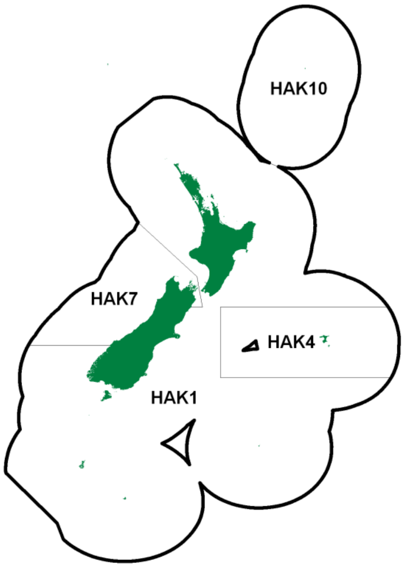
HAKE (HAK)

(Merluccius australis)
Tiikati



1. FISHERY SUMMARY

1.1 Commercial fisheries

Hake was introduced into the Quota Management System on 1 October 1986. Hake are widely distributed throughout the middle depths of the New Zealand EEZ, mostly south of 40° S. Adults are mainly distributed from 250–800 m, but some have been found as deep as 1200 m, while juveniles (0+) are found in inshore regions shallower than 250 m. Hake are taken mainly by large trawlers, often as bycatch in hoki target fisheries, although hake target fisheries do exist.

The largest fishery has been off the west coast of the South Island (HAK 7) with the highest catch (17 000 t) recorded in 1977, immediately before the establishment of the EEZ. The TACC for HAK 7 is the largest, at 7 700 t out of a total for the EEZ of 13 211 t. The WCSI hake fishery has generally consisted of bycatch in the much larger hoki fishery, but it has undergone a number of changes over time (Devine 2009). These include changes to the TACCs of both hake and hoki, and also changes in fishing practices such as gear used, tow duration, and strategies to limit hake bycatch. In some years there has been a hake target fishery in September after the peak of the hoki fishery is over; more than 2 000 t of hake were taken in this target fishery during September 1993 (Ballara 2015). High bycatch levels of hake early in the fishing season have also occurred in some years (Ballara 2012). From 1 October 2005 the TACC for HAK 7 was increased to 7 700 t within an overall TAC of 7 777 t. This new catch limit was set equal to average annual catches over the previous 12 years. However, HAK 7 landings have been relatively low since 2007–08.

On the Chatham Rise and in the Sub-Antarctic, hake have been caught mainly as bycatch by trawlers targeting hoki (Devine 2009). However, significant targeting for hake has occurred in both areas, particularly in Statistical Area 404 (HAK 4), and around the Norwegian Hole between the Snares and Auckland Islands in the Sub-Antarctic. Increases in TACCs from 2610 t to 3632 t in HAK 1 and from 1000 t to 3500 t in HAK 4 from the 1991–92 fishing year allowed the fleet to increase their reported landings of hake from these fish stocks. Reported catches rose over a number of years to the levels of the new TACCs in both HAK 1 and HAK 4. In HAK 1, annual catches remained relatively steady (generally between 3 000 and 4 000 t) up to 2004–05, but have since been generally less than 3 000 t. Landings from HAK 4 declined erratically from over 3000 t in 1998–99 to a low of 161 t in 2011–12. From 2004–05, the TACC for HAK 4 was reduced from 3 500 t to 1 800 t. Annual landings have been markedly lower than the new TACC since then.

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, about 2 000 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 (more than 3700 t) associated with the Chatham Rise. Fishing on aggregated schools in the same area also occurred during October–November 2008 and 2010 (Ballara 2015).

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

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

	New Zealand			Foreign licensed				
Fishing year	**Domestic**	**Chartered**	**Total**	**Japan**	**Korea**	**USSR**	**Total**	**Total**
1975 [1]	0	0	0	382	0	0	382	382
1976 [1]	0	0	0	5 474	0	300	5 774	5 774
1977 [1]	0	0	0	12 482	5 784	1 200	19 466	19 466
1978–79 [2]	0	3	3	398	308	585	1 291	1 294
1979–80 [2]	0	5 283	5 283	293	0	134	427	5 710
1980–81 [2]				No data available				
1981–82 [2]	0	3 513	3 513	268	9	44	321	3 834
1982–83 [2]	38	2 107	2 145	203	53	0	255	2 400
1983 [3]	2	1 006	1 008	382	67	2	451	1 459
1983–84 [4]	196	1 212	1 408	522	76	5	603	2 011
1984–85 [4]	265	1 318	1 583	400	35	16	451	2 034
1985–86 [4]	241	2 104	2 345	465	52	13	530	2 875
1986–87 [4]	229	3 666	3 895	234	1	1	236	4 131
1987–88 [4]	122	4 334	4 456	231	1	1	233	4 689

1. Calendar year.
2. April 1 to March 31.
3. April 1 to September 30.
4. October 1 to September 30.

Table 2: Reported landings (t) of hake by Fishstock from 1983–84 to 2013–14 and actual TACs (t) for 1986–87 to 2013–14. FSU data from 1984–1986; QMS data from 1986 to the present.

Fish stock	**HAK 1**		**HAK 4**		**HAK 7**		**HAK 10**			
FMA(s)	**1, 2, 3, 5, 6, 8 & 9**		**4**		**7**		**10**		**Total**	
	Landings	**TACC**	**Landings**	**TACC**	**Landings**	**TACC**	**Landings**	**TACC**	**Landings**	**TACC**
1983–84 [1]	886	–	180	–	945	–	0	–	2 011	–
1984–85 [1]	670	–	399	–	965	–	0	–	2 034	–
1985–86 [1]	1 047	–	133	–	1 695	–	0	–	2 875	–
1986–87	1 022	2 500	200	1 000	2 909	3 000	0	10	4 131	6 510
1987–88	1 381	2 500	288	1 000	3 019	3 000	0	10	4 689	6 510
1988–89	1 487	2 513	554	1 000	6 835	3 004	0	10	8 876	6 527
1989–90	2 115	2 610	763	1 000	4 903	3 310	0	10	7 781	6 930
1990–91	2 603	2 610	743	1 000	6 148	3 310	0	10	9 494	6 930
1991–92	3 156	3 500	2 013	3 500	3 027	6 770	0	10	8 196	13 780
1992–93	3 525	3 501	2 546	3 500	7 154	6 835	0	10	13 225	13 846
1993–94	1 803	3 501	2 587	3 500	2 974	6 835	0	10	7 364	13 847
1994–95	2 572	3 632	3 369	3 500	8 841	6 855	0	10	14 782	13 997
1995–96	3 956	3 632	3 466	3 500	8 678	6 855	0	10	16 100	13 997
1996–97	3 534	3 632	3 524	3 500	6 118	6 855	0	10	13 176	13 997
1997–98	3 810	3 632	3 524	3 500	7 416	6 855	0	10	14 749	13 997
1998–99	3 845	3 632	3 324	3 500	8 165	6 855	0	10	15 334	13 997
1999–00	3 899	3 632	2 803	3 500	6 898	6 855	0	10	13 599	13 997
2000–01	3 628	3 632	2 784	3 500	7 698	6 855	0	10	14 111	13 997
2001–02	2 870	3 701	1 424	3 500	7 519	6 855	0	10	11 813	14 066
2002–03	3 336	3 701	811	3 500	7 433	6 855	0	10	11 580	14 066
2003–04	3 466	3 701	2 275	3 500	7 945	6 855	0	10	13 686	14 066
2004–05	4 795	3 701	1 264	1 800	7 317	6 855	0	10	13 377	12 366
2005–06	2 742	3 701	305	1 800	6 905	7 700	0	10	9 952	13 211
2006–07	2 025	3 701	899	1 800	7 668	7 700	0	10	10 592	13 211
2007–08	2 445	3 701	865	1 800	2 620	7 700	0	10	5 930	13 211
2008–09	3 415	3 701	856	1 800	5 954	7 700	0	10	10 226	13 211
2009–10	2 156	3 701	208	1 800	2 352	7 700	0	10	4 716	13 211
2010–11	1 904	3 701	179	1 800	3 754	7 700	0	10	5 837	13 211
2011–12	1 948	3 701	161	1 800	4 459	7 700	0	10	6 568	13 211
2012–13	2 079	3 701	177	1 800	5 434	7 700	0	10	7 690	13 211
2013–14	1 883	3 701	168	1 800	3 642	7 700	0	10	5 693	13 211

[1] FSU data

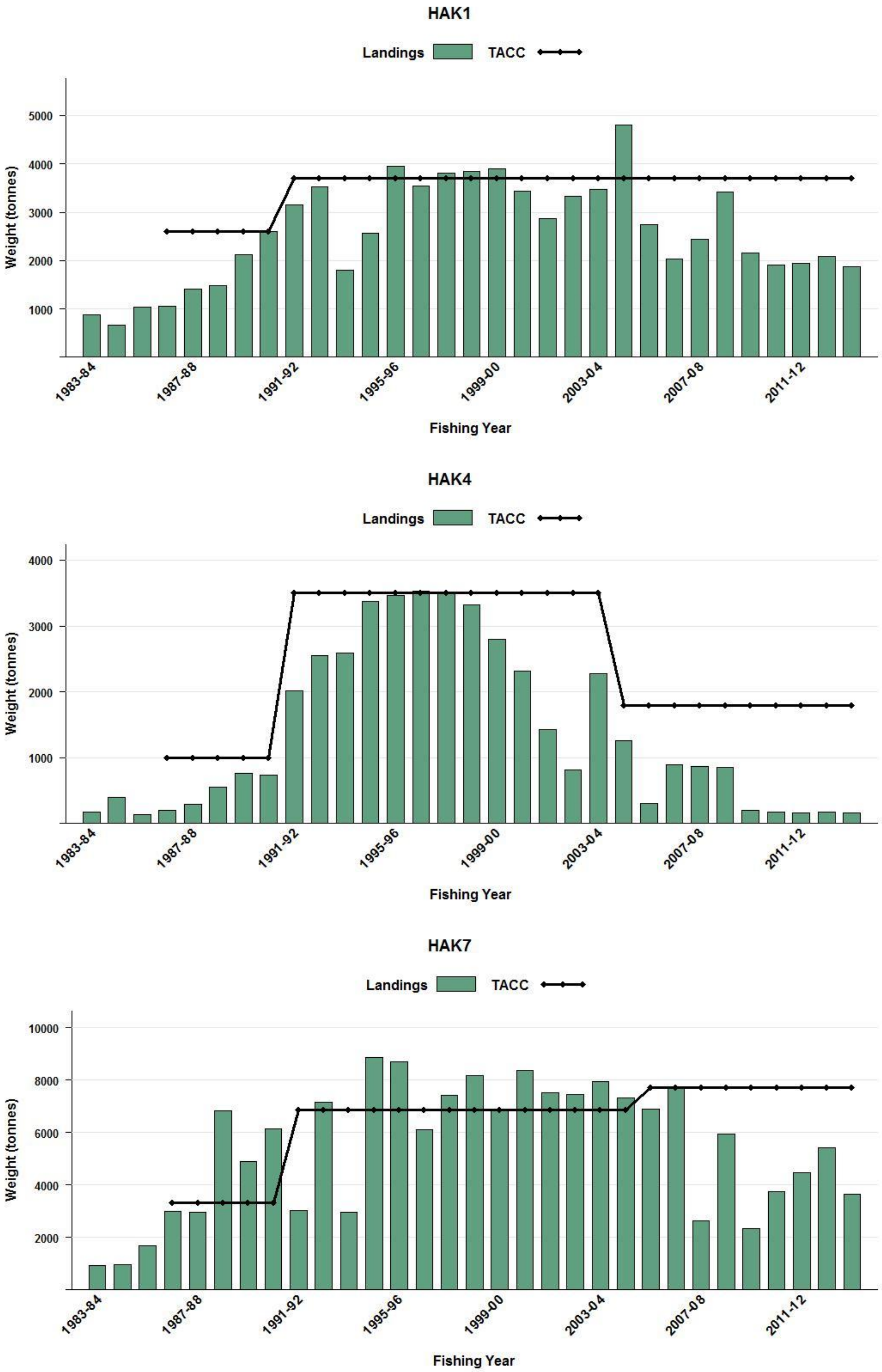


Figure 1: Reported commercial landings and TACC for the three main HAK stocks. From top left: HAK 1 (Sub-Antarctic and part of Chatham Rise), HAK 4 (eastern Chatham Rise), and HAK 7 (Challenger).

1.2 Recreational fisheries
The recreational fishery for hake is negligible.

1.3 Customary non-commercial fisheries
The amount of hake caught by Maori is not known but is believed to be negligible.

1.4 Illegal catch
In late 2001, a small number of fishers admitted misreporting of hake catches between areas, pleading guilty to charges of making false or misleading entries in their catch returns. As a result, the reported catches of hake in each area were reviewed in 2002 and suspect records identified. Dunn (2003) provided revised estimates of the total landings by stocks, estimating that the level of hake over-reporting on the Chatham Rise (and hence under-reporting on the west coast South Island) was between 16 and 23% (700–1000 t annually) of landings between 1994–95 and 2000–01, mainly in June, July, and September. Probable levels of area misreporting prior to 1994–95 and between the west coast South Island and Sub-Antarctic were estimated as small (Dunn 2003). There is no evidence of similar area misreporting since 2001–02 (Devine 2009, Ballara 2015).

In earlier years, before the introduction of higher TACCs in 1991–92, there is some evidence to suggest that catches of hake were not always fully reported. Comparison of catches from vessels carrying observers with those not carrying observers, particularly in HAK 7 from 1988–89 to 1990–91, suggested that actual catches were probably considerably higher than reported catches. For these years, the ratio of hake to hoki in the catch of vessels carrying observers was significantly higher than in the catch of vessels not carrying observers (Colman & Vignaux 1992). The actual hake catch in HAK 7 for these years was estimated by multiplying the total hoki catch (which was assumed to be correctly reported by vessels both with and without observers) by the ratio of hake to hoki in the catch of vessels carrying observers. Reported and estimated catches for 1988–89 were respectively 6 835 t and 8 696 t; for 1989–90, 4 903 t reported and 8 741 t estimated; and for 1990–91, 6 189 t reported and 8 246 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 for 1974–75 to 2012–13 are given in Table 3.

Table 3: Revised landings from fishing years 1974–75 to 2012–13 (t) for the west coast South Island, Sub-Antarctic, and Chatham Rise stocks. [Continued on next page].

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]	8 741	1 927	950
1990–91[1]	8 246	2 370	931
1991–92	3 010	2 750	2 418
1992–93	7 059	3 269	2 798
1993–94	2 971	1 453	2 934
1994–95	9 535	1 852	3 271
1995–96	9 082	2 873	3 959
1996–97	6 838	2 262	3 890

Table 3 [Continued].

Fishing year	West coast S.I.	Sub-Antarctic	Chatham Rise
1997–98	7 674	2 606	4 074
1998–99	8 742	2 796	3 589
1999–00	7 031	3 020	3 174
2000–01	8 346	2 790	2 962
2001–02	7 498	2 510	1 770
2002–03	7 404	2 738	1 401
2003–04	7 939	3 245	2 465
2004–05	7 298	2 531	3 518
2005–06	6 892	2 557	489
2006–07	7 660	1 818	1 081
2007–08	2 583	2 202	1 096
2008–09	5 912	2 427	1 825
2009–10	2 282	1 958	391
2010–11	3 462	1 288	951
2011–12	4 299	1 892	194
2012–13	5 171	1 863	344

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

1.5 Other sources of mortality

There is likely to be some mortality associated with escapement from trawl nets, but the level is not known and is assumed to be negligible.

2. BIOLOGY

The New Zealand hake reach a maximum age of at least 25 years. Males, which rarely exceed 100 cm total length (TL), do not grow as large as females, which can grow to 120 cm TL or more. Horn (1997) validated the use of otoliths to age hake, and produced von Bertalanffy growth parameters. Growth parameters were updated by Horn (2008) using both the von Bertalanffy and Schnute growth models. The Schnute model was found to better fit the data. Chatham Rise hake reach 50% maturity at about 5.5 years for males and 7 years for females, Sub-Antarctic hake at about 6 years for males and 6.5 years for females, and WCSI hake at about 4.5 years for males and 5 years for females (Horn & Francis 2010, Horn 2013a.).

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 from the maximum age (i.e., 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). Recent assessment models for all hake stocks have either assumed a constant *M* of 0.19 yr^{-1} for both sexes, or have estimated age-dependent ogives for *M* (because true *M* is likely to vary with age).

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).

An aggregation of medium size hake fished on the western Chatham Rise in October 2004 may have comprised either spawning or pre-spawning fish. Fishing on aggregated schools in the same area also occurred during October–November 2008 and 2010. Also, the trawl survey took high catches of young, mature fish in this area in January 2009. It is possible that young, mature hake spawn on the western Chatham Rise and slowly move east, towards the main spawning area, as they age.

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).

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

The biological parameters relevant to the stock assessments are given in Table 4.

Table 4: Estimates of biological parameters.

Parameter		Estimate				Source
1. Natural mortality						
	Males	$M = 0.20$				(Dunn et al 2000)
	Females	$M = 0.18$				(Dunn et al 2000)
	Both sexes	$M = 0.19$				(Horn & Francis 2010)
2. Weight = a·(length)^b (Weight in t, length in cm)						
Sub-Antarctic	Males	$a = 2.13 \times 10^{-9}$	$b = 3.281$			(Horn 2013a)
	Females	$a = 1.83 \times 10^{-9}$	$b = 3.314$			(Horn 2013a)
	Both sexes	$a = 1.95 \times 10^{-9}$	$b = 3.301$			(Horn 2013a)
Chatham Rise	Males	$a = 2.56 \times 10^{-9}$	$b = 3.228$			(Horn 2013a)
	Females	$a = 1.88 \times 10^{-9}$	$b = 3.305$			(Horn 2013a)
	Both sexes	$a = 2.00 \times 10^{-9}$	$b = 3.288$			(Horn 2013a)
WCSI	Males	$a = 2.85 \times 10^{-9}$	$b = 3.209$			(Horn 2013a)
	Females	$a = 1.94 \times 10^{-9}$	$b = 3.307$			(Horn 2013a)
	Both sexes	$a = 2.01 \times 10^{-9}$	$b = 3.294$			(Horn 2013a)
3. von Bertalanffy growth parameters						
Sub-Antarctic	Males	$k = 0.295$	$t_0 = 0.06$	$L_\infty = 88.8$		(Horn 2008)
	Females	$k = 0.220$	$t_0 = 0.01$	$L_\infty = 107.3$		(Horn 2008)
Chatham Rise	Males	$k = 0.330$	$t_0 = 0.09$	$L_\infty = 85.3$		(Horn 2008)
	Females	$k = 0.229$	$t_0 = 0.01$	$L_\infty = 106.5$		(Horn 2008)
WCSI	Males	$k = 0.357$	$t_0 = 0.11$	$L_\infty = 82.3$		(Horn 2008)
	Females	$k = 0.280$	$t_0 = 0.08$	$L_\infty = 99.6$		(Horn 2008)
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 2008)
	Females	$y_1 = 22.9$	$y_2 = 109.9$	$a = 0.147$	$b = 1.457$	(Horn 2008)
	Both sexes	$y_1 = 22.8$	$y_2 = 101.8$	$a = 0.179$	$b = 1.350$	(Horn 2013a)
Chatham Rise	Males	$y_1 = 24.6$	$y_2 = 90.1$	$a = 0.184$	$b = 1.742$	(Horn 2008)
	Females	$y_1 = 24.4$	$y_2 = 114.5$	$a = 0.098$	$b = 1.764$	(Horn 2008)
	Both sexes	$y_1 = 24.5$	$y_2 = 104.8$	$a = 0.131$	$b = 1.700$	(Horn & Francis 2010)
WCSI	Males	$y_1 = 23.7$	$y_2 = 83.9$	$a = 0.278$	$b = 1.380$	(Horn 2008)
	Females	$y_1 = 24.5$	$y_2 = 103.6$	$a = 0.182$	$b = 1.510$	(Horn 2008)
	Both sexes	$y_1 = 24.5$	$y_2 = 98.5$	$a = 0.214$	$b = 1.570$	(Horn 2011)

5. Maturity ogives (proportion mature at age)

	Age	2	3	4	5	6	7	8	9	10	11	12	13
SubAnt	Males	0.01	0.04	0.11	0.30	0.59	0.83	0.94	0.98	0.99	1.00	1.00	1.00
	Females	0.01	0.03	0.08	0.19	0.38	0.62	0.81	0.92	0.97	0.99	1.00	1.00
	Both	0.01	0.03	0.09	0.24	0.49	0.73	0.88	0.95	0.98	0.99	1.00	1.00
Chatham	Males	0.02	0.07	0.20	0.44	0.72	0.89	0.96	0.99	1.00	1.00	1.00	1.00
	Females	0.01	0.02	0.06	0.14	0.28	0.50	0.72	0.86	0.94	0.98	0.99	1.00
	Both	0.02	0.05	0.13	0.29	0.50	0.70	0.84	0.93	0.97	0.99	0.99	1.00
WCSI	Males	0.01	0.05	0.27	0.73	0.95	0.99	1.00	1.00	1.00	1.00	1.00	1.00
	Females	0.02	0.07	0.25	0.57	0.84	0.96	0.99	1.00	1.00	1.00	1.00	1.00
	Both	0.01	0.06	0.26	0.65	0.90	0.97	0.99	1.00	1.00	1.00	1.00	1.00

3. STOCKS AND AREAS

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

Analysis of morphometric data (Colman unpublished data) shows little difference between hake from the Chatham Rise and hake from the east coast of the North Island, but shows highly significant differences between these fish and those from the Sub-Antarctic, Puysegur, and on the west coast. No studies have been done on morphometric differences of hake across the Chatham Rise. The Puysegur fish are most similar to those from the west coast South Island, although, depending on which variables are used, they cannot always be distinguished from the Sub-Antarctic hake. Hence, the stock affinity of hake from this area is uncertain.

Present management divides the fishery into three Fishstocks: (a) the Challenger FMA (HAK 7), (b) the Chatham Rise FMA (HAK 4) and (c), the remainder of the EEZ comprising the Auckland, Central, Southeast (Coast), Southland and Sub-Antarctic FMAs (HAK 1). An administrative fish stock (with no recorded landings) exists for the Kermadec FMA (HAK 10).

4. STOCK ASSESSMENT

The stock assessments reported here were completed in 2014 for the Sub-Antarctic stock (Horn 2015), 2012 for the Chatham Rise stock (Horn 2013b), and 2012 for the west coast South Island stock (Horn 2013b). 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 2014 stock assessment was carried out with data up to the end of the 2012–13 fishing year, implemented as a Bayesian model using the general-purpose stock assessment program CASAL v2.30 (Bull et al 2012). The assessment used research time series of abundance indices (trawl surveys of the Sub-Antarctic from 1991 to 2012), catch-at-age from the trawl surveys and the commercial fishery since 1990–91, and estimates of biological parameters. A trawl fishery CPUE series was used in a sensitivity run.

4.1.1 Model structure

The base case model partitioned the Sub-Antarctic stock population into age groups 1–30 with the last age group considered a plus group. It had sex in the partition, but with unsexed observations, unsexed selectivity, and estimation of age-dependent *M*. 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 1974–2013. There were three double-normal selectivity-at-age ogives; commercial fishing selectivity, and 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). Selectivities were assumed constant over all years in the fishery and the surveys, and hence there was no allowance for possible annual changes in selectivity.

Sensitivity models were also run to investigate the effects of down-weighting the catch-at-age data, fixing *M*, estimating *M* as a constant rather than an age-dependent ogive, and including a trawl fishery CPUE series.

Five-year biomass projections were made assuming future catches in the Sub-Antarctic to be 2 000 t annually (the mean annual catch from 2008 to 2013). For each projection scenario, estimated future recruitment variability was sampled from actual estimates between 1997 and 2009.

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.

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

Parameter		Value
Steepness (Beverton & Holt stock- recruitment relationship)		0.80
Proportion spawning		1.0
Proportion of recruits that are male		0.5
Natural mortality (*M*)	Male, Female, Both	0.20 y^{-1}, 0.18 y^{-1}, 0.19 y^{-1}
Maximum exploitation rate (U_{max})		0.7
Ageing error		Normally distributed, with CV = 0.08

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.

Research survey abundance indices are given in Table 6. The catch history assumed in all model runs (Table 7) includes the revised estimates of catch reported by Dunn (2003).

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

Fishing	Vessel	Nov–Dec series [1]		Apr–May series [2]		Sep series [2]	
Year		Biomass (t)	CV	Biomass (t)	CV	Biomass (t)	CV
1989*	*Amaltal Explorer*	2 660	0.21				
1992	*Tangaroa*	5 686	0.43	5 028	0.15	3 760	0.15
1993	*Tangaroa*	1 944	0.12	3 221	0.14		
1994	*Tangaroa*	2 567	0.12				
1996	*Tangaroa*			2 026	0.12		
1998	*Tangaroa*			2 554	0.18		
2001	*Tangaroa*	2 657	0.16				
2002	*Tangaroa*	2 170	0.20				
2003	*Tangaroa*	1 777	0.16				
2004	*Tangaroa*	1 672	0.23				
2005	*Tangaroa*	1 694	0.21				
2006	*Tangaroa*	1 459	0.17				
2007	*Tangaroa*	1 530	0.17				
2008	*Tangaroa*	2 470	0.15				
2009	*Tangaroa*	2 162	0.17				
2010	*Tangaroa*	1 442	0.20				
2012	*Tangaroa*	2 004	0.23				
2013	*Tangaroa*	1 943	0.25				
2015*	*Tangaroa*	1 477	0.25				

* 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.

4.1.3 Model estimation

Model parameters were estimated using Bayesian estimation implemented using the CASAL software (Bull et al 2012). 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 error structure, where estimates of the proportions-at-age and associated CVs by age were estimated using the NIWA catch-at-age software by bootstrap. Biomass indices were fitted with lognormal likelihoods with assumed CVs set equal to the sampling CV.

Table 7: Commercial catch history (t) for the Sub-Antarctic stock. Note that from 1990 totals by model year differ from those for fishing year (see Table 3) because the September catch has been shifted from the fishing year into the following model year. Model year landings from 2014 assume catch similar to the previous year.

Model year	Total	Model year	Total
1975	120	1995	1 995
1976	281	1996	2 779
1977	372	1997	1 915
1978	762	1998	2 958
1979	364	1999	2 854
1980	350	2000	3 108
1981	272	2001	2 820
1982	179	2002	2 444
1983	448	2003	2 777
1984	722	2004	3 223
1985	525	2005	2 592
1986	818	2006	2 541
1987	713	2007	1 711
1988	1 095	2008	2 329
1989	1 237	2009	2 446
1990	1 897	2010	1 927
1991	2 381	2011	1 319
1992	2 810	2012	1 900
1993	3 941	2013	1 859
1994	1 596	2014	1 800

The CVs (for observations fitted with lognormal likelihoods) are assumed to have allowed for sampling error only. Additional variance, assumed to arise from differences between model simplifications and real world variation, was added to the sampling variance for all observations in all model runs. Process error of 0.2 was added to all survey biomass indices following the recommendation of Francis et al. (2001). For CPUE indices, process error CVs were estimated to be 0.15 following Francis (2011). For the proportions-at-age observations from the trawl survey and fishery, a multinomial error distribution was assumed. Process errors for the catch-at-age series were captured by the effective sample sizes per year, used in the multinomial likelihood, which were estimated iteratively using method TA1.8 described in Francis (2011). Ageing error was assumed to occur for the observed proportions-at-age data, by assuming a discrete normally distributed error with a CV of 0.08. The values estimated for process error in the MPD runs were then fixed for the MCMC runs.

Year class strengths were assumed known (and equal to one) for years before 1974 and after 2013, when inadequate or no catch-at-age data were available. Otherwise, year class strengths were estimated under the assumption that the estimates from the model must average one. The Haist parameterisation for year class multipliers was used.

MCMCs were estimated using 2×10^7 iterations, a burn-in length of 1.75×10^7 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 *q* 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 dependent 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*. All trawl *q*s were estimated as free (not nuisance) parameters.

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

Table 8: The assumed priors for key distributions (when estimated) for the Sub-Antarctic stock assessment. The parameters are mean (in natural space) and CV for lognormal.

Parameter description	Distribution	Parameters		Bounds	
B_0	Uniform-log	–	–	5 000	350 000
Year class strengths	Lognormal	1.0	1.1	0.01	100
Trawl survey q[1]	Lognormal	0.16	0.79	0.01	0.4
CPUE q	Uniform-log	–	–	1e-8	1e-3
Selectivities	Uniform	–	–	0	20–200[2]
M (x_0, y_0, y_1, y_2)[3]	Uniform	–	–	3, 0.01, 0.01, 0.01	15, 0.6, 1.0, 1.0

[1] Three trawl survey q values were estimated, but all had the same priors.
[2] A range of maximum values was used for the upper bound.
[3] x_0, age at minimum M; y_0, M at x_0; y_1, M at the minimum age in the partition; y_2, M at the maximum age in the partition.

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) halving the effective sample sizes of the composition data (the half N_{eff} model), (2) the estimation of M as a sex-dependent constant (the estimate M model), (3) fixing M at the previously used default values of 0.20 for males and 0.18 for females (the fixed M model), and (4) including the trawl fishery CPUE series (the CPUE model). 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.

The estimated MCMC marginal posterior distributions from the base case model are shown for year class strength (Figure 2). Median and 95% CI are shown for biomass (Figure 3). Year class strength estimates suggested that the Sub-Antarctic stock is characterised by a group of above average year class strengths in the late 1970s, a very strong year class in 1980, followed by a period of average to less than average recruitment through to 2004. Estimates from 2005 to 2007 are just above average. Consequently, biomass estimates for the stock declined, particularly through the early 1990s, but are currently exhibiting an upturn. Biomass estimates for the stock appear relatively healthy, with estimated current biomass from the base model at 60% of B_0 (Figure 3, Table 9). Annual exploitation rates (catch over vulnerable biomass) were low (less than 0.1) in all years as a consequence of the high estimated stock size relative to the level of catches (Figure 4).

Resource survey and fishery selectivity ogives were essentially logistic (even though they were estimated using double-normal parameterisation). The summer survey ogive was tightly defined and suggested that hake were fully selected by the research gear at age 5. Fishing selectivity (also tightly defined) indicated that hake were fully selected by about age 9 years, as would be expected given the use of larger mesh size than in the trawl survey.

The assessment relied on biomass data from the two Sub-Antarctic trawl survey series (summer, and autumn), and both were reasonably well fitted. It was apparent, however, that there can be marked changes in catchability between adjacent pairs of surveys. Estimated trawl survey catchability constants were very low (in the base model about 4–7% based on doorspread swept area estimates), suggesting that the absolute catchability of the Sub-Antarctic trawl surveys is extremely low. It is not known if the catchability of the Sub-Antarctic trawl survey series is as low as estimated by the model, but hake are believed to be relatively more abundant over rough ground (that is likely to be avoided during a trawl survey), and it is known that hake tend to school off the bottom, particularly during their spring–summer spawning season, hence reducing their availability to the bottom trawl.

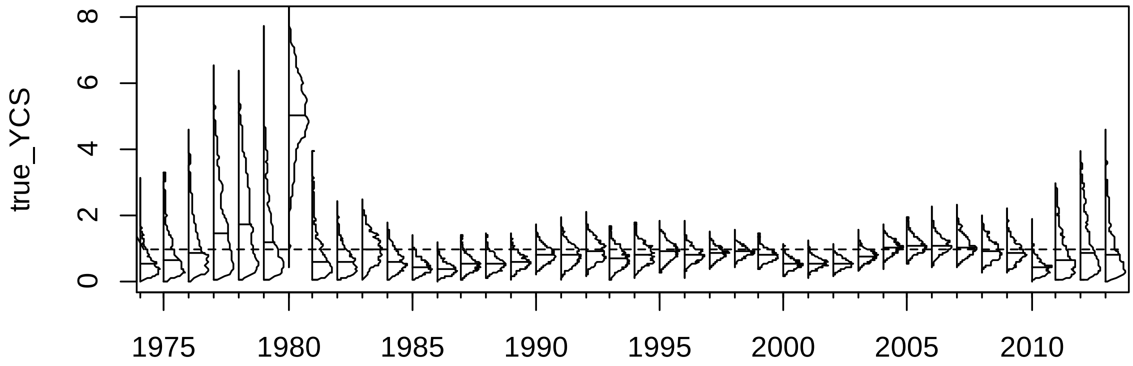


Figure 2: Estimated posterior distributions of year class strengths for the base case for the Sub-Antarctic stock. The dashed horizontal line indicates a year class strength of one. Individual distributions show the marginal posterior distribution, with horizontal lines indicating the median.

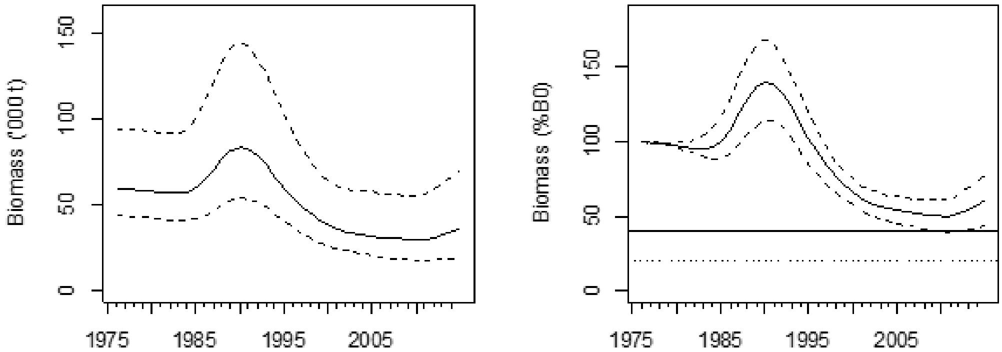


Figure 3: Estimated median trajectories (with 95% credible intervals shown as dashed lines) for the Sub-Antarctic stock base case model for absolute biomass and biomass as a percentage of B_0. The management target (40% B_0, solid horizontal line) and soft limit (20% B_0, dotted horizontal line) are shown on the right-hand panel.

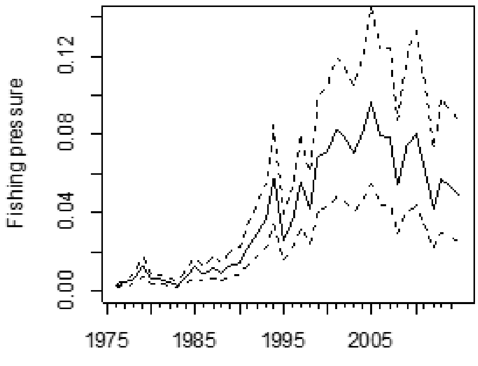


Figure 4: Exploitation rates (catch over vulnerable biomass) for the Sub-Antarctic stock base case model.

Estimates of the status of the Sub-Antarctic stock suggest that there has been a decline in the stock size since the late 1980s, but, owing to an apparent increase in stock size during the mid 1980s (driven by a series of above average year classes) current stock size is healthy relative to the estimated virgin biomass. Catches averaging about 2300 t annually since 1990–91 appear to have had a relatively slight effect on the biomass level, given the generally lower than average recruitment during that time. Consequently, future annual catches of 2000 t (the average since 2008), in tandem with some recent stronger than average year classes, are projected to allow stock size to be maintained or increase slightly by 2019 (Table 10). However, 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 mid 1990s, the absolute level of current biomass is very uncertain.

Table 9: Bayesian median (95% credible intervals) (MCMC) of B_0, B_{2014}, and B_{2014} as a percentage of B_0 for the Sub-Antarctic base model and sensitivity runs.

Model run	B_0	B_{2014}	B_{2014} (% B_0)
Base	59 290 (44 040–94 040)	37 990 (19 740–70 310)	60.4 (43.6–77.6)
Half N_{eff}	50 120 (39 340–77 510)	27 910 (14 890–55 840)	55.4 (37.2–77.5)
Estimate *M*	65 610 (47 940–105 840)	44 900 (25 500–84 370)	67.8 (49.9–89.1)
Fixed *M*	60 270 (46 210–99 970)	33 620 (19 170–67 160)	54.9 (39.8–72.5)
CPUE	79 580 (59 330–102 310)	60 980 (38 140–86 890)	76.2 (62.5–87.0)

Sensitivity runs including trawl CPUE and estimating *M* as a constant both give higher current stock status, while less weight on the ageing data and a fixed *M* at age give slightly lower current stock status. None of the tested sensitivity runs were considered to be better models than the base run, and some were clearly worse. Down-weighting the ageing data resulted in unrealistic survey selectivity ogives and estimates of *M* at younger ages. Estimating a constant *M* also produced unrealistic survey selectivity ogives. The inclusion of CPUE flattened the recent biomass trajectory, resulting in even lower estimates of survey catchability than in the base model.

Table 10: Bayesian median (95% credible intervals) projected biomass in 2019 (B_{2019}), B_{2019} as a percentage of B_0, and B_{2019}/B_{2014} (%) for the Sub-Antarctic base model and sensitivity models where future annual catches are assumed to be 2000 t.

Model run	Future catch (t)	B_{2019}	B_{2019} (% B_0)	B_{2019}/B_{2014} (%)
Base	2 000	39 560 (19 760–79 890)	65.5 (41.8–90.5)	107 (87–135)
Half N_{eff}	2 000	29 290 (14 130–62 070)	57.7 (34.3–87.4)	103 (80–133)
Estimate *M*	2 000	45 420 (23 550–89 220)	68.0 (46.0–102.6)	99 (79–139)
Fixed *M*	2 000	33 680 (16 950–75 050)	55.1 (34.5–83.8)	100 (77–140)
CPUE	2 000	66 350 (36 280–95 320)	81.8 (59.3–101.8)	107 (88–129)

4.1.6 Estimates of sustainable yields
Yield estimates were not reported.

4.2 HAK 4 (Chatham Rise stock)
The 2012 stock assessment was carried out with data up to the end of the 2010–11 fishing year. The assessment used research time series of abundance indices (trawl surveys of the Chatham Rise from 1992 to 2012), catch-at-age from the trawl survey series and the commercial fishery since 1990–91, a CPUE series from the eastern trawl fishery, and estimates of biological parameters.

4.2.1 Model structure
The base case model partitioned the Chatham Rise stock population into unsexed age groups 1–30 with the last age group considered a plus group. No CPUE was included, and a constant *M* was used. The models were initialised assuming an equilibrium age structure at an unfished equilibrium biomass (B_0), i.e., with constant recruitment set equal to the mean of the recruitments over the period 1975–2006. There were three double-normal selectivity-at-age ogives; east and west commercial fishing selectivities and a survey selectivity for the Chatham Rise January trawl survey series. Selectivities were assumed constant over all years in both fisheries and the survey, and hence there was no allowance for possible annual changes in selectivity. The age at full selectivity for the trawl survey series was strongly encouraged to be in the range 8±2 years. This range was determined by visual examination of the at-age plots, and was implemented because unconstrained selectivity resulted in age at full selectivity being older than most of the fish caught in the survey series.

Five-year biomass projections were made assuming future catches on the Chatham Rise equal to the HAK 4 TACC of 1800 t. For the projection, estimated future recruitment variability was sampled from actual estimates between 1984 and 2009, a period including the full range of recruitment successes.

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

Catch-at-age observations were available for each survey on the Chatham Rise, and for commercial trawl fisheries on the eastern and western Rise in some years, from observer data. The catch histories assumed in all model runs (Table 11) include the revised estimates of catch reported by Dunn (2003). Resource survey abundance indices are given in Table 12.

4.2.3 Model estimation

Model parameters were derived using Bayesian estimation implemented using the general-purpose stock assessment program CASAL v2.22 (Bull et al 2008). For final runs, the full posterior distribution was sampled using Markov Chain Monte Carlo (MCMC) methods, based on the Metropolis-Hastings algorithm.

The error distributions assumed were multinomial for the proportions-at-age and lognormal for all other data. Biomass indices had assumed CVs set equal to the sampling CV, with additional process error of 0.2. The multinomial observation error effective sample sizes for the at-age data were adjusted using the reweighting procedure of Francis (2011). Ageing error was assumed to occur for the observed proportions-at-age data, by assuming a discrete normally distributed error with a CV of 0.08.

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

Model year	West	East	Total	Model year	West	East	Total
1975	80	111	191	1994	368	2 912	3 280
1976	152	336	488	1995	597	2 903	3 500
1977	74	1 214	1 288	1996	1 353	2 483	3 836
1978	28	6	34	1997	1 475	1 820	3 295
1979	103	506	609	1998	1 424	1 124	2 547
1980	481	269	750	1999	1 169	3 339	4 509
1981	914	83	997	2000	1 155	2 130	3 285
1982	393	203	596	2001	1 208	1 700	2 908
1983	154	148	302	2002	454	1 058	1 512
1984	224	120	344	2003	497	718	1 215
1985	232	312	544	2004	687	1 983	2 671
1986	282	80	362	2005	2 585	1 434	4 019
1987	387	122	509	2006	184	255	440
1988	385	189	574	2007	270	683	953
1989	386	418	804	2008	259	901	1 159
1990	309	689	998	2009	1 069	832	1 902
1991	409	503	912	2010	231	159	390
1992	718	1 087	1 805	2011	822	118	940
1993	656	1 996	2 652	2012	800	150	950

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

Year	**Vessel**	**Biomass (t)**	**CV**
1989*	*Amaltal Explorer*	3 576	0.19
1992	*Tangaroa*	4 180	0.15
1993	*Tangaroa*	2 950	0.17
1994	*Tangaroa*	3 353	0.10
1995	*Tangaroa*	3 303	0.23
1996	*Tangaroa*	2 457	0.13
1997	*Tangaroa*	2 811	0.17
1998	*Tangaroa*	2 873	0.18
1999	*Tangaroa*	2 302	0.12
2000	*Tangaroa*	2 090	0.09
2001	*Tangaroa*	1 589	0.13
2002	*Tangaroa*	1 567	0.15
2003	*Tangaroa*	890	0.16
2004	*Tangaroa*	1 547	0.17
2005	*Tangaroa*	1 049	0.18
2006	*Tangaroa*	1 384	0.19
2007	*Tangaroa*	1 820	0.12
2008	*Tangaroa*	1 257	0.13
2009	*Tangaroa*	2 419	0.21
2010	*Tangaroa*	1 700	0.25
2011	*Tangaroa*	1 099	0.15
2012	*Tangaroa*	1 292	0.15
2013*	*Tangaroa*	1 877	0.15
2014*	*Tangaroa*	1 377	0.15

* Not used in the reported assessment.

Year class strengths were assumed known (and equal to one) for years before 1975 and after 2009, where 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 $5x10^5$ iterations, with every 2500th sample taken from the next $2.5x10^6$ 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. The priors for B_0 and year class strengths were intended to be relatively uninformed, and had wide bounds. Priors for the trawl fishery selectivity parameters were assumed to be uniform. Priors for the trawl survey selectivity parameters were assumed to have a normal-by-stdev distribution, with a very tight distribution set for age at full selectivity, but an essentially uniform distribution for parameters *aL* and *aR*. The prior for the survey *q* was informative and was estimated using a simple simulation as described in Section 4.1.4 above.

Penalty functions were used a) to constrain the model so that any combination of parameters that resulted in a stock size that was so low that the historical catch could not have been taken was strongly penalised, b) to ensure that all estimated year class strengths averaged 1, and c) to smooth the year class strengths estimated over the period 1975 to 1983.

Table 13: The assumed priors for key distributions (when estimated) for the Chatham Rise stock assessment. The parameters are mean (in natural space) and CV for lognormal.

Parameter description	Distribution	Parameters		Bounds	
B_0	Uniform-log	–	–	10 000	250 000
Year class strengths	Lognormal	1.0	1.1	0.01	100
Trawl survey *q*	Lognormal	0.16	0.79	0.01	0.4
Selectivity (fishery)	Uniform	–	–	1	25–200*
Selectivity (survey, *a1*)	Normal-by-stdev	8	1	1	25
Selectivity (survey, *aL*, *aR*)	Normal-by-stdev	10	500	1	50–200*

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

4.2.5 Model estimates

Estimates of biomass were produced for an agreed base case run (research survey abundance series, constant *M*) using the biological parameters and model input parameters described earlier. Sensitivity models were run to investigate the effects of estimating *M*, including the CPUE series, and removing constraints on the survey selectivity ogive. Stock status from these three models was not markedly different to the base case, and the results are not presented here. For all runs, MPD fits were obtained and qualitatively evaluated. Base case MCMC estimates of the median posterior and 95% percentile credible intervals are reported for virgin, current and projected biomass.

Estimated MCMC marginal posterior distributions from the base case model are shown for year class strengths (Figure 5) and biomass (Figure 6). The year class strength estimates suggested that the Chatham Rise stock was characterised by a group of relatively strong relative year class strengths in the late 1970s to early 1980s, and again in the early 1990s, followed by a period of relatively poor recruitment (except for 2002). Consequently, biomass increased slightly during the late 1980s, then declined to about 2005. The growth of the strong 2002 year class has resulted in a recent slight upturn in biomass. Current stock biomass was estimated at about 47% of B_0 (see Figure 6 and Table 14). Annual exploitation rates (catch over vulnerable biomass) were low (less than 0.1) up to 1993 and since 2007, but moderate (although probably less than 0.25) in the intervening period (Figure 7).

The resource survey and fishery selectivity ogives all had relatively wide bounds after age at peak selectivity. The survey ogive was essentially logistic (even though fitted as double normal) and had hake fully selected by the research gear from about age 9. Recall that age at full selectivity for the trawl survey was strongly influenced by tight priors. Fishing selectivities indicated that hake were fully selected in the western fisheries by about age 6 years, compared to age 11 in the eastern fishery; this is logical given that the eastern fishery concentrates more on the spawning (i.e., older) biomass.

Base case model projections assuming a future annual catch of 1800 t suggest that biomass will decline to about 38% of B_0 by 2017 (Table 15). There is little risk (i.e., < 1%) that the stock will fall below 20% B_0 in the next five years under this catch scenario. Note that 1800 t is higher than recent annual landings from the stock (they have averaged about 1070 t in the last five years), but lower than what could be taken (if all the HAK 4 TACC plus some HAK 1 catch from the western Rise was taken).

Table 14: Bayesian median and 95% credible intervals of B_0, B_{2012}, and B_{2012} as a percentage of B_0 for the Chatham Rise model runs.

Model run	B_0	B_{2012}	B_{2012} (% B_0)
Base case	37 000 (30 110–67 000)	17 250 (11 010–41 550)	46.8 (35.3–63.4)

Table 15: Bayesian median and 95% credible intervals of projected B_{2017}, B_{2017} as a percentage of B_0, and B_{2017}/B_{2012} (%) for the Chatham Rise model runs.

Model run	Future catch (t)	B_{2017}	B_{2017} (% B_0)	B_{2017}/B_{2012} (%)
Base case	1 800	13 930 (6 990–35 800)	38.1 (22.0–57.2)	80 (56–109)

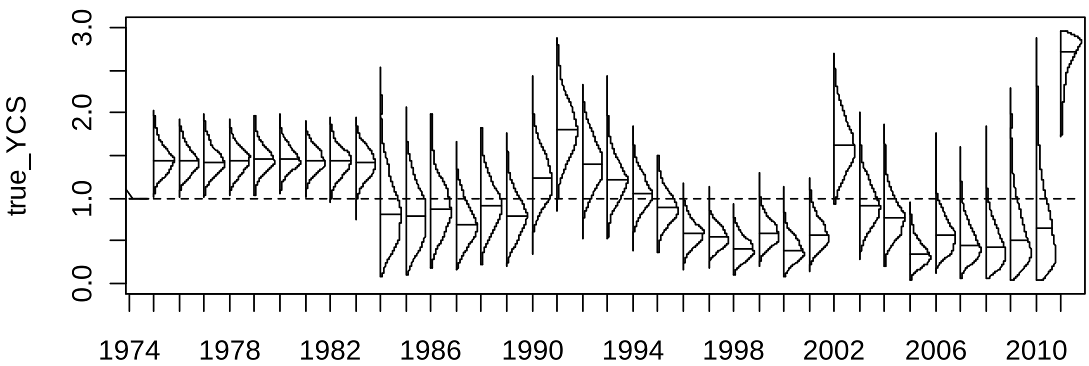


Figure 5: Estimated posterior distributions of year class strengths for the Chatham Rise (HAK 4) base case. The dashed horizontal line indicates a year class strength of one. Individual distributions show the marginal posterior distribution, with horizontal lines indicating the median.

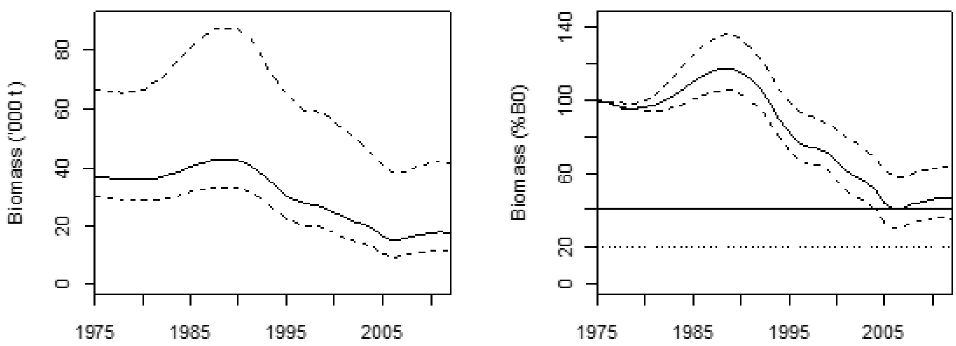


Figure 6: Estimated median trajectories (with 95% credible intervals shown as dashed lines) for the Chatham Rise (HAK 4) base case model for absolute biomass and stock status (biomass as a percentage of B_0).

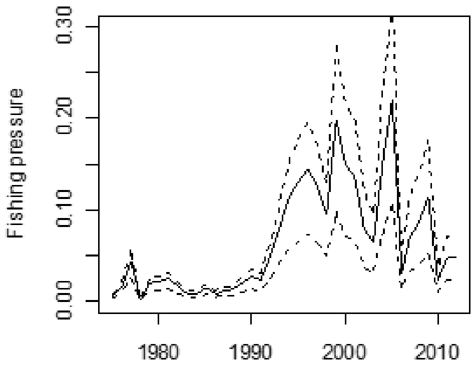


Figure 7: Exploitation rates (catch over vulnerable biomass) for the Chatham Rise stock base case model.

4.2.6 Estimates of sustainable yields

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

4.3 HAK 7 (West coast, South Island)

A new assessment for HAK 7 was carried out in 2012 using fisheries data up to the end of the 2010–11 fishing year. The assessment used catch-at-age from the commercial fishery since 1989–90, two comparable research surveys (in 2000 and 2012), a CPUE series from 2001 to 2011, and estimates of biological parameters. The selected CPUE series incorporated data since the change in 2001 to a new regulatory and reporting regime (involving ACE), and so was considered less likely to be biased by variations in fishing behaviour and catch reporting behaviour.

The stock assessment for HAK 7 had been last updated using data up to the end of the 2008–09 fishing year (Horn 2011). Commercial catch-at-age was the only input data series. No time series of biomass indices were incorporated in the model; no fishery-independent series were available and CPUE indices were considered unreliable.

4.3.1 Model structure

The base case model partitioned the WCSI stock population into unsexed age groups 1–30 with the last age group considered a plus group. The CPUE and survey biomass series were both included, and a constant M was used. The model was initialised assuming an equilibrium age structure at an unfished equilibrium biomass (B_0) in 1974, i.e., with constant recruitment set equal to the mean of the recruitments over the period 1973–2007. There were two double-normal selectivity-at-age ogives; commercial fishing selectivity, and survey selectivity. Selectivities were assumed constant over all years in the fishery and the surveys, and hence there was no allowance for possible annual changes in selectivity. Sensitivities to the base model investigated the effect of estimating M as an age-dependent function, and the effect of excluding the research survey data.

Five-year biomass projections were made assuming future WCSI catches of 4500 t annually (the mean annual catch since 2007–08) and 7700 t annually (the TACC). For each projection scenario, estimated future recruitment variability was sampled from actual estimates from 1995 to 2006, a period including both high and low recruitment success, but excluding the most recent estimated year class (2007).

4.3.2 Fixed biological parameters and observations

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

Commercial fishery catch-at-age observations were available for 1979 (fishing by RV *Wesermünde*) and 1989–90 to 2010–11 (observer data). Research survey biomass and proportions-at-age data (from 2000 and 2012) were also fitted in the model. The catch history assumed in the model runs is shown in Table 3. Resource survey abundance indices are given in Table 16, and CPUE indices in Table 17

Table 16: Research survey indices (and associated CVs) for the WCSI stock.

Year	Vessel	Biomass (t)	CV
2000	*Tangaroa*	803	0.13
2012	*Tangaroa*	583	0.12
2013*	*Tangaroa*	331	0.17

* Not used in the reported assessment.

Table 17: Trawl fishery CPUE indices (and associated CVs) for the WCSI stock.

Year	Index	CV
2000–01	1.17	0.04
2001–02	1.55	0.04
2002–03	1.11	0.04
2003–04	0.95	0.04
2004–05	0.85	0.04
2005–06	0.79	0.04
2006–07	0.64	0.04
2007–08	0.44	0.04
2008–09	0.61	0.04
2009–10	0.68	0.05
2010–11	0.88	0.05

4.3.3 Model estimation

Model parameters were derived using Bayesian estimation implemented using the general-purpose stock assessment program CASAL v2.22 (Bull et al 2012). For final model runs, the full posterior distribution was sampled using Markov Chain Monte Carlo (MCMC) methods, based on the Metropolis-Hastings algorithm.

The error distributions assumed were multinomial for the proportions-at-age and lognormal for all other data. Biomass indices had assumed CVs set equal to the sampling CV. A process error CV of 0.16 for the CPUE series was estimated following Francis (2011). The multinomial observation error effective sample sizes for the at-age data were adjusted using the reweighting procedure of Francis (2011). Ageing error was assumed to occur for the observed proportions-at-age data, by assuming a discrete normally distributed error with a CV of 0.08.

Year class strengths were assumed known (and equal to one) for years before 1973 and after 2007, 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 3×10^6 iterations, a burn-in length of 5×10^5 iterations, and with every 2500th sample kept from the final 2.5×10^6 iterations (i.e., a final sample of length 1000 was taken from the Bayesian posterior).

4.3.4 Prior distributions and penalty functions

The assumed prior distributions used in the assessment are given in Table 18. The priors for B_0 and year class strengths were intended to be relatively uninformed, and had wide bounds. Priors for all selectivity parameters were assumed to be uniform. The prior for the survey *q* was informative and was estimated using the Sub-Antarctic hake survey priors as a starting point (see Section 4.1.4) because the survey series in both areas used the same vessel and fishing gear. However, the WCSI survey area in the 200–800 m depth range in strata 0004 A–C and 0012 A–C comprised 12 928 km^2; seabed area in that depth range in the entire HAK 7 biological stock area (excluding the Challenger Plateau) is estimated to be about 24 000 km^2. So because biomass from only 54% of the WCSI hake habitat was included in the indices, the Chatham Rise prior on μ was modified accordingly (i.e., $0.16 \times 0.54 = 0.09$), and the bounds were also reduced from [0.01, 0.40] to [0.01, 0.25]. Priors for all selectivity parameters were assumed to be uniform.

A penalty function was used to constrain the model so that any combination of parameters that resulted in a stock size that was so low that the historical catch could not have been taken was strongly penalised.

Table 18: The assumed priors for key distributions (when estimated) for the WCSI stock assessment. The parameters are mean (in natural space) and CV for lognormal.

Parameter description	Distribution	Parameters		Bounds	
B_0	Uniform-log	–	–	5 000	250 000
Year class strengths	Lognormal	1.0	1.1	0.01	100
Trawl survey q	Lognormal	0.09	0.79	0.01	0.25
CPUE q	Uniform-log	–	–	1e-8	1e-3
Selectivities	Uniform	–	–	0	20–200*
M (x_0, y_0, y_1, y_2)	Uniform	–	–	3, 0.01, 0.01, 0.01	15, 0.6, 1.0, 1.0

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

4.3.5 Model estimates

Estimates of biomass were produced for an agreed base case run (CPUE and survey abundance series, constant *M*) using the biological parameters and model input parameters described earlier. In addition, two sensitivities were investigated: (1) estimating *M* as a double exponential function thus allowing *M* to vary with age, and (2) excluding the research survey biomass series. 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 and the sensitivity estimating M are reported in detail here. The other sensitivity produced estimates of stock status that were little different to those from the base case.

The estimated MCMC marginal posterior distributions from the base case model are shown for year class strength (Figure 8) and biomass (Figure 9). WCSI year class strength estimates exhibit a relatively low level of between-year variation, although there was a period of generally less than average recruitment from 1993 to 2003, followed by four years of relatively strong year classes. Estimated biomass declined throughout the late 1970s owing to relatively high catch levels, then increased through the mid 1980s concurrent with a marked decline in catch. Biomass then steadily declined from 1988 to 2007 owing to higher levels of exploitation and the recruitment of year classes that were generally of below-average strength. The increase since 2006 is a consequence of the recruitment of the above-average year classes since 2004. Estimated current biomass from the base model was 58% B_0 (Figure 9, Table 19). Annual exploitation rates (catch over vulnerable biomass) were low to moderate (less than 0.2) up to about 1999, but increased to 0.2 to 0.4 in 1977 and throughout the 2000s, and have subsequently declined (Figure 10). The exploitation rate that produced a biomass equal to 40% B_0 was 0.34 (Figure 10); it was determined by running the base MPD model for 1000 years, assuming constant average recruitment.

The median selectivity ogives for both the survey and the fishery were approximately logistic shaped, and their bounds were relatively wide. The ogives suggested that hake were fully selected by the fishery by about age 9, and slightly older in the survey.

The assessment relied on CPUE data since 2001 and biomass data from two trawl surveys. Both abundance series were well fitted. Likelihood profiling indicated that the fishery catch-at-age data dominated, but the abundance indices were consistent with a B_0 in the relatively narrow range of 80 000–100 000 t.

4.3.5.1 Deterministic B_{MSY}

Deterministic B_{MSY} was calculated in the 2013 assessment as 26% B_0. There are several reasons why B_{MSY}, as calculated in this way, is not a suitable target for management of the HAK 7 fishery. First, it assumes a harvest strategy that is unrealistic in that it involves perfect knowledge including perfect catch and biological information and perfect stock assessments (because current biomass must be known exactly in order to calculate target catch), a constant-exploitation management strategy with annual changes in TACC (which are unlikely to happen in New Zealand and not desirable for most stakeholders), and perfect management implementation of the TACC and catch splits with no under- or overruns. Second, it assumes perfect knowledge of the stock-recruit relationship, which is actually very poorly known. Third, it would be very difficult with such a low biomass target to avoid the biomass occasionally falling below 20% B_0, the default soft limit according to the Harvest Strategy Standard. Thus, the actual target needs to be above this theoretical optimum; but the extent to which it needs to be above has not been determined.

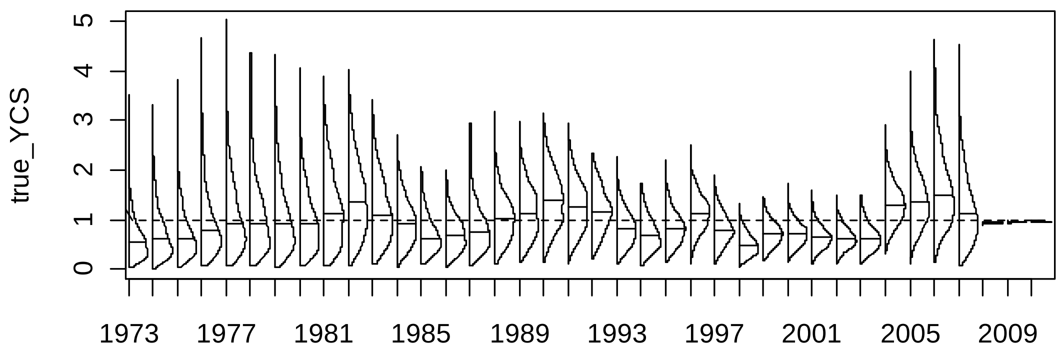


Figure 8: Estimated posterior distributions of year class strengths for the base case for the WCSI stock. The dashed horizontal line indicates a year class strength of one. Individual distributions show the marginal posterior distribution, with horizontal lines indicating the median.

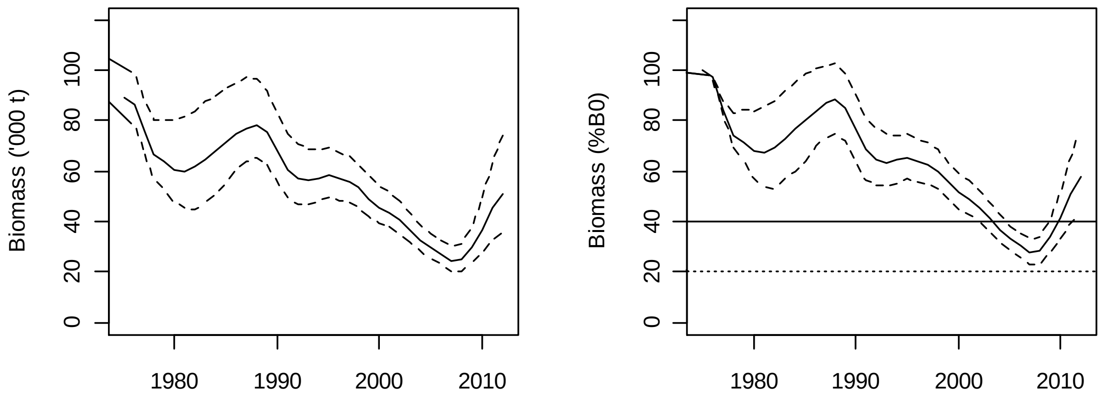


Figure 9: Estimated median trajectories (with 95% credible intervals shown as dashed lines) for the WCSI stock base case model for absolute biomass and biomass as a percentage of B_0. The management target (40% B_0, solid horizontal line) and soft limit (20% B_0, dotted horizontal line) are shown on the right-hand panel.

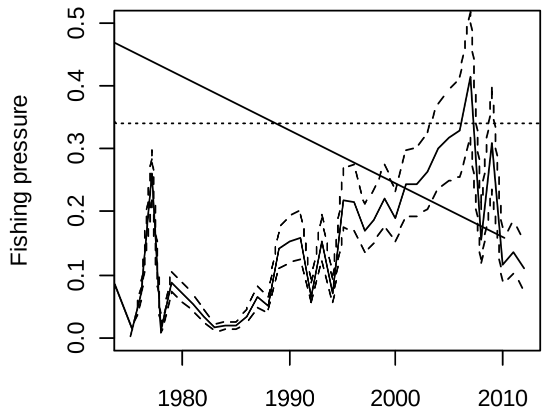


Figure 10: Exploitation rates (catch over vulnerable biomass) for the WCSI stock base case model. The dashed horizontal line shows the exploitation rate (*U*, 0.34) that produces a biomass of 40% B_0 (at equilibrium, and with deterministic recruitment).

Estimates of the status of the WCSI stock suggest that there has been a steady increase in stock size since 2007, when it was about 30% B_0.

4.3.6 Yield estimates and projections

Projections assuming future catches similar to recent levels (i.e., 4500 t annually) will probably allow the stock to grow slightly in the next five years, while catches at the level of the TACC (7700 t) will probably cause the stock to decline slightly but still be above the management target (40% B_0) in 2017 (Table 20).

Table 19: Bayesian median (95% credible intervals) (MCMC) of B_0, B_{2012}, and B_{2012} as a percentage of B_0 for the WCSI base case and the sensitivity.

Model run	B_0	B_{2012}	B_{2012} (% B_0)
Base case	88 920 (80 660–101 210)	51 190 (35 850–74 790)	57.7 (43.1–77.4)
Estimate *M*	88 360 (78 790–114 920)	48 190 (29 260–90 800)	54.2 (35.8–86.4)

Table 20: Bayesian median and 95% credible intervals of projected B_{2017}, B_{2017} as a percentage of B_0, and B_{2017}/B_{2012} (%) for the base run and the sensitivity, under two future annual catch scenarios.

Model run	Future catch (t)	B_{2017}	B_{2017} (% B_0)	B_{2017}/B_{2012} (%)
Base case	4 500	54 320 (33 010–92 820)	61.2 (39.2–97.7)	107 (78–146)
	7 700	41 990 (22 740–79 420)	47.4 (27.4–83.9)	83 (56–122)
Estimate *M*	4 500	54 810 (30 520–104 150)	61.1 (36.2–101.4)	114 (81–158)
	7 700	43 310 (17 390–93 410)	48.1 (20.8–89.1)	88 (55–130)

5. STATUS OF THE STOCKS

Stock Structure Assumptions

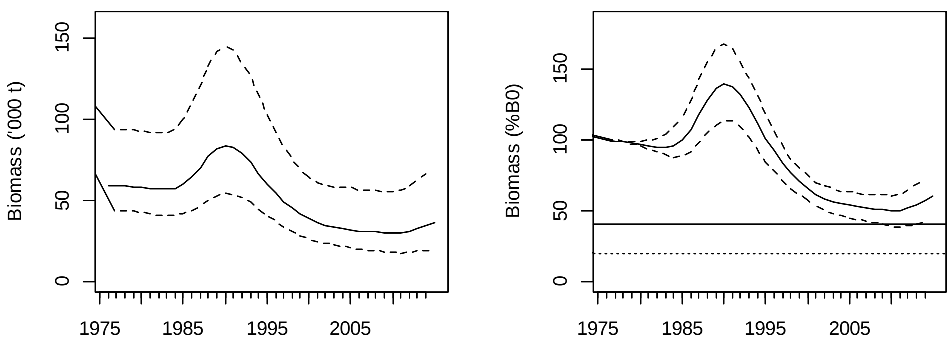
Hake are assessed as three independent biological stocks, based on the presence of three main spawning areas (eastern Chatham Rise, south of Stewart-Snares shelf, and WCSI), and some differences in biological parameters between these areas.

The HAK 1 Fishstock includes all of the Sub-Antarctic biological stock, part of the Chatham Rise biological stock, and all hake around the North Island (which are more likely part of either the WCSI or Chatham Rise stocks). The Sub-Antarctic stock is defined as all of Fishstock HAK 1 south of the Otago Peninsula; the Chatham Rise stock is all of HAK 4 plus that part of HAK 1 north of the Otago Peninsula; the WCSI stock is HAK 7.

- **Sub-Antarctic Stock (HAK 1 South of Otago Peninsula)**

Stock Status	
Year of Most Recent Assessment	2014
Assessment Runs Presented	One base case
Reference Points	Management Target: 40% B_0 Soft Limit: 20% B_0 Hard Limit: 10% B_0 Overfishing threshold: $U_{40\%}$
Status in relation to Target	B_{2014} was estimated at 60% B_0; Very Likely (> 90%) to be at or above the target
Status in relation to Limits	B_{2014} is Exceptionally Unlikely (< 1%) to be below both the Soft and Hard Limits
Status in relation to Overfishing	Overfishing is Very Unlikely (< 10%) to be occurring

Historical Stock Status Trajectory and Current Status



Trajectory over time of spawning biomass (absolute, and % B_0, with 95% credible intervals shown as broken lines) for the Sub-Antarctic hake stock from the start of the assessment period in 1975 to 2014 (the final assessment year). The management target (40% B_0, solid horizontal line) and soft limit (20% B_0, dotted horizontal line) are shown on the right-hand panel. Years on the x-axis indicate fishing year with "1995" representing the 1994–95 fishing year. Biomass estimates are based on MCMC results from the base model.

Fishery and Stock Trends	
Recent Trend in Biomass or Proxy	Biomass is estimated to have been increasing since 2010.
Recent Trend in Fishing Mortality or Proxy	Fishing pressure is estimated to have been relatively low throughout the duration of the fishery.
Other Abundance Indices	–
Trends in Other Relevant Indicators or Variables	–

Projections and Prognosis (2019)	
Stock Projections or Prognosis	The biomass of the Sub-Antarctic stock was expected to increase at a catch level equivalent to the mean since 2008 (i.e., 2000 t annually).
Probability of Current Catch or TACC causing decline below Limits	Soft Limit: Exceptionally Unlikely (< 1%) Hard Limit: Exceptionally Unlikely (< 1%)
Probability of Current Catch or TACC causing Overfishing to continue or commence	Very Unlikely (< 10%)

Assessment Methodology and Evaluation		
Assessment Type	Level 1 - Full quantitative stock assessment	
Assessment Method	Age-structured CASAL model with Bayesian estimation of posterior distributions	
Assessment Dates	Latest assessment: 2014	Next assessment: 2017
Overall assessment quality rank	1 – High Quality	
Main data inputs (rank)	- Research time series of abundance indices (trawl survey: summer, autumn) - Proportions-at-age data from the commercial fisheries and trawl surveys - Estimates of biological parameters New information since the 2011 assessment included two trawl surveys, and updated catch and catch-at-age data	1 – High Quality 1 – High Quality 1 – High Quality
Data not used (rank)	Commercial CPUE (used in sensitivity run only)	3 – Low Quality: potentially biased owing to changes in fishing practice and catch reporting
Changes to Model Structure and Assumptions	Previous assessments excluded sex from the partition. The model runs reported include sex in the partition, but have unsexed observation data and selectivities.	
Major Sources of Uncertainty	- The summer trawl survey series has shown a slight overall decline over time, but individual survey estimates are variable and catchability clearly varies between surveys. The general lack of contrast in this series (the main relative abundance series) makes it difficult to accurately estimate past and current biomass. - The assumption of a single Sub-Antarctic stock (including the Puysegur Bank), independent of hake in all other areas, is the most parsimonious interpretation of available information. However, this assumption may not be correct.	

	- Uncertainty about the size of recent year classes affects the reliability of stock projections. - Although the catch history used in the assessment has been corrected for some misreported catch (see Section 1.4), it is possible that additional misreporting exists.

Qualifying Comments
–

Fishery Interactions
Hake are often taken as a bycatch in hoki target fisheries. Some target fisheries for hake do exist, with the main bycatch species being hoki, ling, silver warehou and spiny dogfish. Incidental interactions and associated mortality are noted for New Zealand fur seals and seabirds.

- **Chatham Rise Stock (HAK 4 plus HAK 1 north of Otago Peninsula)**

Stock Status	
Year of Most Recent Assessment	2012
Assessment Runs Presented	An agreed base case, fitted primarily to a research survey abundance series
Reference Points	Target: 40% B_0 Soft Limit: 20% B_0 Hard Limit: 10% B_0 Overfishing threshold: $F_{40\%B0}$
Status in relation to Target	B_{2012} was estimated to be about 47% B_0; Likely (> 60%) to be at or above target
Status in relation to Limits	B_{2012} is Exceptionally Unlikely (< 1%) to be below the Soft or Hard Limits
Status in relation to Overfishing	Overfishing is Exceptionally Unlikely (< 1%) to be occurring

Historical Stock Status Trajectory and Current Status

Trajectory over time of spawning biomass (absolute, and % B_0, with 95% credible intervals shown as broken lines) for the Chatham Rise hake stock from the start of the assessment period in 1975 to 2012 (the final assessment year). The management target (40% B_0, solid horizontal line) and soft limit (20% B_0, dotted horizontal line) are shown on the right-hand panel. Years on the x-axis indicate fishing year with "2005" representing the 2004-05 fishing year. Biomass estimates are based on MCMC results.

Fishery and Stock Trends	
Recent Trend in Biomass or Proxy	Median estimates of biomass are unlikely to have been below 40% B_0. Biomass has been slowly increasing since 2006.
Recent Trend in Fishing Intensity or Proxy	Fishing pressure is estimated to have been low since 2006 (relative to estimated pressure in most years from 1994 to 2005).
Other Abundance Indices	–
Trends in Other Relevant Indicators or Variables	Recruitment (1995–2009, but excluding 2001) is estimated to be lower than the long-term average for this stock.

Projections and Prognosis	
Stock Projections or Prognosis	The biomass of the Chatham Rise stock is expected to decrease slightly over the next 5 years at catch levels equivalent to those from recent years (i.e., about 1100 t annually), but is projected to decline markedly if future catches are close to the high catch scenario (i.e. annual catch levels equivalent to the HAK 4 TACC of 1800 t).
Probability of Current Catch or TACC causing Biomass to remain below or to decline below Limits	Assuming future catches at the HAK 4 TACC: Soft Limit: About as Likely as Not (40–60%) Hard Limit: Unlikely (< 40%)
Probability of Current Catch or TACC causing Overfishing to continue or to commence	Assuming future catches at the HAK 4 TACC: About as Likely as Not (40–60%)

Assessment Methodology and Evaluation		
Assessment Type	Level 1 - Full quantitative stock assessment	
Assessment Method	Age-structured CASAL model with Bayesian estimation of posterior distributions	
Assessment Dates	Latest assessment: 2013	Next assessment: 2015
Overall assessment quality rank	1 – High Quality	
Main data inputs (rank)	- Research time series of abundance indices (trawl survey) - Proportions-at-age data from the commercial fisheries and trawl surveys - Estimates of biological parameters - New information since the 2009 assessment included three trawl surveys, and updated catch and catch-at-age data.	1 – High Quality 1 – High Quality 1 – High Quality
Data not used (rank)	Commercial CPUE	3 – Low Quality: does not track stock biomass
Changes to Model Structure and Assumptions	The model structure is unchanged from the previous assessment, but the assumed error structure on the at-age data was changed from lognormal to multinomial.	
Major Sources of Uncertainty	- The assumption of a single Chatham Rise stock independent of hake in all other areas is the most parsimonious interpretation of available information. - Uncertainty about the size of recent year classes affects the reliability of stock projections. - Although the catch history used in the assessment has been corrected for some misreported catch (see Section 1.4), it is possible that additional misreporting exists. - It is assumed in the assessment models that natural mortality is constant over all ages. The use of dome-shaped selectivity ogives will compensate for some variation in mortality rate with age.	

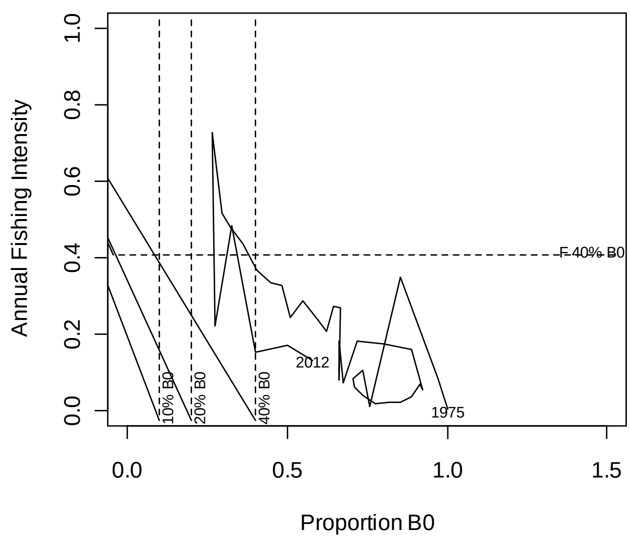
Qualifying Comments
The increase in relative abundance seen since 2006 is the result of good recruitment in 2002. In October 2004, large catches were taken in the western deep fishery (i.e. near the Mernoo Bank). This has been repeated to a lesser extent in 2008 and 2010. There is no information indicating whether these aggregations fished on the western Chatham Rise were spawning; if they were then this might indicate that there is more than one stock on the Chatham Rise. However, the progressive increase in mean fish size from west to east is indicative of a single homogeneous stock on the Chatham Rise.

Fishery Interactions
Hake are often taken as a bycatch in hoki target fisheries. Some target fisheries for hake do exist, with the main bycatch species being hoki, ling, silver warehou and spiny dogfish. Incidental interactions and associated mortality are seen for some protected species, notably New Zealand fur seals and seabirds.

- **West Coast South Island Stock (HAK 7)**

Stock Status	
Year of Most Recent Assessment	2012
Assessment Runs Presented	A base case, with sensitivity run estimating an age-dependent *M*
Reference Points	Target: 40% B_0 Soft Limit: 20% B_0 Hard Limit: 10% B_0 Overfishing threshold: $F_{40\%Bo} = 0.41$
Status in relation to Target	B_{2012} was estimated to be 58% B_0; Very Likely (> 90%) to be at or above the target
Status in relation to Limits	B_{2012} is Very Unlikely (< 10%) to be below the Soft Limit and Exceptionally Unlikely (< 1%) to be below the Hard limit
Status in relation to Overfishing	The fishing intensity in 2012 was Very Unlikely (< 10%) to be above the overfishing threshold

Historical Stock Status Trajectory and Current Status



Trajectory over time of fishing intensity and spawning biomass (Proportion B_0), for WCSI hake from the start of the assessment period in 1975, to 2012. The vertical lines represent the hard limit (10% B_0), the soft limit (20% B_0), and the target (40% B_0). The horizontal line represents the long-term level of fishing mortality that will produce a biomass of 40% B_0. Biomass estimates and fishing intensity are based on MPD results.

Fishery and Stock Trends	
Recent Trend in Biomass or Proxy	Median estimates of biomass are unlikely to have been below 28% B_0. Biomass is estimated to have been decreasing from the late 1980s to 2007, but has been increasing since then.
Recent Trend in Fishing Intensity or Proxy	Fishing pressure is estimated to have been declining since 2007, and is currently lower than in all years since 1995.
Other Abundance Indices	-

Trends in Other Relevant Indicators or Variables	Recent recruitment (2004–2007) is estimated to be higher than the long-term average for this stock.

Projections and Prognosis	
Stock Projections or Prognosis	The biomass of the WCSI stock is expected to increase slightly at a catch level equivalent to the mean since 2007 (i.e., 4 500 t annually), or decline slightly at a catch level equivalent to the TACC (i.e., 7 700 t annually).
Probability of Current Catch or TACC causing Biomass to remain below or to decline below Limits	For either current catches or the TACC: Soft Limit: Very Unlikely (< 10%) Hard Limit: Exceptionally Unlikely (< 1%)
Probability of Current Catch or TACC causing Overfishing to continue or to commence	Unlikely (< 40%)

Assessment Methodology and Evaluation		
Assessment Type	Level 1 - Full quantitative stock assessment	
Assessment Method	Age-structured CASAL model with Bayesian estimation of posterior distributions	
Assessment Dates	Latest assessment: 2012	Next assessment: 2015
Overall assessment quality rank	1 – High Quality	
Main data inputs (rank)	- Trawl fishery CPUE since 2001	1 – High Quality
	- Two comparable research trawl surveys (2000 and 2012)	1 – High Quality
	- Proportions-at-age data from the commercial fishery and two research surveys	1 – High Quality
	- Estimates of fixed biological parameters	1 – High Quality
Data not used (rank)	- Trawl fishery CPUE prior to 2001	3 – Low Quality: may not track stock biomass
Changes to Model Structure and Assumptions	- The model structure is unchanged from the previous assessment, but the assumed error structure on the at-age data was changed from lognormal to multinomial.	
Major Sources of Uncertainty	- The assumption of a single WCSI stock independent of hake in all other areas is the most parsimonious interpretation of available information. - Uncertainty about the size of recent year classes affects the reliability of stock projections. - Although the catch history used in the assessment has been corrected for some misreported catch (see Section 1.4), it is possible that additional misreporting exists. - It is assumed in the assessment models that natural mortality is constant over all ages. The use of dome-shaped selectivity ogives will compensate for some variation in mortality rate with age.	

Qualifying Comments

The fishery-independent abundance series is sparse (i.e., two comparable trawl surveys).
CPUE from this stock has previously been considered too unreliable to be used as an abundance index, but a truncated series from 2001 has been used here under the assumption that any biases owing to changes in fishing or reporting behaviour are small.

Fishery Interactions

Hake are often taken as a bycatch in hoki target fisheries. Some target fisheries for hake do exist, with the main bycatch species being hoki, ling, silver warehou and spiny dogfish. Incidental interactions and associated mortality are seen for some protected species, notably New Zealand fur seals and seabirds.

Table 21: Summary of TACCs (t) and reported landings for the most recent fishing year.

Fishstock	QMA	2013–14 actual TACC	2013–14 reported landings
HAK 1	Auckland, Central Southeast, Southland, Sub-Antarctic (FMAs 1, 2, 3, 5, 6, 8, 9)	3 701	1 883
HAK 4	Chatham Rise (FMA 4)	1 800	168
HAK 7	Challenger (FMA 7)	7 700	3 642
HAK 10	Kermadec	10	–
Total		13 211	5 693

6. FOR FURTHER INFORMATION

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