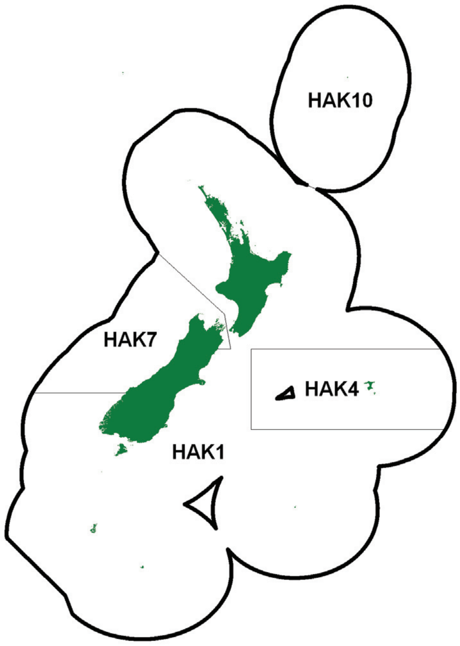
HAKE (HAK)

(Merluccius australis)
Tiikati



1. FISHERY SUMMARY

1.1 Commercial fisheries

Hake are widely distributed throughout the middle depths of the New Zealand EEZ, mostly south of 40° S. Adults are mainly distributed from 250–800 m, but some have been found as deep as 1200 m, while juveniles (0+) are found in inshore regions shallower than 250 m. Hake are taken mainly by large trawlers, often as bycatch in hoki target fisheries, although hake target fisheries do exist.

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 their 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.

An unusually large aggregation of possibly mature or maturing hake was fished on the western Chatham Rise, west of the Mernoo Bank (HAK 1) in October 2004. Over a four week period, approximately 2000 t of hake were caught from that area. In previous years, catches from this area have typically been between 100–800 t. These unusually high catches resulted in the TACC for HAK 1 being over-caught during the 2004–05 fishing year (4795 t against a TACC of 3701 t) and a substantial increase in the landings (> 3700 t) associated with the Chatham Rise. The reasons for the presence of the large aggregation are not known, although periodic and minor aggregations of pre-mature and mature hake have been found in that area in previous years.

Reported catches from 1975 to 1987–88 are shown in Table 1. Reported landings for each Fishstock since 1983–84 and TAC's since 1986–87 are shown in Table 2. Figure 1 shows the historical landings and TACC values for the main hake stocks.

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

	New Zealand			Foreign licensed				
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. April 1 to March 31.
3. April 1 to September 30.
4. October 1 to September 30.

Table 2: Reported landings (t) of hake by Fishstock from 1983–84 to 2008–09 and actual TAC's (t) for 1986–87 to 2008–09. QMS data are from 1986 to the present.

Fish stock	HAK 1		HAK 4		HAK 7		HAK 10			
QMA(s)	1, 2, 3, 5, 6, 8 & 9		4		7		10		Total	
	Landings	TACC	Landings	TACC	Landings	TACC	Landings	TACC	Landings	TACC
1983–84 [1]	886	–	180	–	945	–	0	–	2 011	–
1984–85 [1]	670	–	399	–	965	–	0	–	2 034	–
1985–86 [1]	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	7 781	6 930
1990–91	2 603	2 610	743	1 000	6 148	3 310	0	10	9 494	6 930
1991–92	3 156	3 500	2 013	3 500	3 027	6 770	0	10	8 196	13 780
1992–93	3 525	3 501	2 546	3 500	7 154	6 835	0	10	13 225	13 846
1993–94	1 803	3 501	2 587	3 500	2 974	6 835	0	10	7 364	13 847
1994–95	2 572	3 632	3 369	3 500	8 841	6 855	0	10	14 782	13 997
1995–96	3 956	3 632	3 466	3 500	8 678	6 855	0	10	16 100	13 997
1996–97	3 534	3 632	3 524	3 500	6 118	6 855	0	10	13 176	13 997
1997–98	3 810	3 632	3 524	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	15 334	13 997
1999–00	3 899	3 632	2 803	3 500	6 898	6 855	0	10	13 599	13 997
2000–01	3 628	3 632	2 784	3 500	7 698	6 855	0	10	14 111	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	11 580	14 066
2003–04	3 466	3 701	2 275	3 500	7 945	6 855	0	10	13 686	14 066
2004–05	4 795	3 701	1 264	1 800	7 317	6 855	0	10	13 377	12 366
2005–06	2 742	3 701	305	1 800	6 905	7 700	0	10	9 952	13 211
2006–07	2 025	3 701	899	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

1. FSU data.

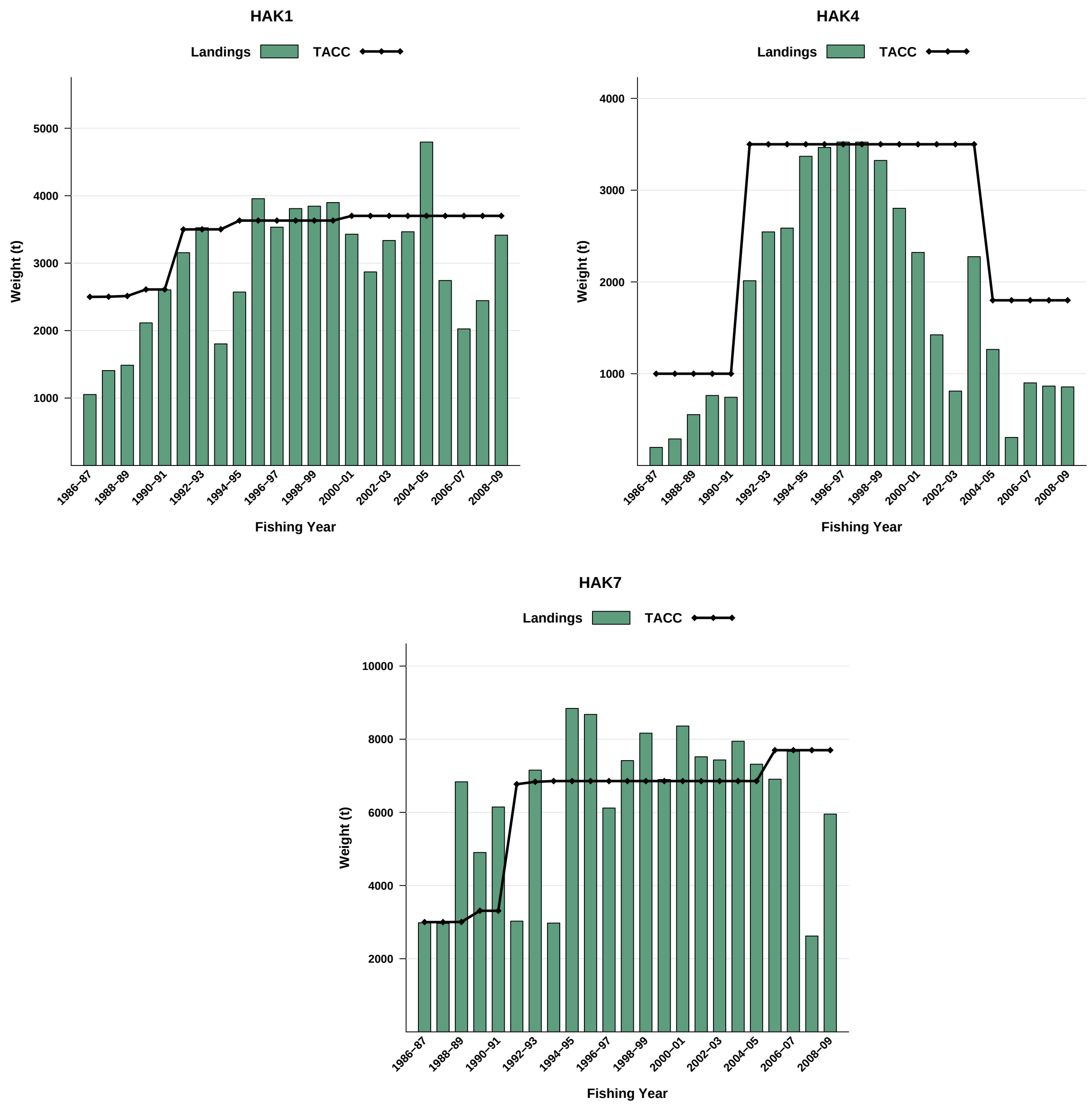


Figure 1: Historical landings and TACC for the three main HAK stocks. From top left: HAK1 (Sub-Antarctic and part of Chatham Rise), HAK4 (eastern Chatham Rise), and HAK7 (Challenger). Note that these figures do not show data prior to entry into the QMS.

1.2 Recreational fisheries

The recreational fishery for hake is negligible.

1.3 Customary non-commercial fisheries

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

1.4 Illegal catch

In late 2001, a small number of fishers admitted misreporting of hake catches between areas, pleading guilty to charges of making false or misleading entries in their catch returns. As a result, the reported catches of hake in each area were reviewed in 2002 and suspect records identified. Dunn (2003) provided revised estimates of the total landings by stocks, estimating that the level of hake over-reporting on the Chatham Rise (and hence under-reporting on the west coast South Island) was between 16 and 23% (700–1000 t annually) of landings between 1994–95 and 2000–01, mainly in June, July, and September. Probable levels of area misreporting prior to 1994–95 and between the west coast South Island and Sub-Antarctic were estimated as small (Dunn 2003). There is no evidence of similar area misreporting since 2001–02 (Devine 2009).

In earlier years, before the introduction of higher TACCs in 1991–92, there is some evidence to suggest that catches of hake were not always fully reported. Comparison of catches from vessels carrying observers with those not carrying observers, particularly in HAK 7 from 1988–89 to 1990–91, suggested that actual catches were probably considerably higher than reported catches. For these years, the ratio of hake to hoki in the catch of vessels carrying observers was significantly higher than in the catch of vessels not carrying observers (Colman & Vignaux 1992). The actual hake catch in HAK 7 for these years was estimated 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. No such corrections have been applied to either the HAK 1 or HAK 4 fishery.

For the purposes of stock assessment, the Chatham Rise stock was considered to include the whole of the Chatham Rise (including the western end currently forming part of the HAK 1 management area). Therefore, catches from this area were subtracted from the Sub-Antarctic stock and added to the Chatham Rise stock. The revised landings estimates for 1974–75 to 2007–08 are given in Table 3.

Table 3: Revised landings 1974–75 to 2007–08 (t) for the west coast South Island, Sub-Antarctic, and Chatham Rise stocks.

Fishing year	West coast S.I.	Sub-Antarctic	Chatham Rise
1974–75	71	120	191
1975–76	5 005	281	488
1976–77	17 806	372	1 288
1977–78	498	762	34
1978–79	4 737	364	609
1979–80	3 600	350	750
1980–81	2 565	272	997
1981–82	1 625	179	596
1982–83	745	448	302
1983–84	945	722	344
1984–85	965	525	544
1985–86	1 918	818	362
1986–87	3 755	713	509
1987–88	3 009	1 095	574
1988–89	8 696	1 237	804
1989–90[1]	4 888	1 917	957
1990–91[1]	6 173	2 370	905
1991–92	3 007	2 743	2 414
1992–93	7 047	3 252	2 808
1993–94	2 935	1 446	2 933
1994–95	9 498	1 844	3 386
1995–96	9 241	2 794	3 913
1996–97	6 952	2 266	3 661
1997–98	7 883	2 615	3 983
1998–99	8 899	2 783	3 372
1999–00	7 420	3 019	2 943
2000–01	8 620	2 839	2 504
2001–02	7 404	2 502	1 769
2002–03	7 360	2 715	1 414
2003–04	8 547	3 244	2 492
2004–05	7 276	2 772	3 753
2005–06	6 423	2 089	359
2006–07	7 631	1 814	1 081
2007–08	2 610	2 214	1 098

1. West coast South Island revised estimates for 1989–90 and 1990–91 are taken from Colman & Vignaux (1992) who corrected for underreporting in 1989–90 and 1990–91, and not from Dunn (2003) who ignored such underreporting.

1.5 Other sources of 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.

2. BIOLOGY

The New Zealand hake reach a maximum age of at least 25 years. Males, which rarely exceed 100 cm total length (TL), do not grow as large as females, which can grow to 120 cm TL or more. Horn (1997) validated the use of otoliths to age hake, and produced von Bertalanffy growth parameters. Growth parameters were updated by Horn (2008) using both the von Bertalanffy and Schnute growth models. The Schnute model was found to better fit the data. Both sexes reach sexual maturity between about 6 and 10 years of age, at lengths of about 67–75 cm TL (males) and 75–85 cm TL (females). Hake in HAK 1 and HAK 4 reach 50% maturity at about 6 years for males, and 7–8 years for females (Horn & Francis in prep.).

Estimates of natural mortality (M) and the associated methodology are given in Dunn *et al.* (2000); M is estimated as 0.18 y^{-1} for females and 0.20 y^{-1} for males. Colman *et al.* (1991) previously estimated M as 0.20 y^{-1} for females and 0.22 y^{-1} for males using the maximum age method of Hoenig (1983) (the maximum ages at which 1% of the population survives in an unexploited stock were estimated at 23 years for females and 21 years for males).

Data collected by observers on commercial trawlers and data from trawl 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, usually with a peak in September. Spawning also occurs to the west of the Chatham Islands during a prolonged period from at least September to January. Spawning on the Campbell Plateau, primarily to the north-east of the Auckland Islands, occurs from September to February with a peak in September–October. Spawning fish have been recorded occasionally on the Puysegur Bank, with a seasonality that appears similar to that on the Campbell Plateau (Colman 1998).

Juvenile hake have been taken in coastal waters on both sides of the South Island and on the Campbell Plateau. They reach a length of about 15–20 cm total length at one year old, and about 35 cm total length at 2 years (Colman 1998). The biological parameters relevant to the stock assessments are given in Table 4.

Table 4: Estimates of biological parameters.

Parameter			Estimates				Source
1. Natural mortality (M)							
		Males	$M = 0.20$				Dunn *et al.* (2000)
		Females	$M = 0.18$				Dunn *et al.* (2000)
		Both sexes	$M = 0.19$				Horn & Francis (in
2. Weight = a·(length)^b (Weight in t, length in cm)							
	Sub-	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	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 (in
	West coast South	Males	$a = 2.75 \times 10^{-9}$	$b = 3.230$			Horn (1998)
		Females	$a = 1.33 \times 10^{-9}$	$b = 3.410$			Horn (1998)
3. von-Bertalanffy growth parameters							
	Sub-	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	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)
	West coast South	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)
4. Schnute growth parameters ($\tau_1 = 1$ and $\tau_2 = 20$ for all stocks)							
	Sub-	Males	$y_1 = 22.3$	$y_2 = 89.8$	$a =$	$b = 1.243$	Horn (2008)
		Females	$y_1 = 22.9$	$y_2 = 109.9$	$a =$	$b = 1.457$	Horn (2008)
	Chatham	Males	$y_1 = 24.6$	$y_2 = 90.1$	$a =$	$b = 1.742$	Horn (2008)
		Females	$y_1 = 24.4$	$y_2 = 114.5$	$a =$	$b = 1.764$	Horn (2008)
		Both sexes	$y_1 = 24.5$	$y_2 = 104.8$	$a =$	$b = 1.700$	Horn & Francis (in
	West coast South	Males	$y_1 = 23.7$	$y_2 = 83.9$	$a =$	$b = 1.380$	Horn (2008)
		Females	$y_1 = 24.5$	$y_2 = 103.6$	$a =$	$b = 1.510$	Horn (2008)

5. Proportion mature at age (from Horn & Francis in prep.)

Age		2	3	4	5	6	7	8	9	10	11	12	13	14	15
Sub-Antarctic	Male	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
	Female	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	Male	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
	Female	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 sexes	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

3. STOCKS AND AREAS

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

Analysis of morphometric data (Colman unpublished data) shows little difference between hake from the Chatham Rise and hake from the east coast of the North Island, but shows highly significant differences between these fish and those from the Sub-Antarctic, Puysegur, and on the west coast. No studies have been done on morphometric differences of hake across the Chatham Rise. 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. Hence, the stock affinity of hake from this area is uncertain.

Present management divides the fishery into three Fishstocks: (a) the Challenger QMA (HAK 7), (b) the 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 (with no recorded landings) exists for the Kermadec QMA (HAK 10).

4. STOCK ASSESSMENT

The stock assessments reported here were completed in 2004 for the west coast South Island stock (A. Dunn unpublished data), in 2007 for the Sub-Antarctic stock (Horn 2008), and in 2009 for the Chatham Rise stock (Horn & Francis in prep.). In stock assessment modelling, the Chatham stock was considered to include the whole of the Chatham Rise (including the western end currently forming part of the HAK 1 management area). The Sub-Antarctic stock was considered to comprise the Southland and Sub-Antarctic management areas. Although fisheries management areas around the North Island are also included in HAK 1, few hake are caught in these areas.

4.1 HAK 1 (Sub-Antarctic stock)

The 2007 stock assessment was carried out with data up to the end of the 2005–06 fishing year, implemented as a Bayesian model using the general-purpose stock assessment program CASAL v2.09 (Bull *et al*. 2005). The assessment used research time series of abundance indices (trawl surveys of the Sub-Antarctic from 1991 to 2006), catch-at-length and catch-at-age from the commercial fishery since 1990–91, and estimates of biological parameters.

4.1.1 Model structure

The stock assessment model partitioned the population into mature and immature fish, two sexes, and age groups 1–30 with the last age group considered a plus group. The model was initialised assuming an equilibrium age structure at an unfished equilibrium biomass (B_0), i.e., with constant recruitment set equal to the mean of the recruitments over the period 1974–2003.

The model used six selectivity at age ogives; male and female commercial fishing selectivities on the Sub-Antarctic, and male and female survey selectivities for each of the November–December and April–May trawl survey series (with the September 1992 survey assumed to have a selectivity equal to the April–May series). In the base case model, trawl survey and fishing selectivities were all assumed to be logistic, with female selectivity estimated relative to male selectivity. Selectivities were assumed constant over all years in each fishery, and hence there was no allowance for possible annual changes in selectivity.

The catch history assumed in all model runs (Table 3) include the revised estimates of catch reported by Dunn (2003) and updated by Devine (2009). The catch for the 2006–07 fishing year was based on the previous year's catch, pro-rated between the Chatham Rise and Sub-Antarctic sections of HAK 1 based on the MHR reports.

Five-year biomass projections were made assuming future catches in the Sub-Antarctic to be 2400 t annually (the mean annual catch from 1990 to 2006). For each projection scenario, recruitment variability was assumed to be lognormally distributed.

4.1.2 Fixed biological parameters and observations

Estimates and assumed values for biological parameters used in the assessments are given in Tables 4 and 5 respectively. Variability in the Schnute age-length relationship was assumed to be lognormal with a constant CV of 0.1. Maturity was estimated within the assessment model from data derived from resource survey samples with information on the gonosomatic index, gonad stage, and age. Individual hake were then classified as either immature or mature at sex and age, where maturity was determined from the gonad stage and gonosomatic index (the ratio of gonad weight to body weight).

Catch-at-age observations were available for each trawl survey of the Sub-Antarctic, and for the commercial fisheries from observer data in some years. A plus group for all the catch-at-age data was set at 30 with the lowest age set at 3.

Resource survey abundance indices are given in Table 6, and CPUE indices are given in Table 7.

Table 5: Fixed biological parameters assumed for the Sub-Antarctic, Chatham Rise and WCSI stock assessment models.

Parameter		Value
Steepness (Beverton & Holt stock- recruitment relationship)		0.90
Proportion spawning		1.0
Proportion of recruits that are male		0.5
Natural mortality (*M*)	Male, Female, Both	0.20 y^{-1}, 0.18 y^{-1}, 0.19 y^{-1}
Maximum exploitation rate (U_{max})		0.7
Ageing error		Normally distributed, with CV = 0.08

Table 6: Research survey indices (and associated CVs) for the Sub-Antarctic stock.

Fishing	Vessel	Nov–Dec series [1]		Apr–May series [2]		Sep series [2]	
Year		Biomass (t)	CV	Biomass (t)	CV	Biomass (t)	CV
1989	*Amaltal Explorer*	2 660	0.21				
1992	*Tangaroa*	5 686	0.43	5 028	0.15	3 760	0.15
1993	*Tangaroa*	1 944	0.12	3 221	0.14		
1994	*Tangaroa*	2 567	0.12				
1996	*Tangaroa*			2 026	0.12		
1998	*Tangaroa*			2 554	0.18		
2001	*Tangaroa*	2 657	0.16				
2002	*Tangaroa*	2 170	0.20				
2003	*Tangaroa*	1 777	0.16				
2004	*Tangaroa*	1 672	0.23				
2005	*Tangaroa*	1 694	0.21				
2006	*Tangaroa*	1 459	0.17				
2007	*Tangaroa*	1 530	0.17				
2008*	*Tangaroa*	2 471	0.15				
2009*	*Tangaroa*	1 074	0.23				
2010*	*Tangaroa*						

* Not used in the reported assessment.

Notes: (1) Series based on indices from 300–800 m core strata, including the 800–1000 m strata in Puysegur, but excluding Bounty Platform, (2) Series based on the biomass indices from 300–800 m core strata, excluding the 800–1000 m strata in Puysegur and the Bounty Platform.

Table 7: Hake CPUE indices (and associated c.v.s) for the Sub-Antarctic fishery.

Year	Index	CV
1989–90	1.31	0.07
1990–91	1.07	0.06
1991–92	1.41	0.04
1992–93	1.11	0.04
1993–94	1.19	0.05
1994–95	0.94	0.05
1995–96	1.01	0.05
1996–97	0.84	0.04
1997–98	0.80	0.04
1998–99	0.88	0.04
1999–00	0.91	0.04
2000–01	0.94	0.04
2001–02	0.84	0.04
2002–03	0.78	0.04
2003–04	1.03	0.04
2004–05	0.77	0.06
2005–06	1.17	0.08

4.1.3 Model estimation

Model parameters were estimated using Bayesian estimation implemented using the CASAL software (Bull *et al*. 2005). For final model runs, the full posterior distribution was sampled using Markov Chain Monte Carlo (MCMC) methods, based on the Metropolis-Hastings algorithm.

Catch-at-age data were fitted to the model as proportions-at-age with a multinomial likelihood, where estimates of the proportions-at-age and associated CVs by age were estimated using the NIWA catch-at-age software by bootstrap (Bull & Dunn 2002). Biomass indices were fitted with lognormal likelihoods with assumed CVs set equal to the sampling CV.

The effective sample sizes (in the case of observations fitted with multinomial likelihoods) or CVs (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 all observations in all model runs. The additional variance, termed process error, was estimated from MPD runs of the each model, and the total error assumed in each run for each observation was calculated by adding process error and observation error. Estimates of the effective sample size for proportions-at-age and proportions-at-length data applied in the model were made via a two-step process; (a) first, the sample sizes were derived by assuming the relationship between the observed proportions, E_i, and estimated CVs, c_i, followed that for a multinomial distribution with unknown sample size N_j. The estimated sample size was then derived using a robust non-linear least squares fit of $\log(c_i) \sim \log(P_i)$, and (b) by estimating an effective sample size, N', by adding additional process error, N_{PE}, to the sample size calculated in (a) above. The values for process error were then fixed for the MCMC runs.

Year class strengths were assumed known (and equal to one) for years prior to 1974 and after 2003, 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 should average one.

MCMCs were estimated using 4×10^6 iterations, a burn-in length of 6×10^5 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).

4.1.4 Prior distributions and penalty functions

The assumed prior distributions used in the assessment are given in Table 8. Most priors were intended to be relatively uninformed, and were estimated with wide bounds. The exceptions were the choice of informative priors for the survey qs.

The priors for survey qs were estimated by assuming that the relativity constant was the product of areal availability, vertical availability, and vulnerability. A simple simulation was conducted that estimated a distribution of possible values for the relativity constant by assuming that each of these factors was uniformly distributed. A prior was then determined by assuming that the resulting, sampled, distribution was lognormally distributed. Values assumed for the parameters were; areal availability (0.50–1.00), vertical availability (0.50–1.00), and vulnerability (0.01–0.50). The resulting (approximate lognormal) distribution had mean 0.16 and CV. 0.79, with bounds assumed to be (0.01–0.40). Note that the values of survey relativity constants are dependant on the selectivity parameters, and the absolute catchability can be determined by the product of the selectivity by age and sex, and the relativity constant *q*. Natural instantaneous mortality (*M*) was estimated in one model run as a double-exponential ogive (both sexes combined) with uniform priors.

Penalty functions were used to constrain the model so that any combination of parameters that did not allow the historical catch to be taken were strongly penalised.

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

Stock	Parameter	Distribution	Parameters		Bounds	
Sub-Antarctic	B_{mean}	Uniform-log	–	–	5 000	350 000
	Survey *q*	Lognormal	0.16	0.79	0.01	0.40
	CPUE *q*	Uniform-log	–	–	1e-8	1e-2
	YCS	Lognormal	1.0	1.1	0.01	100
	M	Uniform	–	–	0.01	1.0

4.1.5 Model estimates

Estimates of biomass were produced for an agreed base case run using the biological parameters and model input parameters described earlier. In addition, four sensitivities were investigated: (1) fitting the fishery selectivity ogives as double-normal, thus allowing selectivity to decrease with increasing age, (2) splitting the summer survey series into early (1992–94) and recent (2001–07) series with independent *q*s, (3) including the trawl CPUE series, and (4) estimating *M* as a double-exponential ogive, thus allowing *M* to vary with age. For all runs, MPD fits were obtained and qualitatively evaluated, and MCMC estimates of the median posterior and 95% percentile credible intervals were determined for current and virgin biomass, and projected states. However, only the estimates from the base case run are reported here.

The estimated MCMC marginal posterior distributions from the base case run for each year for year class strength and biomass for the Sub-Antarctic stock are shown in Figures 2 and 3. Year class strength estimates were poorly estimated at ages where only older fish were available to determine age class strength (i.e., before about 1978). The estimates suggested that the Sub-Antarctic stock is characterised by a group of relatively strong relative year class strengths in the late 1970s, followed by a period of average to less than average recruitment through to the late 1990s. All estimated year class strengths since 2000 have been markedly below average. Consequently, biomass estimates for the stock have slightly declined, particularly through the early 1990s. However, biomass estimates for the stock appear relatively healthy, with estimated current biomass at about 64% of B_0 (95% credible intervals 54–73%) (Figure 3, Table 9). The four sensitivity runs suggested a similar current status to that for the base case, with medians of the posteriors ranging from 60–70% of B_0. Exploitation rates for the Sub-Antarctic appear to be low as a consequence of the high estimated stock size in relationship to the level of relative catches.

Trawl survey selectivities for males and females diverged, with males less selected that females at older ages in both the November–December and the April–May survey series. The posterior density estimates of selectivities indicated considerable uncertainty in the estimates of selectivity by age and sex for the autumn series, but low uncertainty for the summer series. Estimated fishing selectivities were moderately uncertain, with males being more selected than females.

The base case assessment relied on biomass data from the Sub-Antarctic trawl survey series. In this model run, estimated trawl survey catchability constants were very low (about 2–9% based on doorspread swept area estimates), particularly for the summer series, suggesting that the absolute catchability of the Sub-Antarctic trawl surveys is extremely low. It is not known if the catchability of the Sub-Antarctic trawl survey series is as low as estimated by the model, but hake are believed to be relatively more abundant over rough ground (that is likely to 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.

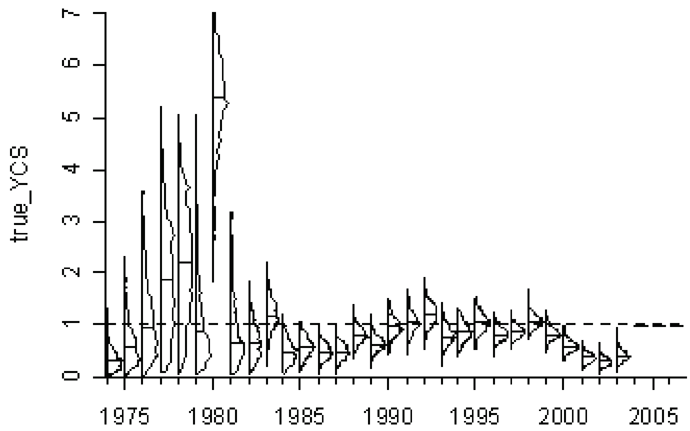


Figure 2: Estimated posterior distributions of year class strengths for the base case for the Sub-Antarctic stock. The grey horizontal line indicates the year class strength of one. Individual distributions show the marginal posterior distribution, with horizontal lines indicating the median.

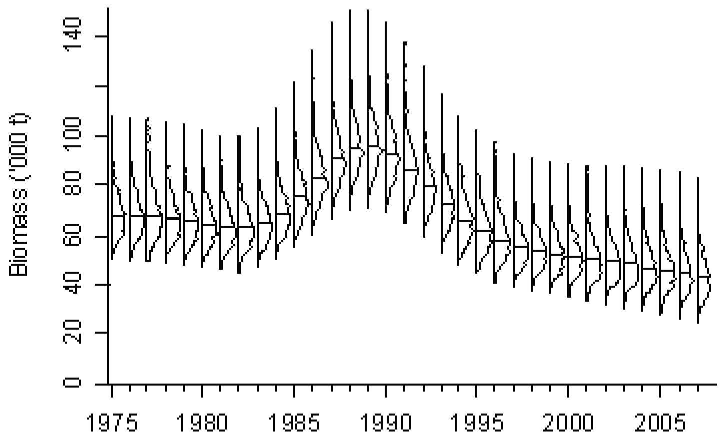


Figure 3: Estimated posterior distributions of spawning stock biomass trajectories for the base case for the Sub-Antarctic stock. Individual distributions show the marginal posterior distribution, with horizontal line indicating the median.

Estimates of the status of the Sub-Antarctic stock suggest that there has been a decline in the stock size since the early 1990s, but, owing to an apparent increase in stock size during the mid-late 1980s (driven by catch-at-age data), current stock size is healthy relative to the estimated virgin biomass. Catches of about 2500 t annually since 1990–91 appear to have had little effect on the biomass level. Consequently, future annual catches of 2400 t will probably have little effect on the projected stock size to 2012 (Table 10). The lack of contrast in abundance indices since 1991 indicates that while the status of the Sub-Antarctic stock is probably similar to that in the early 1990s, the absolute level of current biomass is very uncertain.

Table 9: Bayesian median (95% credible intervals) (MCMC) of B_0, B_{2007}, and B_{2007} as a percentage of B_0 for the Sub-Antarctic base case.

Model run	B_0	B_{2007}	B_{2007} (%B_0)
Base case	67 670 (55 280–88 240)	43 170 (30 370–63 390)	64 (54–73)

Table 10: Bayesian median (95% credible intervals) projected biomass in 2012 (B_{2012}), B_{2012} as a percentage of B_0, and B_{2012}/B_{2007} (%) for the Sub-Antarctic base case where future catches are assumed to be 2400 t.

Future catch	Model run	B_{2012}	B_{2012} (%B_0)	B_{2012}/B_{2007} (%)
2 400 t	Base case	35 570 (21 040–56 780)	52 (37–71)	81 (64–107)

4.1.6 Estimates of sustainable yields
CAY yield estimates were not reported because of the high uncertainty of the estimates of absolute biomass.

4.2 HAK 4 (Chatham Rise stock)
The 2009 stock assessment was carried out with data up to the end of the 2008–09 fishing year, implemented as a Bayesian model using the general-purpose stock assessment program CASAL v2.21 (Bull *et al*. 2005). The assessment used research time series of abundance indices (trawl surveys of the Chatham Rise from 1992 to 2009), catch-at-age from the trawl survey series and the commercial fishery since 1990–91, and estimates of biological parameters.

4.2.1 Model structure
Two stock assessment models were run. The base case model (‘Single sex’) partitioned the Chatham Rise stock population into unsexed age groups 1–30 with the last age group considered a plus group. A sensitivity model (‘Two sex’) was the same as the base case except that sex was included in the partition. The models were initialised assuming an equilibrium age structure at an unfished equilibrium biomass (B_0), i.e., with constant recruitment set equal to the mean of the recruitments over the period 1975–2006.

The Single sex model used three selectivity-at-age ogives; east and west commercial fishing selectivities and a survey selectivity for the Chatham Rise January trawl survey series. All selectivity ogives were fitted using the double-normal parameterisation. Selectivities were assumed constant over all years in both fishery and the survey, and hence there was no allowance for possible annual changes in selectivity. In the Two sex model, ogives were estimated by sex, i.e., there were six ogives.

Five-year biomass projections were made assuming future catches on the Chatham Rise to be either the HAK 4 TACC of 1800 t plus average estimated HAK 1 Chatham catch from 1991–92 to 2004–05 of 1000 t (i.e., 2800 t, “high catch scenario”), or the approximate catch level from recent years of 1150 t (“low catch scenario”). For each projection scenario, estimated future recruitment variability was sampled from actual estimates between 1997 and 2006 (i.e., a period of recruitment lower than the long term average).

4.2.2 Fixed biological parameters and observations
Estimates and assumed values for biological parameters used in the assessments are given in Tables 4 and 5 respectively. Variability in the Schnute age-length relationship was assumed to be lognormal with a constant CV of 0.1.

Catch-at-age observations were available for each survey on the Chatham Rise, and for the commercial fisheries from observer data in some years. A plus group for all the catch-at-age data was set at 30 with the lowest age set at 3.

The catch histories assumed in all model runs (Table 11) include the revised estimates of catch reported by Dunn (2003). Resource survey abundance indices are given in Table 12.

Table 11: Commercial catch history (t) by fishery (East and West) and total, for the Chatham Rise stock.

Model year	West	East	Total	Model year	West	East	Total
1975	80	111	191	1993	656	1 996	2 652
1976	152	336	488	1994	368	2 912	3 280
1977	74	1 214	1 288	1995	597	2 903	3 500
1978	28	6	34	1996	1 353	2 483	3 836
1979	103	506	609	1997	1 475	1 820	3 295
1980	481	269	750	1998	1 424	1 124	2 547
1981	914	83	997	1999	1 169	3 339	4 509
1982	393	203	596	2000	1 155	2 130	3 285
1983	154	148	302	2001	1 208	1 700	2 908
1984	224	120	344	2002	454	1 058	1 512
1985	232	312	544	2003	497	718	1 215
1986	282	80	362	2004	687	1 983	2 671
1987	387	122	509	2005	2 585	1 434	4 019
1988	385	189	574	2006	184	255	440
1989	386	418	804	2007	270	683	953
1990	309	689	998	2008	259	901	1 159
1991	409	503	912	2009	250	890	1 140
1992	718	1 087	1 805				

Table 12: Research survey indices (and associated CVs) for the Chatham Rise stock.

Year	Vessel	Biomass (t)	CV.
1989	*Amaltal Explorer*	3 576	0.19
1992	*Tangaroa*	4 180	0.15
1993	*Tangaroa*	2 950	0.17
1994	*Tangaroa*	3 353	0.10
1995	*Tangaroa*	3 303	0.23
1996	*Tangaroa*	2 457	0.13
1997	*Tangaroa*	2 811	0.17
1998	*Tangaroa*	2 873	0.18
1999	*Tangaroa*	2 302	0.12
2000	*Tangaroa*	2 090	0.09
2001	*Tangaroa*	1 589	0.13
2002	*Tangaroa*	1 567	0.15
2003	*Tangaroa*	890	0.16
2004	*Tangaroa*	1 547	0.17
2005	*Tangaroa*	1 049	0.18
2006	*Tangaroa*	1 384	0.19
2007	*Tangaroa*	1 820	0.12
2008	*Tangaroa*	1 257	0.13
2009	*Tangaroa*	2 419	0.21
2010*	*Tangaroa*	1 700	0.25

* Not used in the reported assessment.

4.2.3 Model estimation

Model parameters were estimated using Bayesian estimation implemented using the CASAL software (Bull *et al*. 2005). Only the mode of the joint posterior distribution (MPD) was estimated in preliminary runs. For final runs, the full posterior distribution was sampled using Markov Chain Monte Carlo (MCMC) methods, based on the Metropolis-Hastings algorithm.

Catch-at-age data were fitted to the model as proportions-at-age with a lognormal likelihood, where estimates of the proportions-at-age and associated CVs by age were estimated using the NIWA catch-at-age software by bootstrap (Bull & Dunn 2002). Biomass indices were fitted with lognormal likelihoods with assumed CVs set equal to the sampling CV.

The CVs (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 the proportion-at-age data in all model runs. The additional variance, termed process error, was estimated from MPD runs of the each model. The values for process error were then fixed for the MCMC runs. No process error was added to the trawl survey biomass estimates, hence encouraging the model to fit this series well.

Year class strengths before 1975 were assumed known (and equal to one), as inadequate or no catch-at-age data were available. Otherwise year class strengths were estimated under the assumption that the estimates from the model should average one.

MCMCs were estimated using a burn-in length of 5×10^5 iterations, with every 2500th sample taken from the next 2.5×10^6 iterations (i.e., a final sample of length 1000 was taken from the Bayesian posterior).

4.2.4 Prior distributions and penalty functions

The assumed prior distributions used in the assessment are given in Table 13. Most priors were intended to be relatively uninformed, and were estimated with wide bounds. The exceptions were the choice of informative priors for the survey *q*s which were estimated using a simple simulation as described in section 4.1.4 above. Note that the values of survey catchability constants are dependant on the selectivity parameters, and the absolute catchability can be determined by the product of the selectivity by age and sex, and the relativity 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 13: The assumed priors assumed for key distributions (when estimated). The parameters are mean (in natural space) and CV for lognormal; and mean and s.d. for normal.

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

4.2.5 Model estimates

Estimates of biomass were produced for the two model runs using the biological parameters and model input parameters described earlier (Table 14). For all runs, MPD fits were obtained and qualitatively evaluated. In addition, MCMC estimates of the median posterior and 95% percentile credible intervals are reported for current and virgin biomass, and projected states based on either the high or low catch scenarios.

Table 14: Model run labels and descriptions for the base case and sensitivity model runs.

Model run	Description
Single sex (Base case)	Two fisheries, survey biomass series, unsexed catch-at-age data, sex excluded from the partition
Two sex	Same as the base case, but including sexed catch-at-age data, and sex in the partition

Estimated MCMC marginal posterior distributions from the Base case model are shown for year class strengths (Figures 4) and biomass (Figure 5). The year class strength estimates suggested that the Chatham Rise stock was characterised by a group of relatively strong relative year class strengths in the late 1970s to early 1980s, and again in the early 1990s, followed by a period of relatively poor recruitment (except for 2002). Consequently, biomass increased slightly during the late 1980s, then declined to about 2005. The growth of the strong 2002 year class has resulted in a recent slight upturn in biomass. Current biomass estimates for the stock were estimated at about 47% of B_0 (95% credible intervals 39–55%) (see Figure 5 and Table 15). Annual exploitation rates (catch over vulnerable biomass) were low (less than 0.1) up to 1993 and since 2007, but moderate (although probably less than 0.25) in the intervening period.

Resource survey and fishery selectivity ogives were relatively tightly defined. 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.

Base case model projections under two assumed future catch scenarios (1150 t or 2800 t annually from 2010 to 2014) suggested that biomass will decline slightly to about 44% of B_0 (lower catch) or

31% of B_0 (higher) by 2014 (Table 16). There is little risk that the stock will fall below 20% B_0 in the next five years under either catch scenario.

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 base and sensitivity case.

Model run	B_0	B_{2009}	B_{2009} (%B_0)
Base case (Single sex)	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)

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 base and sensitivity case where future catches are assumed to be 2800 t or 1150 t.

Model run	Future catch (t)	B_{2014}	B_{2014} (%B_0)	B_{2014}/B_{2009} (%)
Base case (Single sex)	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)

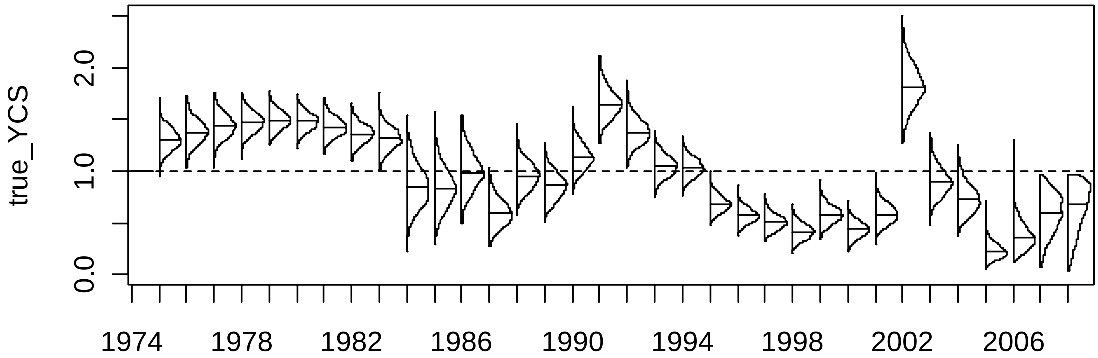


Figure 4: Estimated posterior distributions of year class strengths for the base case. The dashed horizontal line indicates the year class strength of one. Individual distributions show the marginal posterior distribution, with horizontal lines indicating the median.

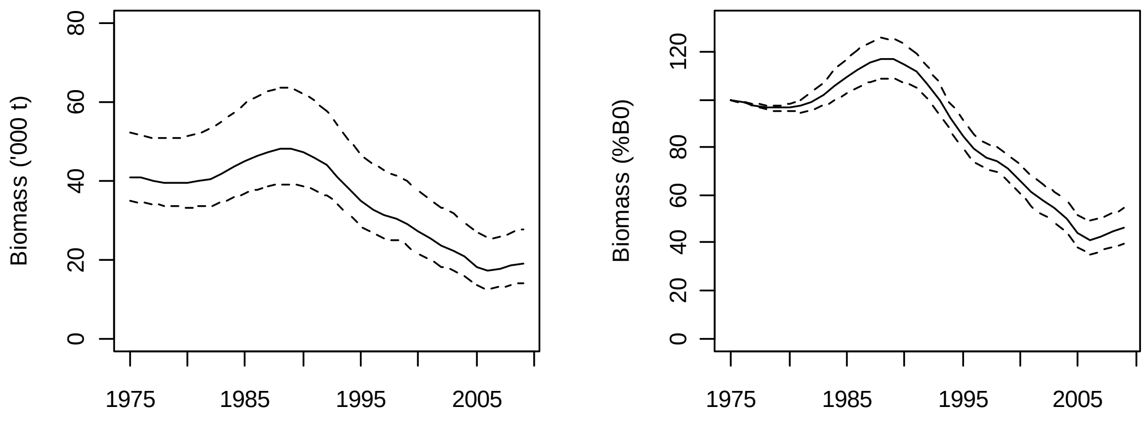


Figure 5: Estimated median trajectories (with 95% credible intervals shown as dashed lines) for the base case model for absolute biomass and biomass as a percentage of B_0.

Estimated MCMC marginal posterior distributions from the Two sex model for year class strengths were virtually identical to those from the base case. Absolute biomass was estimated to be greater, and stock status estimated to be better, than for the base case, i.e., current biomass at about 56% of B_0 (Figure 6, Table 15). Annual exploitation rates have been generally low (i.e., unlikely to have been greater than 0.2 in the years of peak exploitation). Selectivity ogives were relatively tightly defined. The survey ogive suggested that hake of both sexes were not fully selected until about age 14. Fishing selectivities indicated full selection in the western and eastern fisheries by about ages 7 and 12, respectively.

Two sex model projections under two assumed future catch scenarios (1150 t or 2800 t annually from 2010 to 2014) suggested that biomass will decline slightly to about 53% of B_0 (lower catch) or 45% of B_0 (higher) by 2014 (Table 16). There is negligible risk that the stock will fall below 20% B_0 in the next five years under either catch scenario.

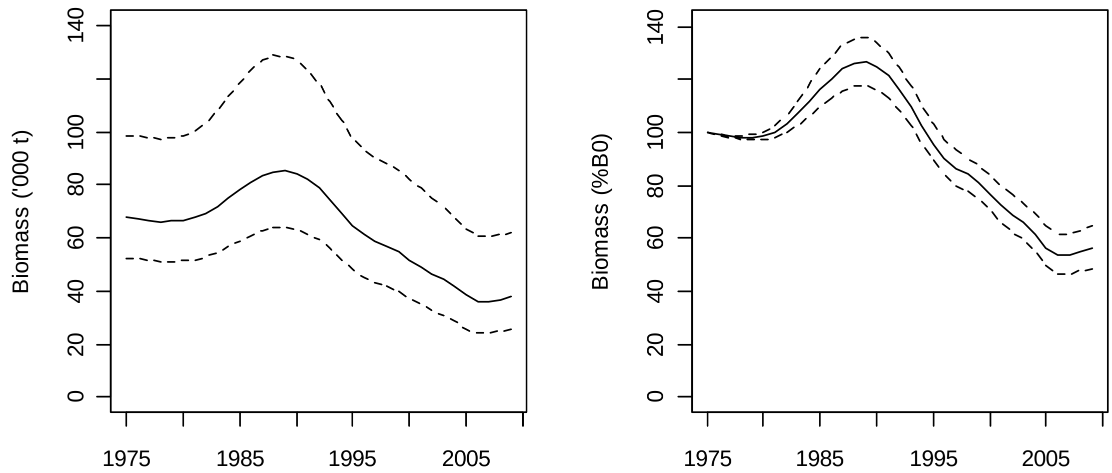


Figure 6: Estimated median trajectories (with 95% credible intervals shown as dashed lines) for the Two sex model for absolute biomass and biomass as a percentage of B_0.

The Single sex model was considered to be better than the Two sex model (and was chosen as the base case) because it fitted the research biomass series and the observer catch-at-age data best, and it does not have to try and account for the apparent changes in population sex ratios over time.

4.2.6 Estimates of sustainable yields

CAY yield estimates were not reported because of the uncertainty of the estimates of absolute biomass.

4.3 HAK 7 (West coast, South Island)

A preliminary investigation of the stock status of the west coast South Island stock was reported to the Working Group. A stock assessment was carried out, using data up to the end of the 2003–04 fishing year, and implemented as a Bayesian stock model using the general-purpose stock assessment program CASAL v2.06 (Bull *et al*. 2005).

The stock assessment for HAK 7 had been last updated by Dunn (1998). Dunn (1998) attempted a MIAEL model using the least squares and MIAEL estimation techniques. That model estimated that the virgin (equilibrium) spawning stock biomass was about 85 000 t (range 42 000–185 000 t), but conclusions on current stock status were very uncertain, and further, that the estimates of stock size were unlikely to be reliable. No time series of biomass indices are available for the west coast South Island stock, and CPUE indices previously calculated for the stock have been highly suspect (Annala *et al*. 1999). In addition, the commercial catch-at-age data lack any sign of year class tracking — either because the commercial catch sampling of hake has been inadequate to detect such trends, or (less likely) that west coast South Island hake have had very low recruitment variability.

4.3.1 Model structure

The stock assessment model partitioned the population into two sexes and age groups 1–30, with the last age class considered a plus group. The west coast South Island stock was considered to reside in a single area (Colman 1998), with the proportion mature considered to be a constant proportion at age. The model was implemented in CASAL (Bull *et al*. 2005), as a Bayesian two-sex single-stock single-area model with three time steps. The models were initialised assuming an equilibrium age structure at an unfished equilibrium biomass (B_0), i.e., with constant recruitment set equal to the mean of the recruitments over the period 1974–1999.

The model's annual cycle was based on the fishing year, with the time steps describing the spawning, recruitment, fishing, and nominal age increment. The spawning stock-recruitment relationship was assumed to be a Beverton-Holt relationship with steepness equal to 0.9.

The models used four selectivity ogives; male and female fishing selectivities, and male and female survey selectivities for resource survey series. Selectivities were assumed to either be logistic (with female selectivity curves estimated relative to male selectivity) or domed (parameterised by a double normal selectivity, with female selectivity curves estimated relative to male selectivity), depending on the model run. Selectivity values for males at age were defined to have maximum selectivity at 1, and female selectivity set relative to males. Annual selectivity shifts were also used in some model runs that allowed the selectivity to 'shift' to the left or right with changes in an exogenous variable (i.e., the mean depth of the fishery). Recruitment was assumed to occur at the beginning of the first (summer) time step.

In total, five model runs were conducted (Table 19). In the first ("initial") model, and model runs 3–5, recruitment was parameterised as a year class strength multiplier (assumed to have mean equal to one over a defined range of years), multiplied by an average (unfished) recruitment (R_0) and a spawning stock-recruitment relationship. For the second model ("YCS"), year class strength multipliers were assumed to be constant and equal to 1. The third model scenario ("depth shifted") assumed that the annual fishing selectivity was shifted by $a(E-\bar{E})$, where a is a shift factor and E was the mean depth fished (weighted by the catch) of all hake tows in each year. The fourth ("domed") and fifth ("domed-shift") model runs used domed selectivities, with the latter also employing the same depth shift algorithm as described above.

Table 19: Model run labels and descriptions for the initial and alternative model runs.

	Model run	Description
1	Initial	Initial model
2	YCS	Initial case, but assuming constant YCS
3	Depth shifted	Initial case, but with fishing selectivity shifted by mean depth fished each season
4	Domed	Initial case, but with domed fishing selectivity
5	Domed shift	Initial case, but with domed fishing selectivity and shifted by mean depth fished each season

4.3.2 Fixed biological parameters and observations

Estimates and assumed values for biological parameters used in the assessments are given in Tables 4 and 5, respectively. Variability in the von Bertalanffy age-length relationship was assumed to be lognormal with a constant CV (coefficient of variation) of 0.1.

Colman (1988) found that hake reach sexual maturity between 6 and 10 years of age, at total lengths of about 67–75 cm (males) and 75–85 cm (females). He concluded that hake reached 50% maturity at between 6 and 8 years in HAK 1, and 7–8 years in HAK 4. We assume 50% maturity at ages between 6 and 7 with full maturity at age 9, where the relative proportions mature at age were those estimated by Dunn (1998) for the west coast South Island.

Catch-at-age observations were available for commercial observer data from 1989–90 to 2002–03. These data, along with the proportions-at-age data from the *Wesermünde* in 1979, were fitted to the model as proportions-at-age, where estimates of the proportions-at-age were estimated using the NIWA catch-at-age software by bootstrap (Bull & Dunn 2002). Age data from each year were compiled into year-specific age-length keys, and these were applied to the stratified, scaled length-frequency distributions to produce proportions-at-age distributions. Strata were determined using tree-based regression methods, with three strata defined as (i) depth ≥ 629 m, (ii) depth < 629 m and latitude ≥ 42º 33' S, and (iii) depth < 629 m and latitude < 42º 33' S. Tows where less than 5 fish were measured were ignored. Ageing error was assumed to occur for the observed proportions-at-age data, by assuming a discrete normally distributed error with CV 0.08.

4.3.3 Model estimation

Model parameters were estimated using Bayesian estimation implemented using CASAL (Bull *et al.* 2005). However, only the mode of the joint posterior distribution (MPD) was estimated in preliminary runs. For final runs, the full posterior distribution was sampled using Monte Carlo Markov Chain (MCMC) methods, based on the Metropolis-Hastings algorithm.

Multinomial errors, with estimated sample sizes, were assumed for the proportions-at-age observations. The effective sample sizes 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 all observations in all model runs. Estimates of the effective sample size for proportions-at-age data applied in the model were made as described in section 4.1.3 above. The values for process error were then fixed for the MCMC runs.

Year class strengths were assumed known (and equal to one) for years prior to 1974 and after 1999, 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.

MCMCs were estimated using a burn-in length of $1x10^6$ iterations, with every 5000^{th} sample taken from the next $5x10^6$ iterations (i.e., a final sample of length 1000 was taken from the Bayesian posterior). Convergence diagnostics for the MCMC for the parameters of the model were not formally investigated, but visual inspection suggested no strong evidence of lack of convergence.

4.4.4 Prior distributions and penalty functions

The assumed prior distributions used in the model were intended to be relatively uninformed or conservative. Priors for B_0 were assumed to be uniform-log, with bounds 2 500–250 000 t; priors for the relative year class strengths were assumed to be lognormal with mean 1.0 and CV 1.1; and priors on selectivity parameters were assumed to be uniform with arbitrary wide bounds. Penalty functions were used to constrain the model so that any combination of parameters that did not allow the historical catch to be taken was strongly penalised. A small penalty was applied to the estimates of year class strengths to encourage estimates that average to 1.0.

4.4.5 Model estimates

The estimated MCMC marginal posterior distributions for selected parameters of the initial model for the west coast South Island stock are shown in Figure 7 and Figure 8. Year class strength estimates (Figure 7) were poorly estimated for most years, particularly where only old or young fish were available to determine age class strength. In addition, it is difficult to determine any evidence of year classes tracking through the commercial catch proportions-at-age data. Biomass for the initial model declined from 1990 (Figure 8). Current biomass estimates for the stock were estimated at about 45–50% of B_0 (with range 33–70%) (Table 20).

Fishing selectivities for males and females were divergent; with the selectivities for males significantly higher than for females in all cases. While the relative proportions of male to females is unusual, the selectivities are representative of the input data; proportions of male fish in the catch suggest that 59% of the catch (by number) was male, though the ratio has declined in recent years. Under the logistic assumption (cases 1–3), maximum selectivity was typically at about ages 8–10 for both males and females.

Alternative model runs suggested that there was considerable uncertainty in the shape of the selectivity function. For the “domed” scenario, selectivities were significantly dome shaped, with the maximum selectivity at ages 10–12, and rapidly declining right hand limbs.

The initial case model fits showed considerable evidence of poor fit to observations of the number of older aged fish, with MCMC runs predicting greater numbers of fish aged over 15 and over 20 in the population than that supported by the catch proportions-at-age observations. However, domed selectivities appeared to fit the observations more closely, and gave more satisfactory diagnostics. Inclusion of a shift parameter (“depth-shifted” and “domed shift”) suggested that there appears to be an increase in mean fish age with depth.

Table 20: Bayesian median and 95% credible intervals of B_0, B_{2004}, and B_{2004} as a percentage of B_0 for the initial and sensitivity cases.

Model run	B_0	B_{2004}	B_{2004} (% B_0)
Initial case	92 280 (81 100–107 750)	49 210 (32 220–74 780)	53 (39–70)
YCS	90 760 (82 310 – 99 040)	41 230 (32 340–49 680)	45 (39–50)
Depth shifted	92 350 (79 790–106 920)	49 730 (30 550–74 790)	54 (38–70)
Domed	114 200 (99 370–152 870)	53 900 (34 670–101 650)	47 (33–70)
Domed shift	110 930 (97 900–135 080)	50 740 (34 220–86 050)	46 (34–65)

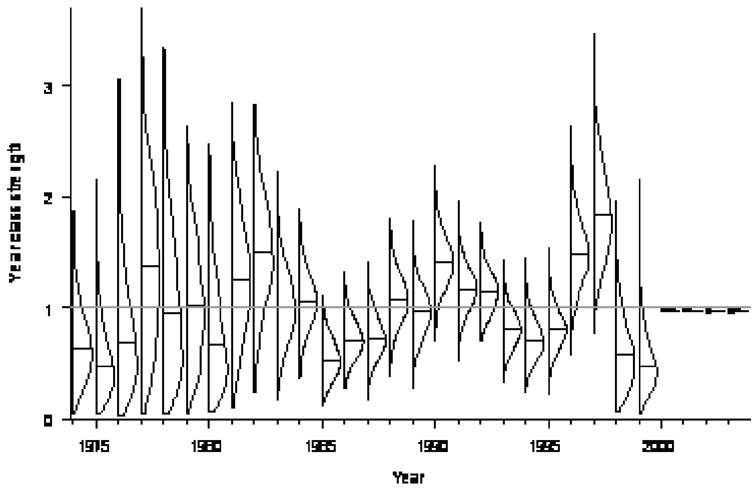


Figure 7: Estimated posterior distributions estimated year class strengths for the initial case. The grey horizontal line indicates the mean year class strength of one. Individual distributions show the marginal posterior distribution, with horizontal lines indicating the median.

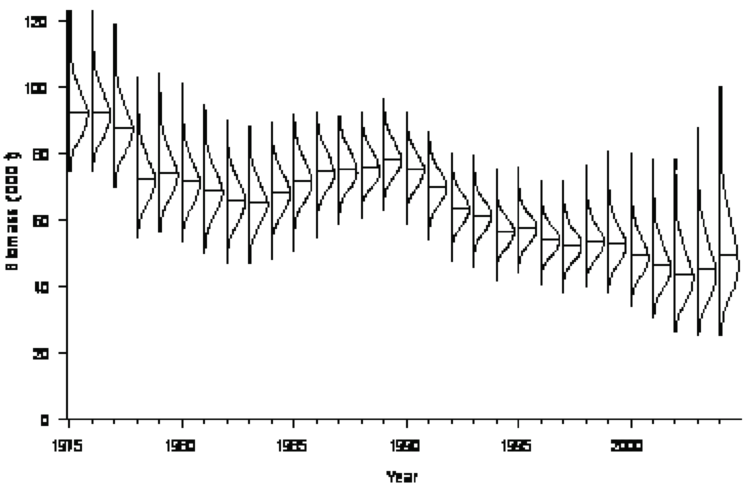


Figure 8: Estimated posterior distributions of the spawning stock biomass trajectories for the initial case. Individual distributions show the marginal posterior distribution, with horizontal lines indicating the median.

6. STATUS OF THE STOCKS

Stock Structure Assumptions

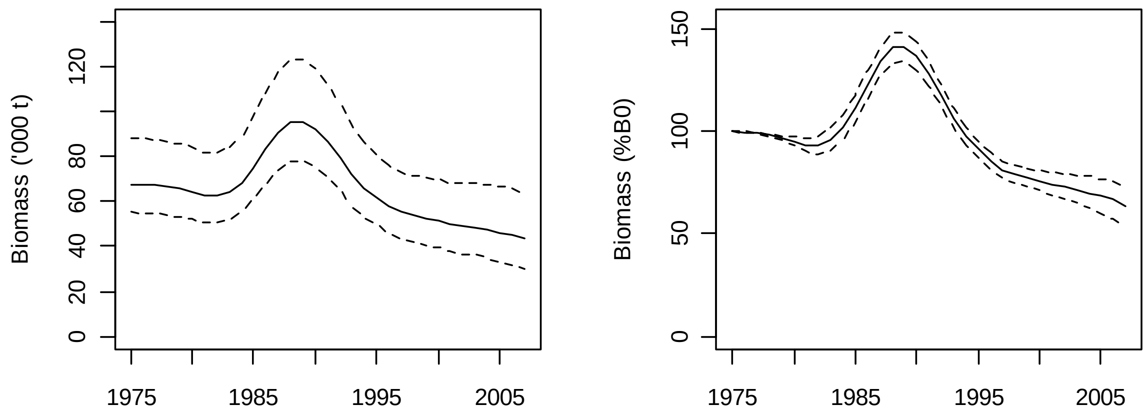
Hake are assessed as three independent biological stocks, based on the presence of three main spawning areas (eastern Chatham Rise, south of Stewart-Snares shelf, and WCSI), and some differences in biological parameters between these areas.

The HAK 1 Fishstock includes all of the Sub-Antarctic biological stock, part of the Chatham Rise biological stock, and all hake around the North Island (which are more likely part of either the WCSI or Chatham Rise stocks). The Sub-Antarctic stock is defined as all of Fishstock HAK 1 south of the

Otago Peninsula; the Chatham Rise stock is all of HAK 4 plus that part of HAK 1 north of the Otago Peninsula; the WCSI stock is HAK 7.

- **Sub-Antarctic Stock**

Stock Status	
Year of Most Recent Assessment	2007
Assessment Runs Presented	A base case and four sensitivity runs.
Reference Points	Management Target: 40% B_0 Soft Limit: 20% B_0 Hard Limit: 10% B_0
Status in relation to Target	B_{2007} was estimated to be about 64% B_0; Virtually Certain (> 99%) to be at or above the target
Status in relation to Limits	B_{2007} is Exceptionally Unlikely (< 1%) to be below both the Soft and Hard Limits
Historical Stock Status Trajectory and Current Status	



Trajectory over time of spawning biomass (absolute, and %B_0, with 95% credible intervals shown as broken lines) for the Sub-Antarctic hake stock from the start of the assessment period in 1975 to 2007 (the final assessment year). Years on the x-axis indicate fishing year with "1995" representing the 1994–95 fishing year. Biomass estimates are based on MCMC results.

Fishery and Stock Trends	
Recent Trend in Biomass or Proxy	Median estimates of biomass are unlikely to have been below 64% B_0. Biomass is estimated to have been decreasing since the late 1980s.
Recent Trend in Fishing Mortality or Proxy	Fishing pressure is estimated to have been low since the late 1990s.
Other Abundance Indices	–
Trends in Other Relevant Indicators or Variables	Recent recruitment (1999–2003) is estimated to be lower than the long-term average for this stock.

Projections and Prognosis (2007)	
Stock Projections or Prognosis	The biomass of the Sub-Antarctic stock was expected to decrease at a catch level equivalent to the mean from 1990 to 2006 (i.e., 2400 t annually).
Probability of Current Catch or TACC causing decline below Limits	Soft Limit: Very Unlikely (< 10%) Hard Limit: Very Unlikely (< 10%)

Assessment Methodology	
Assessment Type	Level 1 – Quantitative stock assessment
Assessment Method	Age-structured CASAL model with Bayesian estimation of posterior distributions.

Main data inputs	- Two research time series of abundance indices (trawl surveys). - Proportions-at-age data from the commercial fisheries and trawl surveys. - Estimates of biological parameters.	
Period of Assessment	Latest assessment: 2007	Next assessment: 2011
Changes to Model Structure and Assumptions	No significant changes since the previous assessment.	
Major Sources of Uncertainty	The summer trawl survey series has shown a slight overall decline over time, but individual survey estimates are variable. The general lack of contrast in this series (the main relative abundance series) makes it difficult to accurately estimate past and current biomass. The assumption of a single Sub-Antarctic stock (including the Puysegur Bank), independent of hake in all other areas, is the most parsimonious interpretation of available information. However, this assumption may not be correct Uncertainty about the size of recent year classes affects the reliability of stock projections. Although the catch history used in the assessment has been corrected for some misreported catch (see section 1.4), it is possible that additional significant misreporting exists. It is assumed in the assessment models that natural mortality is constant over all ages.	

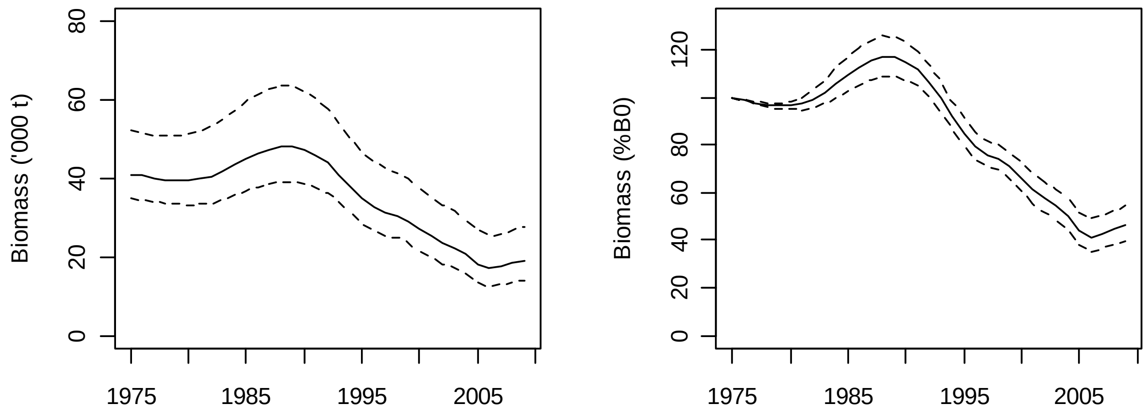
Qualifying Comments
Four sensitivity model runs reported in a FAR but not in the Plenary Report all produced similar estimates of stock status to the base case (i.e., B_{2007} = 60–70% B_0).

Fishery Interactions
Hake are often taken as a bycatch in hoki target fisheries. Some target fisheries for hake do exist, with the main bycatch species being hoki, ling, silver warehou and spiny dogfish. Bycatch species of concern include deepsea sharks and skates, fur seals and seabirds.

- **Chatham Rise Stock**

Stock Status	
Year of Most Recent Assessment	2009
Assessment Runs Presented	Two alternate model runs: the “Single sex” (base case) model was considered more plausible than the “Two sex” model.
Reference Points	Management Target: 40% B_0 Soft Limit: 20% B_0 Hard Limit: 10% B_0
Status in relation to Target	B_{2009} was estimated to be about 47% B_0; Likely (> 60%) to be at or above target
Status in relation to Limits	B_{2009} is Very Unlikely (< 10%) to be below the Soft Limit and Exceptionally Unlikely (< 1%) to be below the Hard Limit

Historical Stock Status Trajectory and Current Status



Trajectory over time of spawning biomass (absolute, and %B_0, with 95% credible intervals shown as broken lines) for the Chatham Rise hake stock from the start of the assessment period in 1975 to 2009 (the final assessment year). Years on the x-axis indicate fishing year with "2005" representing the 2004–05 fishing year. Biomass estimates are based on MCMC results.

Fishery and Stock Trends	
Recent Trend in Biomass or Proxy	Median estimates of biomass are unlikely to have been below 41% B_0. Biomass has subsequently been increasing.
Recent Trend in Fishing Mortality or Proxy	Fishing pressure is estimated to have been low since 2006 (relative to estimated pressure in most years from 1994 to 2005).
Other Abundance Indices	–
Trends in Other Relevant Indicators or Variables	Recent recruitment (1995–2006) is estimated to be lower than the long-term average for this stock.

Projections and Prognosis (2009)	
Stock Projections or Prognosis	The biomass of the Chatham Rise stock is expected to decrease slightly over the next 5 years at catch levels equivalent to those from recent years (i.e., about 1150 t annually), but is projected to decline markedly if future catches are close to the high catch scenario (i.e. annual catch levels equivalent to the HAK 4 TACC of 1800 t plus the average HAK 1 Chatham Rise catch from 1991–92 to 2004–05 of 1000 t per year).
Probability of Current Catch or TACC causing decline below Limits	Soft Limit: Unlikely (< 10%) Hard Limit: Very Unlikely (< 1%)

Assessment Methodology		
Assessment Type	Level 1 – Quantitative stock assessment	
Assessment Method	Age-structured CASAL model with Bayesian estimation of posterior distributions.	
Main data inputs	- Research time series of abundance indices (trawl survey). - Proportions-at-age data from the commercial fisheries and trawl surveys. - Estimates of biological parameters. New information since the 2006 assessment included three trawl surveys, and updated catch and catch-at-age data.	
Period of Assessment	Latest assessment: 2009	Next assessment: Unknown
Changes to Model Structure and Assumptions	Previous assessments included sex in the partition. The base case (Single sex) model reported above excludes sex from the partition.	

Major Sources of Uncertainty	While the Single sex model is considered more credible than the Two sex model, it is not clear why the addition of sex in the partition results in a 66% increase in B_0. It is possible that a larger stock allows the model to better fit the variable catch-at-age by sex data when biomasses are higher. However, the Two sex model should not be considered completely unreliable. The assumption of a single Chatham Rise stock independent of hake in all other areas is the most parsimonious interpretation of available information. Uncertainty about the size of recent year classes affects the reliability of stock projections. Although the catch history used in the assessment has been corrected for some misreported catch (see section 1.4), it is possible that additional misreporting exists. It is assumed in the assessment models that natural mortality is constant over all ages. The use of dome-shaped selectivity ogives will compensate for some variation in mortality rate with age.

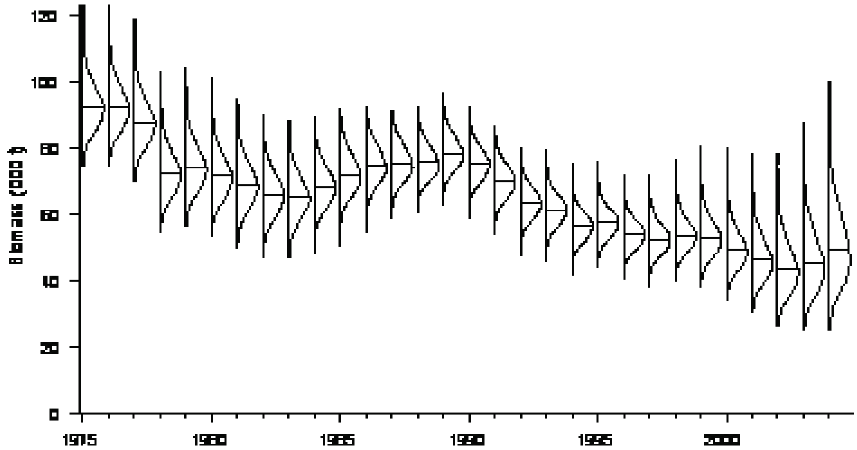
Qualifying Comments
The increase in relative abundance seen since 2005 is the result of good recruitment in 2002. In October 2004, large catches were taken in the western deep fishery (i.e. near the Mernoo Bank). This has not been repeated in subsequent years, nor did it occur in previous years. There is no information indicating whether the 2004 aggregation fished on the western Chatham Rise was spawning; if it was then this might indicate that there is more than one stock on the Chatham Rise. However, the progressive increase in mean fish size from west to east is indicative of a single homogeneous stock on the Chatham Rise.

Fishery Interactions
Hake are often taken as a bycatch in hoki target fisheries. Some target fisheries for hake do exist, with the main bycatch species being hoki, ling, silver warehou and spiny dogfish. Bycatch species of concern include deepsea sharks and skates, fur seals and seabirds.

- **West coast South Island Stock**

Stock Status	
Year of Most Recent Assessment	2004
Assessment Runs Presented	A base case and four sensitivity model runs.
Reference Points	Management Target: 40% B_0 Soft Limit: 20% B_0 Hard Limit: 10% B_0
Status in relation to Target	B_{2004} was estimated to be about 53% B_0; Very Likely (> 90%) to be at or above the target
Status in relation to Limits	B_{2004} is Exceptionally Unlikely (< 1%) to be below both the Soft and Hard Limits

Historical Stock Status Trajectory and Current Status



Trajectory over time of spawning biomass (t) for the WCSI hake stock from the start of the assessment period in 1975 to 2004 (the final assessment year). Individual distributions show the marginal posterior distribution, with horizontal lines indicating the median. Years on the x-axis are fishing year with "1995" representing the 1994–95 fishing year. Biomass estimates are based on MCMC results.

Fishery and Stock Trends	
Recent Trend in Biomass or Proxy	Median estimates of biomass are unlikely to have been below 44% B_0 (in the year 2002). Biomass was estimated to have decreased throughout the 1990s, but has recovered slightly since 2002.
Recent Trend in Fishing Mortality or Proxy	Not reported.
Other Abundance Indices	–
Trends in Other Relevant Indicators or Variables	Recruitment is estimated to have been poor in 1998 and 1999.

Projections and Prognosis (2004)	
Stock Projections or Prognosis	No projections were reported.
Probability of Current Catch or TACC causing decline below Limits	Soft Limit: Very Unlikely (< 10%) Hard Limit: Very Unlikely (< 10%)

Assessment Methodology		
Assessment Type	Level 1 – Quantitative stock assessment	
Assessment Method	Age-structured CASAL model with Bayesian estimation of posterior distributions.	
Main data inputs	- Proportions-at-age data from the commercial fishery and one research survey. - Estimates of biological parameters.	
Period of Assessment	Latest assessment: 2004	Next assessment: Unknown
Changes to Model Structure and Assumptions	The previous assessment had used the MIAEL estimation technique.	
Major Sources of Uncertainty	There are no abundance estimates in the stock assessment; the model relies on changes in the catch data to determine the fishing mortality rates for the stock. There are strong selectivity patterns for each sex estimated in the model that may be the result of poor sampling of the fishery rather than representing real selectivity differences between the sexes. The assumption of a single WCSI stock independent of hake in all other areas is the most parsimonious interpretation of the available	

	information. Although the catch history used in the assessment has been corrected for some misreported catch (see section 1.4), it is possible that additional misreporting exists. It is assumed in the assessment models that natural mortality is constant over all ages.

Qualifying Comments
The four sensitivity model runs reported in the Plenary document all produced estimates of stock status similar to that from the base case (i.e., median B_{2004} = 45–57% B_0). However, owing to the lack of an index of abundance in the assessments, this range of results may underestimate the true level of uncertainty in B_{2004},which may liemore appropraitely between 30% and 70% B_0.

Fishery Interactions
Hake are often taken as a bycatch in hoki target fisheries. Some target fisheries for hake do exist, with the main bycatch species being hoki, ling, silver warehou and spiny dogfish. Bycatch species of concern include deepsea sharks and skates, fur seals and seabirds.

Summary of TACCs (t) and reported landings for the most recent fishing year.

Fishstock[1]	QMA	B_{MAY}	MAY	CAY	2008–09 actual TACC	2008–09 reported landings
HAK 1	Auckland, Central Southeast, Southland, Sub-Antarctic (QMA 1, 2, 3, 5, 6, 8, 9)				3 701	3 415
HAK 4	Chatham Rise (QMA 4)				1 800	856
HAK 7	Challenger (QMA 7)				7 700	5 954
HAK 10					10	–
Total					13 211	10 226

1. Yield estimates are based on stock areas used in these assessments, i.e., Chatham Rise stock includes HAK 4 and that part of HAK 1 on the western end of the Chatham Rise, and Sub-Antarctic stock includes the remainder of HAK 1.

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