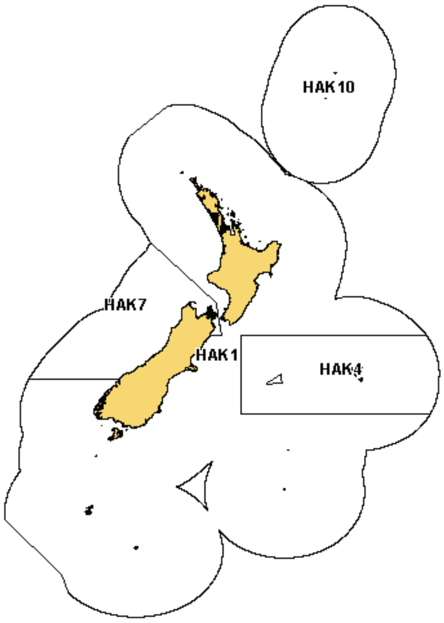
HAKE (HAK)

(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 west coast South Island hake fishery has generally consisted of bycatch in the much larger hoki fishery, but it has undergone a number of changes during the last 15 years. These include changes to the TACCs of both hake and hoki, and also changes in fishing practices such as gear used, tow duration, and strategies to limit hake bycatch. In some years, notably in 1992 and 1993, there was a hake target fishery in September after the peak of the hoki fishery was over; more than 2000 t of hake were taken in this target fishery during September 1993. Bycatch levels of hake early in the fishing season in the years 1994–95, 1995–96, and 1997–89 to 2000–01 were relatively high.

In HAK 1 (where most of the catch is taken from the Sub-Antarctic) and HAK 4 (Chatham Rise), hake have also been caught mainly as bycatch by trawlers targeting hoki. However, in both areas some targeting for hake occurs, particularly in Statistical Area 404 in HAK 4, which is a known spawning area for hake north-west of the Chatham Islands.

Increases in TACC's 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 TACC's in both HAK 1 and HAK 4, with catches in HAK 1 remaining relatively steady since. Landings from HAK 4 steadily declined from 1997–98 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. 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 the average catch level over the last 12 years, as the latest stock assessment indicated that the current catch levels were sustainable in the short term.

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. Total landings of hake in 2007–08 were markedly lower on the WCSI (HAK 7) than in previous years.

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 2007–08 and actual TAC's (t) for 1986–87 to 2007–08. QMS data from 1986–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

1. FSU data.

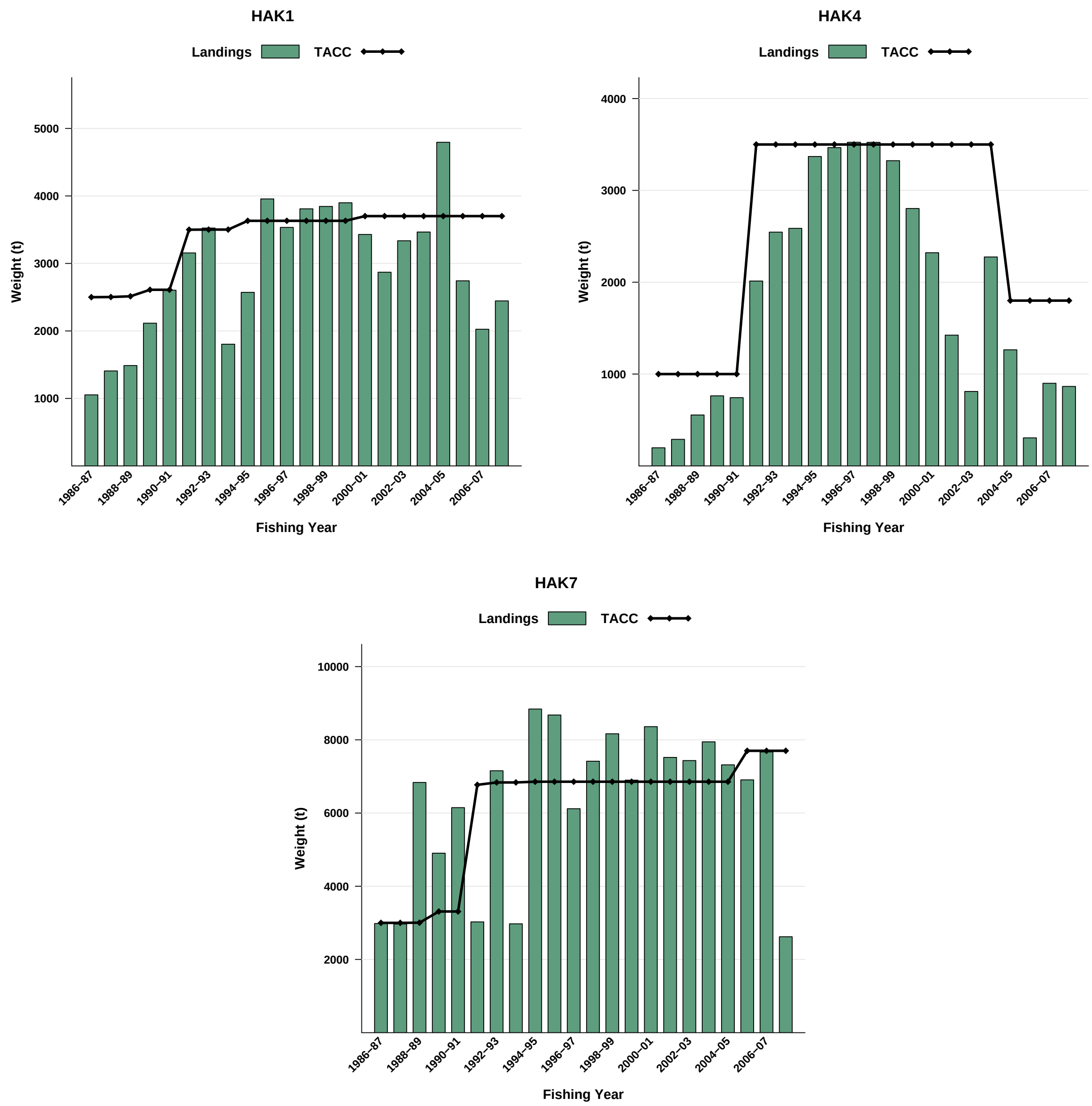


Figure 1: Historical landings and TACC for the three main HAK stocks. From top left: HAK1 (Auckland East), HAK4 (Chatham Rise), and HAK7 (Challenger). Note that these figures do not show data prior to entry into the QMS.

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 2000–01 (Devine 2008).

In earlier years, before the introduction of higher TACC's 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 2006–07 are given in Table 3.

Table 3: Revised landings 1974–75 to 2006–07 (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	2 416
1992–93	7 047	3 252	2 811
1993–94	2 944	1 446	2 936
1994–95	9 507	1 844	3 391
1995–96	9 248	2 794	3 916
1996–97	6 961	2 266	3 664
1997–98	7 888	2 615	3 986
1998–99	8 922	2 785	3 378
1999–00	7 456	3 020	2 947
2000–01	8 641	2 841	2 508
2001–02	7 414	2 504	1 777
2002–03	7 371	2 717	1 416
2003–04	8 559	3 244	2 498
2004–05	7 292	2 773	3 754
2005–06	6 905	2 447	600
2006–07	–	2 400	–

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.
2. Predicted value from pro-rated MHR returns up to July 2007.

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. Both sexes reach sexual maturity between 6 and 10 years of age, at lengths of about 67–75 cm TL (males) and

75–85 cm TL (females). Colman (1998) suggested that hake reached 50% maturity at between 6–8 years for HAK 1, and 7–8 years for HAK 4.

Horn (1997) validated the use of otoliths to age hake, and produced von Bertalanffy growth parameters. Growth parameters were updated by Horn (in prep.) using both the von Bertalanffy and Schnute growth models. The Schnute model was found to better fit the data. Readings of otoliths have been used in age-length keys to scale length frequency distributions for hake collected from trawl surveys in HAK 1 and HAK 4 and from commercial vessels in the HAK 1, HAK 4, and HAK 7 fisheries to produce catch at age distributions.

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)
2. Weight = a·(length)^b (Weight in t, length in cm)							
	Sub-Antarctic	Males	a = 3.95 x10^{-9}	b = 3.130			Horn (1998)
		Females	a = 1.86 x10^{-9}	b = 3.313			Horn (1998)
	Chatham Rise	Males	a = 2.49 x10^{-9}	b = 3.234			Horn (1998)
		Females	a = 1.70 x10^{-9}	b = 3.328			Horn (1998)
	West coast South Island	Males	a = 2.75 x10^{-9}	b = 3.230			Horn (1998)
		Females	a = 1.33 x10^{-9}	b = 3.410			Horn (1998)
3. von-Bertalanffy growth parameters							
	Sub-Antarctic	Males	$K = 0.295$	$t_0 = 0.06$		$L_\infty = 88.8$	Horn (in prep.)
		Females	$K = 0.220$	$t_0 = 0.01$		$L_\infty = 107.3$	Horn (in prep.)
	Chatham Rise	Males	$K = 0.330$	$t_0 = 0.09$		$L_\infty = 85.3$	Horn (in prep.)
		Females	$K = 0.229$	$t_0 = 0.01$		$L_\infty = 106.5$	Horn (in prep.)
	West coast South Island	Males	$K = 0.357$	$t_0 = 0.11$		$L_\infty = 82.3$	Horn (in prep.)
		Females	$K = 0.280$	$t_0 = 0.08$		$L_\infty = 99.6$	Horn (in prep.)
4. 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 (in prep.)
		Females	$y_1 = 22.9$	$y_2 = 109.9$	$a = 0.147$	$b = 1.457$	Horn (in prep.)
	Chatham Rise	Males	$y_1 = 24.6$	$y_2 = 90.1$	$a = 0.184$	$b = 1.742$	Horn (in prep.)
		Females	$y_1 = 24.4$	$y_2 = 114.5$	$a = 0.098$	$b = 1.764$	Horn (in prep.)
	West coast South Island	Males	$y_1 = 23.7$	$y_2 = 83.9$	$a = 0.278$	$b = 1.380$	Horn (in prep.)
		Females	$y_1 = 24.5$	$y_2 = 103.6$	$a = 0.182$	$b = 1.510$	Horn (in prep.)
5. Age at 50% maturity							
		Males	$A_{50} = 6–7$				Colman (1998)
		Females	$A_{50} = 7–8$				Colman (1998)

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. However, the data are not unequivocal so the stock affinity 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 Chatham Rise and west coast South Island stocks (Dunn *et al*. 2006), and in 2007 for the sub-Antarctic stock (Horn in prep.). Subsequent assessments of the Chatham Rise stock were completed in 2005 (Dunn 2006) and 2006 (Horn & Dunn 2007). This work improved the understanding of the biological and fishery processes operating in that stock, resulting in improvements in the model structure. However, this work is still in progress and did not produce an assessment that the Working Group believed was any more reliable than that completed in 2004. Hence, the results are not reported in the Plenary document, but a description of the advancements made is given in section 4.2.7 below. 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.

Maximum exploitation rates for hake are assumed to be 0.7 for the sub-Antarctic stock. As this applies to those age classes that are fully selected, the maximum catch/biomass ratio would be lower than this value. The choice of the maximum exploitation rate has the effect of determining the minimum possible virgin biomass allowed by the model.

The catch history assumed in all model runs (Table 3) include the revised estimates of catch reported by Dunn (2003) and updated by Devine (2008). 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 and Chatham Rise 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	0.20 y^{-1}, 0.18 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 Year	Vessel	Nov–Dec series [1]		Apr–May series [2]		Sep series [2]	
		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				

* 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 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).

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 *q*s.

The priors for survey *q*s 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.

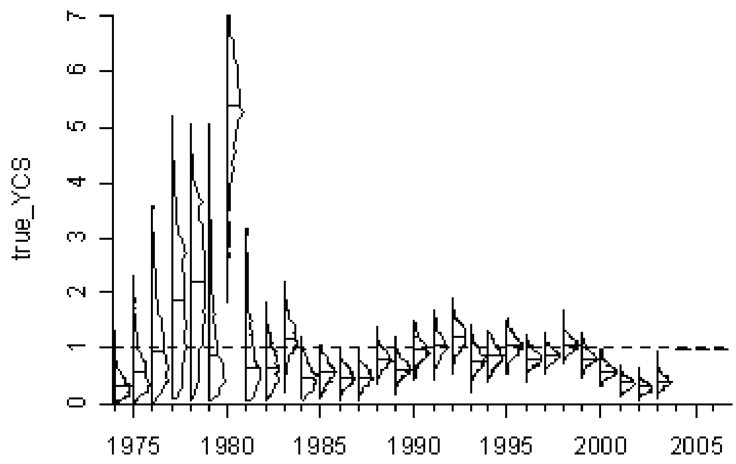


Figure 2: Estimated posterior distributions of year class strengths for the base case for the sub-Antarctic stock. The grey horizontal line indicates the year class strength of one. Individual distributions show the marginal posterior distribution, with horizontal lines indicating the median.

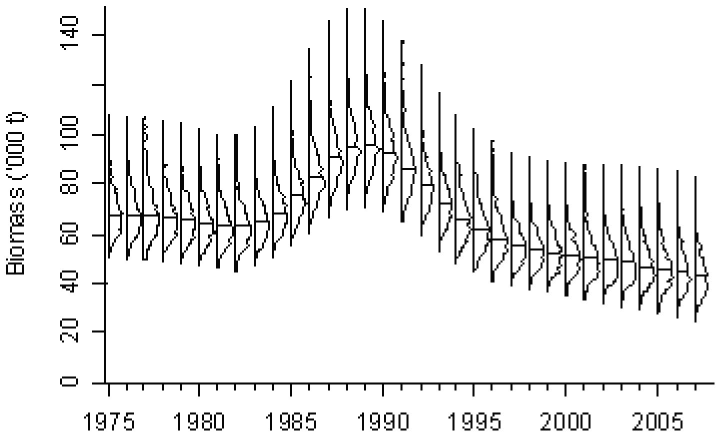


Figure 3: Estimated posterior distributions of spawning stock biomass trajectories for the base case for the sub-Antarctic stock. Individual distributions show the marginal posterior distribution, with horizontal line indicating the median.

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.

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 2004 stock assessment was carried out with data up to the end of the 2003–04 fishing year, implemented as a Bayesian model using the general-purpose stock assessment program CASAL v2.07 (Bull *et al*. 2005). The assessment used research time series of abundance indices (trawl surveys of the Chatham Rise from 1992 to 2004), catch-at-length and catch-at-age from the commercial fishery since 1990–91, and estimates of biological parameters.

In addition, a sensitivity run was completed using the Statistical Area 404 CPUE as an index of vulnerable abundance for the Chatham stock. The WG preferred the CPUE indices from Statistical Area 404 as this area has a target fishery for hake during the spawning season.

4.2.1 Model structure

The stock assessment model partitioned the Chatham Rise stock 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 1975–2000.

The model used four selectivity at age ogives; male and female commercial fishing selectivities, and male and female survey selectivities for the Chatham Rise January trawl survey series. The 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.

Maximum exploitation rates for hake are assumed to be 0.7 for the Chatham Rise stock. As this applies to those age classes that are fully selected, the maximum catch/biomass ratio would be lower than this value. The choice of the maximum exploitation rate has the effect of determining the minimum possible virgin biomass allowed by the model.

The catch histories assumed in all model runs (Table 3) include the revised estimates of catch reported by Dunn (2003). The catch for the 2003–04 fishing year was assumed to be the sum of the reported landings for HAK 4 in 2003–04, plus HAK 1 landings from the Chatham Rise in 2002–03.

Five-year biomass projections were made assuming future catches on the Chatham Rise to be either the sum of the current HAK 4 TACC plus half the HAK 1 TACC (i.e., 3616 t, “high catch scenario”) or just equal to the current HAK 4 TACC of 1800 t (“low catch scenario”). For each projection scenario, recruitment variability was assumed to be lognormally distributed.

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 von Bertalanffy age-length relationship was assumed to be lognormal with a constant CV. (coefficient of variation) of 0.1. Maturity was estimated within the assessment model from data derived from those 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 the gonad weight to body weight).

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.

Resource survey abundance indices are given in Table 11, and CPUE indices are given in Table 12.

Table 11: 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

* Not used in the reported assessment.

Table 12: Hake CPUE indices (and associated CVs) for the four Chatham Rise fisheries (Devine in prep.). For definitions of the Chatham Rise fisheries see Figure 5.

	West shallow		West deep		East (excl. 404)		Chatham Rise Area 404	
Year	Index	CV	Index	CV.	Index	CV.	Index	CV.
1990–91	0.36	0.10	–	–	1.72	0.07	–	–
1991–92	0.67	0.08	–	–	1.03	0.07	2.34	0.16
1992–93	0.43	0.08	0.71	0.07	1.57	0.06	1.47	0.09
1993–94	0.66	0.10	0.86	0.09	1.18	0.07	1.15	0.11
1994–95	1.41	0.06	0.86	0.06	0.81	0.05	1.62	0.11
1995–96	1.57	0.05	1.31	0.05	0.85	0.07	1.92	0.10
1996–97	1.17	0.05	1.28	0.04	1.00	0.05	1.46	0.11
1997–98	1.17	0.04	1.15	0.04	0.97	0.04	1.85	0.10
1998–99	1.20	0.04	0.95	0.04	0.89	0.03	1.42	0.08
1999–00	1.07	0.04	1.12	0.04	1.13	0.04	1.02	0.11
2000–01	1.10	0.04	1.17	0.04	1.09	0.04	0.77	0.09
2001–02	1.10	0.05	1.04	0.04	1.10	0.04	0.83	0.08
2002–03	1.16	0.04	0.90	0.04	0.91	0.04	0.60	0.10
2003–04	0.90	0.05	0.74	0.04	0.75	0.04	0.62	0.07
2004–05	1.00	0.05	1.15	0.05	0.48	0.05	0.54	0.07
2005–06	1.18	0.05	0.75	0.05	0.51	0.06	0.16	0.24

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 multinomial likelihood, where estimates of the proportions-at-age and associated c.v.s 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 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 1975 and after 2000, when inadequate or no catch-at-age data were available. Otherwise year class strengths were estimated under the assumption that the estimates from the model should average one.

MCMCs were estimated using a burn-in length of 1×10^6 iterations, with every 5000th sample taken from the next 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*.

The prior on natural mortality (when estimated) was determined by assuming that the current estimate of natural mortality was a reasonable approximation to the true value with the assumption that the true value could differ from the current point estimate by about 0.05, and not more than 0.1. Natural mortality was parameterised by the average of male and female, with the difference estimated with an associated normal prior with mean 0.0, standard deviation of 0.05, and bounds (-0.2, 0.2).

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

Stock	Parameter	Distribution	Parameters		Bounds	
Chatham Rise	B_0	Uniform-log	–	–	2 500	250 000
	Survey *q*	Lognormal	0.16	0.79	0.01	0.40
	YCS	Lognormal	1.0	1.1	0.01	100
	M (mean)	Lognormal	0.20	0.20	0.10	0.35
	M (difference)	Normal	0.0	0.05	-0.20	0.20

4.2.5 Model estimates

Estimates of biomass were produced for an agreed bases case run using the biological parameters and model input parameters described earlier. One sensitivity run is also reported; ("CPUE") where the trawl survey biomass indices were replaced with CPUE abundance indices. Other sensitivity runs evaluated included estimating natural mortality *M* ("estimate *M*"); and adding additional process error to the resource survey series (c.v. 20%, "Cvs") (Table 14).

For all runs, MPD fits were obtained and qualitatively evaluated. In addition, for the base and two CPUE sensitivity runs, 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
Base case	Base case model
CPUE	Same as the base case, but excluding survey data and including CPUE indices
Estimate *M*	Same as the base case, but also estimating natural mortality (*M*)
Cvs	Same as the base case, but with the addition of process error (20%) on survey abundance indices

The estimated MCMC marginal posterior distributions for selected parameters are shown in Figures 4 and 5. Year class strength estimates were poorly estimated at ages where only older fish were available to determine age class strength (i.e., before about 1980). 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, and again in the late 1980s and early 1990s, followed by a period of rapidly declining recruitment. Consequently, biomass estimates for the stock have declined. Current biomass estimates for the stock were estimated at about 35% of B_0 (95% credible intervals 29–41%) (see Figure 5 and Table 15). Exploitation rates (catch over vulnerable biomass) for the Chatham Rise appear to be increasing, with upper estimates bounded at 0.7 in the most recent year.

Trawl survey selectivities for males and females diverged, with the selectivities for males higher than females at older ages (15+) in the January survey series. The posterior density estimates of selectivities indicated considerable uncertainty in the estimates of selectivity by age and sex. Fishing selectivities were also very uncertain.

The CPUE sensitivity run (using the Statistical Area 404 CPUE indices) did not suggest any great departure from the base case estimate of biomass (Table 15). All sensitivity runs showed a similar pattern of reducing recruitment in recent years, and rapidly declining stock status. The most optimistic run was when natural mortality was estimated within the model — although this resulted in unlikely estimates of natural mortality (i.e., 0.28 y^{-1} and 0.29 y^{-1} for females and males respectively).

Base case model projections with "high" catches (3616 t) suggested that biomass will decline to about 6–26% B_0 by 2009 (Table 16). At "low" catches (1800 t), projections suggested that biomass will decline more slowly (12–43 % B_0). Risks that the stock will fall below 20% B_0 are given in Table 17. Under both catch scenarios, the risks to the stock increase with time — reaching about 88% in 2009 at higher catch levels and 28% at current catch levels.

Table 15: Bayesian median and 95% credible intervals of B_0, B_{2004}, and B_{2004} as a percentage of B_0 for the Chatham Rise base and sensitivity case.

Model run	B_0	B_{2004}	B_{2004} (%B_0)
Base case	26 920 (25 040–29 500)	9 410 (7 460–12 020)	35.0 (29.2–41.4)
CPUE	24 200 (22 050–28 230)	6 220 (3 900–10 350)	25.7 (17.5–37.5)

Table 16: Bayesian median and 95% credible intervals of projected B_{2009}, B_{2009} as a percentage of B_0, and B_{2009}/B_{2004} (%) for the Chatham Rise base and sensitivity case where future catches are assumed to be 3616 t and 1800 t.

Future catch	Model run	B_{2009}	B_{2009} (%B_0)	B_{2009}/B_{2004} (%)
High (3 616 t)	Base case	3 430 (1 640–7 230)	12.8 (6.1–25.9)	36.7 (18.1–70.6)
	CPUE	2 430 (1 250–5 100)	9.9 (5.3–19.8)	38.5 (22.0–70.1)
Low (1 800 t)	Base case	6 360 (3 230–11 820)	23.6 (12.3–43.0)	66.9 (38.9–117.2)
	CPUE	4 410 (1 380–10 040)	17.9 (5.9–37.2)	68.7 (29.8–126.0)

Table 17: Estimates of stock risk for 2005–2009, i.e., the probability that the stock will fall below 20% B_0, for the Chatham Rise base and sensitivity case where future catches are assumed to be 3616 t and 1800 t.

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

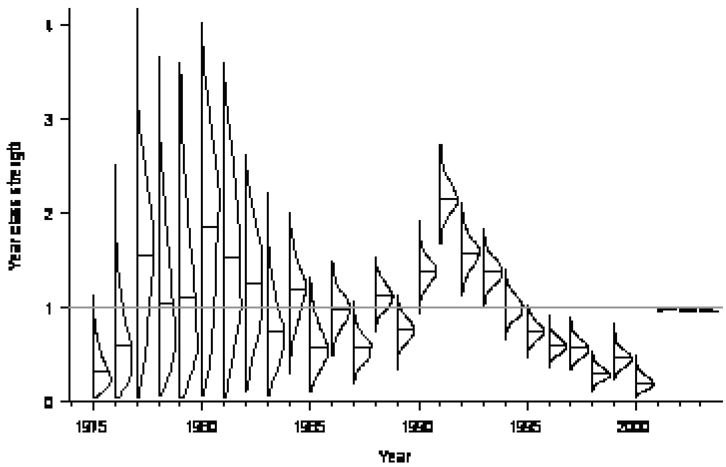


Figure 4: Estimated posterior distributions of year class strengths for the base case for the Chatham Rise stock. The grey horizontal line indicates the year class strength of one. Individual distributions show the marginal posterior distribution, with horizontal lines indicating the median.

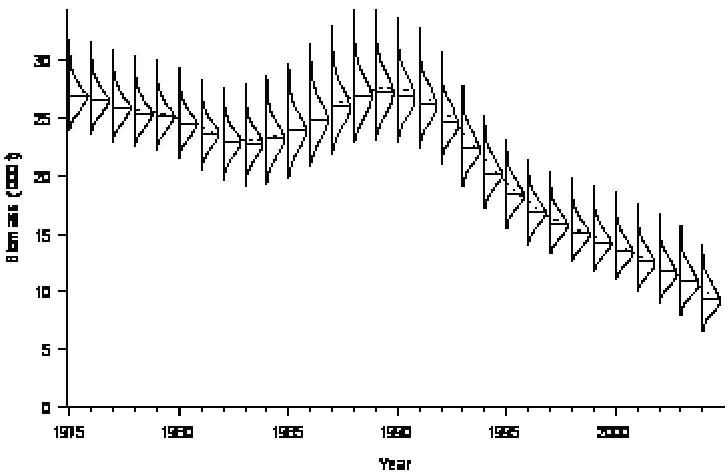


Figure 5: Estimated posterior distributions of spawning stock biomass for the base case for the Chatham Rise stock. Individual distributions show the marginal posterior distribution, with horizontal line indicating the median, and the dashed line indicating the MPD trajectory.

4.2.6 Estimates of sustainable yields

CAY yield estimates were based on the 1000 samples from the Bayesian posterior for each stock with stochastic simulations run over 100 years (Francis 1992); yields were maximised subject to the constraint that spawning stock biomass should not fall below 20% of B_0 more than 10% of the time. The Chatham Rise base case estimates of MAY and CAY were 2230 t and 2330 t respectively (B_{MAY} = 7500 t).

4.2.7 Recent assessment advances

The Chatham Rise assessment was updated in 2006, and the research results are described here. Previous assessments had shown that the commercial catch-at-age distributions varied markedly between years and were not well fitted by the model. It was suspected that this was a function of areal or temporal differences in the available Observer samples. A tree regression analysis (where mean length of hake per tow was related to location, depth, and date) indicated four distinct fisheries (Figure 6) based on area and depth, as follows.

- West shallow — west of 178.1° E, and depth < 530 m
- West deep — west of 178.1° E, and depth ≥ 530 m
- East excl. 404 — east of or equal to 178.1° E, but excluding statistical area 404
- Area 404 — statistical area 404 (latitude 42.17°–43.73° S, longitude 178°–179.5° W)

Mean fish size increased from west to east, and from shallow to deep. Consequently, catch-at-age or catch-at-length distributions were created for each fishery in each year where there were sufficient data (i.e., catch-at-age if there were at least 400 length measurements and the mean weighted CV over all age classes was less than 30%; catch-at-length if the catch-at-age criteria were not met but there were at least 278 length measurements). It was also necessary to partition the catch history into the four fisheries (Table 18) and calculate separate CPUE indices for each fishery (see Table 12). A descriptive analysis indicated that the fisheries occurred mainly from September to January, so catch histories (Table 18) were calculated for years beginning 1 September, rather than 1 October.

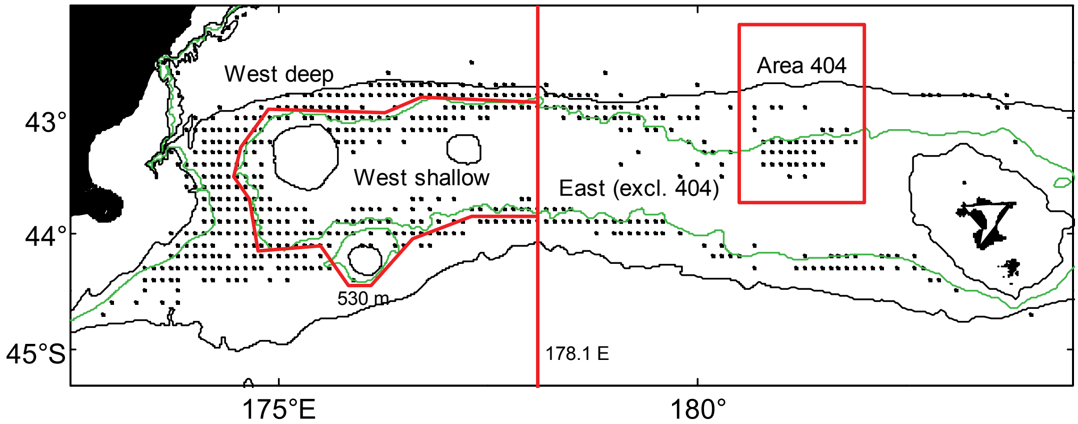


Figure 6: Fishery strata defined for the Chatham Rise hake fishery. Dots show positions of tows included in the analysis; one point may represent many tows. The stratum boundary defined by depth (530 m) is shown only approximately. Isobaths at 1000, 500, and 250 m are also shown.

Table 18: Estimated catch (t) by fishery from the Chatham Rise stock, and total catch, by model year. Landings from 2006 are estimated from MHR reports.

Model year	West shallow	West deep	East excl. 404	Area 404	Total
1975	46	35	21	90	191
1976	86	65	63	273	488
1977	42	32	229	986	1 288
1978	16	12	1	5	34
1979	59	44	95	411	609
1980	274	207	51	218	750
1981	520	394	16	68	997
1982	224	170	38	165	596
1983	88	66	28	120	302
1984	127	97	23	97	344
1985	132	100	59	253	544
1986	160	122	15	65	362
1987	220	167	23	99	509
1988	219	166	36	154	574
1989	220	166	79	339	804
1990	117	192	113	576	998
1991	131	278	369	134	912
1992	405	313	190	897	1 805
1993	376	280	253	1 743	2 652
1994	244	124	244	2 668	3 280
1995	391	206	183	2 720	3 500
1996	1 031	323	102	2 381	3 836
1997	976	499	188	1 632	3 295
1998	835	589	267	856	2 547
1999	729	441	387	2 953	4 509
2000	771	384	263	1 868	3 285
2001	731	476	367	1 333	2 908
2002	200	254	133	925	1 512
2003	248	249	166	552	1 215
2004	376	312	897	1 086	2 671
2005	263	2 322	223	1 211	4 019
2006	170	130	150	150	600

Initial modelling of the stock using the new multi-fishery structure resulted in good fits to the catch-at-age data, believable and logical fishery ogives, and reasonable fits to the eastern fishery CPUE series. Also, the unrealistically high exploitation rate in 2005 estimated in the previous single-fishery assessment was no longer an issue. However, the western CPUE series and the catch-at-length data were poorly fitted. The reasons for the poor fits are still being investigated. The western CPUE series match well the biomass indices from the trawl survey (when the survey is split into eastern and western series), so it is likely that some inappropriate selectivity ogive (one or a combination of the survey selectivities or the western fishery selectivities) is the cause of the poor CPUE fits. The poor fits to the catch-at-length data are not a consequence of inaccurate or flat-topped growth curves. They may be better fitted if *M* is modelled as a U-shaped ogive rather than a constant (this is also likely to improve the fits to the catch-at-age series). Inaccurate fishery selectivity ogives may also cause the poor fits. These ogives are based almost exclusively on catch-at-age data, and some of the fisheries are data poor (the eastern and area 404 fisheries have only 3 and 1 years of data, respectively).

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 $a(E-\overline{E})$, 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 20, 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 6–7 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 c.v. 0.08.

Table 20: Fixed biological parameters assumed for the west coast South Island assessment model.

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	0.20 y^{-1}, 0.18 y^{-1}
Maximum exploitation rate (U_{max})		0.5
Ageing error		Normally distributed, with c.v. = 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 1×10^6 iterations, with every 5000th sample taken from the next 5×10^6 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 21).

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 21: Bayesian median and 95% credible intervals of B0, B2004, and B2004 as a percentage of B0 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)

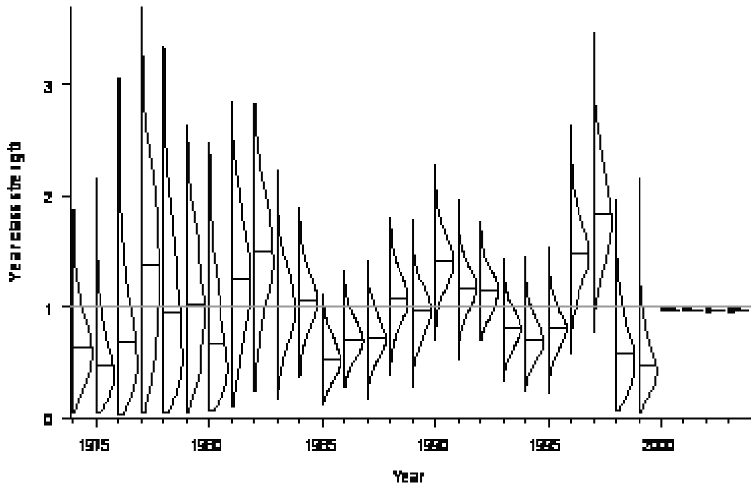


Figure 7: Estimated posterior distributions estimated year class strengths for the initial case. The grey horizontal line indicates the mean year class strength of one. Individual distributions show the marginal posterior distribution, with horizontal lines indicating the median.

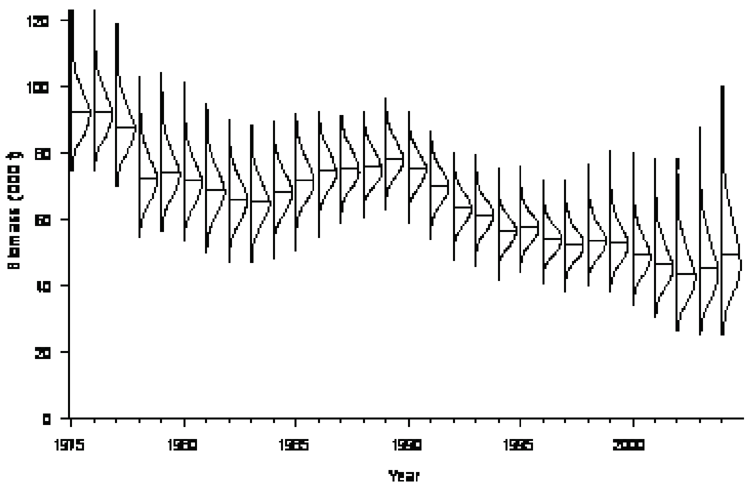


Figure 8: Estimated posterior distributions of the spawning stock biomass trajectories for the initial case. Individual distributions show the marginal posterior distribution, with horizontal lines indicating the median.

6. OTHER FACTORS THAT MAY MODIFY ASSESSMENT RESULTS

The WG considered that there were a number of other factors that should be considered in relation to the stock assessment results presented here:

Chatham Rise

- 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. The 2005–06 catch was lower than in any year since 1988.
- The large October 2004 catch resulted in model estimates of exploitation that were unrealistically high, and raised concerns that the assessment model may not be adequately reflecting the stock status. However, splitting the catch into four fisheries (and the subsequent new selectivity ogives this produced) resulted in an acceptable exploitation level in that year (i.e., ~0.25 y^{-1}).
- Analysing the catch data as four fisheries with independently estimated ogives has resulted in better fits to the catch-at-age data. However, there are still some fitting problems that may be a result of poor sampling of the fishery, particularly the spawning fishery in Area 404.

- 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.
- In trawl surveys from 2004 to 2007, small hake have been relatively abundant suggesting the 2002 (and possibly the 2003) year class may be stronger than average. The projections use estimates of YCS with a mean of one, which may be more pessimistic in the short term.
- Catches from HAK 4 were low in 2004–05 and 2005–06, particularly relative to the assumed catches used to estimate projected biomass and stock risk. Consequently, the projections reported previously are likely to be pessimistic.

Sub-Antarctic

- Estimates of biomass from the summer trawl survey series were relatively constant from 2003 to 2007. However, the most recent 2008 survey biomass estimate was higher than all the others since 2001 (see Table 7). The age composition from the 2008 survey has yet to be calculated, and the Working Group has not yet evaluated the survey results.

West coast, South Island

- 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 fitted in the model that may be the result of poor sampling of the fishery rather than representing real selectivity differences between the sexes.

7. STATUS OF THE STOCKS

Since the 2005 Plenary report was published, an update of only the sub-Antarctic assessment in 2008 has been reported in this document series. Other assessments have been completed, but either were not markedly different to the results already reported, or were not considered sufficiently more reliable to justify their inclusion. In addition, refinements to the hake model structure are still being investigated. The stock assessments reported here for the Chatham Rise and west coast South Island stocks were carried out in 2004. For the purposes of stock assessment modelling, 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). The sub-Antarctic stock was considered to contain hake in the Southland and sub-Antarctic management areas; although fisheries management areas around the North Island are also included in HAK 1, catches of hake in these areas are very small.

Sub-Antarctic stock (HAK 1, excluding the Chatham Rise)
Although estimates of current and reference spawning stock biomass may not be reliable, it is likely that the current TACC is sustainable, as current catches do not appear to be having a marked impact on biomass levels. Absolute biomass is probably large relative to catches, and recent declines in biomass are largely due to recent levels of poor recruitment (see Figure 1).

Chatham Rise stock (HAK 4 and western Chatham Rise HAK 1)
Since the assessment completed in 2004 there have been changes in the pattern of this fishery (see section 6 above) and changes in the model structure (see section 4.2.7). The Working Group did not finalise an updated model for the 2006–07 fishing year that adequately addressed all the issues raised.

The 2004 model results suggested a decline in biomass, with biomass in 2004 at about 35% B_0. [Subsequent assessments, although not reported in the Plenary document, have not been at odds with this result.] Year class strengths from 1995 to 2000 are estimated to be weaker than average. In the projections, the model assumes average year class strength since 2001, although more small hake have been caught in the most recent trawl surveys, suggesting that the 2002 year class may be above average. Projections for the Chatham Rise stock estimated the risk of reducing the stock below 20% B_0 in 2009 to be 88% with catches of 3616 t, and 28% with catches of 1800 t. The higher assumed catch of 3616 t represents the current HAK 4 TACC plus half the HAK 1 TACC, while the lower catch level of 1800 t represents the HAK 4 TACC only (see section 4.1.1).

West coast South Island stock (HAK 7)

An attempt was made in 2004 to determine the stock status of this stock by inclusion of all the available data in a Bayesian assessment model. The assessment suffers from a lack of an independent abundance index for the stock. Hence these results should be treated with caution.

The model was fitted to catch at age data from the commercial fishery with the catch history and biological parameters (including *M*) assumed to be known without error. Selectivity assumptions were varied to determine the sensitivity of the model results to the catch at age data. In the initial case the logistic assumption for the selectivity ogives is considered a conservative assumption. This run suggested current biomass was between 30% and 70% B_0. The other runs gave similar estimates of biomass and stock status. All the model results indicated that current catches appear to be sustainable in the short term.

Table 22: Summary of TACCs (t) and reported landings for the most recent fishing year.

Fishstock[1]	QMA	B_{MAY}	MAY	CAY	2007–08 actual TACC	2007–08 reported landings
HAK 1	Auckland, Central Southeast, Southland, Sub-Antarctic (QMA 1, 2, 3, 5, 6, 8, 9)				3 701	2 445
HAK 4	Chatham Rise (QMA 4)	7 500	2 230	2 330	1 800	865
HAK 7	Challenger (QMA 7)				7 700	2 620
HAK 10					10	–
Total					13 211	5 930

1. Estimates based on stock areas used in the assessment, 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.

8. FOR FURTHER INFORMATION

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