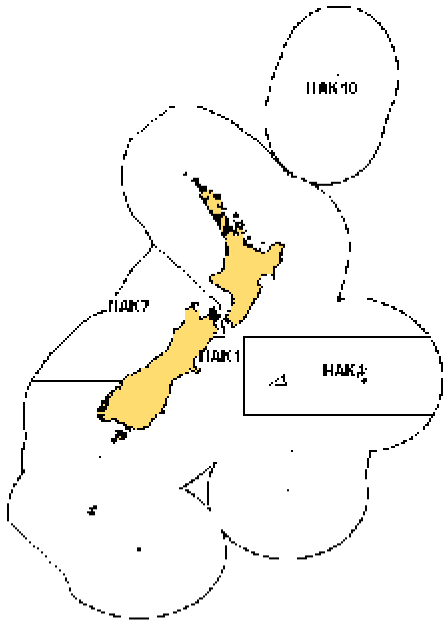
HAKE (HAK)

(Merluccius australis)



1. FISHERY SUMMARY

(a) Commercial fisheries

Hake are widely distributed throughout the middle depths of the New Zealand EEZ, mostly south of latitude 40° S. Adults are mainly distributed from 250–800 m, though some have been found as deep as 1200 m, while juveniles (0+) are found in shallower inshore regions less than 250 m (Hurst et al. 2000). Hake are taken by large trawlers — often as bycatch in fisheries targeting hoki, although target fisheries also 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 1998–99 to a low of 811 t in 2002–03. However, catches increased to 2275 t in 2003–04. In 2003–04, 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 (>3300 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 1987–1988 are shown in Table 1. Reported landings for each Fishstock since 1983–84 and TAC's since 1986–87 are shown in Table 2.

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 2004–05 and actual TAC's (t) for 1986–87 to 2004–05.

Fish stock	**HAK 1**		**HAK 4**		**HAK 7**		**HAK 10**			
QMA(s)	**1, 2, 3, 5, 6, 8 & 9**		**4**		**7**		**10**		**Total**	
	Landings	**TAC**	**Landings**	**TAC**	**Landings**	**TAC**	**Landings**	**TAC**	**Landings**	**TAC**
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 [2]	1 022	2 500	200	1 000	2 909	3 000	0	10	4 131	6 510
1987–88 [2]	1 381	2 500	288	1 000	3 019	3 000	0	10	4 689	6 510
1988–89 [2]	1 487	2 513	554	1 000	6 835	3 004	0	10	8 876	6 527
1989–90 [2]	2 115	2 610	763	1 000	4 903	3 310	0	10	7 781	6 930
1990–91 [2]	2 603	2 610	743	1 000	6 148	3 310	0	10	9 494	6 930
1991–92 [2]	3 156	3 500	2 013	3 500	3 027	6 770	0	10	8 196	13 780
1992–93 [2]	3 525	3 501	2 546	3 500	7 154	6 835	0	10	13 225	13 846
1993–94 [2]	1 803	3 501	2 587	3 500	2 974	6 835	0	10	7 364	13 847
1994–95 [2]	2 572	3 632	3 369	3 500	8 841	6 855	0	10	14 782	13 997
1995–96 [2]	3 956	3 632	3 466	3 500	8 678	6 855	0	10	16 100	13 997
1996–97 [2]	3 534	3 632	3 524	3 500	6 118	6 855	0	10	13 176	13 997
1997–98 [2]	3 810	3 632	3 524	3 500	7 416	6 855	0	10	14 749	13 997
1998–99 [2]	3 845	3 632	3 324	3 500	8 165	6 855	0	10	15 334	13 997
1999–00 [2]	3 899	3 632	2 803	3 500	6 898	6 855	0	10	13 599	13 997
2000–01 [2]	3 628	3 632	2 784	3 500	7 698	6 855	0	10	14 111	13 997
2001–02 [2]	2 870	3 701	1 424	3 500	7 519	6 855	0	10	11 813	14 066
2002–03 [2]	3 336	3 701	811	3 500	7 433	6 855	0	10	11 580	14 066
2003–04 [3]	3 466	3 701	2 275	3 500	7 945	6 855	0	10	13 686	14 066
2004–05 [3]	4 795	3 701	1 264	1 800	7 317	6 855	0	10	13 376	12 366

1. FSU data.
2. QMS data.
3. MHR data

(b) Recreational fisheries

The recreational fishery for hake is negligible.

(c) Maori customary fisheries

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

(d) 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, predominantly in the months of 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 (A. Dunn, NIWA, pers comm.).

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 estimates used in the stock assessment for 1974–75 to 2003–04 are given in Table 3.

Table 3: Revised landings 1974–75 to 2003–04 (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	4 903	1 920	957
1990–91	6 201	2 387	906
1991–92	3 027	2 754	2 415
1992–93	7 154	3 260	2 810
Table 3 *(Continued)*			
1993–94	2 974	1 453	2 935
1994–95	9 543	1 905	3 330
1995–96	9 308	2 896	3 916

1996–97	7 056	2 273	3 667
1997–98	7 924	2 629	4 045
1998–99	9 037	2 797	3 378
1999–00	7 374	3 028	3 184
2000–01	8 738	2 857	2 510
2001–02	7 504	2 516	1 778
2002–03	7 432	2 732	1 416
2003–04	7 940	3 252	2 484
2004–05		2 384	3 311

1. Note: 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.

(e) 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. 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 4 fishery 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). These are similar to the values proposed by Horn (1997), who determined the age of hake by counting zones in sectioned otoliths and concluded that M was likely to be in the range of 0.20–0.25 y^{-1}.

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 assessment are given in Table 4.

Table 4: Estimates of biological parameters.

Parameter					Estimate	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	$a = 3.95 \times 10^{-9}$	$b = 3.130$		(Horn 1998)
		Females	$a = 1.86 \times 10^{-9}$	$b = 3.313$		(Horn 1998)
	Chatham Rise	Males	$a = 2.49 \times 10^{-9}$	$b = 3.234$		(Horn 1998)
		Females	$a = 1.70 \times 10^{-9}$	$b = 3.328$		(Horn 1998)
	West coast South Island	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-Antarctic	Males	$k = 0.263$	$t_0 = -0.06$	$L_\infty = 90.8$	(Horn 1998)
		Females	$k = 0.188$	$t_0 = -0.13$	$L_\infty = 115.0$	(Horn 1998)
	Chatham Rise	Males	$k = 0.277$	$t_0 = -0.11$	$L_\infty = 90.3$	(Horn 1998)
		Females	$k = 0.202$	$t_0 = -0.20$	$L_\infty = 113.4$	(Horn 1998)
	West coast South Island	Males	$k = 0.308$	$t_0 = -0.00$	$L_\infty = 83.5$	(Horn 1998)
		Females	$k = 0.194$	$t_0 = -0.16$	$L_\infty = 111.1$	(Horn 1998)
4. 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 frequency 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. In addition, the recent high catches of hake on the western Chatham Rise have raised concerns that the Chatham Rise stock may consist of two stocks.

Analysis of morphometric data (Horn 1998) 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 most recent stock assessments were completed in 2004 for the Chatham Rise, sub-Antarctic, and west coast South Island stocks. 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.

4.1 HAK 1 & 4 (Sub-Antarctic and Chatham Rise stocks)

The 2004 stock assessment was carried out with data up to the end of the 2003–04 fishing year for the sub-Antarctic and Chatham Rise stocks. The stock assessment of hake on the sub-Antarctic and Chatham Rise was implemented as a Bayesian two stock model using the general-purpose stock assessment program CASAL v2.06 (Bull et al. 2004). The assessment used research time series of abundance indices (trawl surveys of the Chatham Rise and sub-Antarctic), catch-at-length and catch-at-age from the commercial fishery, and estimates of biological parameters.

The new information included in the assessment for the sub-Antarctic stock included data from a trawl survey in November–December 2003 (O'Driscoll & Bagley 2004) and an additional year of observer proportions-at-age data (2003). New information for the Chatham Rise stock included data from the January 2004 trawl survey (Livingston & Stevens 2005) and an additional year of observer proportions-at-age data (2003). In addition, commercial catch-at-age data were included, for the first time, for the years 1992–1997 (Chatham Rise) and 1991, 1993, and 1994 (sub-Antarctic) using resource survey age-length keys. Commercial catch-at-length data were included from 1990 onwards where appropriate resource survey age-length keys were unavailable.

In addition, sensitivity runs employed CPUE indices (N.L. Phillips, NIWA, pers comm.), using the Statistical Area 404 indices as an index of vulnerable abundance for the Chatham Rise stock, and similarly, the sub-Antarctic indices for the sub-Antarctic stock. The WG preferred the CPUE indices from Statistical Area 404 as this area has a target fishery for hake during the spawning season.

(a) Model structure

The stock assessment model partitioned the sub-Antarctic and Chatham Rise stock populations into mature and immature fish, two sexes, and age groups 1–30 with the last age group considered a plus group. Each stock was considered to reside in a single area (sub-Antarctic or Chatham Rise), with no interaction between the stocks. 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 1974–2000 (sub-Antarctic) or 1975–2000 (Chatham Rise).

The model used ten selectivity at age ogives; male and female commercial fishing selectivities on the sub-Antarctic and Chatham Rise, 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 November–December series), 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.

Where model runs included the two 1989 *Amaltal Explorer* surveys, their catchability constants were assumed to differ from that of the *Tangaroa* survey series but were constrained so that the ratio of the *q*s from the Chatham Rise and the November–December sub-Antarctic *Tangaroa* surveys was equal to the ratio of the catchability constants from the Chatham Rise and sub-Antarctic *Amaltal Explorer* surveys. The constraint was imposed in the form of a prior on the ratio and is described below. Selectivities for these surveys, when used, were assumed equal to the selectivity for an appropriate *Tangaroa* series (i.e., the January series for the Chatham Rise or the November–December series for the sub-Antarctic).

Maximum exploitation rates for hake are assumed to be 0.7 for both the sub-Antarctic and Chatham Rise stocks. 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 for the sub-Antarctic and Chatham Rise reported by Dunn (2003) and updated by Phillips (2004). The assumed catch for the 2003–04 fishing year was assumed to be (a) for the Chatham Rise, the sum of the reported landings for HAK 4 in 2003–04, plus HAK 1 landings that were made on the Chatham Rise in 2002–03, and (b) for the sub-Antarctic, the same as that recorded for the sub-Antarctic in 2002–03.

Five-year biomass projections were made assuming future catches in the sub-Antarctic to be either equal to the current HAK 1 TACC of 3632 t ("high catch scenario") or half the current TACC i.e., 1816 t ("low catch scenario"). For the Chatham Rise, future catches were assumed 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, with variability (σ_R) assumed to be equal to σ_R from the estimated year class strengths for each MCMC sample. For the base case sub-Antarctic model, σ_R had mean 0.68 (95% intervals 0.53–0.88), and for the base case Chatham Rise model, σ_R had mean 0.71 (95% intervals 0.57–0.88).

(b) Fixed biological parameters and observations

Estimates and assumed values for biological parameters used in the assessments are given in Table 4 and Table 5 respectively. The stock-recruitment relationship assumed was the Beverton-Holt relationship with steepness 0.9. Variability was assumed in the von-Bertalanffy age-length relationship, assumed to be lognormal with a constant c.v. (coefficient of variation) of 0.1.

The proportion of males at recruitment was assumed to be 0.5 of all recruits. Maturity was estimated for the Chatham Rise and sub-Antarctic 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 sub-Antarctic and 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 6 and Table 7 for the Chatham Rise and sub-Antarctic stocks respectively, and CPUE indices are given in Table 10.

Table 5: Fixed biological parameters assumed for the sub-Antarctic and Chatham Rise stock assessment model.

Parameter		Value
Steepness (Beverton & Holt stock- recruitment relationship)		0.90
Proportion spawning		1.0
Proportion of recruits that are male		0.5
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 c.v. = 0.08

Table 6: Research survey indices (and associated c.v.s) for the Chatham Rise stock.

Year	Vessel	Biomass (t)	c.v.
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

* Not used in the most recent assessment.

Table 7: Research survey indices (and associated c.v.s) for the sub-Antarctic stock.

Fishing Year	Vessel	Nov–Dec series [1]		Apr–May series [2]		Sep series [2]	
		Biomass (t)	c.v.	Biomass (t)	c.v.	Biomass (t)	c.v.
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				

* Not used in the most recent 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 8: Hake CPUE indices (and associated c.v.s) for the Chatham Rise, Statistical Area 404, and the sub-Antarctic (N.L. Phillips, NIWA, pers. comm.).

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

(c) Model estimation

Model parameters were estimated using Bayesian estimation implemented using the CASAL software (Bull et al. 2004). 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 c.v.s set equal to the sampling c.v.

The effective sample sizes (in the case of observations fitted with multinomial likelihoods) or c.v.s (for observations fitted with lognormal likelihoods) are assumed to have allowed for sampling error only. Additional variance, assumed to arise from differences between model simplifications and real world variation, was added to the sampling variance for 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 c.v.s, c_i, followed that for a multinomial distribution with unknown sample size N_j. The estimated sample size was then derived using a robust non-linear least squares fit of $\log(c_i) \sim \log(P_i)$, and (b) by estimating an effective sample size, N', 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. An exception to this was for the CPUE and Cvs runs (described later), where additional process error was included over and above any estimated process error from the initial MPD run (Table 9).

Year class strengths were assumed known (and equal to one) for years prior to 1974 (sub-Antarctic) or 1975 (Chatham Rise) 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).

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

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

(d) Prior distributions and penalty functions

The assumed prior distributions used in the assessment are given in Table 10. 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 c.v. 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*.

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).

As described earlier, the catchability constants for the *Amaltal Explorer* surveys were constrained so that the ratio of the *q*s from the Chatham Rise and the November–December sub-Antarctic *Tangaroa* surveys was equal to the ratio of the catchability constants from the Chatham Rise and sub-Antarctic

Amaltal Explorer surveys. The constraint was imposed in the form of a lognormal prior on the relative ratio, *r*, with mean 1.0 and c.v. 0.05, where the *r* was defined as;

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

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 10: 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
Sub-Antarctic	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

(e) <u>Model estimates</u>

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 the inclusion of the *Amaltal Explorer* data ("AEX"); estimating natural mortality *M* over both stocks simultaneously ("estimate *M*"); adding additional process error to the resource survey series (c.v. 20%, "Cvs"); and excluding the November-December resource survey series from the sub-Antarctic model ("November") (Table 11).

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 11: 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
AEX	Same as the base case model, with the inclusion of *Amaltal Explorer* data
Estimate *M*	Same as the base case, but also estimating natural mortality (*M*)
Cvs	Same as the base case, but with the addition of process error (20%) on survey abundance indices
November	Same as the base case, but excluding the November sub-Antarctic survey series

<u>Sub-Antarctic results</u>

The estimated MCMC marginal posterior distributions for each year for year class strength and biomass for the sub-Antarctic stock are shown in Figures 1 and 2. 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, see Figure 1). 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 moderate or slightly less than average recruitment. Consequently, biomass estimates for the stock have slightly declined, in particular since the early 1990s. Biomass estimates for the stock appear relatively healthy, with estimated current biomass at about 65% of B_0 (95% credible intervals 55–75%) (Figure 2 and Table 12). The CPUE sensitivity run suggested a similar status to that for the base case (Table 12). 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. Nevertheless, the posterior density estimates of selectivities indicated considerable uncertainty in the estimates of selectivity by age and sex. Estimated fishing selectivities were also very uncertain.

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

The most optimistic MPD run ("estimate M") was when natural mortality was estimated within the model — although this resulted in unlikely estimates of natural mortality (i.e., 0.28 y^{-1} and 0.29 y^{-1} for females and males respectively). MPD model estimates that excluded the November–December trawl survey series ("November") suggested lower estimates of B_0, although this model also indicated above average year class strengths in the early 1980s. For this model, estimated (MPD) estimates of biomass in 2004 were about 63% B_0.

Estimates of the status of the sub-Antarctic stock suggest that there has been a small decline in the stock size since the early 1990s, and consequently, projections with either "high" or "low" catches (3612 and 1816 t respectively) had little effect on the projected stock size to 2009 (see Tables 13 and 14). 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 difficult to determine. The working group noted that the relative biomass estimate from the 2004 survey (1694 t) was similar to the estimate for the previous year (1672 t).

Table 12: MPD and Bayesian median (95% credible intervals) (MCMC) of B_0, B_{2004}, and B_{2004} as a percentage of B_0 for the sub-Antarctic base and sensitivity case.

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

Table 13: Bayesian median (95% credible intervals) projected biomass in 2009 (B_{2009}), B_{2009} as a percentage of B_0, and B_{2009}/B_{2004} (%) for the sub-Antarctic base and sensitivity case where future catches are assumed to be 3632 t and 1816 t.

Future catch	Model run	B_{2009}	B_{2009} (%B_0)	B_{2009}/B_{2004} (%)
High (3 632 t)	Base case	42 930 (23 110–77 060)	62.0 (42.1–90.2)	93.6 (72.4–129.8)
	CPUE	43 460 (16 690–143 130)	52.8 (30.0–82.8)	73.7 (51.3–105.2)
Low (1 816 t)	Base case	48 860 (30 130–79 230)	69.9 (53.0–91.7)	106.7 (88.0–136.6)
	CPUE	49 220 (22 240–152 250)	59.4 (39.0–87.6)	82.7 (64.2–119.9)

Table 14: Estimates of stock risk for the sub-Antarctic for 2005–2009, i.e., the probability that the stock will fall below 20% B_0, for the base and sensitivity case where future catches are assumed to be 3632 t and 1816 t.

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

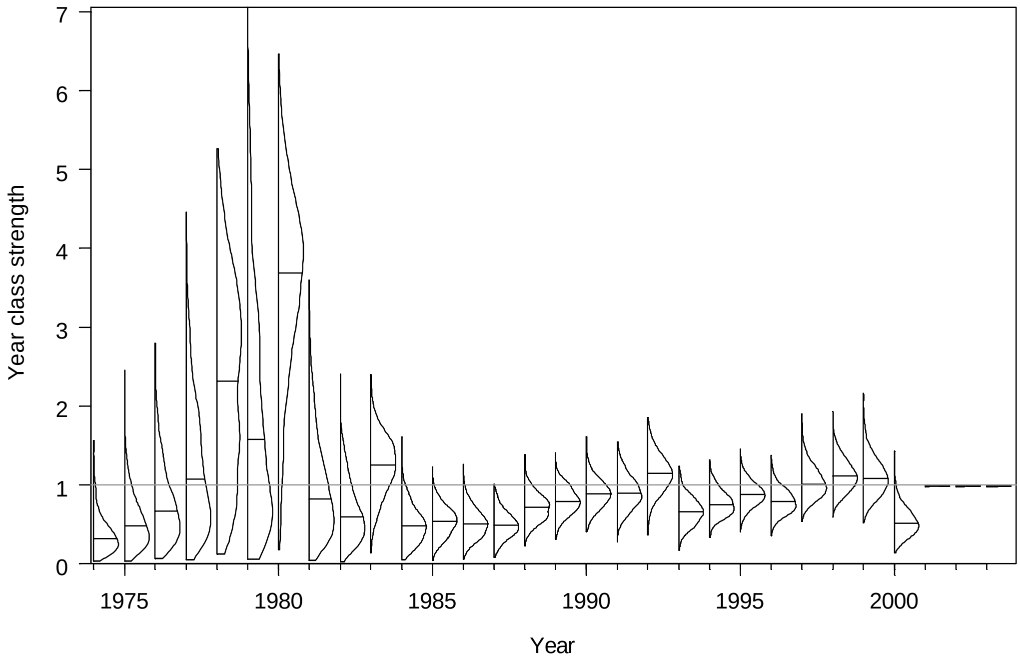


Figure 1: Estimated posterior distributions of year class strengths for the base case for the sub-Antarctic stock. The grey horizontal line indicates the year class strength of one. Individual distributions show the marginal posterior distribution, with horizontal lines indicating the median.

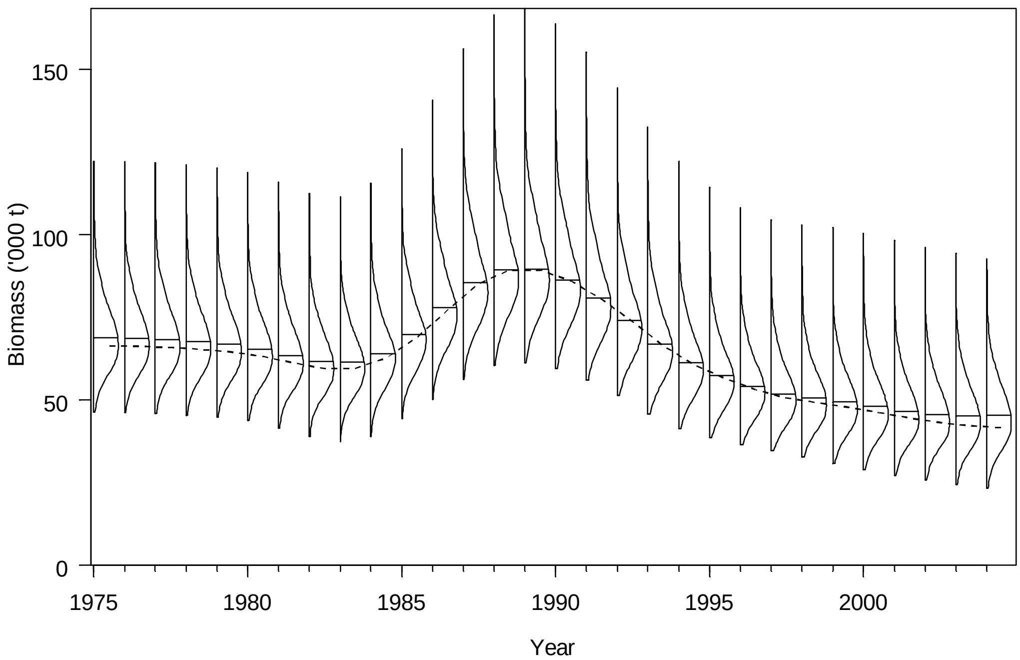


Figure 2: Estimated posterior distributions of spawning stock biomass trajectories for the base case for the sub-Antarctic stock. Individual distributions show the marginal posterior distribution, with horizontal line indicating the median, and the dashed line indicating the MPD trajectory.

<u>Chatham Rise results</u>

The estimated MCMC marginal posterior distributions for selected parameters for the Chatham Rise stock are shown in Figure 3 and Figure 4. 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 4 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.

As with the sub-Antarctic trawl survey selectivity estimates, selectivities for males and females diverged, with the selectivities for males higher than females in the trawl surveys at older ages (15+) in the January survey series. Survey selectivities on the sub-Antarctic and Chatham Rise both showed a very similar pattern, although 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 15). 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 16. 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: MPD and Bayesian median and 95% credible intervals (MCMC) 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)
	MCMC	MCMC	MCMC
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

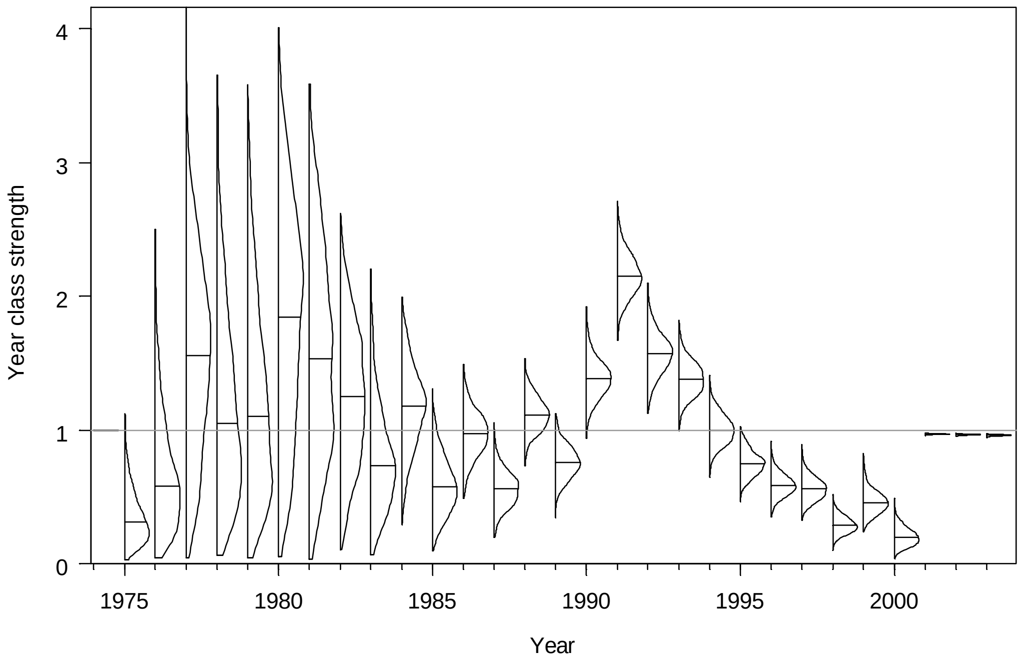


Figure 3: Estimated posterior distributions of year class strengths for the base case for the Chatham Rise stock. The grey horizontal line indicates the year class strength of one. Individual distributions show the marginal posterior distribution, with horizontal lines indicating the median.

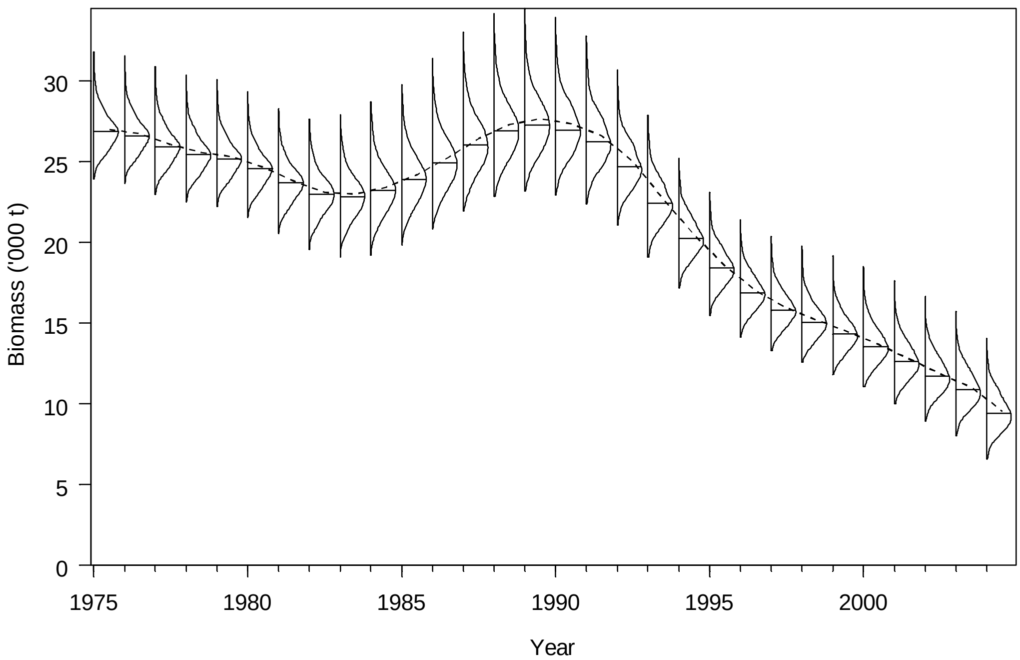


Figure 4: Estimated posterior distributions of spawning stock biomass for the base case for the Chatham Rise stock. Individual distributions show the marginal posterior distribution, with horizontal line indicating the median, and the dashed line indicating the MPD trajectory.

(f) Estimates of sustainable yields

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

For the sub-Antarctic, the base case model estimates of MAY and CAY were 6300 t and 13800 t respectively (B_{MAY} = 19 810 t). For the Chatham Rise, base case model estimates of MAY and CAY were 2230 t and 2330 t respectively (B_{MAY} = 7500 t).

4.2 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. 2004).

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 of Cordue (1995) with a single stock model as detailed in Cordue (1998). That model estimated that the virgin (equilibrium) spawning stock biomass was about 85 000 t (with 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.

(a) 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. 2004), 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 18). 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 18: 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

(b) Fixed biological parameters and observations

Estimates and assumed values for biological parameters used in the assessments are given in Table 4 and Table 19 respectively. The stock-recruitment relationship assumed was the Beverton-Holt relationship with steepness 0.9. Variability was assumed in the von-Bertalanffy age-length relationship, assumed to be lognormal with a constant c.v. (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 the tree-based regression methods described in Francis (2002), with three strata defined as (i) depth ≥ 620.5 m, (ii) depth < 620.5 m and latitude ≥ 42º 33' S, and (iii) depth < 620.5 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 19: 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

(c) Model estimation

Model parameters were estimated using Bayesian estimation implemented using CASAL (Bull et al. 2004). However, only the mode of the joint posterior distribution (MPD) was estimated in preliminary runs. For final runs, the full posterior distribution was sampled using Monte Carlo Markov Chain (MCMC) methods, based on the Metropolis-Hastings algorithm.

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. Hence, estimates of the effective sample size applied in the model were made via a two-step process; (a) first, the sample sizes for the proportions-at-age data were derived by assuming the relationship between the observed proportions, E_i, and estimated c.v.s, c_i, followed that for a multinomial distribution with unknown sample size N_j. The estimated sample size was then derived using a robust non-linear least squares fit of $\log(c_i) \sim \log(P_i)$, and (b) by estimating an effective sample size, N', 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 (Table 20).

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.

Table 20: Number of tows, number of fish measured, and number of fish aged from observer sampled tows on the west coast South Island hake fishery, and the estimated sample size (N). The effective sample size used for the multinomial likelihood (Effective N) in the initial case with a process error of N_{PE}=254 is shown in the last column.

Year	Tows	No. fish measured		No. fish aged		Sample size	
		Male	Female	Male	Female	*N*	Effective *N*
1990	57	578	567	210	261	351	147
1991	146	2 288	1 653	286	358	540	173
1992	121	2 592	1 193	196	261	441	161
1993	93	2 129	979	188	163	303	138
1994	174	1 598	1 643	151	272	227	120
1995	152	2 528	2 769	271	342	386	153
1996	193	2 862	1 753	287	326	440	161
1997	234	3 286	1 720	262	198	414	157
1998	237	2 339	1 497	257	253	400	155
1999	307	4 186	3 744	269	240	728	188
2000	285	2 705	2 330	258	269	454	163
2001	192	1 529	1 723	176	280	412	157
2002	380	2 281	2 434	93	385	347	147
2003	296	1 917	2 063	227	234	674	184

(d) 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 c.v. 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.

(e) 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 5 and Figure 6. Year class strength estimates (Figure 5) 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 6). 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 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)

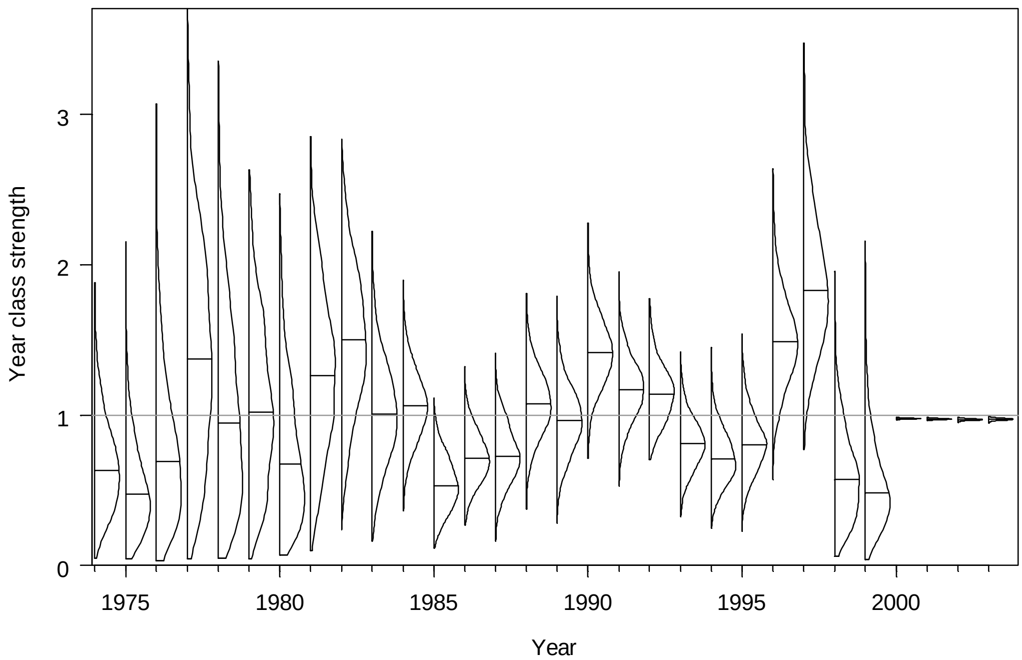


Figure 5: Estimated posterior distributions estimated year class strengths for the initial case. The grey horizontal line indicates the mean year class strength of one. Individual distributions show the marginal posterior distribution, with horizontal lines indicating the median.

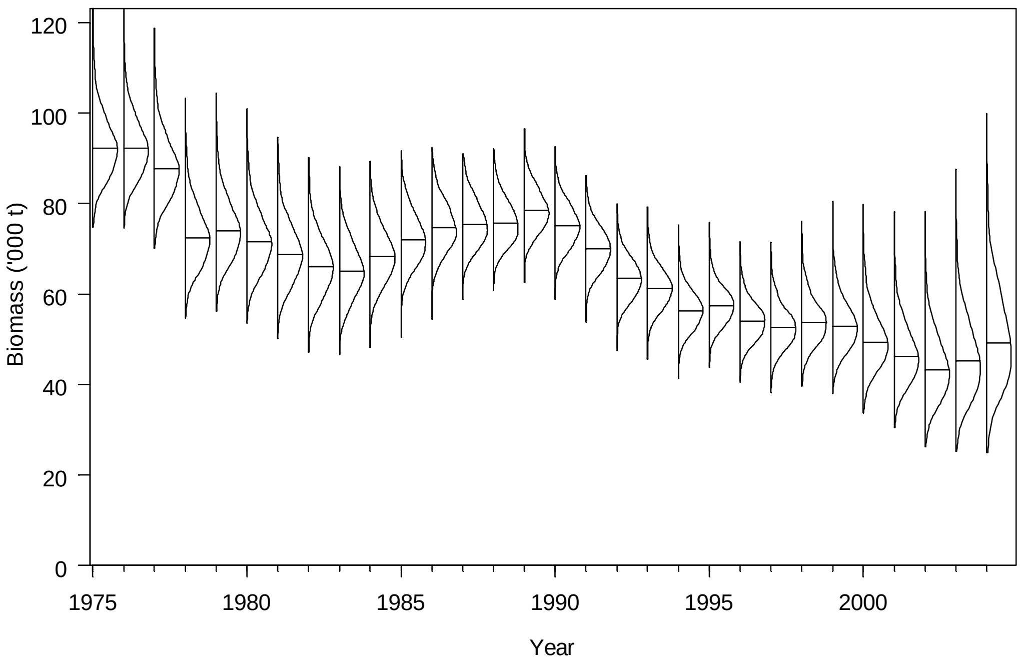


Figure 6: Estimated posterior distributions of the spawning stock biomass trajectories for the initial case. Individual distributions show the marginal posterior distribution, with horizontal lines indicating the median.

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 2004–05, large catches were taken in the HAK 1 area of the Mernoo Bank at the start of the fishing year. This has not been included in the model and represented a large change in the fishery in the last year from the historical pattern.
- The large catches have raised concerns that the assessment model may not be adequately reflecting the stock status. In particular,
    - The model estimates of the exploitation rate (i.e., catch divided by vulnerable biomass), for 2005 were estimated to be unrealistically high.
    - If the aggregation found on the western Chatham Rise was a spawning aggregation, this might indicate that there was more than one stock on the Chatham Rise. Hence, the model estimates resulting from an assumption of a single homogeneous stock on the Chatham Rise would be incorrect.
- In the most recent trawl surveys (2004 and 2005), more small hake have been taken in the survey suggesting the 2002 year class may be stronger than average. This year class was also found to be strong in the 2006 survey. The projections use estimates of YCS with a mean of one, which may be more pessimistic in the short term.
- 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.
- Following the decline in catches from HAK 4 in the previous 2 years catches increased to 2275 t in 2003-04, although these dropped to 1264 t in 2004–05.

Sub-Antarctic

- The lack of contrast in abundance indices collected since 1991 suggests that while the status of the sub-Antarctic stock is probably similar to that in the early 1990s, the absolute level of current biomass may difficult to determine. Model structural improvements since the previous assessment have resulted in lower estimates of current biomass that reflect the recent small decline in the survey abundance estimates, but are still at relatively high levels.
- 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.

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, no new stock assessments for hake have been completed. The stock assessments reported here for the Chatham Rise, sub-Antarctic, 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.

(a) Sub-Antarctic stock (HAK 1, excluding the Chatham Rise)

Model estimates of the state of the sub-Antarctic stock suggest that there has been only small reduction in the available biomass since the mid-199s. 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 measurable impact on biomass levels.

(b) Chatham Rise stock (HAK 4 and western Chatham Rise HAK 1)

Since the assessment was completed in 2004 there have been changes in the pattern of this fishery which are discussed in “Other factors” (section 6 above). The Working Group was not able to finalise an updated model for the 2005 fishing year that adequately addressed those issues.

The 2004 model results suggested a decline in biomass, with biomass in 2004 at about 35% B_0. 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 a).

(c) 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 (see section 6 above).

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.

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

Fishstock[1]	QMA	B_{MAY}	MAY	CAY	2004-05 actual TACC	2004-05 reported landings
HAK 1	Auckland, Central Southeast, Southland, Sub-Antarctic (QMA 1, 2, 3, 5, 6, 8, 9)	19 810	6 300	13 800	3 701	4 795
HAK 4	Chatham Rise (QMA 4)	7 500	2 230	2 330	1 800	1 264
HAK 7	Challenger (QMA 7)				6 855[2]	7 317
HAK 10					10	-
Total					12 366	13 376

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.
2. The TACC for HAK 7 was increased to 7 700 t for the 2005-06 fishing year.

8. FOR FURTHER INFORMATION

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