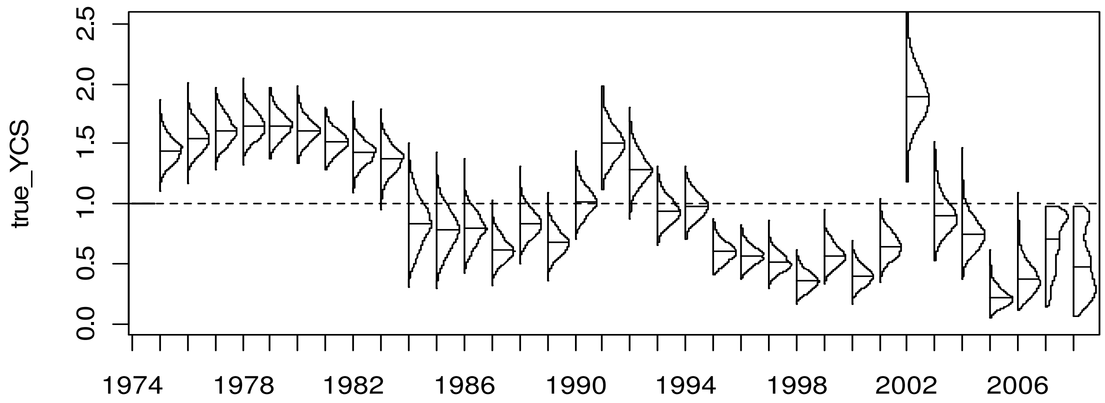


Figure 35: Two sex — Estimated posterior distributions of year class strengths for the Chatham Rise stock. The dashed horizontal line indicated the year class strength of one. Individual distributions are the marginal posteriors, with horizontal lines indicating the median.

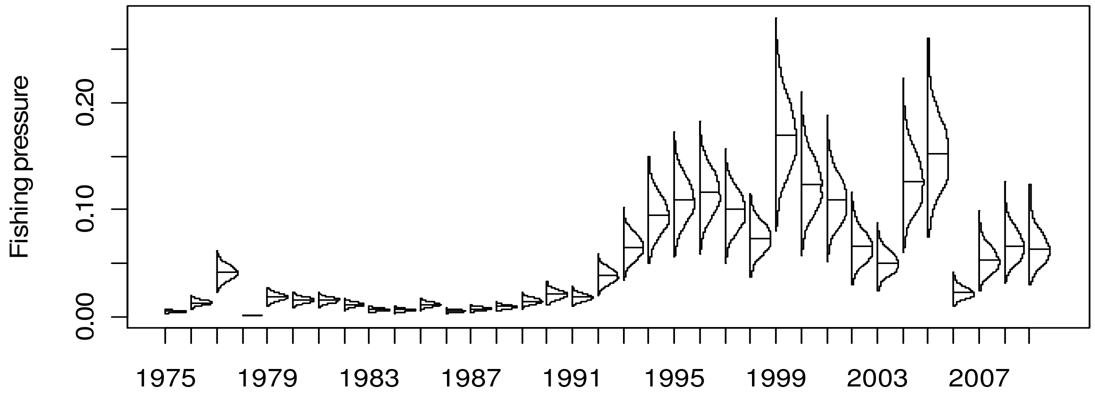


Figure 36: Two sex — Estimated posterior distributions of exploitation rates for the Chatham Rise stock. Individual distributions are the marginal posteriors, with horizontal lines indicating the median.

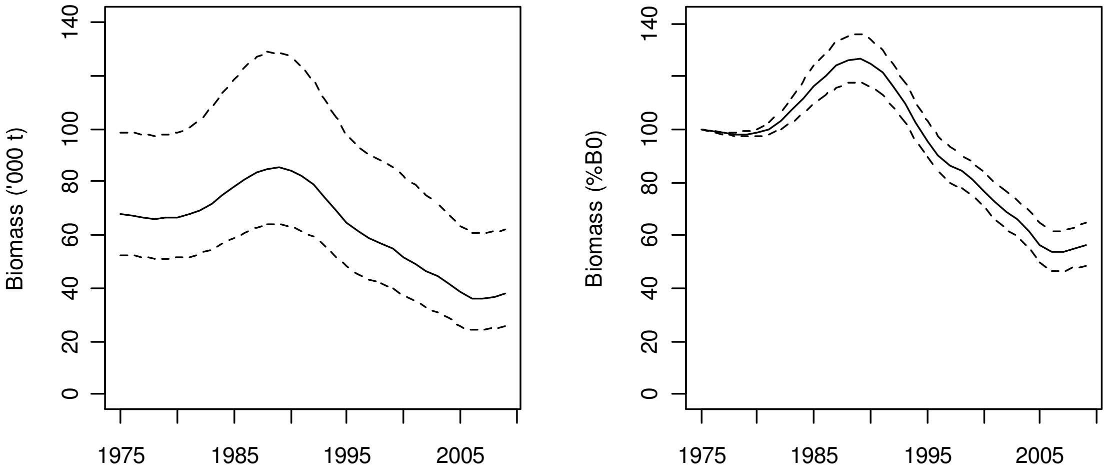


Figure 37: Two sex — Estimated median trajectories (with 95% credible intervals shown as dashed lines) for absolute biomass and biomass as a percentage of B_0, for the Chatham Rise stock.

5.1 Biomass projections

Biomass projections from the base case and two sex models were made under two assumed future catch scenarios (1150 t or 2800 t annually from 2010 to 2014). The low catch scenario (1150 t) approximates the catch level from recent years (2007–09). The high catch scenario (2800 t) is the highest likely level of catch. It equates to the HAK 4 TACC of 1800 t plus the average estimated catch from the Chatham Rise section of HAK 1 from 1992 to 2005 of 1000 t.

In the projections, the assumption that unestimated year class strengths were equal to one was rejected. Here, relative year class strengths from 2007 onwards were selected randomly from the previously estimated year class strengths from 1997 to 2006. It was considered prudent to base the projections on recent recruitment levels because these had generally been lower than the long term average (see Figure 30).

Projections from the base case model suggested that biomass will decline slightly to about 44% of B_0 (lower catch) or 31% of B_0 (higher) by 2014 (Table 16, Figure 38). Similarly under the two sex model, biomass was projected to decline under two assumed future catch scenarios. However, the extent of the projected declines (i.e., to about 53% of B_0 (lower catch) or 45% of B_0 (higher) by 2014) are not as great as for the Base case (Table 16, Figure 39).

Table 16: Bayesian median and 95% credible intervals of projected B_{2014}, B_{2014} as a percentage of B_0, and B_{2014}/B_{2009} (%) for the Chatham Rise model runs, under two future annual catch scenarios.

Model run	Future catch (t)	B_{2014}	B_{2014} (%B_0)	B_{2014}/B_{2009} (%)
Base case	1 150	18 080 (12 740–27 300)	44.1 (35.0–54.9)	94 (83–107)
	2 800	12 850 (7 370–22 450)	31.1 (20.4–43.9)	67 (51–82)
Two sex	1 150	35 910 (22 960–60 250)	52.8 (42.4–68.8)	93 (83–113)
	2 800	30 760 (18 010–55 870)	45.0 (33.2–62.0)	79 (66–101)

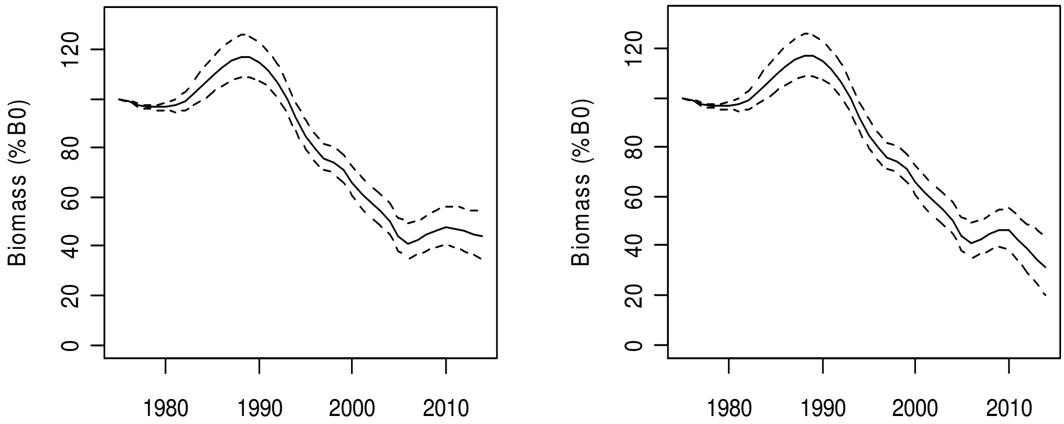


Figure 38: Base case — Estimated median trajectories (with 95% credible intervals shown as dashed lines) for biomass as a percentage of B_0, for the Chatham Rise stock, projected to 2014 with future catches assumed to be 1150 t (left panel) or 2800 t (right panel) annually.

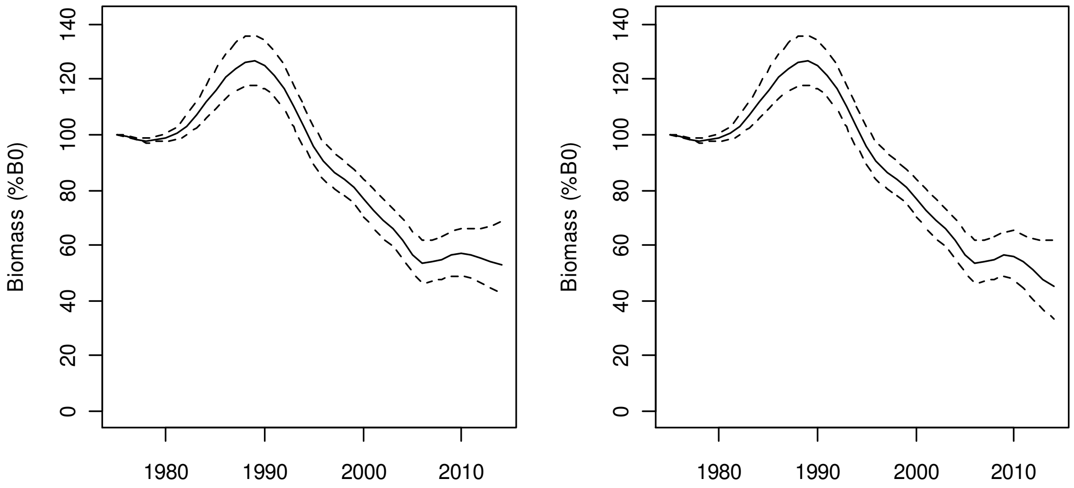


Figure 39: Two sex — Estimated median trajectories (with 95% credible intervals shown as dashed lines) for biomass as a percentage of B_0, for the Chatham Rise stock, projected to 2014 with future catches assumed to be 1150 t (left panel) or 2800 t (right panel) annually.

5.2 Estimates of sustainable yields

Absolute estimates of biomass from the Base case model are probably reasonable (assuming that the trawl survey series provides an accurate index of abundance), so estimates of sustainable yields were obtained for the Base case (Table 17). 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 are 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.

Table 17: Yield estimates (MCY, MAY, and CAY) and associated parameters for the Chatham Rise stock from the Base case model run.

Model run	B_{MCY} (t)	MCY (t)	B_{MAY} (t)	MAY (t)	F_{CAY}	CAY (t)
Base case	14 960	1 540	11 260	1 940	0.16	3 320

6. DISCUSSION

The base case model estimates that the Chatham Rise spawning stock is currently at about 47% B_0, and the continued fishing at recent catch levels is likely to cause the stock to decline slowly. The Chatham Rise stock models presented above for the 2009–10 fishing year gave slightly more pessimistic estimates of the current state than those estimated by Horn & Dunn (2007) for the 2006–07 fishing year. In a comparison of base cases, the current assessment estimates a lower B_0 than the 2007 assessment (41 000 t vs. 54 000 t), lower stock status in 2006 (41%B_0 vs. 49%B_0), and lower 'current' status (47%B_0 vs. 49%B_0). The current assessment also clearly fits the trawl survey biomass better (i.e., compare the residual trend in Figure 28 with that in figure 13 of Horn & Dunn (2007)).

Preliminary investigations showed how the relatively sparse at-age data resulted in erratic and erroneous estimates of the pre-1984 year classes owing to the ageing error applied to these data. Further, these erroneous estimates produced a marked increase in biomass in the late 1980s. Smoothing the earlier year class strengths allowed the information from the early age data to be used while still retaining ageing error. It became apparent that the 1974–83 year classes were generally stronger than average, but not so much so that they produced a massive increase in biomass in the late 1980s. It is likely that other assessments of hake, ling, and other species would benefit from a similar verification of year class strengths based on sparse data.

It also became apparent that the sex ratios in the at-age data were inconsistent (see Figure 21). This appears primarily to be a consequence of inadequate levels of observer sampling, but it is also possible that some changes in population sex ratio occurred as a consequence of the strongly male biased catch from the spawning fishery in Area 404. The subsequent removal of sex from the partition overcame the problem of changing sex ratios, and resulted in better fits to the research biomass series and the at-age data. Consequently, the model without sex in the partition (the 'Single sex' model) was chosen as the Base case. A sensitivity model (the 'Two sex' model) was identical to the Base case except that it included sex in the partition and increased the process error on the at-age series.

Information about the stock status of hake on the Chatham Rise appears reasonably strong. Biomass estimates from the Chatham Rise research trawl series strongly suggest a uniform decline in biomass, with biomass in 2005 at about one-third 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 except for 2002. However, this single strong year class has resulted in an upturn in the survey estimates of biomass. The two model runs produced almost identical patterns of year class strengths, so the better fits to the survey biomass and age data in the 'Single sex' model are not at the expense of year class strength estimates.

The year class strengths from 1995 to 2006 (excluding 2002) were estimated to be weaker than average. Consequently, it was considered desirable to conduct biomass projections assuming that year class strengths after 2006 would continue the generally 'lower than average' trend. Future year class strengths were sampled randomly from those estimated over the 10-year period from 1997 to 2006. If actual year class strengths after 2006 improve on the recent trend then the projected biomasses will be overly pessimistic. Future biomass is also dependent on future catches. 'High' and 'low' future catch scenarios were modelled, but all runs indicated a decline in biomass. It is therefore concluded that biomass in this stock will increase only if future annual catches are lower than 1150 t and/or if future year class strengths are stronger than the recent average.

However, estimates of stock size and projected stock status rely on the shape of the selectivity ogives. All ogives were estimated using the double-normal parameterisation, and, for the two model runs, all but one were clearly bell-shaped (see Figures 29 and 34). The rate of natural mortality (M) was assumed constant, but in reality it is likely to vary with age, being relatively greater for very young and very old fish. The assumption of constant M will also influence the shapes of the selectivity ogives, as relatively high natural mortality at older ages will be manifested as relatively lower selectivity at those ages.

Estimates of resource survey catchability (qs) are moderately low in the Base case assessment (i.e., about 0.10), and even lower in the sensitivity run (i.e., about 0.045). It is not known if the catchability of the trawl survey series is as low as estimated by the model, but hake are believed to be relatively more abundant over rough ground (that would be avoided during a trawl survey), and it is known that hake tend to school off the bottom, particularly during their spring–summer spawning season, hence reducing their availability to the bottom trawl. However, the Chatham Rise trawl survey series does appear to be providing a relatively precise index of relative abundance for this stock. The series declined steadily, but not radically, from 1992 to about 2005, and has since shown a slight recovery (which is supported by the appearance of a strong year class). There has been little year-to-year variation in the biomass indices, i.e., the series is relatively smooth.

The available CPUE series were generally poorly fitted; the reasons for this have not been established. The eastern (spawning) fishery series does mirror the estimated biomass reasonably, so it may be reliable. However, the western fishery series both exhibit marked increases around 1994–96 which is totally at odds with the research biomass series. It is most likely that these increases are a consequence of some currently unknown change in fishing behaviour or catch reporting behaviour. Consequently, we conclude that CPUE currently adds little information to the assessment of the Chatham Rise hake stock, and may even be misleading.

The structural assumptions of the model reported here are likely to lead to the Bayesian posteriors of stock status underestimating the true level of uncertainty. The projected stock status relies on adequate estimation of recent recruitment. The sample sizes of age data from the resource survey are generally small, and the commercial catch proportions-at-age distributions can be sporadic (particularly for the eastern fishery) and based on relatively small samples. Consequently, the projections of future stock status are likely to underestimate the true level of uncertainty. It is particularly unfortunate that the most productive fishery centred on Statistical Area 404 is the worst sampled, necessitating the combination of the two fisheries east of 178° E (see Section 3.4.1). Horn & Dunn (2007) found that the selectivity ogives from the two eastern fisheries differed markedly, both in terms of age at peak selectivity and sex ratios in the catch. The necessity to combine these two fisheries (because of the paucity of data) means that some information will be lost. However, when sex is removed from the partition (as in the Base case presented above), differences in sex ratios in the catch are not important.

The ‘Single sex’ model was chosen as the Base case and is considered to be better than the ‘Two sex’ model because it fits the research biomass series better and it does not have to try and deal with conflicting information about changes in sex ratios over time. The ‘Two sex’ model is markedly more optimistic than the ‘Single sex’ model (for both absolute biomass and stock status). However, we think it is unlikely that sex alone provides sufficient ‘logical’ information to increase B_0 by about 66% and current stock status by about 22%. Hence, we believe that the ‘Two sex’ model should be rejected at this stage.

The assessment for Chatham Rise hake has been updated, and is indicative of a stock that has been steadily fished down throughout the 1990s, but that it is within the interim management target of 35–50% B_0 set by the Middle Depth Species Working Group. Strong recruitment in 2002 has slowed the rate of stock decline, but future annual catches of about 1150 t will still result in a decline in biomass over the next five years. The stock is probably being well monitored by the January trawl survey series.

7. ACKNOWLEDGMENTS

We thank the many NIWA staff and Ministry of Fisheries observers who were involved in the collection of data at sea, and members of the Middle Depth Fishery Assessment Working Group who provided useful comments and suggestions. The work was funded by the Ministry of Fisheries under project HAK2007-01.

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.

Bagley, N.W.; O'Driscoll, R.L.; Francis, R.I.C.C; Ballara, S.L. (2009). Trawl survey of middle depth species in the Southland and Sub-Antarctic areas, November–December 2007 (TAN0714). *New Zealand Fisheries Assessment Report 2009/9*. 63 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. (Unpublished report held in NIWA library, Wellington.)

Bull, B.; Francis, R.I.C.C.; Dunn, A.; McKenzie, A.; Gilbert, D.J.; Smith, M.H.; Bian, R. (2008). CASAL (C++ algorithmic stock assessment laboratory): CASAL User Manual v2.20-2008/02/14. *NIWA Technical Report 130*. 275 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. (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. (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. (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. (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. (Unpublished report held in NIWA library, Wellington.)

Devine, J. (2009). Descriptive anlaysis of the commercial catch and effort data for New Zealand hake (*Merluccius australis*) for the 1989–90 to 2005–06 fishing years. *New Zealand Fisheries Assessment Report 2009/21*. 74 p.

Devine, J. (2010). Catch per unit effort (CPUE) analysis of hake (*Merluccius australis*) for HAK 1 and HAK 4 from 1989–90 to 2007–08. *New Zealand Fisheries Assessment Report 2010/15*. 76 p.

Devine, J.; Dunn, A. (2008). Catch and effort (CPUE) analysis of hake (*Merluccius australis*) for HAK 1 and HAK 4 from 1989–90 to 2004–05. *New Zealand Fisheries Assessment Report 2008/10*. 64 p.

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. (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. (2006). Stock assessment of hake (*Merluccius australis*) in HAK 1 & 4 for the 2005–06 fishing year. Final Research Report for Ministry of Fisheries Project HAK2003-01 Objective 4. 47 p. (Unpublished report held by MFish, Wellington.)

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. *New Zealand Fisheries Assessment Report 2006/11*. 63 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.

Dunn, A.; Phillips, N.L. (2006). Catch and effort (CPUE) analysis of hake (*Merluccius australis*) for the Chatham Rise from 1989–90 to 2004–05. Final Research Report for Ministry of Fisheries Project HAK2003-01 Objective 3. 32 p. (Unpublished report held by MFish, Wellington.)

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. (Unpublished report held in NIWA library, Wellington.)

Francis, R.I.C.C.; Hurst, R.J.; Renwick, J.A. (2003). Quantifying annual variation in catchability for commercial and research fishing. *Fishery Bulletin 101*: 293–304.

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. (Unpublished report held in NIWA library, Wellington.)

Horn, P.L. (2008). Stock assessment of hake (*Merluccius australis*) in the Sub-Antarctic for the 2007–08 fishing year. *New Zealand Fisheries Assessment Report 2008/49*. 66 p.

Horn, P.L.; Dunn, A. (2007). Stock assessment of hake (*Merluccius australis*) on the Chatham Rise for the 2006–07 fishing year. *New Zealand Fisheries Assessment Report 2007/44*. 62 p.

Horn, P.L.; Sutton, C.P. (2009). Catch-at-age for hake (*Merluccius australis*) and ling (*Genypterus blacodes*) in the 2007–08 fishing year and from trawl surveys in summer 2008–09, with a summary of all available data sets. *New Zealand Fisheries Assessment Report 2009/41*. 53 p.

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. (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. (2006a). Trawl survey of middle depth species in the Southland and Sub-Antarctic areas, November–December 2004 (TAN0414). *New Zealand Fisheries Assessment Report 2006/2*. 60 p.

O'Driscoll, R.L.; Bagley, N.W. (2006b). Trawl survey of middle depth species in the Southland and Sub-Antarctic areas, November–December 2005 (TAN0515). *New Zealand Fisheries Assessment Report 2006/45*. 64 p.

O'Driscoll, R.L.; Bagley, N.W. (2008). Trawl survey of hoki, hake, and ling in the Southland and Sub-Antarctic areas, November–December 2006 (TAN0617). *New Zealand Fisheries Assessment Report 2008/30*. 61 p.

O'Driscoll, R.L.; Bagley, N.W. (2009). Trawl survey of middle depth species in the Southland and Sub-Antarctic areas, November–December 2008 (TAN0813). *New Zealand Fisheries Assessment Report 2009/56*. 67 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.

Schnute, J. (1981). A versatile growth model with statistically stable parameters. *Canadian Journal of Fisheries and Aquatic Sciences 38*: 1128–1140.

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. (2006). Trawl survey of hoki and middle depth species on the Chatham Rise, January 2005 (TAN0501). *New Zealand Fisheries Assessment Report 2006/13*. 73 p.

Stevens, D.W.; O'Driscoll, R.L. (2007). Trawl survey of hoki and middle depth species on the Chatham Rise, January 2006 (TAN0601). *New Zealand Fisheries Assessment Report 2007/5*. 73 p.

Stevens, D.W.; O'Driscoll, R.L.; Gauthier, S. (2008). Trawl survey of hoki and middle depth species on the Chatham Rise, January 2007 (TAN0701). *New Zealand Fisheries Assessment Report 2008/52*. 81 p.

Stevens, D.W.; O'Driscoll, R.L.; Horn, P.L. (2009a). Trawl survey of hoki and middle depth species on the Chatham Rise, January 2008 (TAN0801). *New Zealand Fisheries Assessment Report 2009/18*. 86 p.

Stevens, D.W.; O'Driscoll, R.L.; Horn, P.L. (2009b). Trawl survey of hoki and middle depth species on the Chatham Rise, January 2009 (TAN0901). *New Zealand Fisheries Assessment Report 2009/55*. 91 p.

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

Table A1: 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 1990	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 A1 ctd.

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 2006a
			1991 area [4]	1 694	0.21	O'Driscoll & Bagley 2006a
			1996 area [7]	1 774	0.20	O'Driscoll & Bagley 2006a
Tangaroa	Nov–Dec 2005	TAN0515	300–800 [3]	1 133	0.20	O'Driscoll & Bagley 2006b
			1991 area [4]	1 459	0.17	O'Driscoll & Bagley 2006b
			1996 area [7]	1 624	0.17	O'Driscoll & Bagley 2006b
Tangaroa	Nov–Dec 2006	TAN0617	300–800 [3]	998	0.22	O'Driscoll & Bagley 2008
			1991 area [4]	1 530	0.17	O'Driscoll & Bagley 2008
			1996 area [7]	1 588	0.16	O'Driscoll & Bagley 2008
Tangaroa	Nov–Dec 2007	TAN0714	300–800 [3]	2 188	0.17	Bagley et al. 2009
			1991 area [4]	2 470	0.15	Bagley et al. 2009
			1996 area [7]	2 622	0.15	Bagley et al. 2009
Tangaroa	Nov–Dec 2008	TAN0813	300–800 [3]	1 074	0.23	O'Driscoll & Bagley 2009
			1991 area [4]	2 162	0.17	O'Driscoll & Bagley 2009
			1996 area [7]	2 355	0.16	O'Driscoll & Bagley 2009

1. Although surveys by *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. in 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 800–1000 m 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 A2: 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	1 048	0.18	Stevens & O'Driscoll 2006
Tangaroa	Jan 2006	TAN0601	200–800	1 384	0.19	Stevens & O'Driscoll 2007
Tangaroa	Jan 2007	TAN0701	200–800	1 824	0.12	Stevens et al. 2008
			200–1000	1 976	0.12	Stevens et al. 2008
Tangaroa	Jan 2008	TAN0801	200–800	1 257	0.13	Stevens et al. 2009a
			200–1000	1 323	0.13	Stevens et al. 2009a
Tangaroa	Jan 2009	TAN0901	200–800	2 419	0.21	Stevens et al. 2009b

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

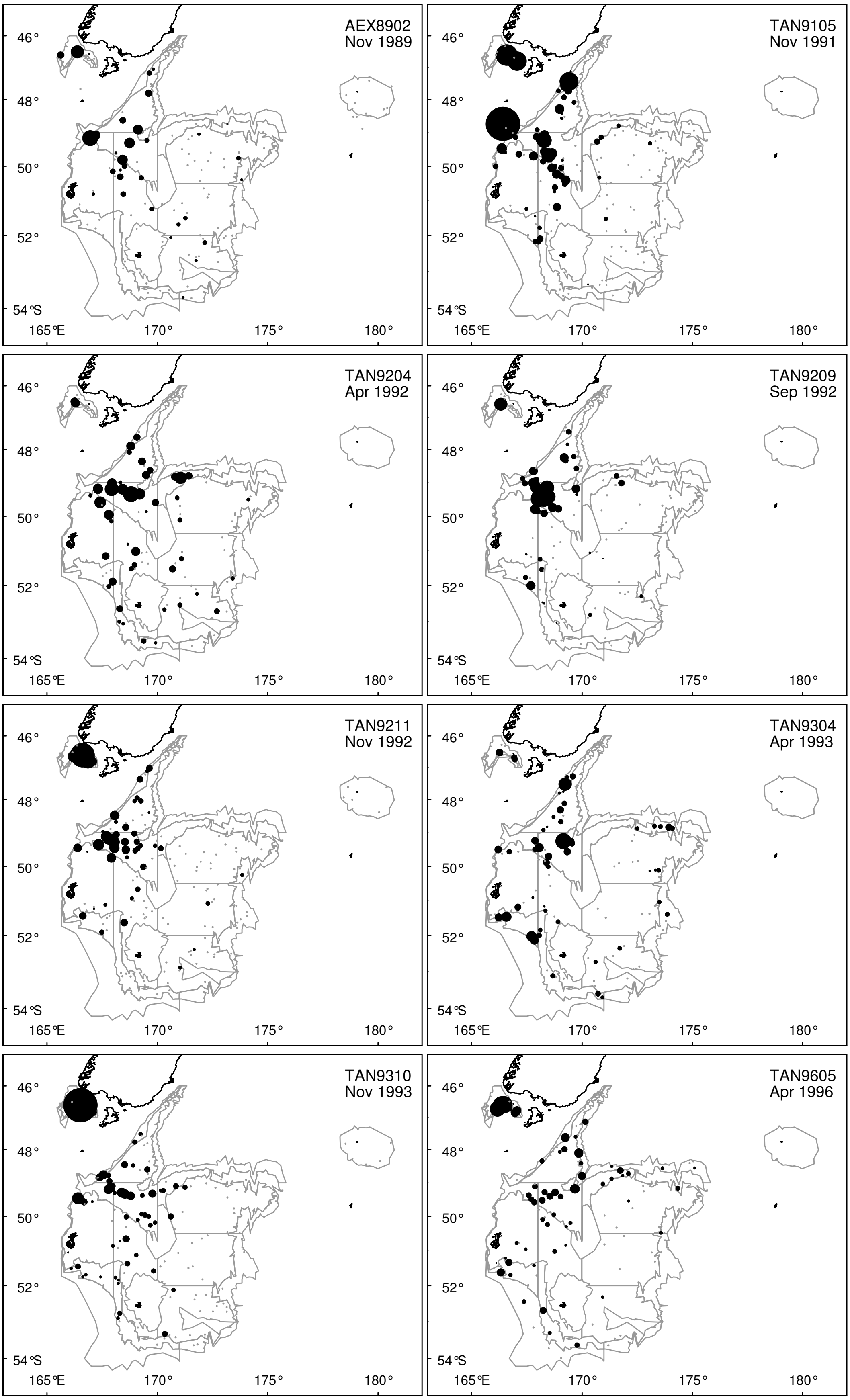


Figure A1: Density of hake by location from the 1989–1996 Sub-Antarctic resource surveys. Tow density (kg/km^2) proportional to symbol area, zero values indicated in grey.

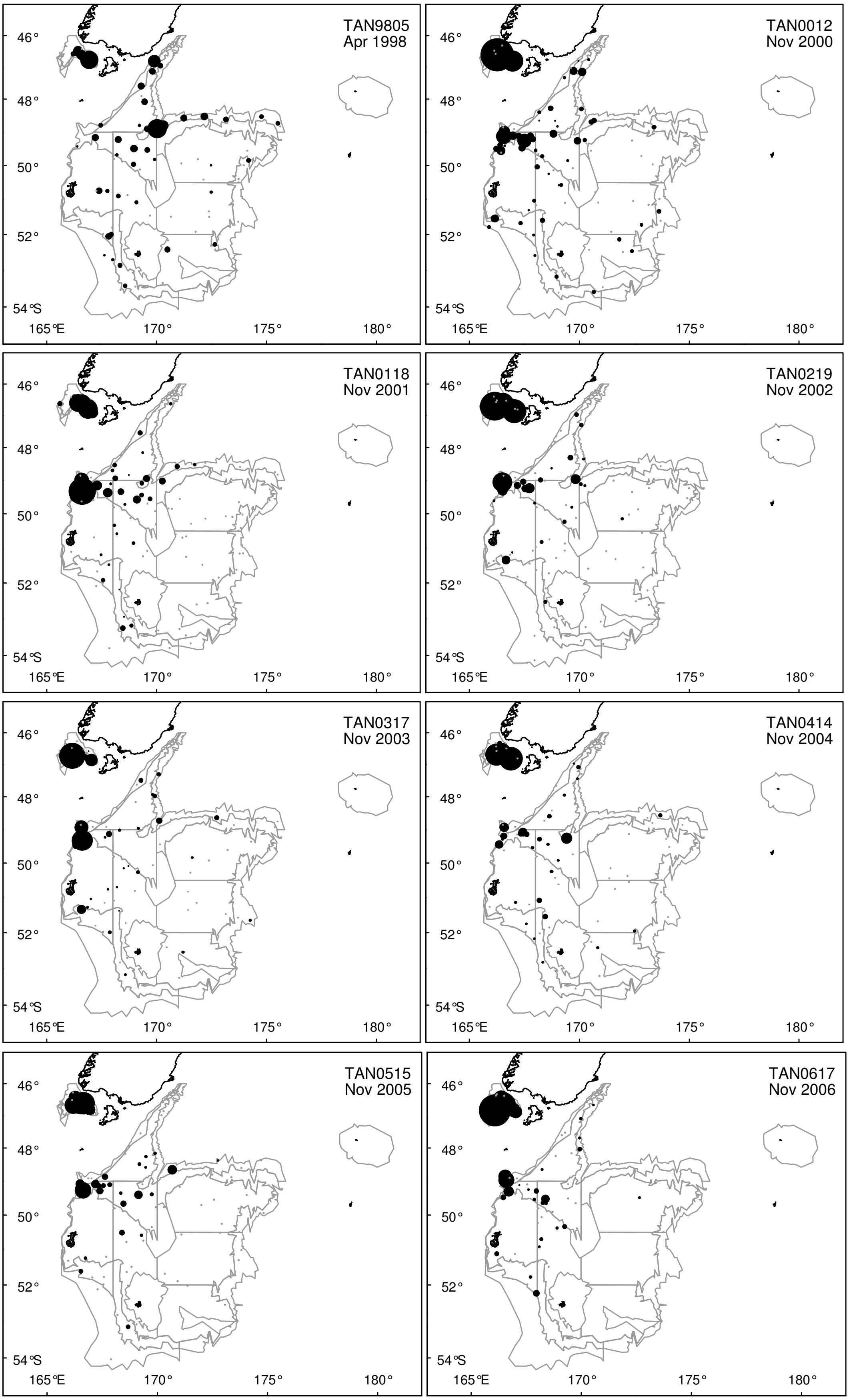


Figure A1 ctd: Density of hake by location from the 1998–2006 Sub-Antarctic resource surveys. Tow density (kg/km^2) proportional to symbol area, zero values indicated in grey.

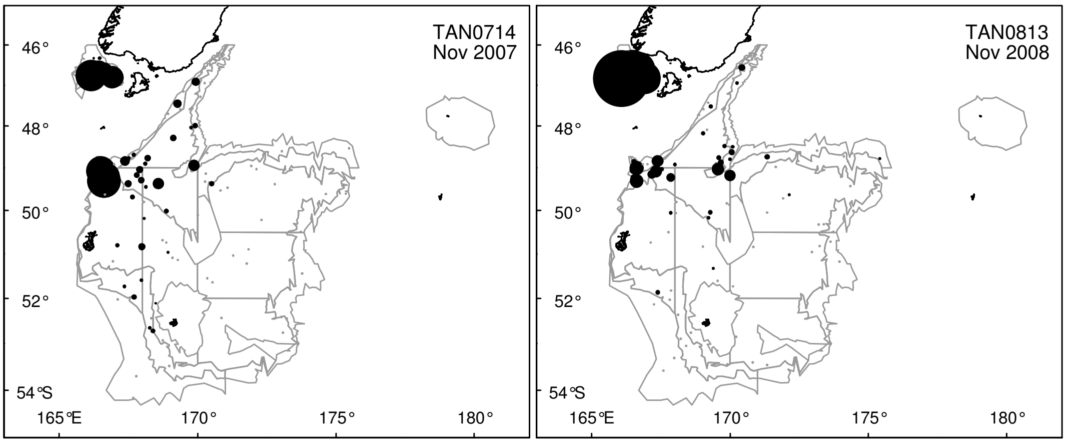


Figure A1 ctd: Density of hake by location from the 2007–2008 Sub-Antarctic resource surveys. Tow density (kg/km^2) proportional to symbol area, zero values indicated in grey.

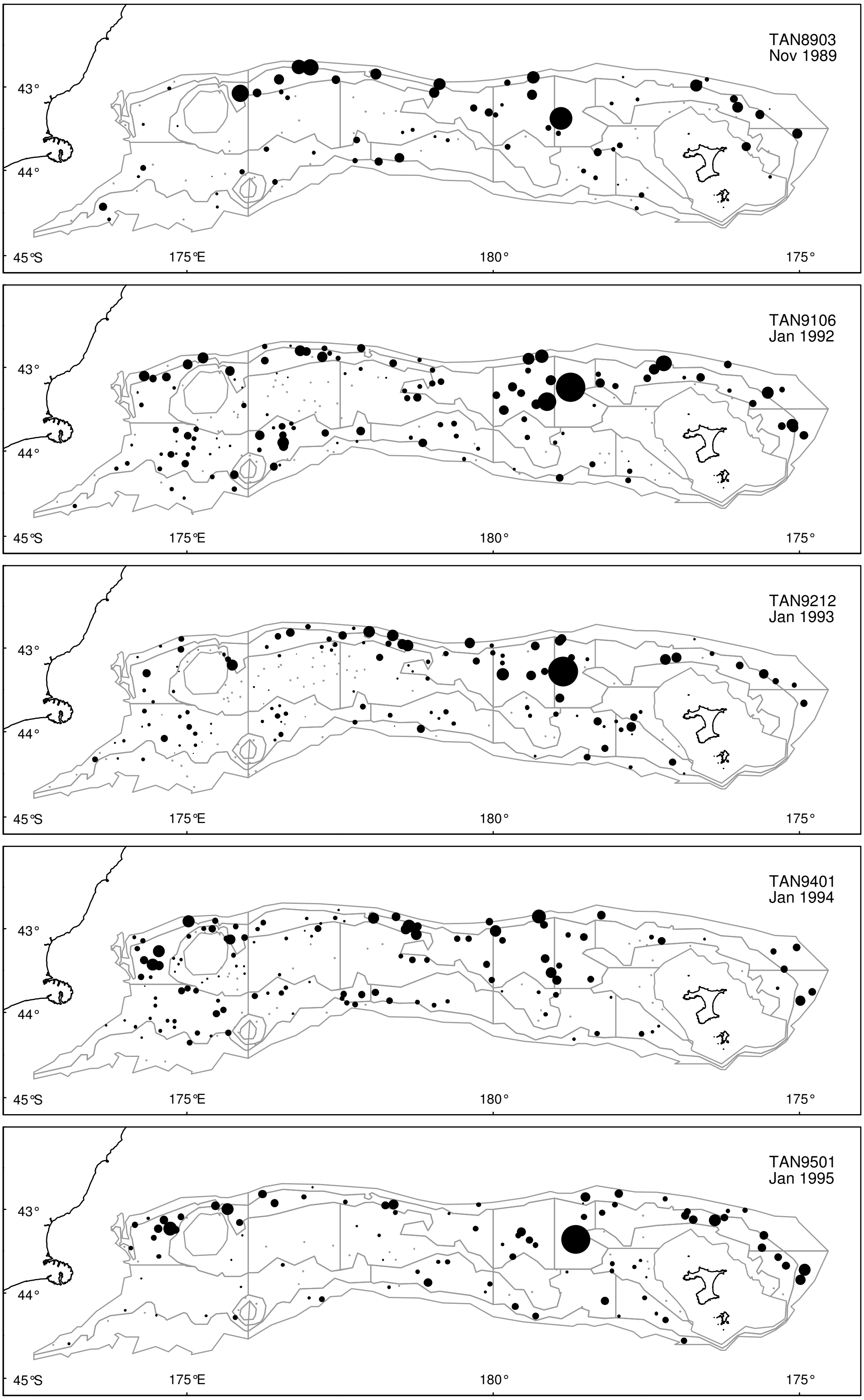


Figure A2: Density of hake by location from the 1989 to 1995 Chatham Rise resource surveys. Tow density (kg/km^2) proportional to symbol area, zero values indicated in grey.

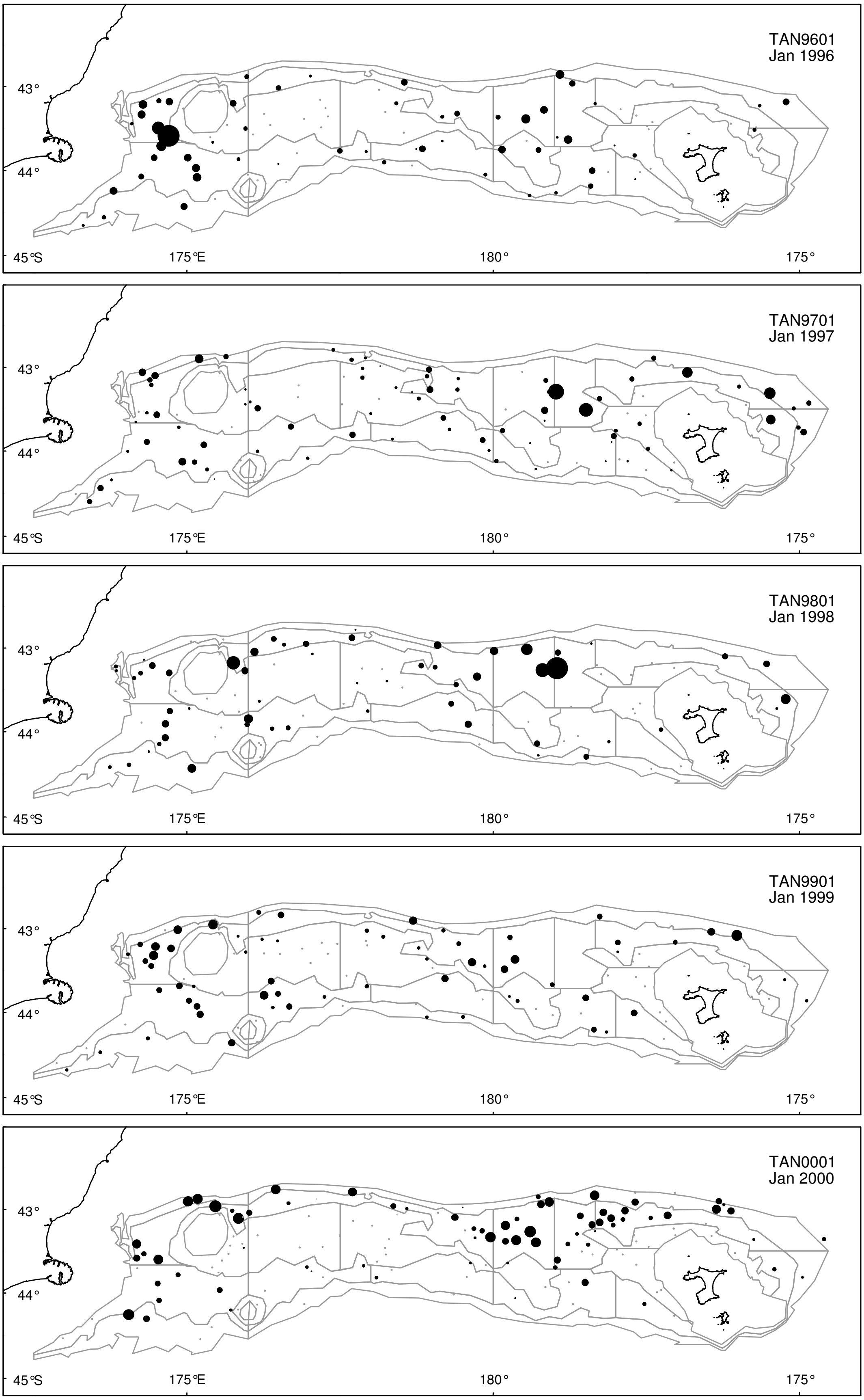


Figure A2 ctd: Density of hake by location from the 1996 to 2000 Chatham Rise resource surveys. Tow density (kg/km^2) proportional to symbol area, zero values indicated in grey.

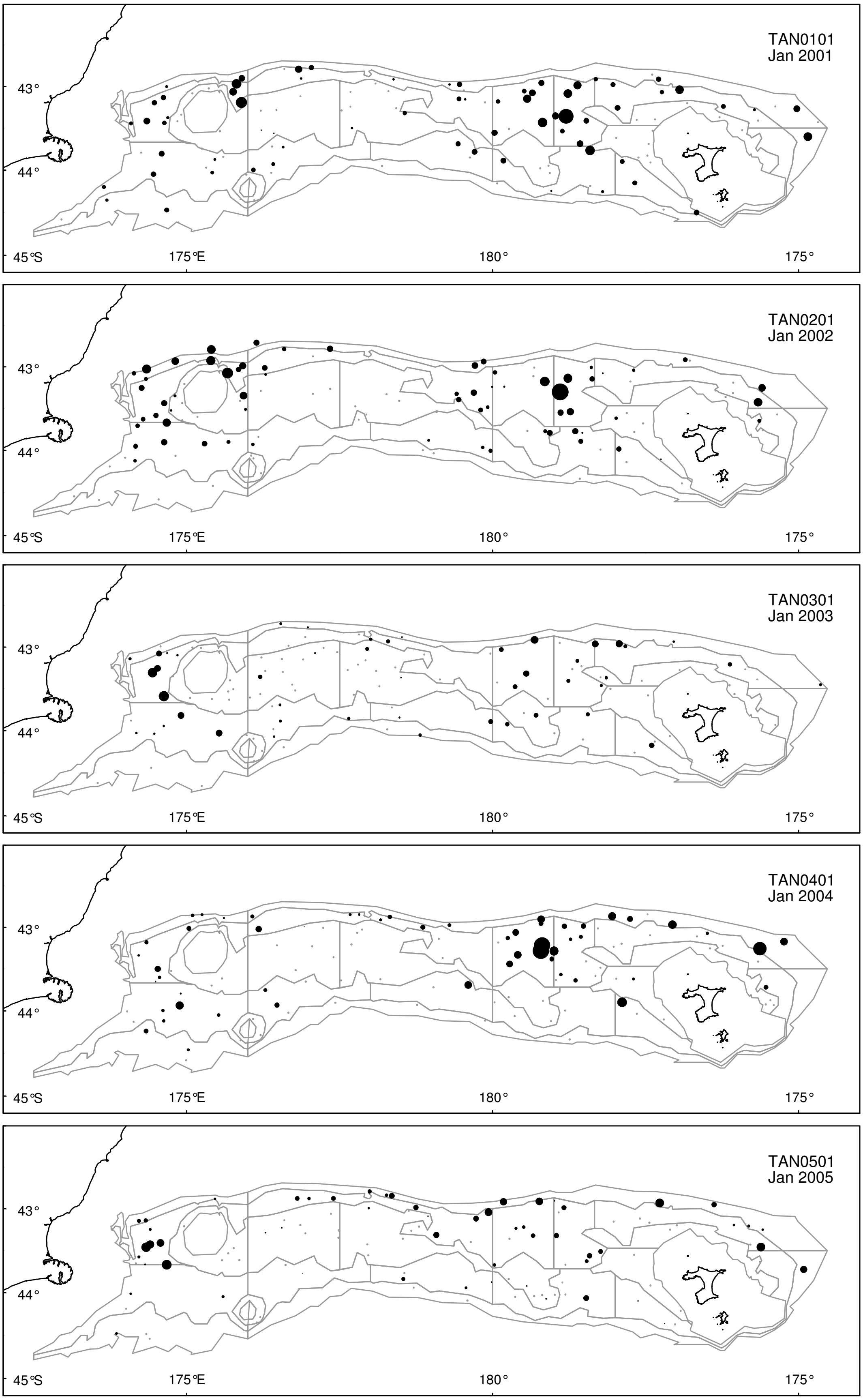


Figure A2 ctd: Density of hake by location from the 2001 to 2005 Chatham Rise resource surveys. Tow density (kg/km^2) proportional to symbol area, zero values indicated in grey.

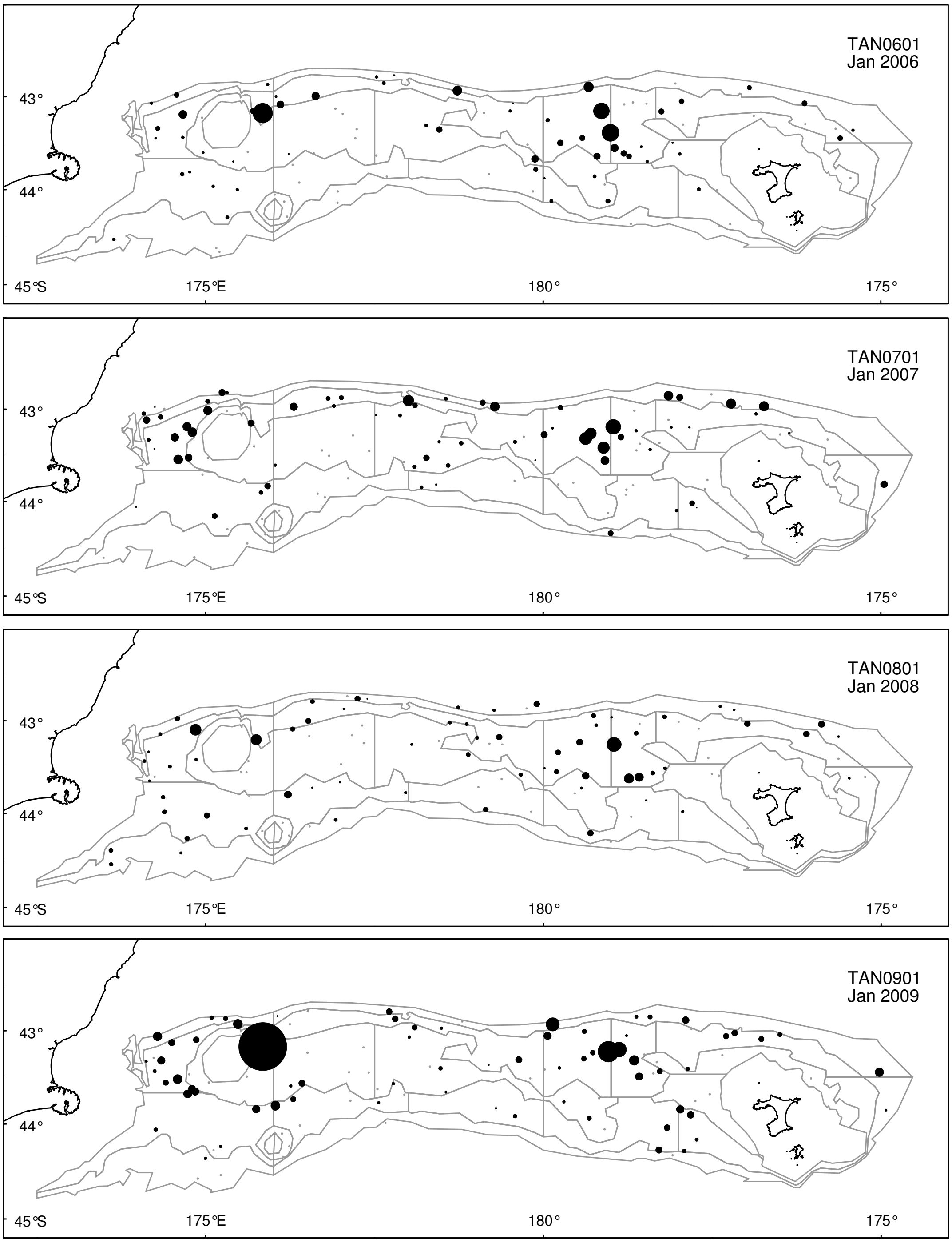


Figure A2 ctd: Density of hake by location from the 2006 to 2009 Chatham Rise resource surveys. Tow density (kg/km^2) proportional to symbol area, zero values indicated in grey.

APPENDIX B: Base case (Single sex) MPD model fits to the catch-at-age data

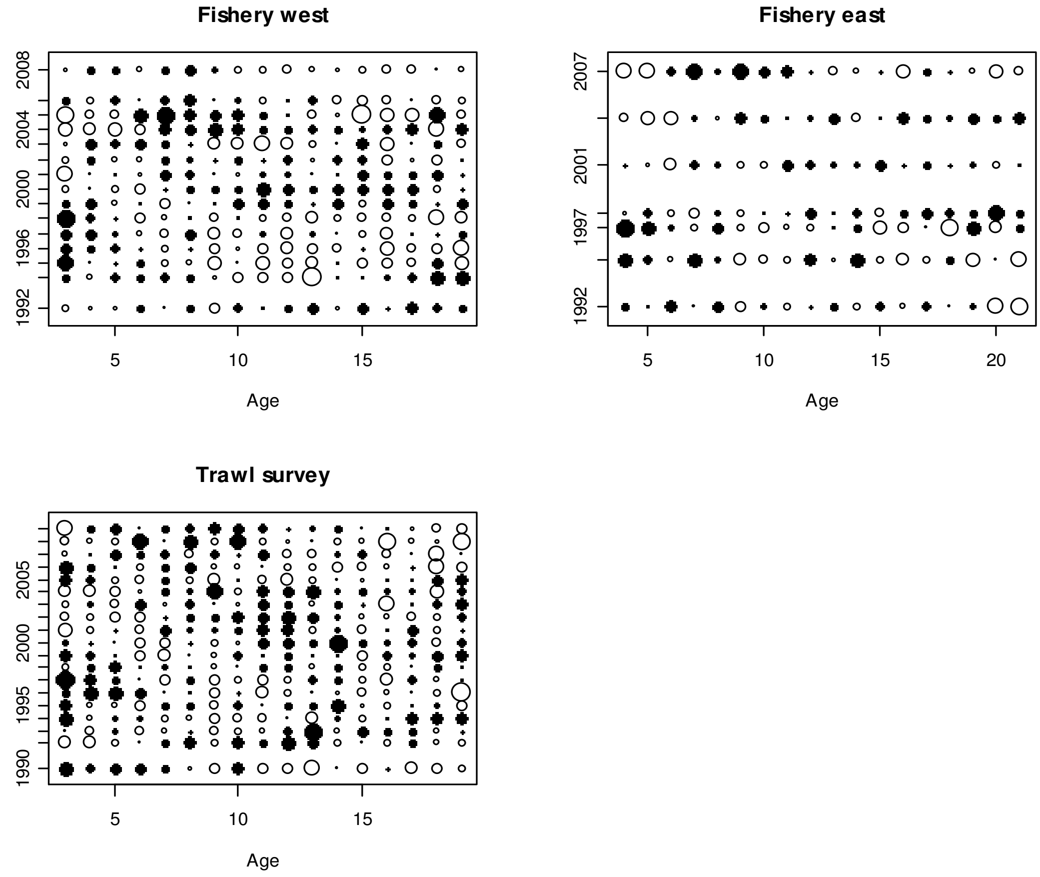


Figure B1: MPD residual values for the proportions-at-age data for the Chatham Rise fisheries (west and east) and resource survey series. Symbol area is proportional to the absolute value of the residual, with filled circles indicating positive residuals and open circles indicating negative residuals.

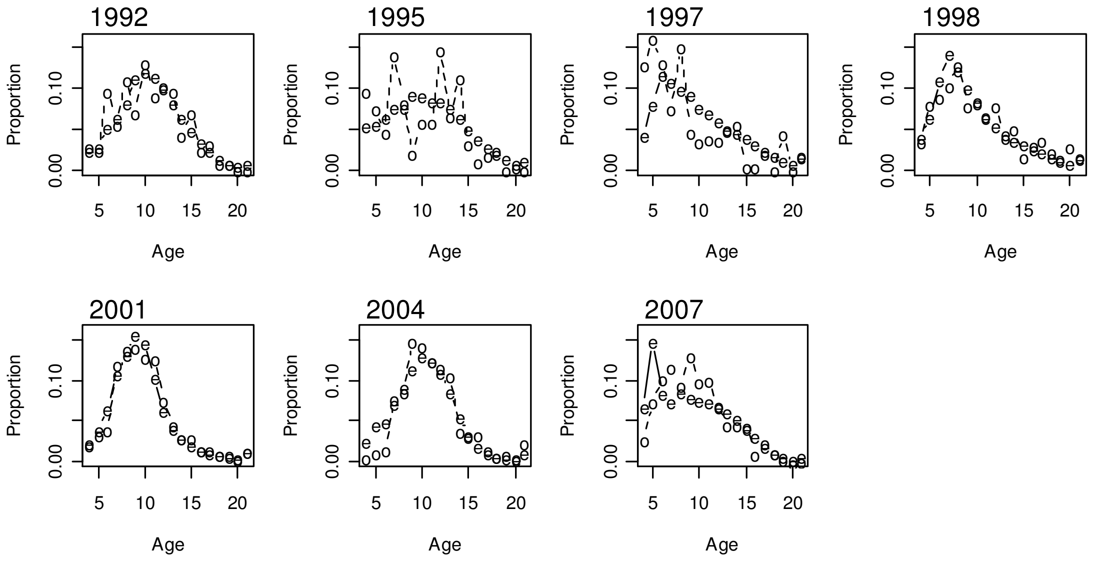


Figure B2: MPD fits to the proportions-at-age data for the eastern Chatham Rise trawl fishery observer sampling series. o, observed data; e, expected fit.

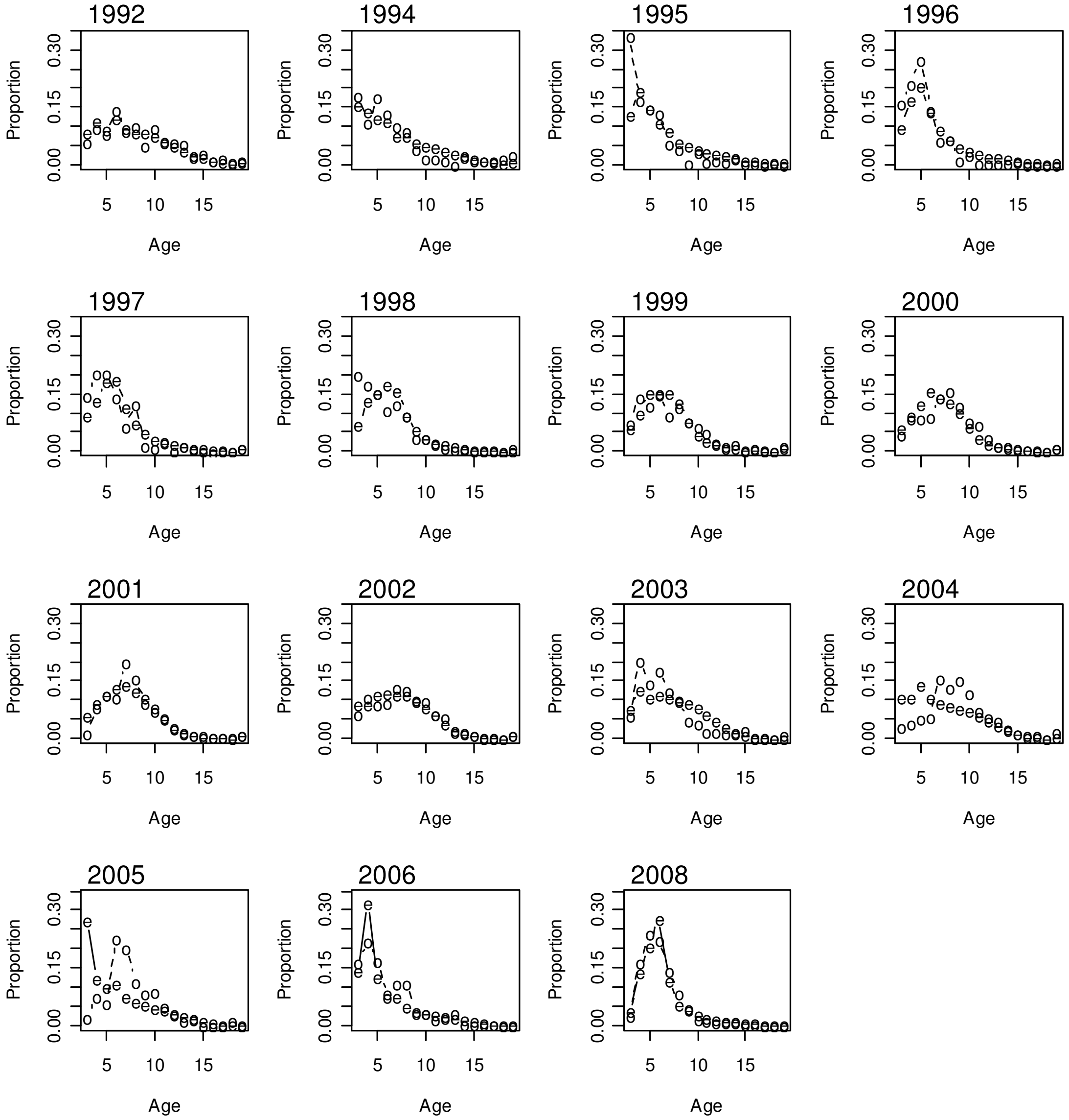


Figure B3: MPD fits to the proportions-at-age data for the western Chatham Rise trawl fishery observer sampling series. o, observed data; e, expected fit.

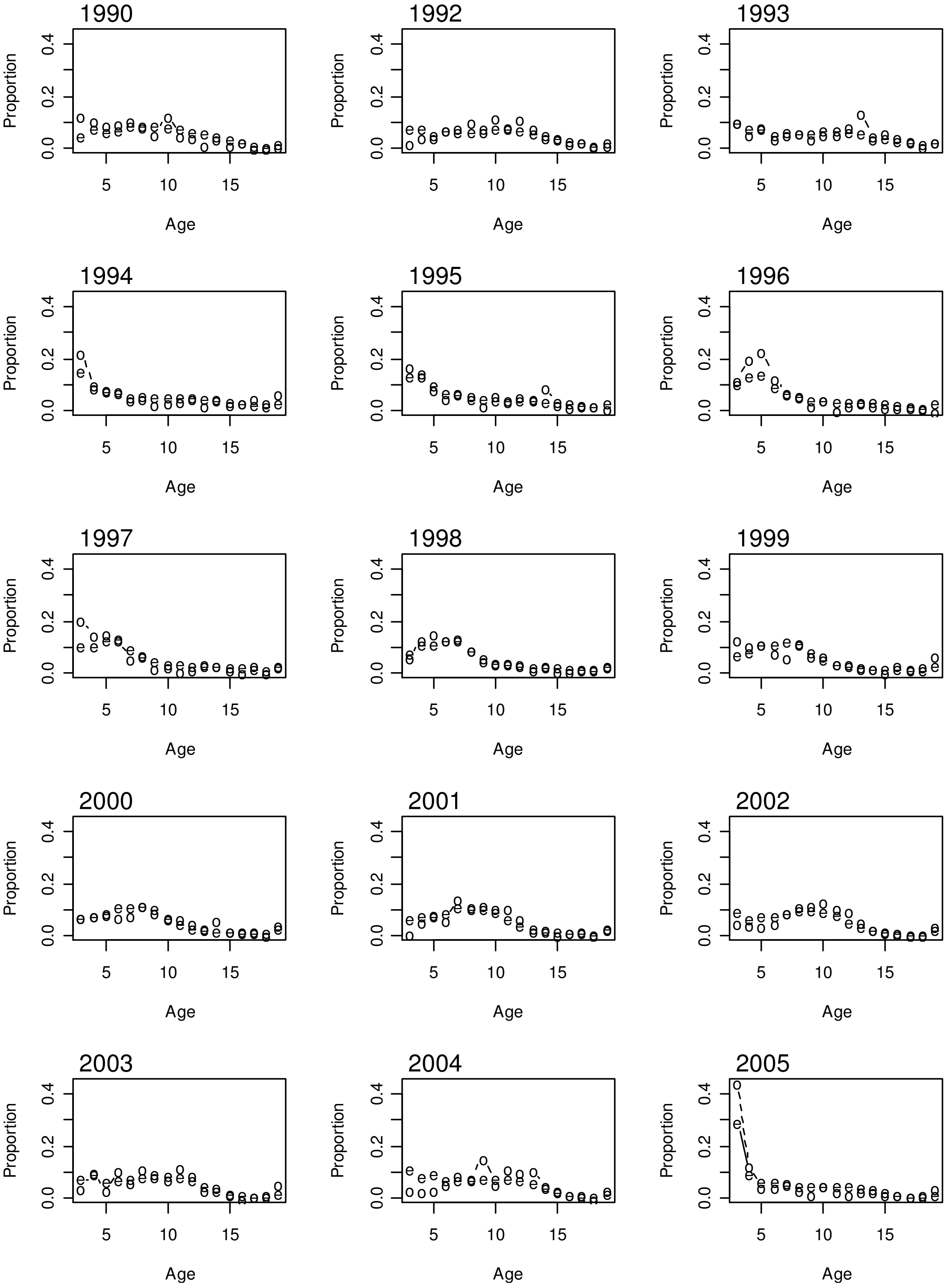


Figure B4: MPD fits to the proportions-at-age data from the January Chatham Rise trawl survey series, 1990–2005. o, observed data; e, expected fit.

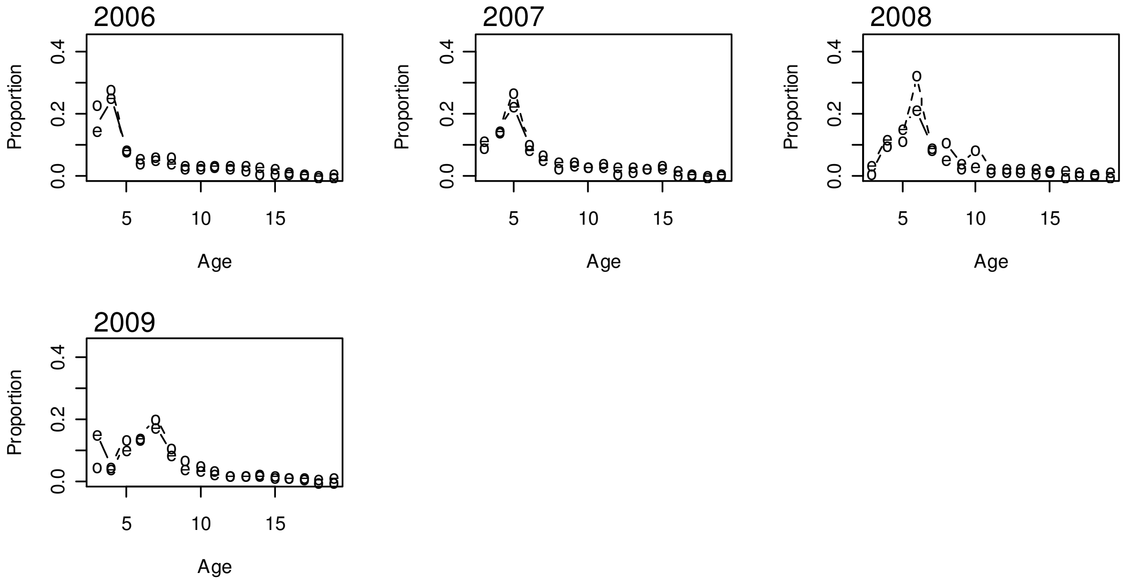


Figure B4 ctd.: MPD fits to the proportions-at-age data from the January Chatham Rise trawl survey series, 2005–2009. o, observed data; e, expected fit.