Stock assessment of hake (*Merluccius australis*) off the west coast of South Island (HAK 7) for the 2010–11 fishing year

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EXECUTIVE SUMMARY

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This report summarises the stock assessment of hake in Quota Management Area HAK 7 (west coast South Island) for the 2010–11 fishing year. An updated Bayesian assessment was conducted using the general-purpose stock assessment program CASAL v2.22. The assessment incorporated all relevant biological parameters, the commercial catch histories, updated CPUE series, and series of proportion-at-age data from the commercial trawl fishery and a single research survey. The analysis includes fishery data up to the end of the 2008–09 fishing year. New model input data and revised catch histories for all three hake stocks (Sub-Antarctic, Chatham Rise, and west coast South Island) are also reported here.

Initial investigations of the available data indicated that the sex ratios in the at-age data were inconsistent. Consequently, a base case model was developed, excluding sex from the partition. The available CPUE series indicated trends in biomass that were markedly different to those indicated by the at-age data. As in previous assessments of the WCSI hake stock, the CPUE was rejected as a valid index of abundance as catch rates of hake were likely influenced more by fisher behaviour than by abundance of the species. Consequently, there are no relative abundance series available for this stock; the model is driven by the at-age data.

The base case model indicated that the WCSI spawning stock is currently at about 65% B_0, and that B_0 was about 82 000 t. Sensitivity model runs using two different values of instantaneous natural mortality (*M*) did not markedly alter the absolute estimate of B_0, but did strongly influence estimates of current biomass. However, none of the model runs were indicative of current biomass being lower than 38% of B_0, and all projected an increase in biomass over the next five years with catches equal to those from recent years (6000 t) or at a higher level equal to the current TACC (7700 t). The assessment indicated that the stock had been steadily fished down throughout the 1990s, but that relatively strong recruitment from 2000 to 2004 has resulted in recent growth in stock size. However, the assessment is clearly very uncertain as it is based only on proportion-at-age data; it was not accepted as reliable by the Fisheries Assessment Working Group. Improved confidence in the assessment of this hake stock will be achieved only after a reliable index of relative abundance is developed.

1. INTRODUCTION

This report outlines the stock assessment of hake (*Merluccius australis*) in Quota Management Area (QMA) HAK 7, the west coast South Island hake stock, with the inclusion of data up to the end of the 2008–09 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 off WCSI 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 HAK2007-01B "To update the stock assessment of hake, including biomass estimates and sustainable yields", funded by the Ministry of Fisheries. The hake stock to be assessed under this project was not finalised by the Working Group until after the initial data input updates had been produced. Consequently, revised catch histories for all three hake stocks are reported here, as are any new model input data and research results. Although some of these data are not relevant to the assessment reported here, they are included to provide in one place an up-to-date summary of the available knowledge and literature on *Merluccius australis* in New Zealand waters.

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 divides 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. Currently, 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 3500 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. The TACC for HAK 1 has risen in several small jumps since then to its current level of 3701 t. 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 with an overall TAC of 1818 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 with 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 WCSI landings were misreported as deriving from Chatham Rise, 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).

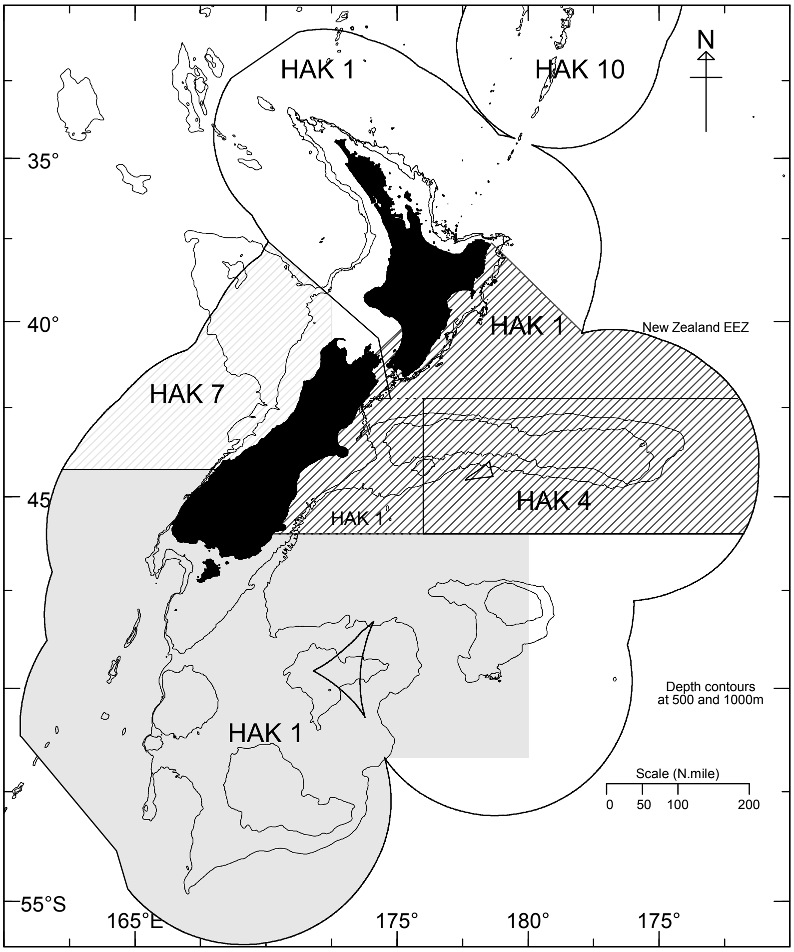

Figure 1: Quota Management Areas (QMAs) HAK 1, 4, 7, & 10; and the west coast South Island (light shading), Chatham Rise (dark shading), and Sub-Antarctic (medium shading) hake stock boundaries assumed in this report.

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 2004a, 2004b), 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 & Francis 2010), Sub-Antarctic (Horn 2008), and WCSI (Dunn 2004b).

Since 1991, resource surveys have been carried out from R.V. *Tangaroa* in the Sub-Antarctic in November–December 1991–1993 and 2000–2009 (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, 2011, 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 1992–2010 (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 2008–09 fishing year (Ballara & Horn 2011). These update the indices estimated by Phillips & Livingston (2004), Kendrick (1998), Dunn et al. (2000), Dunn & Phillips (2006), Devine & Dunn (2008), and Devine (2010). 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 TACCs since 1986–87 are shown in Table 2. Revised estimates of landings by QMA for 1989–90 to 2008–09 (Table 3) were derived by examining the reported tow-by-tow catches of hake and correcting for possible misreporting, using the method of Dunn (2003a).

Revised landings by stock are given in Table 4. The derivation of the catch from 1974–75 to 1988–89 was described for the Chatham Rise and Sub-Antarctic stocks by Dunn et al. (2000) and for WCSI by Dunn (2004b). Landings since 1989–90 from Chatham Rise and Sub-Antarctic and since 1991–92 for WCSI were obtained from the corrected data used to produce Table 3, but this time summing the landings reported in each of the three shaded areas shown on Figure 1. WCSI revised estimates for 1988–89 to 1990–91 are taken from Colman & Vignaux (1992), who 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.

The catch from the most recent year was assumed based on landings from recent previous years.

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 TACCs (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	TACC	Landings	TACC	Landings	TACC	Landings	TACC	Landings	TACC
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
2009–10	2 156	3 701	208	1 800	2 351	7 700	0	10	4 715	13 211

Table 3: Revised landings (t) by QMA 1989–90 to 2008–09 from Ballara & Horn (2011).

Fishing		QMA		Total
Year	HAK 1	HAK 4	HAK 7	
1989–90	2 115	763	4 903	7 781
1990–91	2 593	725	6 176	9 494
1991–92	3 156	2 013	3 026	8 195
1992–93	3 522	2 546	7 157	13 225
1993–94	1 787	2 587	2 990	7 364
1994–95	2 346	2 919	9 537	14 802
1995–96	3 810	3 080	9 235	16 125
1996–97	3 313	3 189	6 880	13 382
1997–98	3 681	3 251	7 809	14 741
1998–99	3 611	2 727	8 984	15 322
1999–00	3 796	2 773	7 046	13 615
2000–01	3 504	2 472	8 134	14 110
2001–02	2 870	1 424	7 519	11 813
2002–03	3 336	811	7 433	11 580
2003–04	3 466	2 275	7 945	13 686
2004–05	4 795	1 264	7 317	13 376
2005–06	2 743	305	6 906	9 954
2006–07	2 006	900	7 687	10 593
2007–08	2 445	865	2 620	5 930
2008–09	3 415	856	5 954	10 225

Table 4: Revised landings from 1974–75 to 2008–09 (t) for the Sub-Antarctic (Sub-A), Chatham Rise (Chat), and west coast South Island (WCSI) stocks. The landing from the most recent year is assumed based on recent trends in the fishery.

Fishing year	Sub-A	Chat	WCSI	Fishing year	Sub-A	Chat	WCSI
1974–75	120	191	71	1992–93	3 254	2 805	7 059
1975–76	281	488	5 005	1993–94	1 450	2 936	2 952
1976–77	372	1 288	17 806	1994–95	1 852	3 386	9 519
1977–78	762	34	498	1995–96	2 870	4 018	9 198
1978–79	364	609	4 737	1996–97	2 271	4 234	6 833
1979–80	350	750	3 600	1997–98	2 628	4 258	7 768
1980–81	272	997	2 565	1998–99	2 802	3 554	8 880
1981–82	179	596	1 625	1999–00	3 030	3 533	6 942
1982–83	448	302	745	2000–01	2 849	3 126	8 049
1983–84	722	344	945	2001–02	2 512	1 775	7 455
1984–85	525	544	965	2002–03	2 729	1 416	7 385
1985–86	818	362	1 918	2003–04	3 252	2 486	7 908
1986–87	713	509	3 755	2004–05	2 528	3 533	7 279
1987–88	1 095	574	3 009	2005–06	2 554	491	6 878
1988–89	1 237	804	8 696	2006–07	1 815	1 080	7 660
1989–90	1 917	957	8 741	2007–08	2 204	1 093	2 583
1990–91	2 370	905	8 246	2008–09	2 432	1 829	5 922
1991–92	2 743	2 414	3 010	2009–10	–	–	6 000

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

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 as age-length keys to scale up 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 (2010). The 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 to the west coast South Island stock presented by Dunn (1998).

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 ≥ 0.005 (males) or GSI ≥ 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. The values for Chatham Rise combined sexes maturity were taken as the mean of the male and female values. In the absence of sufficient data to estimate an ogive for WCSI hake, maturity for this stock was assumed to be the same as for Chatham Rise hake.

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}.

Dunn et al. (2010) found that the diet of hake on the Chatham Rise was dominated by teleost fishes, in particular Macrouridae. Macrouridae accounted for 44% of the prey weight and consisted of at least six species, of which javelinfish, *Lepidorhynchus denticulatus*, was most frequently identified. Hoki were less frequent prey, but being relatively large accounted for 37% of prey weight. Squids were found in 7% of the stomachs, and accounted for 5% of the prey weight. Crustacean prey were predominantly natant decapods, with pasiphaeid prawns occurring in 19% of the stomachs.

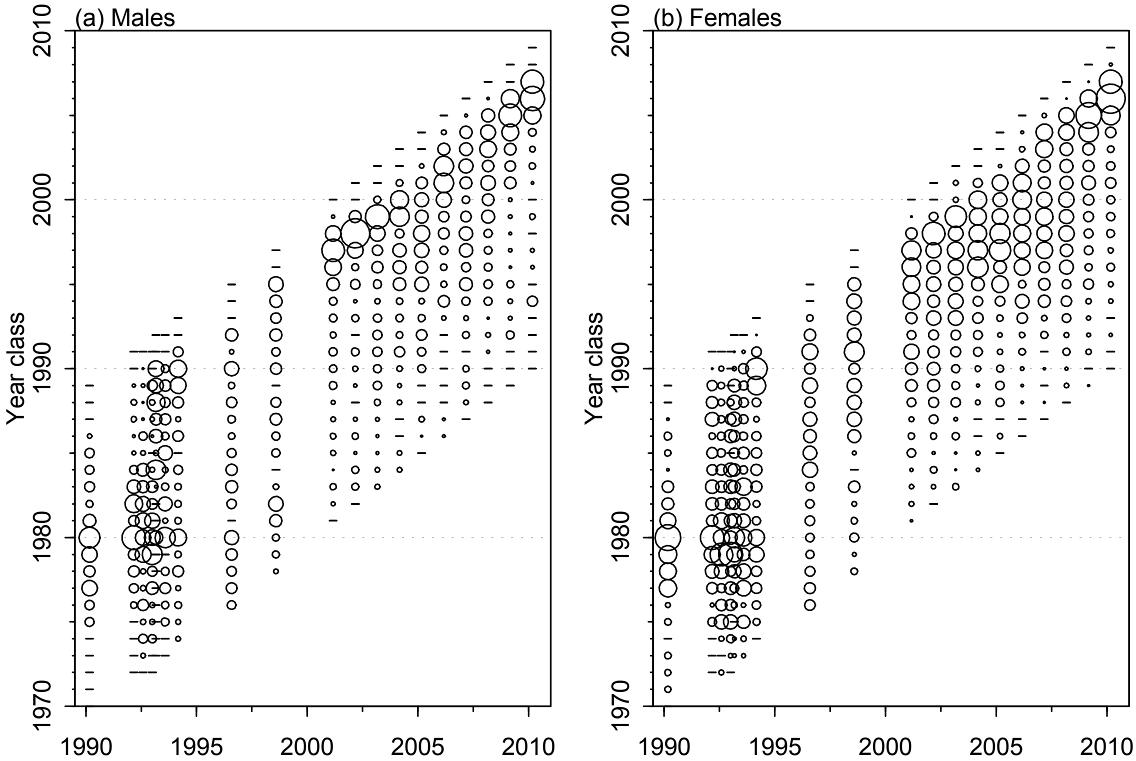

Figure 2: Age frequencies (ages 1 to 20+) by year class and year (symbol area proportional to the proportions-at-age within sampling event) in the Sub-Antarctic resource surveys, 300–800 m strata. Zero values are represented by a dash.

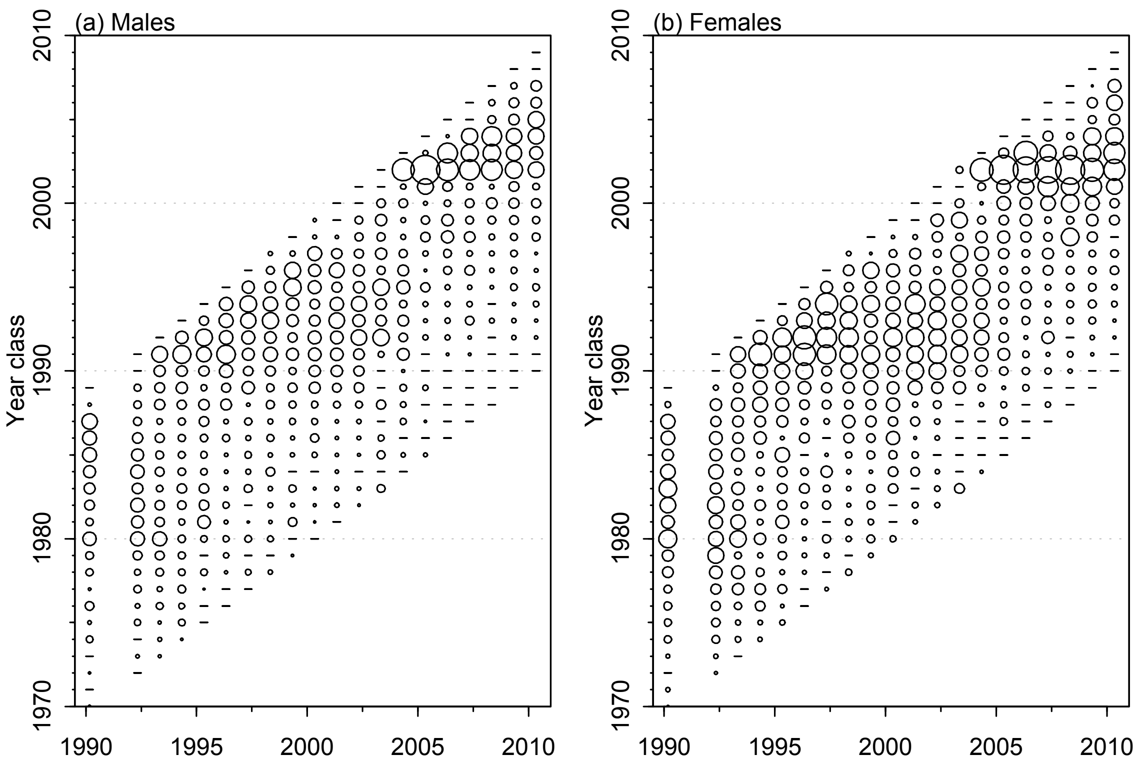

Figure 3: Age frequencies (ages 1 to 20+) by year class and year (symbol area proportional to the proportions-at-age within sampling event) on the Chatham Rise resource surveys, 200–800 m strata. Zero values are represented by a dash.

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 (and assumed for WCSI)						
	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	$a = 2.12 \times 10^{-9}$	$b = 3.275$			(Horn & Francis 2010)
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	$y_1 = 24.5$	$y_2 = 104.8$	$a = 0.131$	$b = 1.700$	(Horn & Francis 2010)
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)
	Both sexes	$y_1 = 24.5$	$y_2 = 98.5$	$a = 0.214$	$b = 1.570$	(Current study)

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 (and assumed for WCSI)														
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

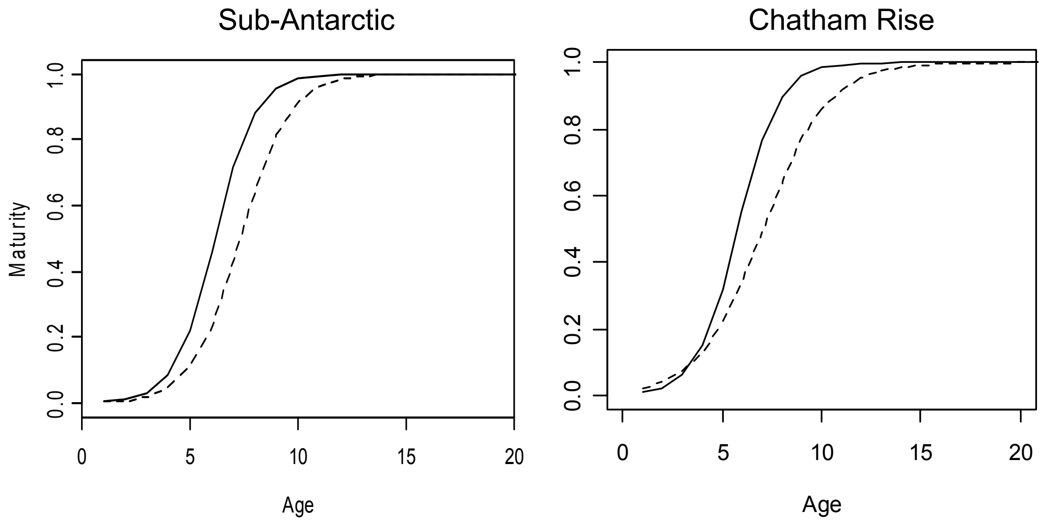

Figure 4: Estimated ogives of proportions mature by age for Sub-Antarctic and Chatham Rise hake males (solid lines) and females (broken lines).

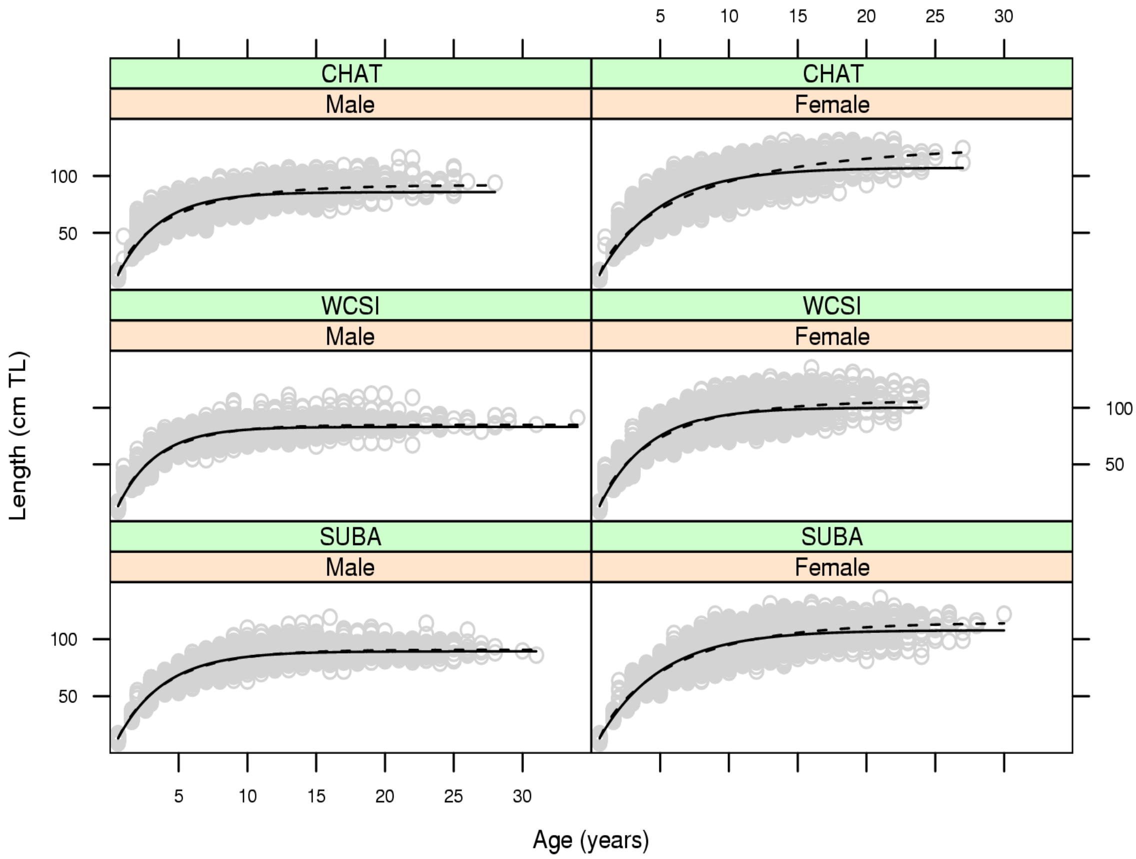

Figure 5: Raw age-length data, by sex, for hake from Chatham Rise (CHAT), west coast South Island (WCSI), and Sub-Antarctic (SUBA), with fitted von Bertalanffy curves (solid lines) and Schnute curves (broken lines).

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 from 2000 to 2009. 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 with further details 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 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. Since 2000 some of the *Tangaroa* surveys included deepwater strata (i.e., 800–1300 m) on the Chatham Rise, although data from these strata were excluded from 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 with further details in Appendix A. Catch distributions from these surveys are plotted by Stevens et al. (2011).

Research surveys of hoki and hake have been conducted periodically off WCSI, but these have been ‘one-off’ surveys by different vessels (i.e., *Shinkai Maru* in 1976, *James Cook* in 1978–79, *Wesermünde* in 1979, *Giljanes* in 1990, and *Tangaroa* in 2000) so any biomass estimates from them are not useful model inputs. It is possible that the 2000 *Tangaroa* survey (O'Driscoll et al. 2004) may be able to be linked to a trawl and acoustic survey series due to commence off WCSI in winter 2012 to produce a future series. A long-running trawl survey series of inshore waters off WCSI by *Kaharoa* has not provided a useful index of hake biomass as it surveys no deeper than 400 m (Stevenson & Hanchet 2000). Age data, and consequent estimates of proportion-at-age, are available for only the 1979 *Wesermünde* survey; these are incorporated in the WCSI assessment model.

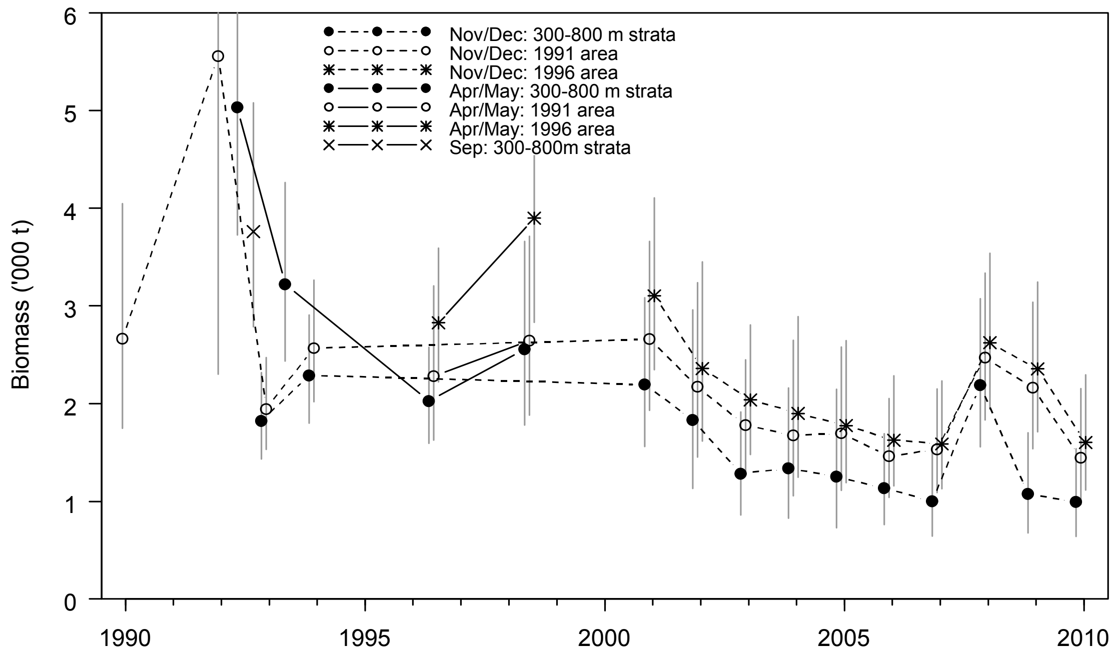

Figure 6: Hake biomass estimates from the *Amaltal Explorer* (October–November 1989) and *Tangaroa* (1991–2009 including the November–December, April–May, and September series) surveys of the Sub-Antarctic, with approximate 95% confidence intervals. (See also Appendix A.)

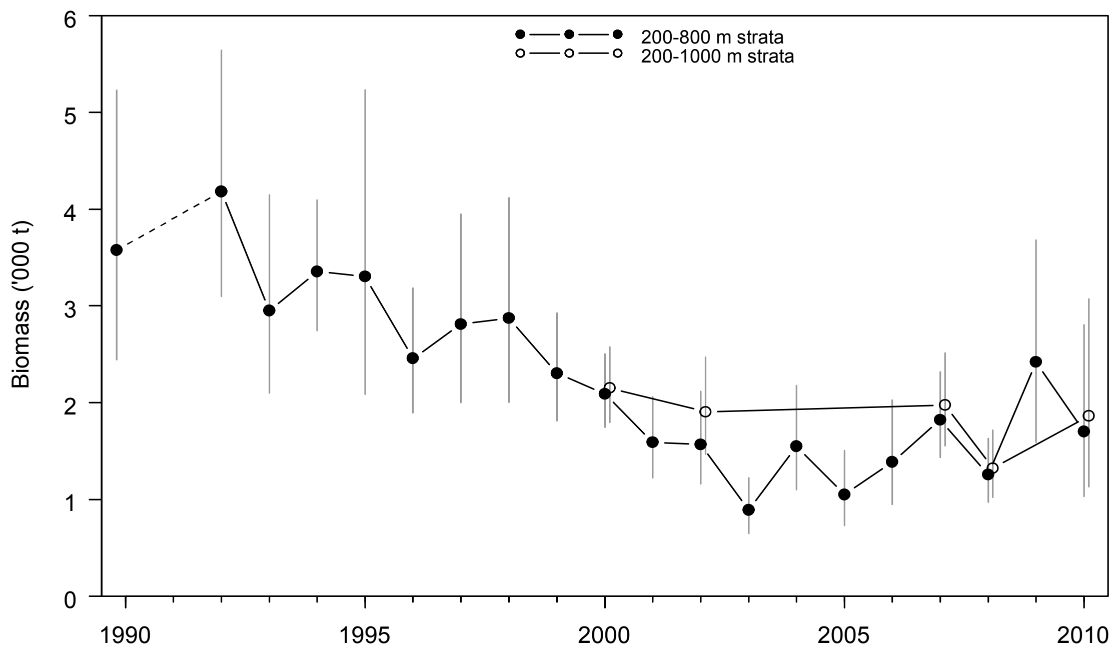

Figure 7: Hake biomass estimates from the *Amaltal Explorer* (November–December 1989) and *Tangaroa* (1992–2019 for the January series) of the Chatham Rise, with approximate 95% confidence intervals. (See also Appendix A.)

3.4 Observer 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. Where sufficient data were available, catch-at-age series and fishery ogives were developed separately for each fishery in the assessment of this stock by Horn & Dunn (2007).

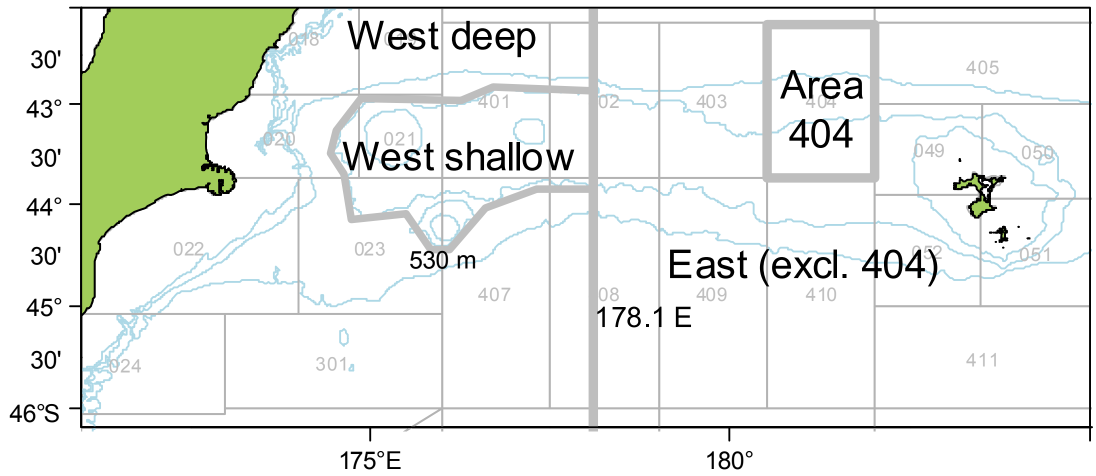

Figure 8: Fishery strata defined for the Chatham Rise hake fishery. Large numbers show longitudes or depths of fishery boundaries; small numbers denote statistical areas. The stratum boundary defined by depth (530 m) is shown only approximately. Isobaths at 1000, 500, and 250 m are also shown.

However, Horn & Francis (2010) showed that the two western fisheries had similar age-frequency distributions, and the two eastern fisheries were data poor. Consequently, they used two strata, eastern and western, divided at 178.1° E. 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%. The available data (described by Horn & Sutton (2010)) are from 1991–92 and 1993–94 to 2008–09. Although the observer length data from each year were partitioned into fisheries (i.e., two strata in each of the two fisheries, as shown in Figure 8), 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.

3.4.2 Sub-Antarctic

The Sub-Antarctic hake observer data were found to be best stratified into the four areas shown in Figure 9 (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 2008–09 (Horn & Sutton 2010).

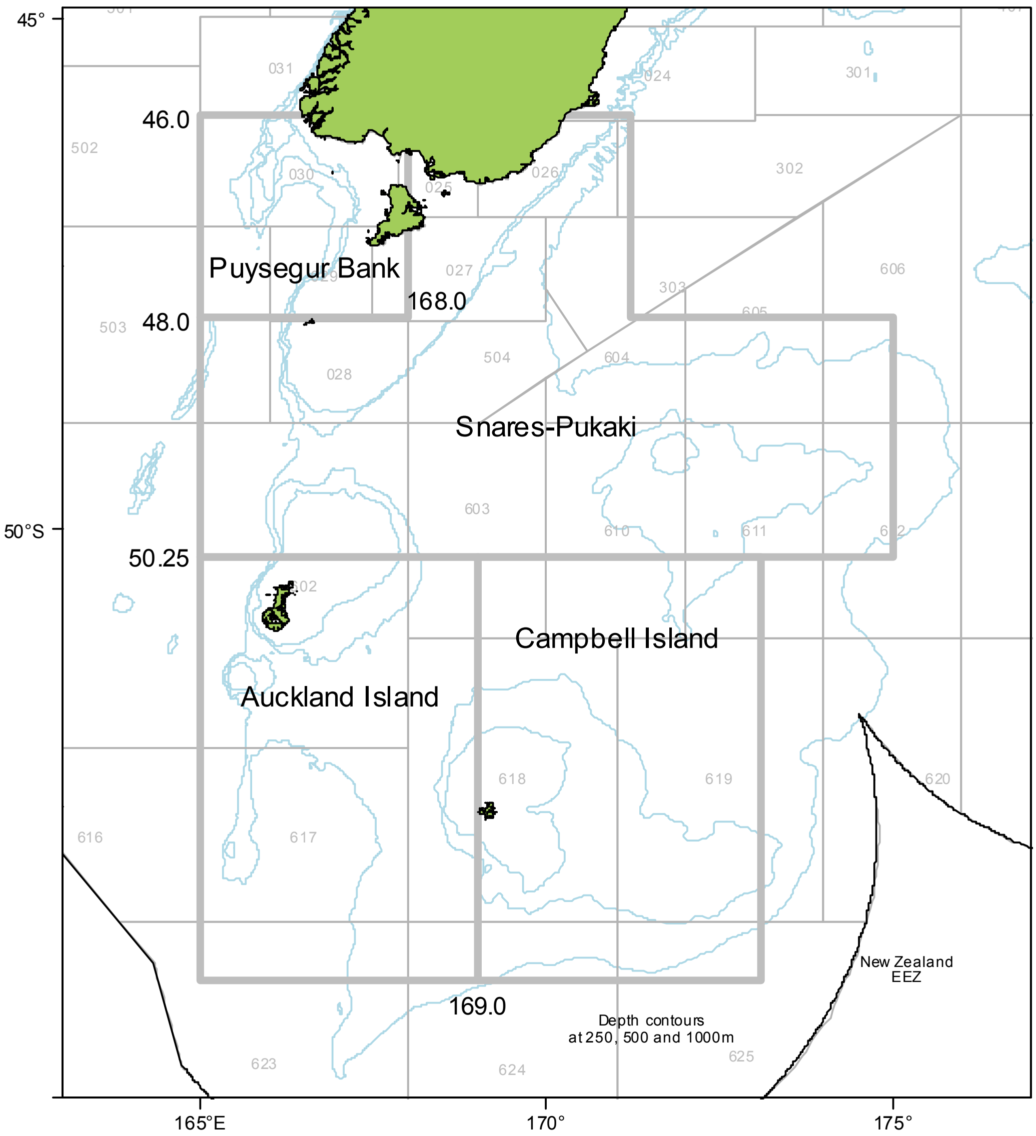

Figure 9: Fishery strata defined for the Sub-Antarctic hake fishery. Large numbers show latitudes or longitudes of fishery boundaries; small numbers denote statistical areas. Isobaths at 1000, 500, and 250 m are also shown.

3.4.3 WCSI

The fishery off WCSI 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). A single catch-at-age distribution was estimated for each year, stratified as shown in Figure 10. Catch-at-age distributions from the WCSI trawl fishery are available from all years from 1989–90 to 2008–09 (Horn & Sutton 2010).

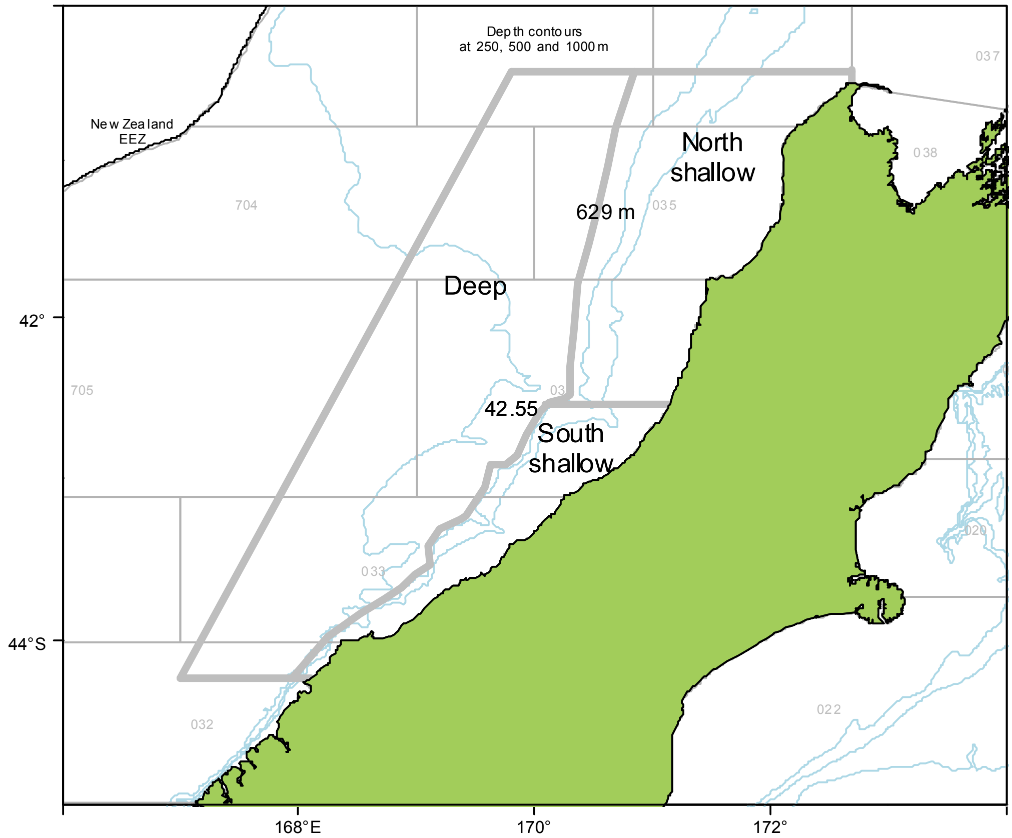

Figure 10: Fishery strata defined for the WCSI hake fishery. Large numbers show latitudes or depths of fishery boundaries; small numbers denote statistical areas. The stratum boundary defined by depth (629 m) is shown only approximately. Isobaths at 1000, 500, and 250 m are also shown.

3.5 CPUE indices

Standardised CPUE indices were calculated by Ballara & Horn (2011) from daily processed summary data up the end of the 2008–09 fishing season. Series were produced for the separate eastern and western fisheries on the Chatham Rise, for all areas combined on the Chatham Rise, and for all areas on the Sub-Antarctic and WCSI (Table 6). CPUE using estimated tow-by-tow data from WCSI is also presented (Table 6).

Table 6: Hake CPUE indices (and associated c.v.s) for the two fisheries on the Chatham Rise, Chatham Rise all areas, Sub-Antarctic all areas, and WCSI all areas (from Ballara & Horn 2011).

					Chatham Rise		Sub-Antarctic	
	West combined		East combined		All areas		All areas	
Year	Index	c.v.	Index	c.v.	Index	c.v.	Index	c.v.
1989–90	0.53	0.08	–	–	1.41	0.08	–	–
1990–91	0.72	0.06	1.43	0.09	0.88	0.06	1.61	0.06
1991–92	0.68	0.06	1.79	0.11	1.02	0.05	1.58	0.05
1992–93	0.90	0.07	1.26	0.08	0.88	0.04	1.27	0.05
1993–94	1.04	0.05	1.59	0.07	1.24	0.05	1.26	0.06
1994–95	1.41	0.04	1.11	0.06	1.05	0.03	0.97	0.05
1995–96	1.42	0.03	1.43	0.07	1.32	0.03	1.05	0.05
1996–97	1.17	0.03	1.14	0.07	1.28	0.03	0.90	0.04
1997–98	1.04	0.03	0.87	0.07	1.10	0.03	0.87	0.04
1998–99	1.11	0.03	1.06	0.06	0.93	0.02	0.98	0.04
1999–00	1.10	0.03	1.25	0.07	1.05	0.03	0.99	0.04
2000–01	1.06	0.03	0.96	0.06	1.00	0.03	1.12	0.04
2001–02	0.95	0.03	0.63	0.07	0.94	0.03	0.88	0.03
2002–03	1.01	0.03	0.61	0.07	0.81	0.03	0.81	0.04
2003–04	0.71	0.03	0.88	0.05	0.86	0.03	0.97	0.04
2004–05	0.93	0.03	0.50	0.05	0.60	0.03	0.73	0.05
2005–06	0.95	0.04	0.41	0.09	0.72	0.03	0.93	0.07
2006–07	1.00	0.04	0.76	0.07	0.87	0.03	0.61	0.06
2007–08	1.27	0.04	0.63	0.06	0.89	0.03	0.64	0.06
2008–09	0.53	0.08	0.69	0.07	1.14	0.03	0.81	0.06

			WCSI all areas	
	Daily processed		Tow-by-tow	
Year	Index	c.v.	Index	c.v.
1989–90	0.53	0.05	0.46	0.04
1990–91	0.67	0.05	0.59	0.04
1991–92	0.60	0.05	0.69	0.04
1992–93	1.05	0.05	1.20	0.04
1993–94	0.57	0.04	0.81	0.03
1994–95	0.91	0.03	1.16	0.02
1995–96	1.52	0.03	1.75	0.02
1996–97	1.31	0.03	1.38	0.02
1997–98	1.35	0.03	1.25	0.02
1998–99	1.14	0.03	1.23	0.02
1999–00	1.16	0.03	1.20	0.02
2000–01	0.90	0.03	0.91	0.02
2001–02	1.46	0.03	1.32	0.02
2002–03	1.17	0.03	1.05	0.02
2003–04	1.11	0.03	0.92	0.02
2004–05	0.92	0.03	0.91	0.02
2005–06	1.05	0.03	0.96	0.02
2006–07	0.88	0.03	0.77	0.03
2007–08	0.64	0.04	0.56	0.03
2008–09	1.04	0.04	0.89	0.03

4. MODEL STRUCTURE, INPUTS, AND ESTIMATION

4.1 Introduction

An updated assessment of the west coast South Island (WCSI) stock is presented here. In the previous assessment of this stock (Dunn 2004b) 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 October (i.e., the fishing year) and divided into three steps. The current assessment model was based on the same year but divided into two steps (Table 7). Note that model references to "year" within this document are labelled as the most recent calendar year, i.e., the year 1 October 1998 to 30 September 1999 is referred to as "1999".

Table 7: Annual cycle of the WCSI 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 fraction[1]	Age fraction[2]	Description	$\%Z$[3]
1	Oct–May	Recruitment	0.42	0.50		
2	Jun–Sep	Fishing, spawning & increment age	0.58	0.00	Proportions-at-age	50

1. The proportion of natural mortality that was assumed to have occurred in that time step.
2. 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.

For all models discussed below, assumed values of fixed biological parameters 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.

Catch-at-age observations were available from a single research voyage by *Wesermünde* in 1979 and from commercial observer data for the fishery (1990–2009). Lognormal errors, with known c.v.s, were assumed for all 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 same selectivity ogives were assumed to apply to both the research and commercial fishery proportion-at-age data.

The c.v.s for the at-age observations 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 in all model runs. The additional variance, termed process error, was estimated in an initial MPD run of the model.

Year class strengths were assumed known (and equal to one) for years before 1973 and after 2004, 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 is shown in Table 4.

4.2 Developing a 'base' model

Some initial investigations were completed to develop a '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 these preliminary models, the only parameters estimated were B_0, year class strengths, selectivity parameters, and (where CPUE was used) CPUE catchability.

An initial model 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 two selectivity ogives: male and female selectivities for the commercial fishery. Male selectivity was estimated relative to female selectivity. Selectivities were assumed constant over all years in the fisheries and the single research survey. All selectivity ogives were estimated using the double-normal parameterisation. Process error for all the catch-at-age series was estimated in the initial model to have a c.v. of 0.45, and this value was used in all subsequent models. No CPUE data were incorporated, i.e., this model included no relative abundance series.

B_0 was 132 300 t, and stock status in 2010 was estimated to be 83% of B_0. However, the selectivity ogives were markedly different between sexes (Figure 11), and this was believed to be unsatisfactory and unrealistic.

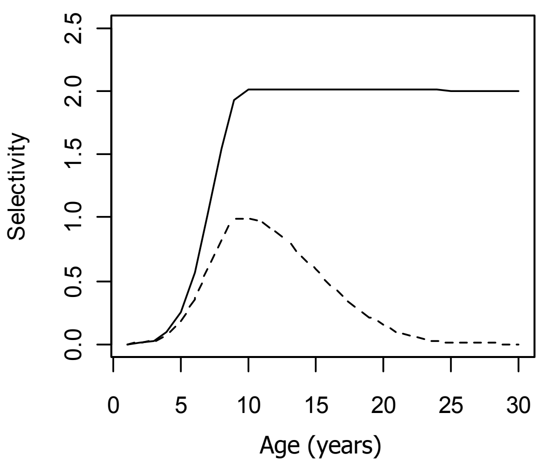

Figure 11: MPD estimates of trawl selectivity from the initial model, for male (solid line) and female (dashed line) hake.

MPD fits to the at-age data are generally better before 2000 than after (Figure 12). Poor fits generally manifest as greater numbers of younger fish occurring in the catch than would be expected (i.e., see the fits for 2003 and 2005–07).

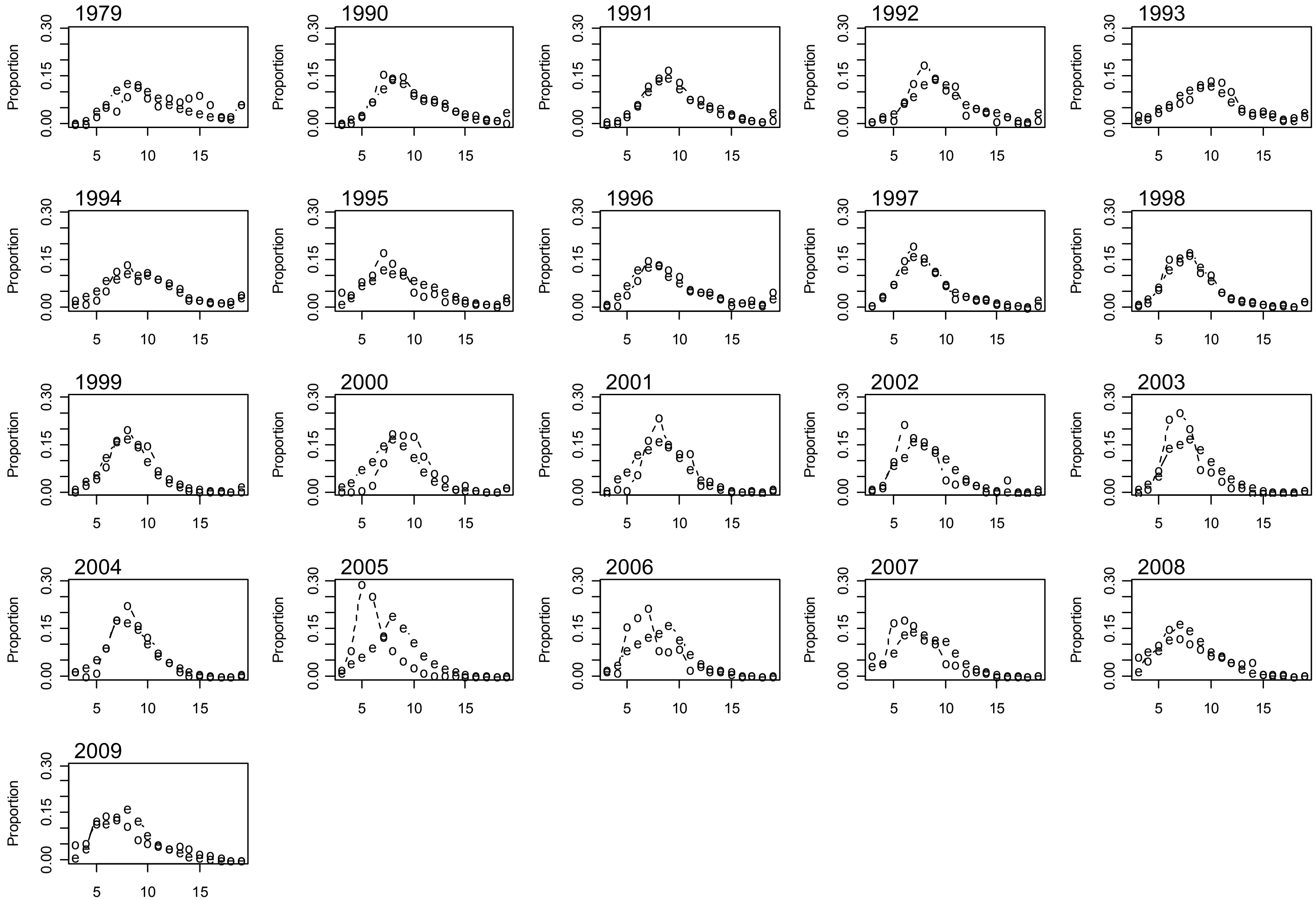

Figure 12: MPD fits to the proportions-at-age data from the research survey (1979) and trawl fishery (1990–2009). o, observed data; e, expected fit.

It was apparent, from the proportion-at-age data, that males were more abundant than females in the commercial catch. But it was also clear that sex ratios in the catch varied markedly between years (Figure 13), and also between trips within years. There may also have been some systematic change in sex ratios over time, e.g., a steady increase in the proportion of females from 1996 to 2002. It was also found that male proportion-at-age data were consistently poorly fitted relative to female data; the residuals for male data points were, on average, 1.5 times greater than for female data. Similar characteristics were observed in the Chatham Rise hake fishery, but the subsequent modelling problems were alleviated by removing sex from the partition (Horn & Francis 2010).

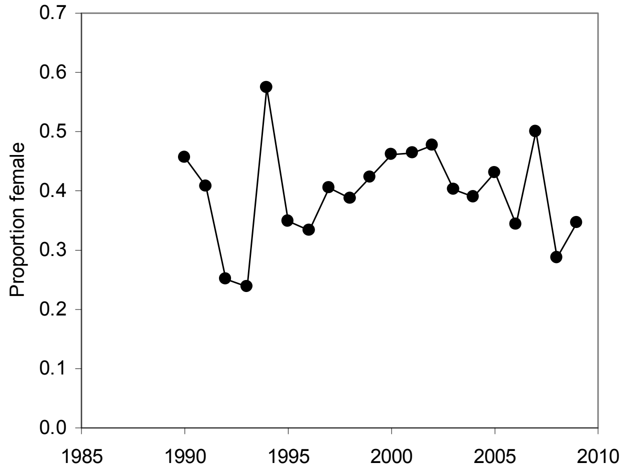

Figure 13: Proportion of female fish recorded in the observer length data scaled to total catch, by year.

Consequently, a single-sex model 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), and all catch-at-age data were unsexed.

Removing sex from the model substantially reduced the estimate of B_0 (from 132 000 t to 82 000 t) (Figure 14). It had comparatively little effect on the estimated year class strengths, generally flattening the estimates and reducing the need to have such a high value for the 2004 year class (Figure 14). Because of the lower B_0, stock status in 2010 was also lower at 51% of B_0 (compared to 83%B_0 for the initial model). The lower current stock status is also driven by the generally lower year class strengths from 1999 to 2004. Despite the single sex model being less optimistic, the fishing pressure in most years is still less than 0.25.

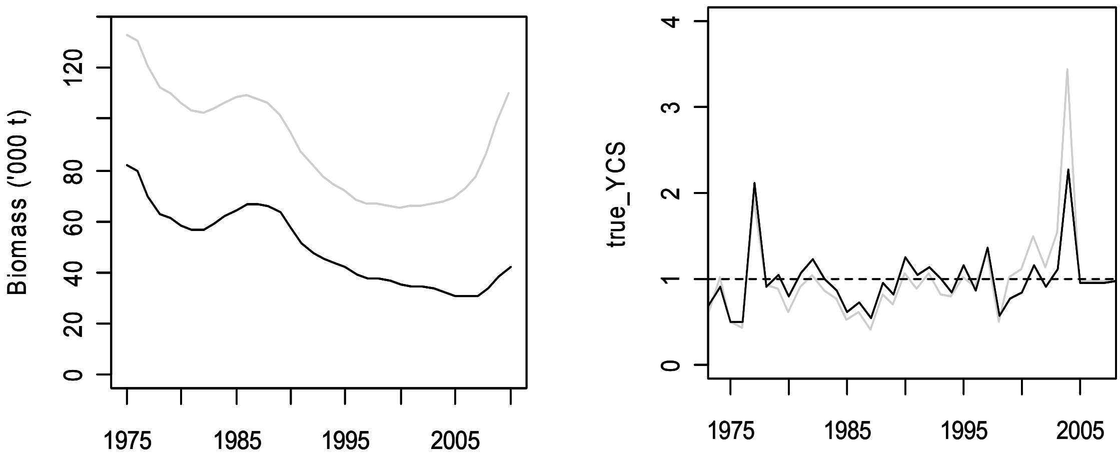

Figure 14: Biomass trajectories and estimates of year class strengths from the initial two-sex model (grey lines) and the subsequent single-sex model (black lines).

The impact of adding a CPUE series was investigated in the final preliminary model. Two CPUE series were available (see Table 6), but they exhibited virtually identical trends, so the results when including either series would be similar. The series derived from 1990–2009 trawl daily processed catch (see Table 6) was input into the single-sex model. Adding the CPUE series slightly increased the estimate of B_0 (from 82 000 t to 89 000 t) (Figure 15). It had comparatively little effect on the estimated year class strengths, generally reducing earlier estimates and increasing later ones (Figure 15). It encouraged a flatter biomass trajectory, and consequently a better stock status in 2010 of 66% of B_0 (compared to 51%B_0 for the single-sex model). However, it is clear that the signals about biomass from the proportion-at-age data and the CPUE are contradictory (Figure 16). Consequently, in a model dominated by at-age data, the CPUE series is very poorly fitted and the residuals are unbalanced (Figure 16). It is known that fishing (particularly target fishing) and reporting practices for hake off WCSI have varied markedly over time, and this could easily have resulted in CPUE series that do not track abundance (Ballara & Horn 2011). Previous assessments of the WCSI hake stock considered CPUE to be an unreliable index of abundance (e.g., Dunn 2004b). The Middle Depth Species Fishery Assessment Working Group drew a similar conclusion about the CPUE series presented here, so it was not used in any subsequent stock modelling

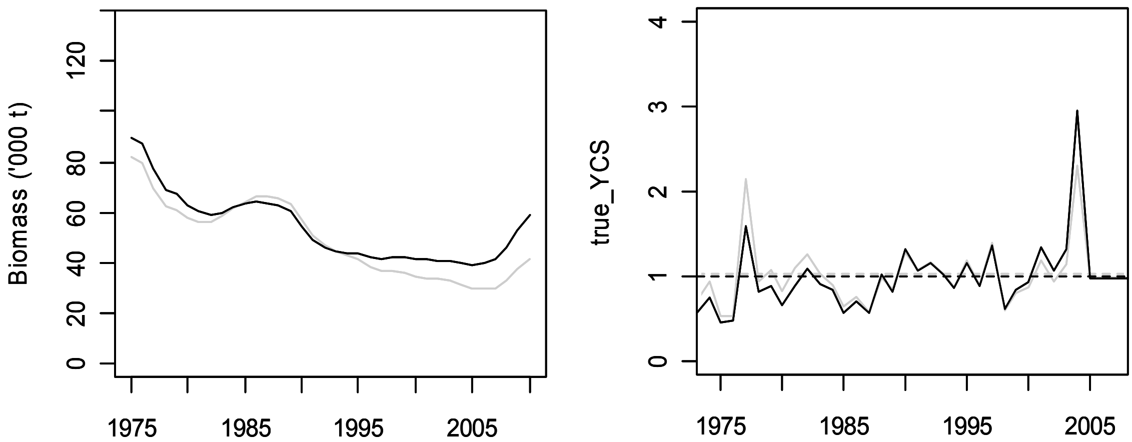

Figure 15: Biomass trajectories and estimates of year class strengths from the single-sex model without CPUE (grey lines) and with CPUE (black lines).

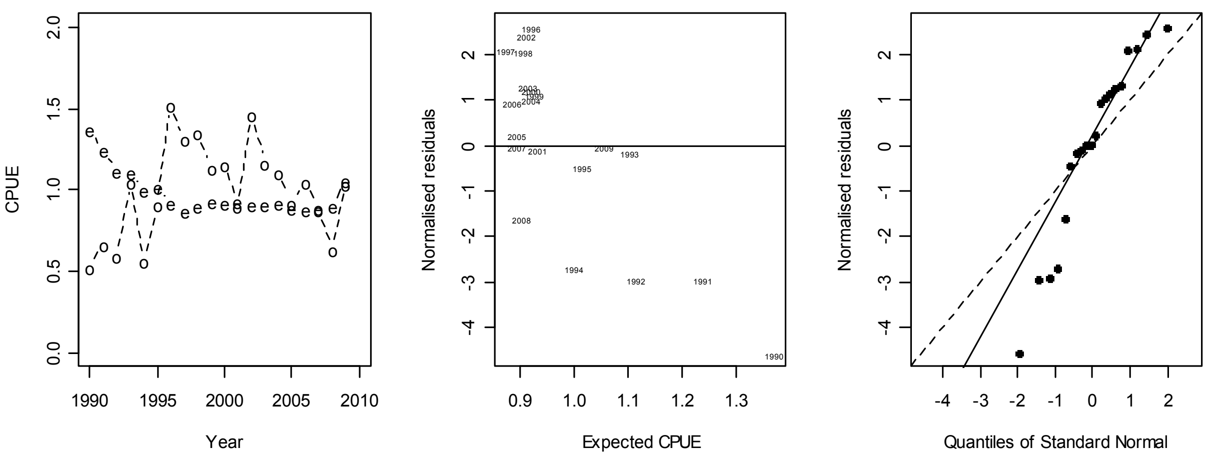

Figure 16: CPUE fits ('o', observed; 'e', expected) and diagnostics.

Following the investigations above with MPD model fits it was concluded that the best base case model for MCMC estimation was the single-sex model without CPUE. There are no series of relative abundance available to this model; only catch-at-age data are available to infer biomass trends. The Middle Depth Species Fishery Assessment Working Group requested that the sensitivity of the model to changes in instantaneous natural mortality (*M*) be investigated by running the model with *M* values of 0.15 and 0.24 (compared to the base value of 0.19).

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 2500^{th} 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 2005–08 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 8. The priors for B_0 and year class strengths were intended to be relatively uninformed, and had wide bounds. Priors for all selectivity parameters were assumed to be uniform.

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, and b) to ensure that all estimated year class strengths averaged 1.

Table 8: The assumed priors for key distributions (when estimated). The parameters are mean (in natural space) and c.v.

Stock	Parameter	Distribution	Parameters		Bounds	
WCSI	B_0	Uniform-log	–	–	5 000	350 000
	YCS	Lognormal	1.0	1.1	0.01	100
	Selectivity	Uniform	–	–	1	25–200*

* A range of maximum values was used for the upper bound.

5. MODEL ESTIMATES

Base case estimates of biomass were made using the biological parameters (see Table 5) and model input parameters described earlier. Two sensitivities (i.e., *M* = 0.15 or 0.24) were investigated.

MCMC estimates of the posterior distribution were obtained for all three 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. The MCMC chains for estimates of B_0 and B_{2010} from the base model appear moderately well converged (Figure 17). The distributions of estimates of B_0 and B_{2010} (as $\%B_0$) from the base model are reasonably consistent between the first, middle, and last thirds of the chain (Figure 17), and hence convergence is probably adequate for stock-assessment purposes.

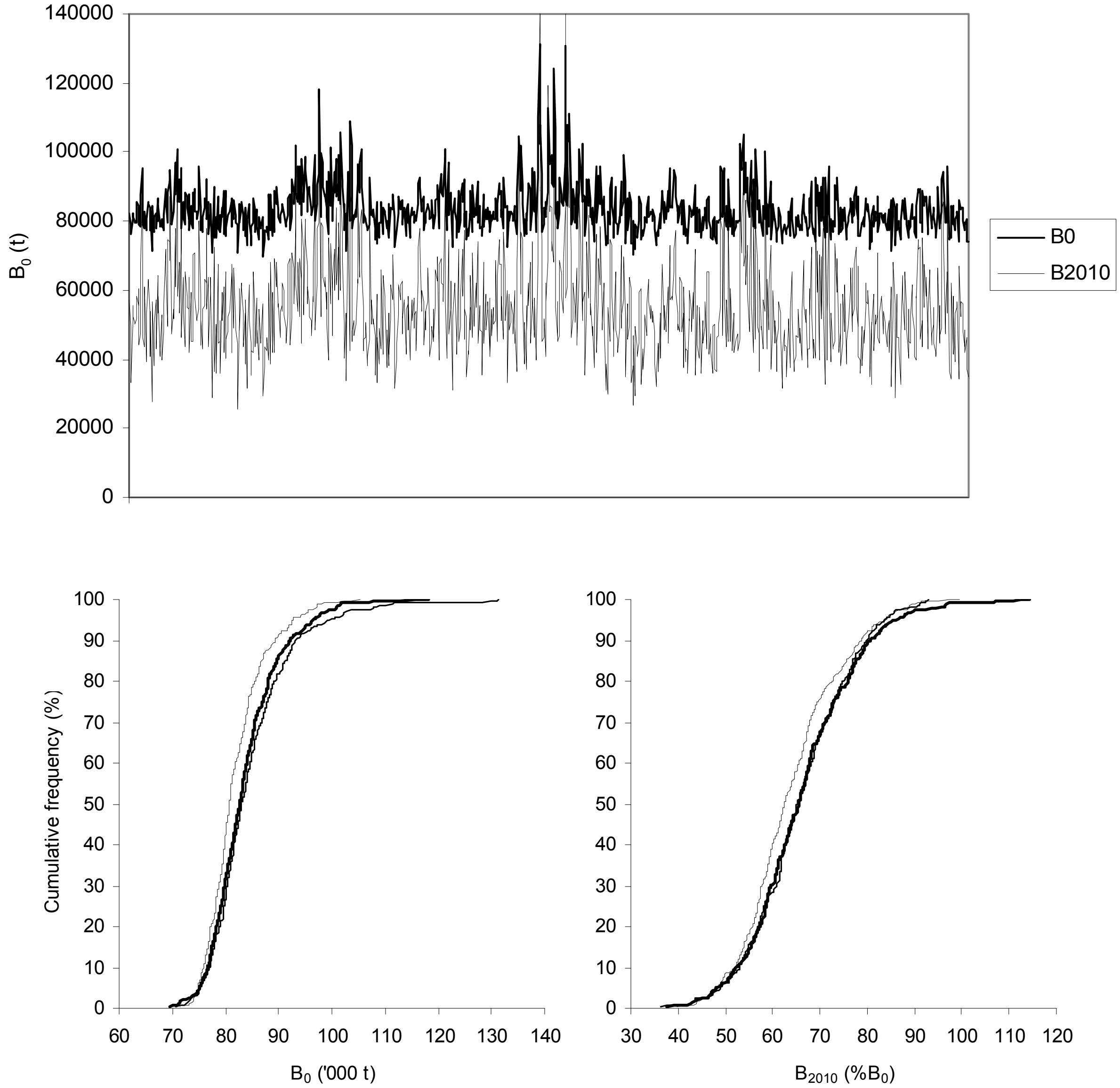

Figure 17: Trace diagnostic plot of the MCMC chains for estimates of B_0 and B_{2010} for the base model run (upper panel). MCMC diagnostic plots showing the cumulative frequencies of B_0 and B_{2010} (%B_0) for the first (thick line), middle (medium line), and last (thin line) third of the MCMC chain for the base model (lower panel).

The estimated MCMC marginal posterior distributions for selected parameters from the Base case model are shown in Figures 18–21. The median fishery selectivity ogive was approximately logistic shaped, but its bounds were relatively wide (Figure 18). The ogive suggested that hake were fully selected by the fishery by age 10. There is no information outside the model that allows the shape of the estimated selectivity ogive to be verified.

Year class strength estimates were moderately well estimated for all years (Figure 19). Variation in year class strength does not appear to be great; virtually all median estimates are between 0.5 and 2.

Estimated biomass for the WCSI stock declined throughout the late 1970s owing to relatively high catch levels, then increased through the mid 1980s owing to a marked decline in catch (Figure 20). Biomass then steadily declined from 1988 to 2005 owing to higher levels of exploitation and the recruitment of year classes that were generally of below-average strength. The slight increase since 2005 is a consequence of the recruitment of four year classes since 2001 that are estimated to be of above average strength. Bounds around the biomass estimates are reasonably tight, with current stock size being about 65% of B_0 (95% credible interval 46–89%) (see Figure 20 and Table 9). Exploitation rates (catch over vulnerable biomass) were less (often much less) than 0.2 up to 1995 (except in 1977), but have been moderate (0.2–0.3 yr^{-1}) from 1996 to 2007 (Figure 21). The exploitation rate has dropped again in recent years.

Table 9: Bayesian median and 95% credible intervals of B_0, B_{2010}, and B_{2010} as a percentage of B_0 for all model runs.

Model run	B_0	B_{2010}	B_{2010} (%B_0)
Base case	82 060 (73 780–100 660)	53 300 (34 160–87 240)	64.7 (45.8–88.7)
M = 0.15	98 280 (86 190–120 510)	55 490 (33 700–93 960)	56.2 (38.4–77.4)
M = 0.24	92 490 (80 370–111 340)	84 500 (52 720–134 800)	92.1 (65.0–123.1)

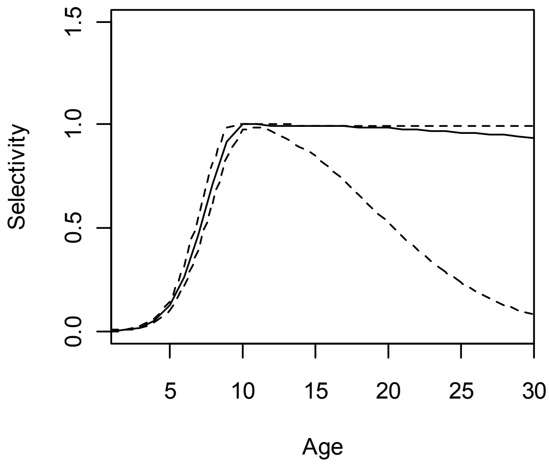

Figure 18: Base case — Estimated median selectivity ogive (with 95% credible intervals shown as dashed lines) for the trawl fishery.

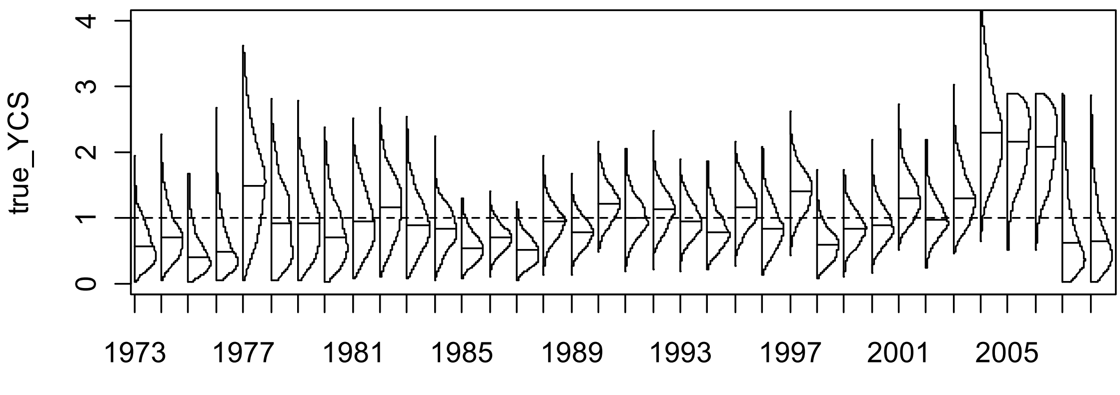

Figure 19: Base case — Estimated posterior distributions of year class strengths. The dashed horizontal line indicates the year class strength of one. Individual distributions are the marginal posteriors, with horizontal lines indicating the median.

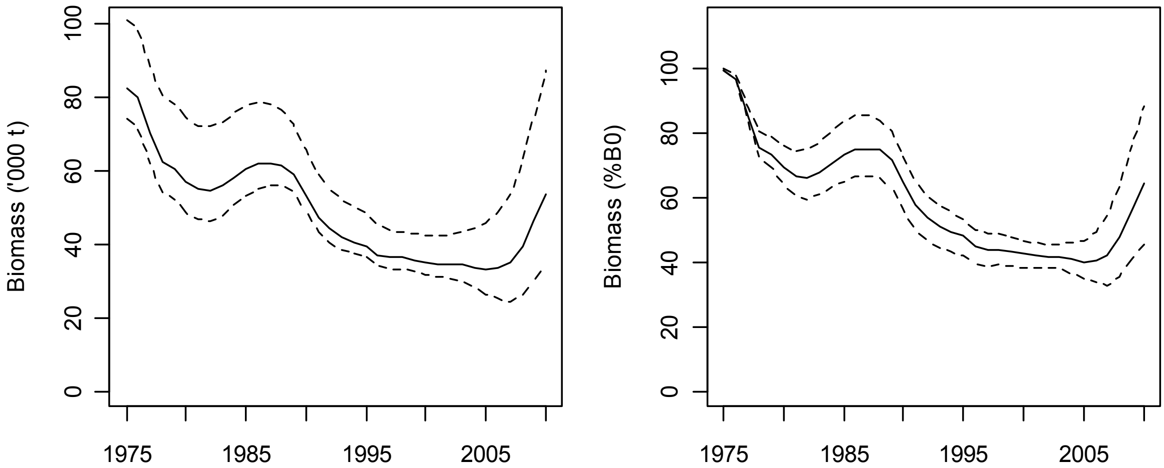

Figure 20: Base case — Estimated median trajectories (with 95% credible intervals shown as dashed lines) for absolute biomass and biomass as a percentage of B_0.

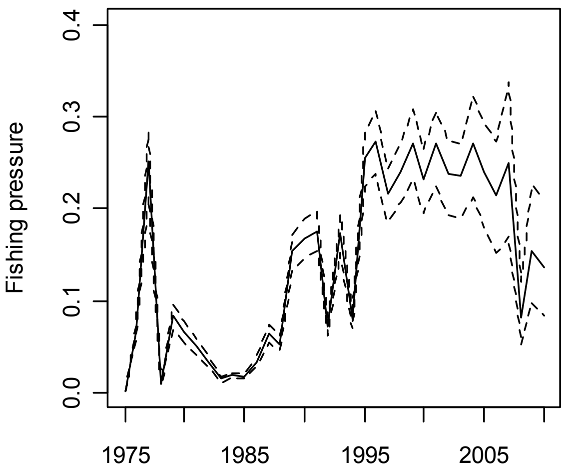

Figure 21: Base case — Estimated median trajectory of exploitation rate (with 95% credible intervals shown as dashed lines).

The two sensitivity runs investigated the effects of varying *M*. The estimated MCMC marginal posterior distributions for selected parameters from the two models are shown in Figures 22–25. Selectivity ogives were relatively tightly defined, but were different from each other and from the base model (Figure 22). For *M* = 0.15, selectivity was strongly domed. For *M* = 0.24, median selectivity was essentially logistic (as in the base model), but unlike the base model the confidence bounds were very tight and precluded any possibility of domed selectivity. Age at full selectivity was the same in all three models (i.e., about 10 years).

There was little difference between the base case and *M* = 0.15 sensitivity models in the estimated pattern or absolute size of year class strengths (Figure 23, compared with Figure 19). With *M* = 0.24, the year class pattern was similar to the base case, but the confidence intervals tended to be broader.

Exploitation rates were little different between the base case and *M* = 0.15 sensitivity models (Figure 24, compared with Figure 21). With *M* = 0.24, exploitation rates were slightly lower than for the base case, and the confidence intervals tended to be narrower.

Trends in biomass were quite similar between the base and *M* = 0.15 models (Table 9; Figure 25, compared with Figure 20). However, the biomass trajectory for the *M* = 0.24 model is markedly flatter than for the other two models (Figure 25). Consequently, stock status from the *M* = 0.24 model is much more optimistic. The different trends between the three models in current relative to virgin biomass are a consequence of both the changes in *M* and changes in the shape of the selectivity ogive. A profiling exercise (Figure 26) shows that MPD estimates of B_0 and B_{2010} converge as *M* increases; a higher *M* is indicative of a more productive stock that is less affected by fishing extractions. However, in concert with the changing *M* there is a relatively distinct point (between an *M* of 0.20 and 0.21) at which the best selectivity ogive changes from being strongly domed to being essentially logistic.

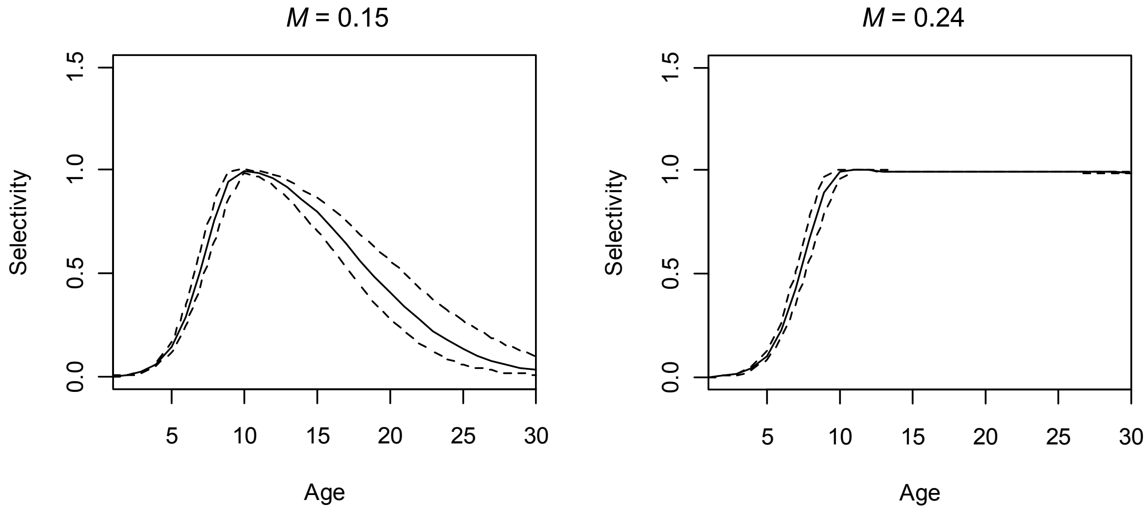

Figure 22: Estimated median selectivity ogives (with 95% credible intervals shown as dashed lines) for the two sensitivity models (*M* = 0.15 or *M* = 0.24).

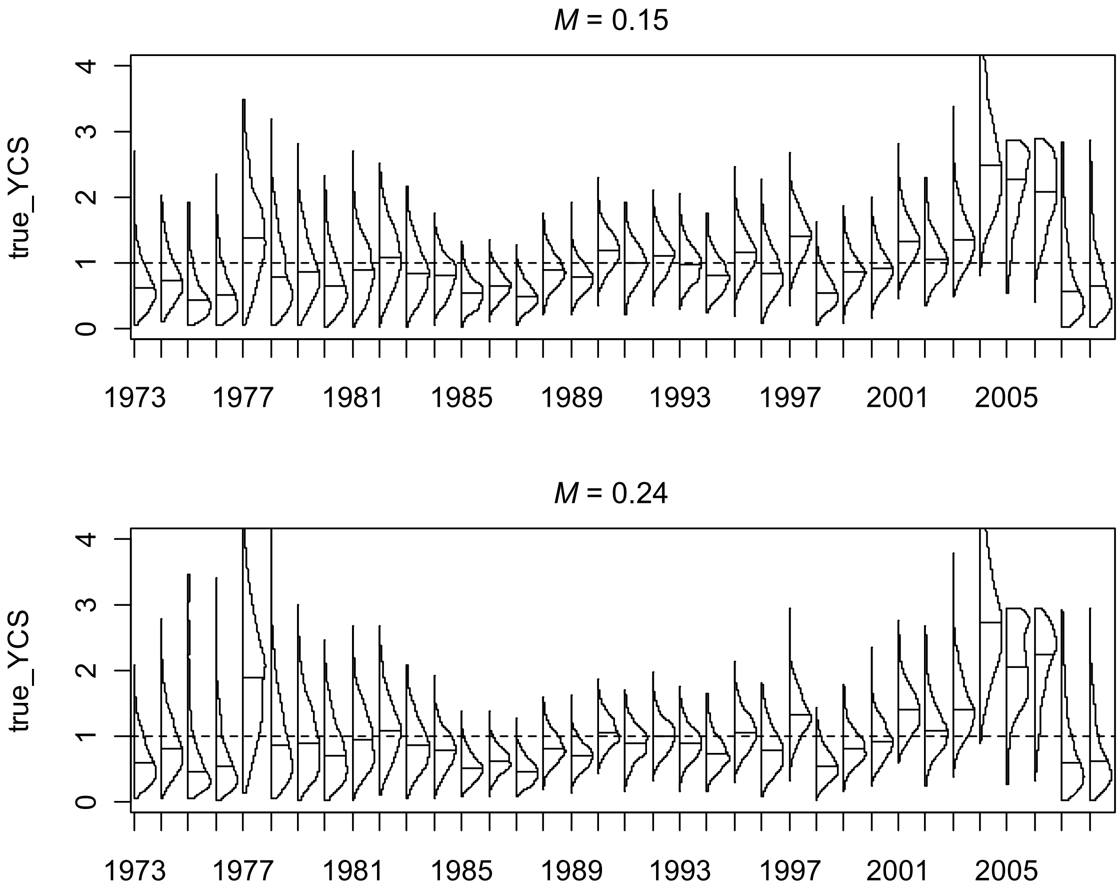

Figure 23: Estimated posterior distributions of year class strengths for the two sensitivity models (*M* = 0.15 or *M* = 0.24). The dashed horizontal line indicated the year class strength of one. Individual distributions are the marginal posteriors, with horizontal lines indicating the median.

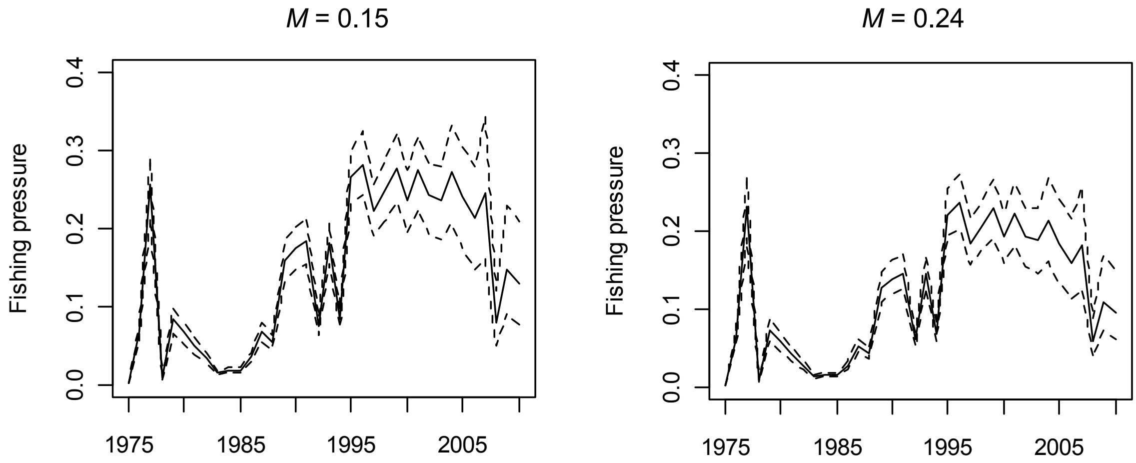

Figure 24: Estimated median trajectory of exploitation rate (with 95% credible intervals shown as dashed lines) for the two sensitivity models (*M* = 0.15 or *M* = 0.24).

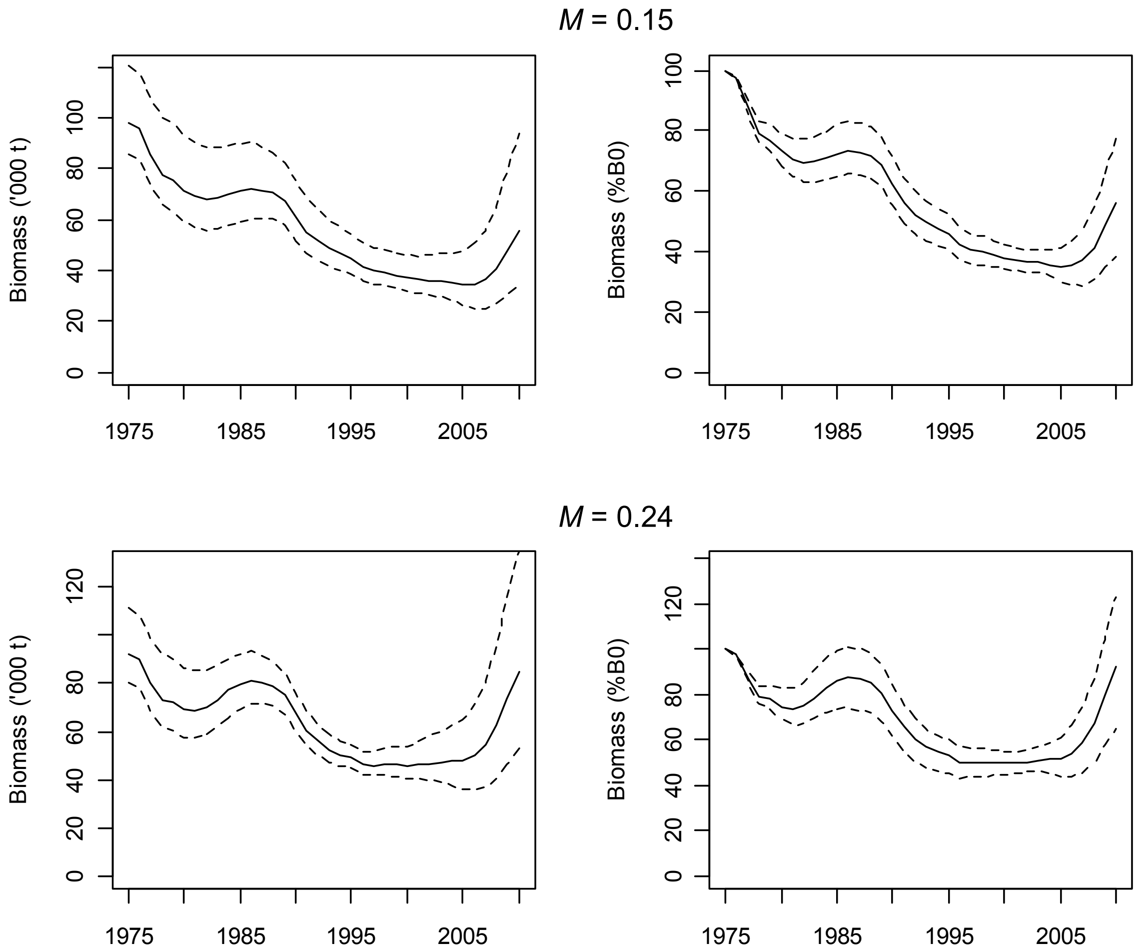

Figure 25: Estimated median trajectories (with 95% credible intervals shown as dashed lines) for absolute biomass and biomass as a percentage of B_0, for the two sensitivity models (M = 0.15 or M = 0.24).

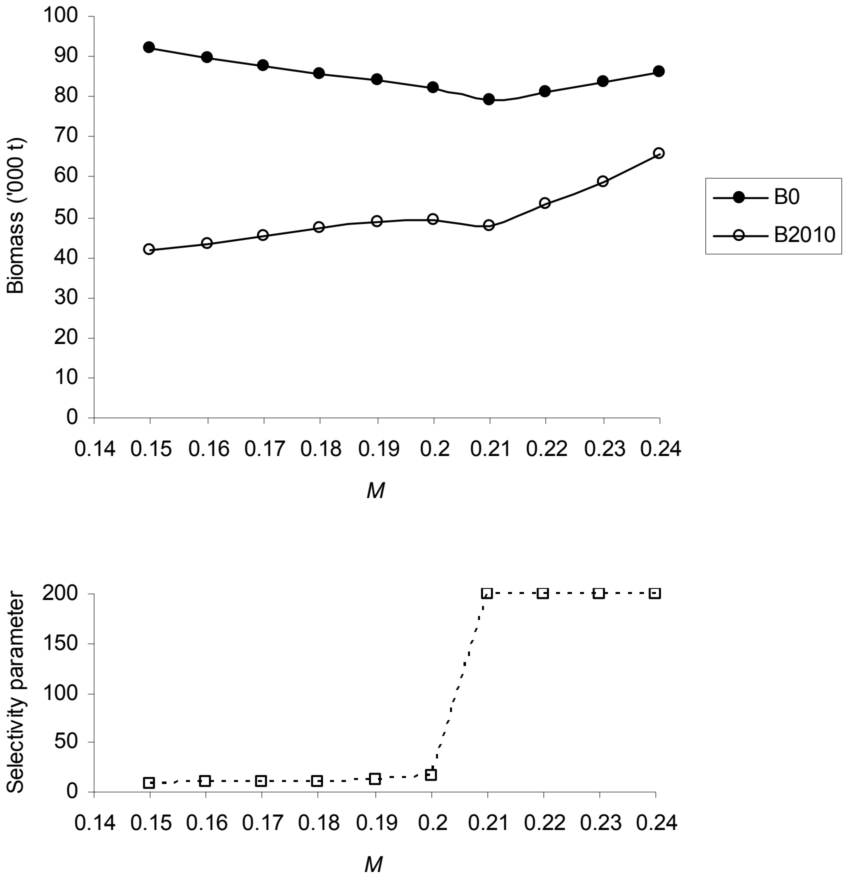

Figure 26: Profiles showing the effects of changes to *M* on MPD estimates of biomass (B_0 and B_{2010}) and the parameter that defines the slope of the right-hand limb of the double-normal fishery selectivity ogive.

5.1 Biomass projections

Biomass projections from the base case and two sensitivity models were made under two assumed future catch scenarios (6000 t or 7700 t annually from 2011 to 2015). The low catch scenario (6000 t) approximates the catch level from recent years. The high catch scenario (7700 t) is the highest likely level of catch as it equates to the HAK 7 TACC.

Year class strengths from 2005 onwards were selected randomly from the previously estimated year class strengths from 1995 to 2004.

Projections from the base case model suggested that biomass will increase slightly to be about 72% of B_0 (lower catch) or 67% of B_0 (higher) by 2015 (Table 10, Figure 27). Similarly under the two sensitivity models, biomass was projected to increase slightly under the two assumed future catch scenarios (Figure 28). However, these projections are quite uncertain as indicated by the rapidly spreading confidence intervals after 2010 in Figures 27 and 28.

Table 10: Bayesian median and 95% credible intervals of projected B_{2015}, B_{2015} as a percentage of B_0, and B_{2015}/B_{2010} (%) for all model runs, under two future annual catch scenarios.

Model run	Future catch (t)	B_{2015}	B_{2015} (%B_0)	B_{2015}/B_{2010} (%)
Base case	6 000	59 720 (30 750–112 470)	72.4 (41.3–117.8)	119 (92–156)
	7 700	54 660 (27 540–105 310)	66.5 (36.2–111.5)	109 (78–145)
M = 0.15	6 000	67 390 (33 580–132 170)	67.8 (38.3–113.0)	127 (98–168)
	7 700	59 960 (29 060–119 270)	61.0 (33.7–103.0)	115 (86–156)
M = 0.24	6 000	91 530 (52 120–167 700)	98.6 (67.2–156.6)	114 (90–150)
	7 700	85 860 (47 460–164 520)	93.4 (57.3–156.0)	108 (83–147)

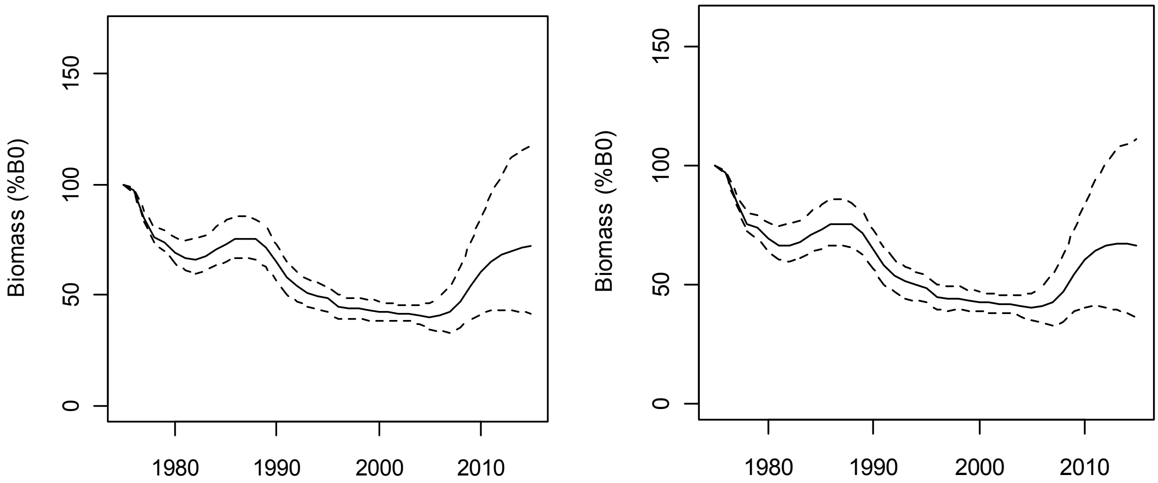

Figure 27: Base case — Estimated median trajectories (with 95% credible intervals shown as dashed lines) for biomass as a percentage of B_0, projected to 2015 with future catches assumed to be 6000 t (left panel) or 7700 t (right panel) annually.

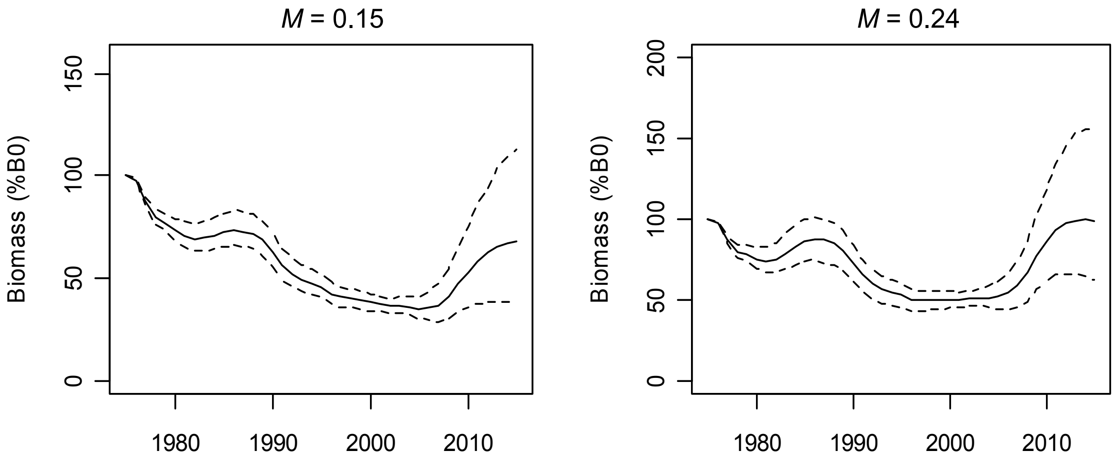

Figure 28: Estimated median trajectories (with 95% credible intervals shown as dashed lines) for biomass as a percentage of B_0, for the two sensitivity models (M = 0.15 or M = 0.24), projected to 2015 with future catches assumed to be 6000 t annually.

5.2 Management biomass targets

Probabilities that current and projected biomass will drop below selected management reference points (i.e., target, 40%B_0; soft limit, 20%B_0; hard limit, 10%B_0) are shown for the base model and both sensitivity runs in Table 11. It appears extremely unlikely (i.e., < 1%) that B_{2015} will be lower than the soft target of 20%B_0.

Table 11: Probabilities that current (B_{2010}) and projected (B_{2015}) biomass will be less than 40%, 20% or 10% of B_0. Projected biomass probabilities are presented for two scenarios of future annual catch (i.e., 6000 t, and 7700 t).

Model run	Biomass	Management reference points		
		40% B_0	20% B_0	10% B_0
Base	B_{2010}	0.019	0.000	0.000
	B_{2015}, 6000 t catch	0.021	0.000	0.000
	B_{2015}, 7700 t catch	0.048	0.000	0.000
$M = 0.15$	B_{2010}	0.075	0.000	0.000
	B_{2015}, 6000 t catch	0.033	0.000	0.000
	B_{2015}, 7700 t catch	0.078	0.001	0.000
$M = 0.24$	B_{2010}	0.000	0.000	0.000
	B_{2015}, 6000 t catch	0.000	0.000	0.000
	B_{2015}, 7700 t catch	0.002	0.000	0.000

5.3 Estimates of sustainable yields

Absolute estimates of biomass from any of the models are neither precise enough nor considered reliable enough to justify the estimation of sustainable yields (i.e., MCY or CAY).

5.4 Estimates of total instantaneous mortality (*Z*) from fishery age data

Estimates of total instantaneous mortality rates (*Z*) were derived from the scaled trawl fishery age-frequency distributions for each year from 1990 to 2009. *Z* was derived using a maximum likelihood procedure (Chapman & Robson 1960), i.e.,

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

where *a* is the mean age above recruitment age. For this estimator, age at recruitment (*R*) should be an age at which 100% of fish are vulnerable to the sampling method (rather than the often used age at 50% recruitment). The age at full selectivity estimated in the model results reported above is about 10 years. The most abundant age class in each of the estimated age-frequency distributions for the fishery ranges from 5 to 9 years (see Figure 12). Consequently, *Z* was estimated each year using *R* values of 8, 10, and 12 years. Note, however, that these estimates assume non-domed selectivity in the fishery, a characteristic not ruled out by the chosen base assessment model. Consequently, the estimates produced here will be positively biased if true trawl fishery selectivity is domed.

The point estimates are very variable, ranging from 0.24 to 0.56 (Figure 29). There appear to be two distinct groups of values: 1990–98, 1999–2009. The mean *Z* (when $R = 10$ years) is 0.31 for the early group, and 0.43 for the late group. Assuming that 0.19 is a reasonably accurate estimate of *M*, then instantaneous fishing mortality (*F*) in the peak exploitation years of the fishery has averaged about 0.24 annually. This value is close to those estimated in the base model (see Figure 21), as would be expected given that the same data are used for both sets of estimates and that the base model had a median selectivity ogive that was essentially non-domed (see Figure 18).

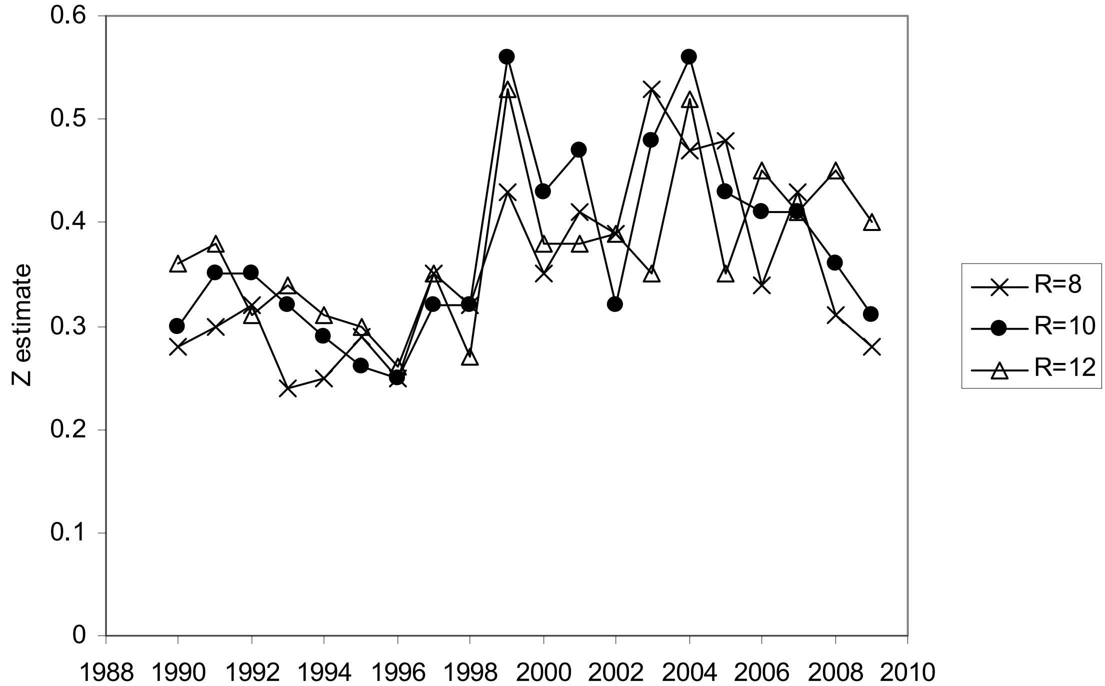

Figure 29: Maximum likelihood estimates of instantaneous total mortality (*Z*), by year, from the commercial trawl fishery proportion-at-age distributions. *Z* has been derived in each year using three values of age at full selectivity (*R*).

6. DISCUSSION

This document reports on the first full assessment of the HAK 7 (west coast South Island) stock since that by Dunn (2004a). This stock has not been regularly assessed because it lacks a reliable index of relative abundance. While CPUE series have been produced previously (e.g., Kendrick 1998, Ballara & Horn 2011) the trends in these series have generally not been logical and it was concluded that catch rates of hake off WCSI are influenced more by fisher behaviour than by abundance of the species. Consequently, adding the available CPUE to the model would probably be misleading. Several 'one-off' research surveys of hoki and hake have been conducted by different vessels off WCSI, but these provide no useful relative biomass series. A long-running trawl survey series of inshore waters off WCSI by *Kaharoa* did not provide a useful index of hake biomass as it surveys no deeper than 400 m (Stevenson & Hanchet 2000). It is possible that a *Tangaroa* survey in 2000 (O'Driscoll et al. 2004) may be able to be linked to a future trawl and acoustic survey series due to commence off WCSI in winter 2012. Owing to the lack of any useful relative abundance series the assessment model for WCSI hake includes only biological parameters, a catch history, and proportion-at-age data from the commercial fishery since 1990 and the *Wesermünde* survey in 1979. While catch-at-age data can provide information on trends in biomass, they are likely to be much more informative when tuned using a relative abundance series. The Middle Depth Species Fisheries Assessment Working Group considered this assessment to be too unreliable to be reported in the 2011 Plenary Document.

An exploratory analysis of the length and sex data collected by observers from the commercial trawl fishery showed that the sex ratios in catches varied markedly between tows, trips, and years. Horn & Francis (2010) found the same problem in an assessment of the Chatham Rise hake stock. They found that a 'single sex' model fitted the research biomass series and the commercial fishery proportion-at-age data better as it did not have to try and deal with conflicting information about changes in sex ratios over time. A similar solution was adopted here for the WCSI assessment. As for the Chatham Rise assessment, an initial 'two sex' model was markedly more optimistic than the 'single sex' model (for both absolute biomass and stock status). However, it is unlikely that sex alone provides sufficient 'logical' information to increase B_0 by about 61% and current stock status by about 63%. Hence, the 'two sex' model is rejected at this stage.

The base case model estimates that the WCSI spawning stock is currently at about 65% B_0, and that continued fishing at recent catch levels is likely to allow stock size to increase slowly. Sensitivity model runs using two different values of instantaneous natural mortality (M) that are strongly believed to bound the true value did not markedly alter the absolute estimate of B_0, but did strongly influence estimates of current biomass. However, none of the model runs were indicative of current biomass being lower than 38% of B_0, and all projected an increase in biomass over the next five years with catches equal to those from recent years (6000 t) or at a higher level equal to the current TACC (7700 t).

Estimated year class strengths often have quite wide 95% bounds, particularly at the start and the end of the estimated series. However, the median estimates suggest that variation in year class strength is not great for this stock; only two of the estimates from 1973 to 2004 are outside the range 0.5–2 (i.e., 1975 is lower, and 2004 is higher). A similar relatively low level of year class strength variation was estimated for the hake stock on the Chatham Rise (Horn & Francis 2010). However, it is not possible to tell whether the low variability in year class strengths is correct (i.e., the actual variability is low) or is a consequence of uninformative data (e.g., the year-class signal in the observer data could be poor either because these data are not representative of the catch, or because it is masked by year-to-year variation in selectivity).

The MPD fits to the at-age data appear to be better before 2000 than they are after that year (see Figure 12). The poor fits generally have observed values of young fish higher than expected values (i.e., 2003, 2005–07). This may be indicative of some change in fishing selectivity. However, the assessment model described above used a single selectivity ogive for all years.

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 commercial catch proportions-at-age distributions (which drive the year class strength estimates and the overall assessment) are not collected systematically over time or space. Although the stratification used in the analyses of these data coupled with the removal of sex from the partition is believed to produce reasonable estimates of catch-at-age for the fishery, the projections of future stock status based on these data are likely to underestimate the true level of uncertainty.

Information about the stock status of hake off WCSI is probably quite weak owing to the lack of any reliable relative abundance series. The proportion-at-age data do indicate an overall decline in biomass since the fishery started. However, estimates of stock size and projected stock status are clearly strongly influenced by the shape of the selectivity ogive. The ogive was estimated using the double-normal parameterisation, and was clearly bell-shaped for low values of M and approximately logistic for high values of M (see Figure 22). For the base model run, the median of the posterior ogive was logistic, but the 95% confidence bound clearly allowed for many bell-shaped ogives (see Figure 18).

The assessment for WCSI hake has been updated, and is indicative of a stock that has been steadily fished down throughout the 1990s, but that it is likely to be above the management target of 40% B_0 set by the Ministry of Fisheries. Relatively strong recruitment from 2000 to 2004 has resulted in recent growth in stock size. Future annual catches even as high as the TACC (which has not been reached in recent years) will likely result in a continued slight growth in biomass over the next five years. However, the assessment is clearly very uncertain as it is based only on proportion-at-age data, with no indices of relative abundance. Improved confidence in the assessment of this hake stock will be achieved only after a reliable index of relative abundance is developed.

Some tentative conclusions about stock status can be drawn from the available catch history, catch-at-age distributions, and estimates of mortality rates. The maximum likelihood estimates of total mortality rate suggest that in the years of peak exploitation, fishing mortality averaged about 0.24, which is only slightly higher than the estimate of natural mortality (0.19). Assuming no recruitment failure, a stock should be able to sustain such a level of fishing in the medium term. The relative constancy of the trawl catch-at-age distributions since 1990 suggests that recruitment has not failed during that period, and that the current population still comprises reasonable numbers of fish older than the age at full recruitment and up to about 20 years old. The relatively constant catch history from 1989 to 2007 (an average of 7500 t annually) suggests that future catches at that level can probably be maintained without causing the stock size to decline markedly. However, catches have been much lower in the three most recent years. This will, at least in part, be a consequence of lower levels of targeting from hoki off WCSI, but reports from fishing companies also indicate that hake are now harder to find and catch.

7. ACKNOWLEDGMENTS

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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

Table A1 ctd.

Vessel	Date	Trip code	Depth		Biomass	c.v.	Reference
Tangaroa	Nov–Dec 2009	TAN0911	300–800	3	992	0.22	O'Driscoll & Bagley 2011
			1991 area	4	1 442	0.20	O'Driscoll & Bagley 2011
			1996 area	7	1 602	0.18	O'Driscoll & Bagley 2011

1. Although surveys by *Wesermünde* were carried out in 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	888	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
Tangaroa	Jan 2010	TAN1001	200–800	1 701	0.25	Stevens et al. 2011
			200–1300	1 862	0.25	Stevens et al. 2011

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.