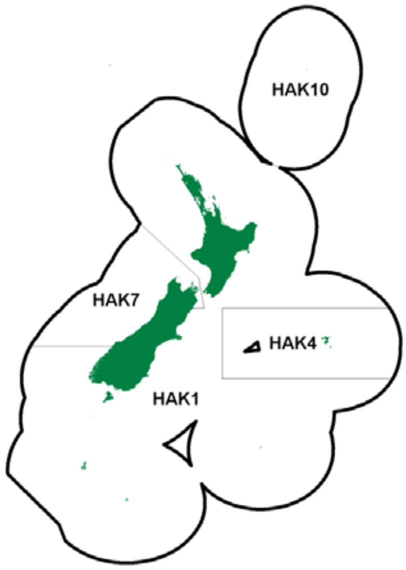
HAKE (HAK)

(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 5 064 t out of a total for the EEZ of 10 575 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 2015). 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. From 1 October 2008 the TACC for HAK 7 was reduced to 5064 tonnes. This new catch limit was set equal to the average annual catches over the previous five years. HAK 7 landings have been well below the TACC since the 2017–18 fishing year (referred to as the 2018 fishing year).

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 2 610 t to 3 632 t in HAK 1 and from 1 000 t to 3 500 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 were generally less than 3 000 t from 2005–06 until 2009–10, and generally less than 2 000 t since then. Landings from HAK 4 declined erratically from over 3 000 t in 1998–99 to a low of 161 t in 2011–12. From 2004–05, the TACC for HAK 4 was reduced from 35 00 t to 18 00 t. Annual landings have been markedly lower than the new TACC since then, and lower than 300 t in all but one year since 2009–10.

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 (4 795 t against a TACC of 3 701 t) and a substantial increase in the landings (more than 3 700 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 2017–18 and actual TACCs (t) for 1986–87 to 2017–18. 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
2014–15	1 725	3 701	304	1 800	6 219	7 700	0	10	8 248	13 211
2015–16	1 584	3 701	274	1 800	2 864	7 700	0	10	4 722	13 211
2016–17	1 175	3 701	268	1 800	4 701	7 700	0	10	6 144	13 211
2017–18	1 349	3 701	267	1 800	3 086	5 064	0	10	4 702	10 575

[1] FSU data

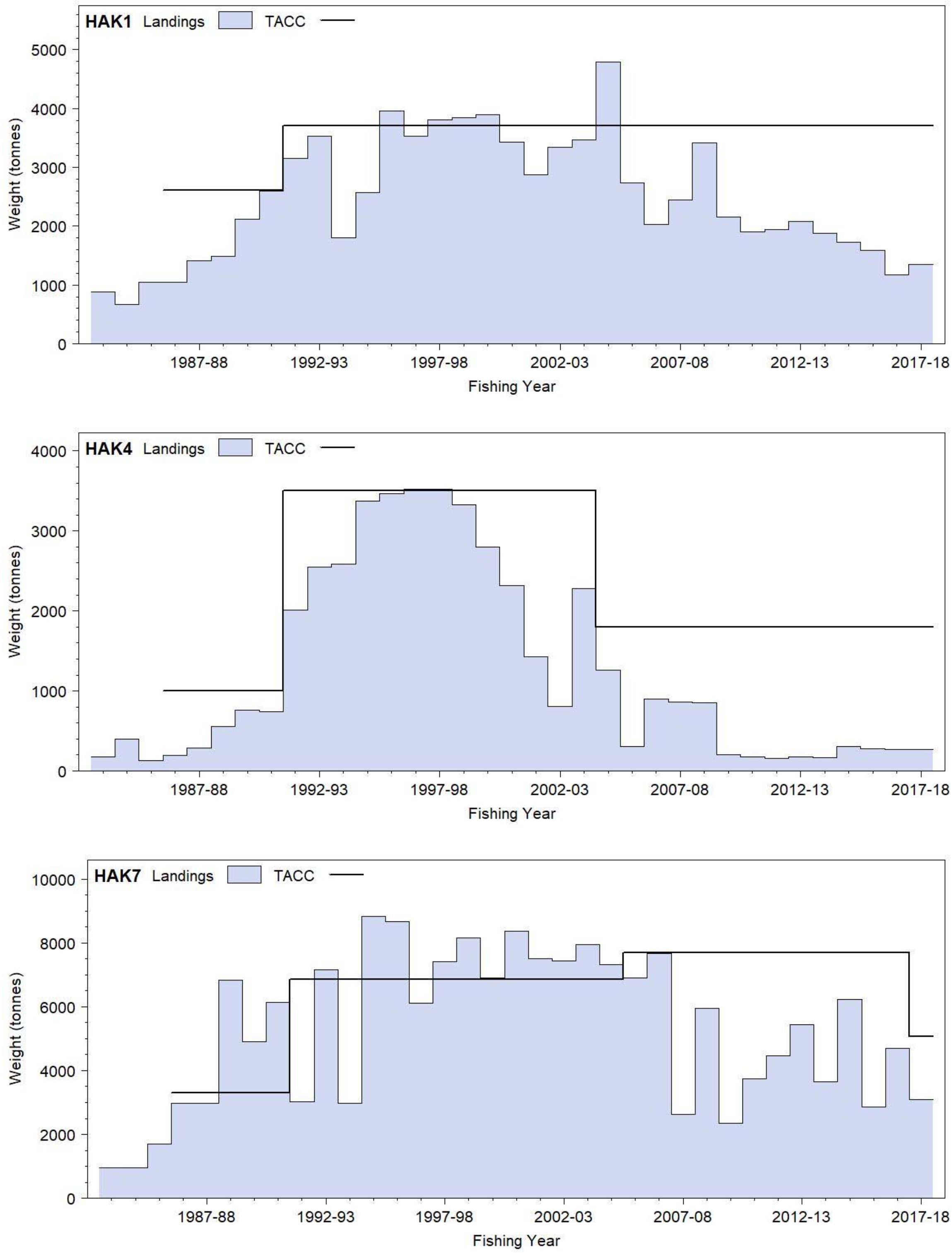


Figure 1: Reported commercial landings and TACC for the three main HAK stocks. From top: HAK 1 (Sub-Antarctic and part of Chatham Rise), HAK 4 (eastern Chatham Rise), and HAK 7 (Challenger).

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 stock, 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% (700–1 000 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 2017–18 are given in Table 3.

Table 3: Revised landings from fishing years 1975 to 2018 (t) for Sub-Antarctic, and Chatham Rise stocks and 1975–2018 fishing years for the West Coast South Island. Note, these relate to biological stocks, not QMAs.

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
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

Table 3 [Continued]

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
2013–14	3 387	1 830	187
2014–15	5 966	1 630	348
2015–16	2 733		
2016–17	4 599		
2017–18	2 968		

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* (0.19 yr^{-1} for both sexes), estimated a constant *M*, 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 2018 for the Sub-Antarctic stock (Dunn et al, in prep) and in 2017 for the Chatham Rise stock (Horn 2017) and in 2019 for the West Coast South Island stock. 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 2018 stock assessment was carried out with data up to the end of the 2016–17 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 2016), 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 model had a single area, and was single-sex and age-structured, partitioned into age groups 1–30 with the last age group considered a plus group. Maturity was fixed and estimated outside of the model.

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 1974–2014. The selectivity for the fishery was assumed to be logistic, and the selectivities were domed (double normal) 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 across all years in the fishery and the surveys, and hence there was no allowance for possible annual changes in selectivity. Growth was assumed to be constant and fixed. Natural mortality was estimated as a constant. Year class strengths were estimated.

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.

4.1.2 Fixed biological parameters and observations

There were five main data sources: the catch history; research trawl survey biomass indices from November-December 1992–2017, April–May 1992–98, and September 1992; catch-at-age estimates from the research surveys; catch-at-age estimates from the commercial fishery 1990–2017; and a commercial CPUE biomass index 1991–2017 (sensitivity run only).

Catch history

In order to more closely align with the seasons of the fishery, the model year was set as September to August, rather than the fishing year (October to September). The catch history was modified accordingly (Table 5). The catch history includes the revised estimates of catch reported by Dunn (2003).

Table 5: 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 2018 assume catch to be the same as the previous year.

Model year	Total	Model year	Total
1975	120	1997	1 915
1976	281	1998	2 958
1977	372	1999	2 854
1978	762	2000	3 108
1979	364	2001	2 820
1980	350	2002	2 444
1981	272	2003	2 777
1982	179	2004	3 223
1983	448	2005	2 592
1984	722	2006	2 541
1985	525	2007	1 711
1986	818	2008	2 329
1987	713	2009	2 446
1988	1 095	2010	1 927
1989	1 237	2011	1 319
1990	1 897	2012	1 900
1991	2 381	2013	1 859
1992	2 810	2014	1 800
1993	3 941	2015	1 600
1994	1 596	2016	1 464
1995	1 995	2017	1 033
1996	2 779	2018	1 033

Biological parameters

All biological parameters other than natural mortality rate *M* were estimated outside of the model. Estimated and assumed values for biological parameters used in the assessments are given in Table 4.

Growth was constant and followed the Schnute parameterisation. *M* was constant, and estimated with an informed prior (Table 6). A Beverton-Holt stock recruitment relationship was used with an assumed steepness *h* of 0.8. Year class strengths were estimated for the period 1974–2014, following the Haist parameterisation, with a lognormal prior. Ageing error was assumed (with C.V. = 0.08). All mature fish were assumed to spawn every year.

Table 6: 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	600 000
Year class strengths	Lognormal (μ, cv)	1.0	1.1	0.01	100
Trawl survey *q*[1]	Lognormal (μ, cv)	0.16	0.79	0.01	0.4
CPUE *q*	Uniform-log	–	–	1e-8	1e-3
Selectivities	Uniform	–	–	1	20–200[2]
M	Normal (μ, sd)	0.19	0.05	0.05	0.40

[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.

Research trawl surveys

The biomass estimates from the research trawl surveys are given in Table 7.

Table 7: Research survey indices (and associated CVs) for the Sub-Antarctic stock.

Fishing Year	Vessel	Nov–Dec series [1]		Apr–May series [2]		Sep series [2]	
		Biomass (t)	CV	Biomass (t)	CV	Biomass (t)	CV
1989*	*Amaltal Explorer*	2 660	0.21				
1992	*Tangaroa*	5 686	0.43	5 028	0.15	3 760	0.15
1993	*Tangaroa*	1 944	0.12	3 221	0.14		
1994	*Tangaroa*	2 567	0.12				
1996	*Tangaroa*			2 026	0.12		
1998	*Tangaroa*			2 554	0.18		
2001	*Tangaroa*	2 657	0.16				
2002	*Tangaroa*	2 170	0.20				
2003	*Tangaroa*	1 777	0.16				
2004	*Tangaroa*	1 672	0.23				
2005	*Tangaroa*	1 694	0.21				
2006	*Tangaroa*	1 459	0.17				
2007	*Tangaroa*	1 530	0.17				
2008	*Tangaroa*	2 470	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				
2017[3]	*Tangaroa*	1 000	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. (3) Due to bad weather, the core survey strata were unable to be completed in 2017; biomass estimates were scaled-up using factors based on the proportion of hake biomass in those strata in previous surveys from 2000 to 2014. This introduced additional uncertainty into the 2017 biomass estimate (O'Driscoll et al., in prep.)

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) (Table 6). 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.

Biomass indices were fitted with lognormal likelihoods with assumed CVs set equal to the sampling CV. The CVs (for observations fitted with lognormal likelihoods) are assumed to have allowed for sampling error only. Additional variance, assumed to arise from differences between model simplifications and real world variation, was added to the sampling variance for 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 the CPUE index, the process error CV was assumed to be 0.25.

Catch-at-age

Catch-at-age observations were available for each trawl survey of the Sub-Antarctic, and for the commercial fisheries from observer data. A plus group for all the catch-at-age data was set at 21 with the lowest age set at 3. Catch-at-age distributions were fitted assuming multinomial errors, with an effective sample size set following Francis (2011) (Table 8).

Table 8: Catch-at-age data for the Sub-Antarctic stock, giving the multinomial effective sample sizes assumed for each sample. The effective sample size is proportional to the weight given to the data in the model fit.

	Research survey			
Fishing year	**Nov-Dec**	**Apr-May**	**September**	**Commercial catch-at-age**
1990	19			7
1991				
1992	21	16	17	17
1993	30	16		14
1994	36			5
1995				
1996		12		10
1997				
1998		13		16
1999				31
2000				49
2001	58			14
2002	46			21
2003	52			10
2004	38			18
2005	30			6
2006	40			21
2007	51			6
2008	49			16
2009	59			18
2010	45			31
2011				48
2012	49			42
2013	60			16
2014				47
2015	22			18
2016				31
2017				31

4.1.3 Model estimation

In the base model, the main parameters estimated were: virgin (unfished, equilibrium) biomass (B_0), trawl-survey selectivity, fishery selectivity, natural mortality rate, and year class strengths (YCS) from 1974 to 2014.

A wide range of sensitivity models were run. Sensitivity models reported here were run to investigate the effect of estimating *M* as an age-dependent ogive while assuming a double normal selectivity for the fishery (to match the assumptions of the previous assessment) and alternative assumptions for the prior on year class strength. Additional sensitivity models not reported included one that used only data from the commercial fishery (CPUE series and catch-at-age).

The fits to the biomass indices were acceptable (Figure 2). Fits to the catch-at-age were generally good, although relatively strong recruitment from around 1992 apparent in the observer samples was not well fitted (Figure 3); this recruitment was not apparent in the research survey samples (Figure 4).

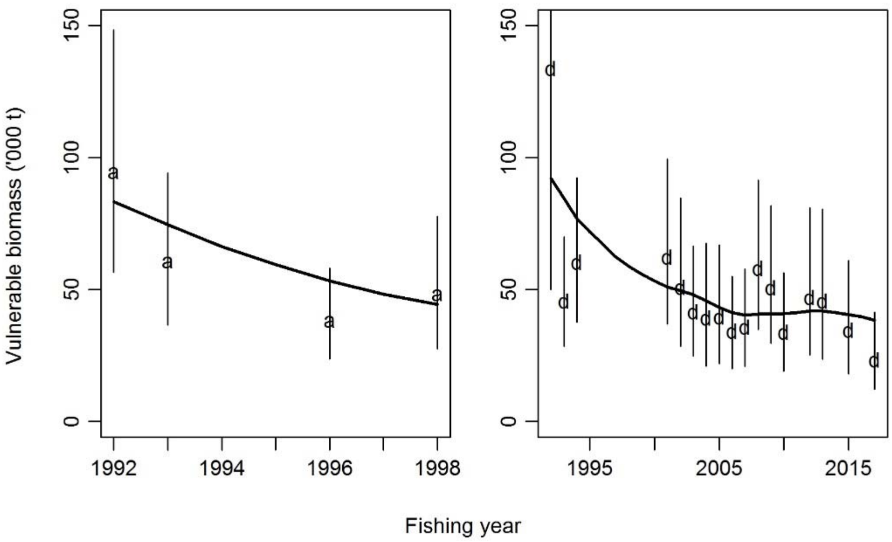


Figure 2: Fits of the base model for the Sub-Antarctic stock (solid lines) to the April-May (a) and November-December (d) research trawl biomass indices. Vertical lines indicate the 95% CI.

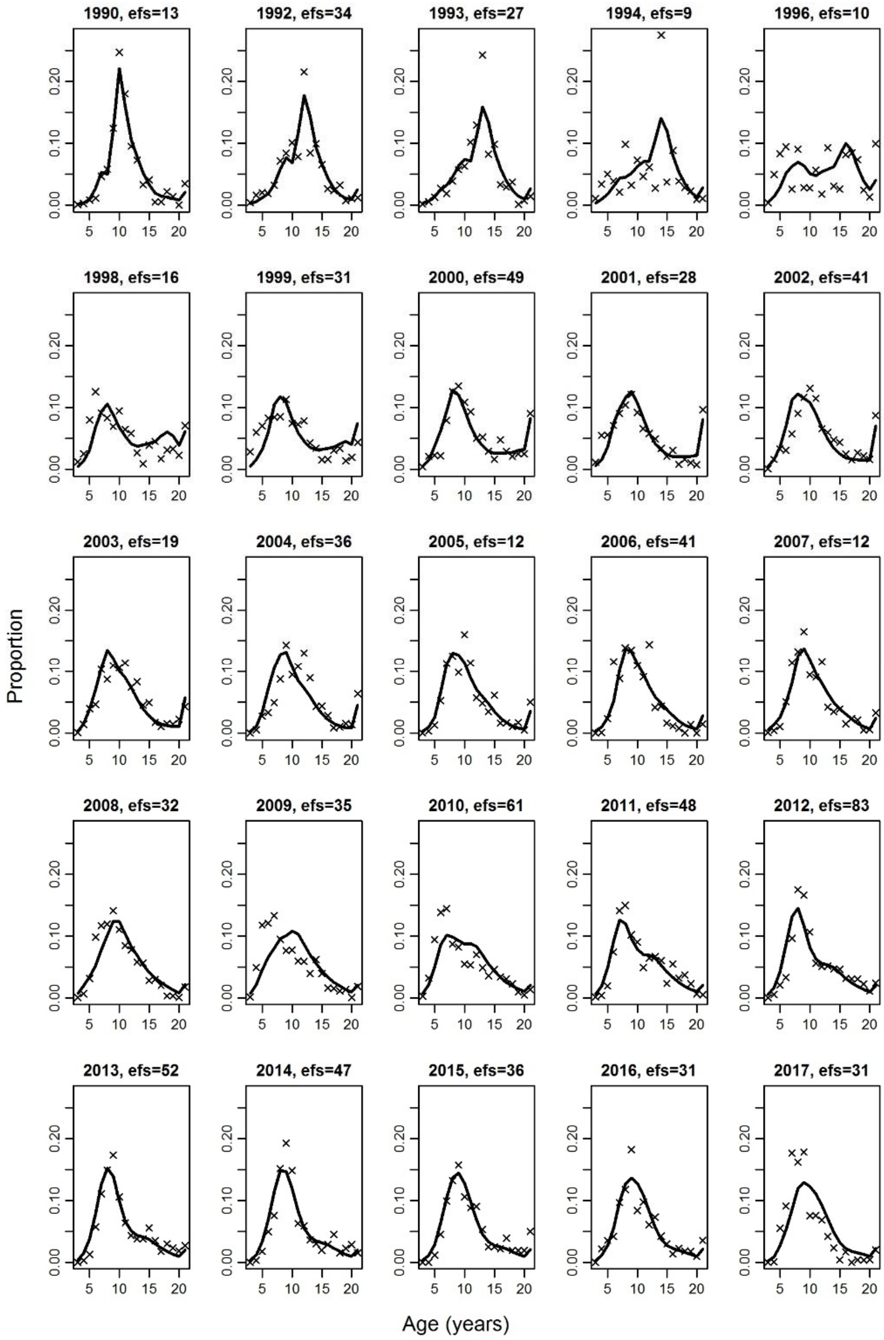


Figure 3: Model fit (solid lines) to the catch-at-age observations from the observer commercial fishery samples (×) for the base model run for the Sub-Antarctic stock. EFS, multinomial effective sample size.

Estimated selectivities for the surveys were not strongly domed (even though they were estimated using double-normal parameterisation). Hake were fully selected by the November-December survey at age 4.5, by the April-May and September surveys at age 15, and by the fishery at about age 10.

Year class strength estimates suggested that the Sub-Antarctic stock was 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 2014 (Figure 5).

The absolute catchability of the Sub-Antarctic trawl surveys was estimated to be extremely low (Figure 6). Although catchability was expected to be higher, 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.

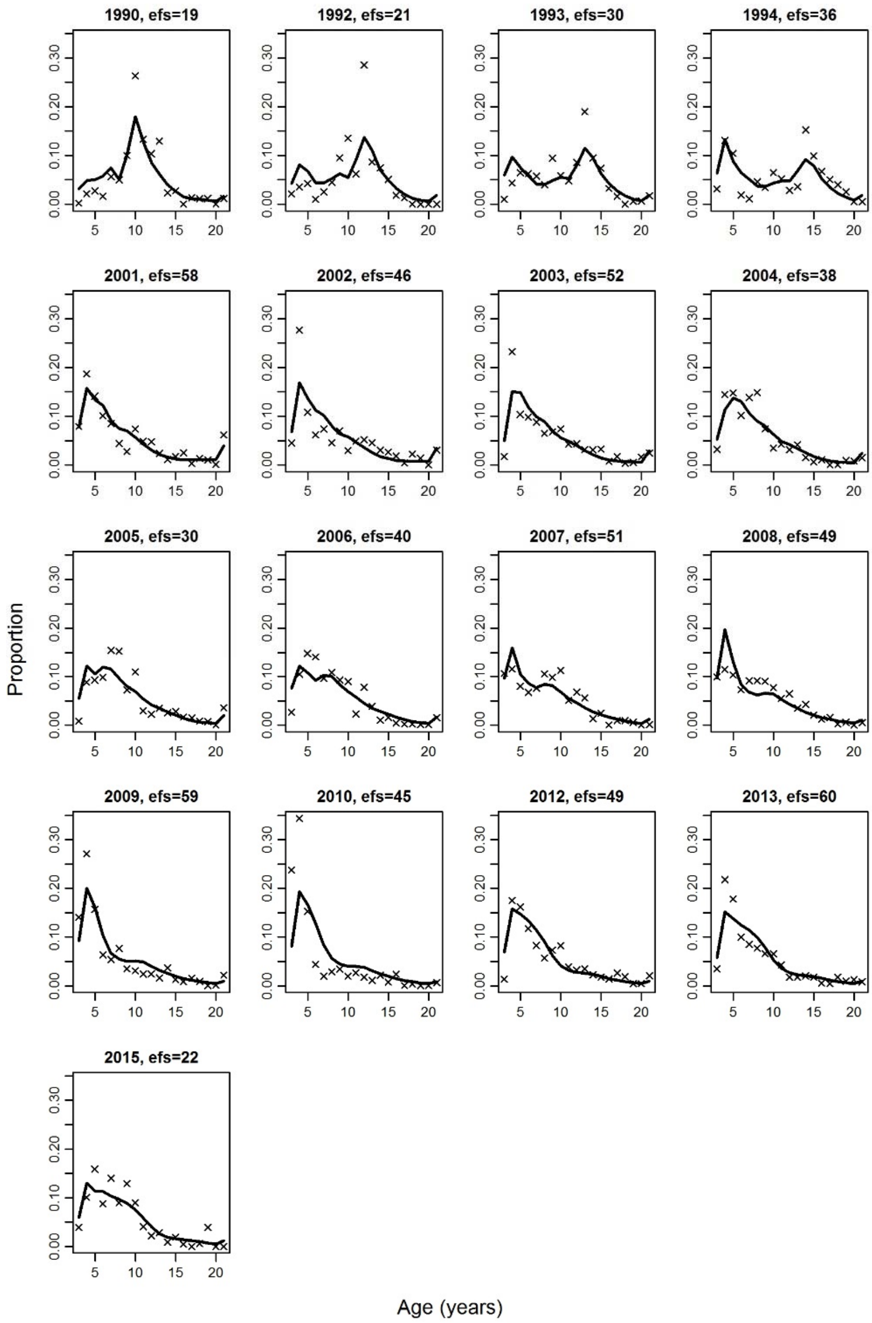


Figure 4: Model fit (solid lines) to the catch-at-age observations from the November-December research trawl survey samples (×) for the base model run for the Sub-Antarctic stock. EFS, multinomial effective sample size.

Biomass estimates for the stock appeared relatively healthy, with estimated current biomass from the base model at about 55% B_0 (Figure 7, Table 9). Annual exploitation rates (catch over vulnerable biomass) were low in all years as a consequence of the high estimated stock size relative to the level of catches (Figure 8).

A wide range of sensitivity runs was conducted, but in general these produced similar estimates of stock size and status. The 2018 assessment model was different to the previous (2014) model in assuming a logistic rather than domed selectivity for the fishery, and a constant rather than at-age natural mortality rate. However, the biomass estimates from the base model and previous model (run Previous) were similar (Table 9). The MPD model runs were found to be sensitive to the assumed prior on year class strengths (the CV, σ_R), but modifying σ_R to 0.7 made little difference to MCMC results (run Base 0.7). The sensitivity run using only commercial fishery data (run Commercial; CPUE and observer catch-at-age only) did not allow the observer catch-at-age to be better fitted, and was not considered plausible.

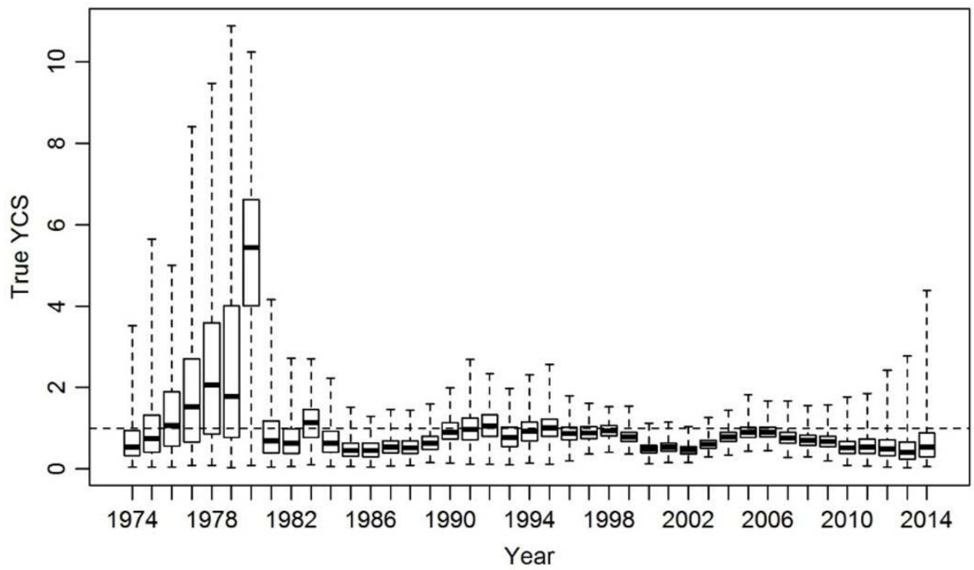


Figure 5: Estimated posterior distributions of year class strengths for the base case for the Sub-Antarctic stock. The dashed horizontal line indicates a year class strength of one. Individual distributions show the marginal posterior distribution, with horizontal lines indicating the median.

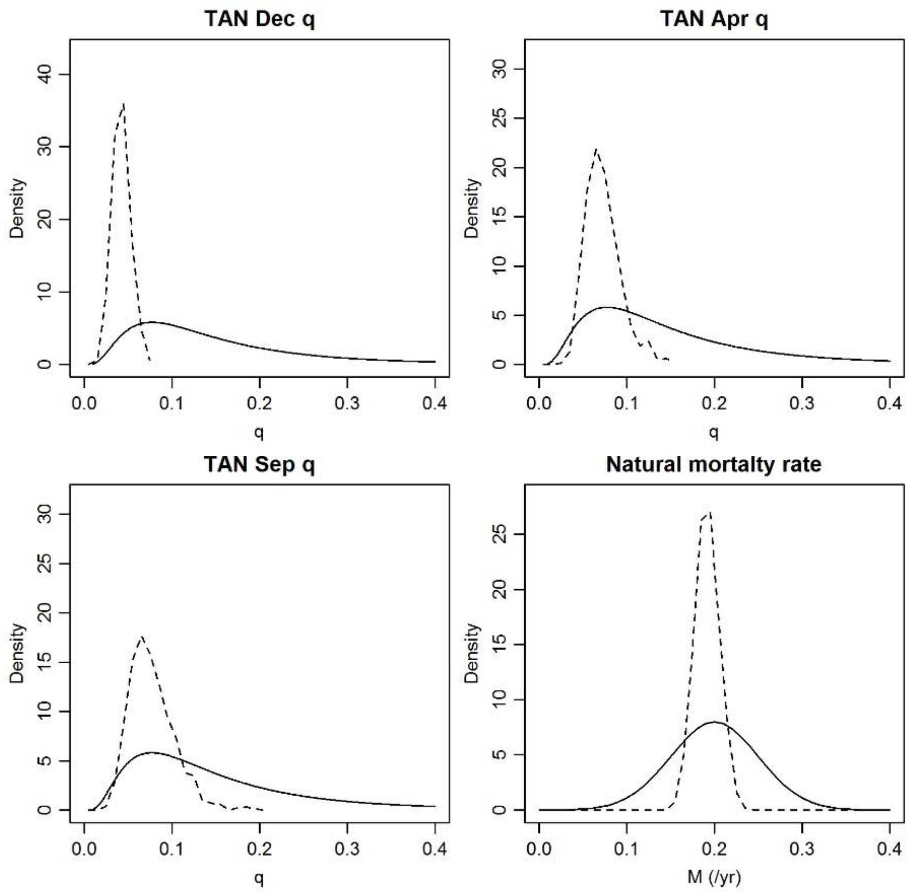


Figure 6: Estimated prior (solid lines) and posterior distributions (broken line) of catchability for the research trawl surveys, and natural mortality rate, for the base case for the Sub-Antarctic stock.

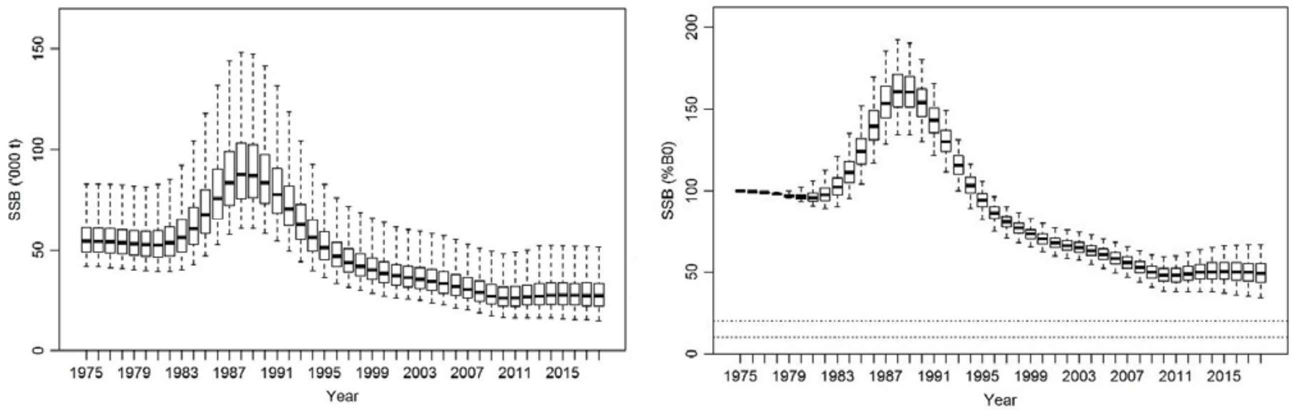


Figure 7: Estimated median trajectories (with 95% credible intervals shown as dashed lines) for the Sub-Antarctic stock base case model for absolute biomass and biomass as a percentage of B_0. The management target (40% B_0, solid horizontal line) and soft limit (20% B_0, dotted horizontal line) are shown on the right-hand panel.

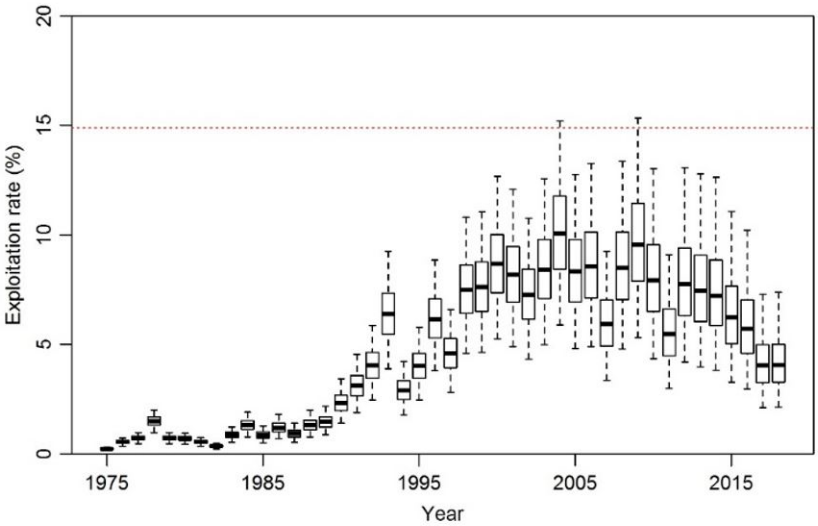


Figure 8: Exploitation rates (catch over vulnerable biomass) for the Sub-Antarctic stock base case model. The horizontal broken line indicates the exploitation rate at 40% B_0 (U_{40}; median derived from MCMC samples).

Table 9: Bayesian median (95% credible intervals) (MCMC) of B_0, B_{2018}, B_{2018} as a percentage of B_0, and the probability of B_{2018} being below the target (40% B_0), for the Sub-Antarctic base model and sensitivity runs.

Model run	B_0	B_{2018}	B_{2018} (%B_0)	P(B_{2018} > 0.4 B_0)
Base	54 600 (41 500–83 200)	27 200 (14 800–51 300)	49 (34–67)	0.11
Previous	54 400 (40 100–85 400)	31 700 (16 900–61 200)	57 (40–78)	0.03
Base 0.7	52 600 (41 700–80 100)	27 900 (16 100–52 100)	53 (38–70)	0.05

Projections

Five-year biomass projections were made for the Base model run assuming future catches in the Sub-Antarctic to be an average of the catch from the last three years (1366 t), or the TACC (3701 t). For each projection scenario, future recruitment variability was sampled from actual estimates between 1974 and 2012 (entire time series, where all year classes measured at least three times), or 2003 and 2012 (last ten years).

Table 10: HAK 1 Bayesian median and 95% credible intervals (in parentheses) of projected B_{2023}, B_{2023} as a percentage of B_0, and B_{2023}/B_{2018} (%) for the model runs.

Model run	Catch	B_{2023}	B_{2023} (%B_0)	B_{2023}/B_{2018} (%)	p(B_{2023} < 0.2 B_0)	p(B_{2023} < 0.1 B_0)
Base 1974–2012	1 366	28 800 (14 500–59 500)	52 (33–81)	104 (76–154)	0	0
	3 701	21 000 (7 000–51 800)	38 (16–71)	76 (40–131)	0.05	0.01
Base 2003–2012	1 366	26 200 (13 300–53 200)	47 (30–72)	95 (73–130)	0	0
	3 701	18 400 (5 600–46 100)	33 (12–61)	67 (34–103)	0.12	0.01

At the current catch (1 366 t), SSB is predicted to remain stable over the next five years (Table 10). At a catch of the TACC (3 701 t), SSB is predicted to decrease. At the current catch, the estimated probability of SSB falling below the soft or hard limits is zero. At the TACC, the probability of the SSB dropping below the soft limit is 5% if large year classes such as those seen around 1980 are possible, and 12% if year class strength remains at recent levels.

4.2 HAK 4 (Chatham Rise stock)

The 2017 stock assessment was carried out with data up to the end of the 2015–16 fishing year. The assessment used research time series of abundance indices (trawl surveys of the Chatham Rise from 1992 to 2016), 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 1975–2013. 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 across 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 1 800 t or the mean annual catch over the last six years (400 t). For the projections, estimated future recruitment variability was sampled from actual estimates between 1984 and 2013, 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 Table 4. 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 v2.30 (Bull et al 2012). 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 0.15 estimated from an MPD run. A process error CV of 0.20 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.

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	1996	1 353	2 483	3 836
1976	152	336	488	1997	1 475	1 820	3 295
1977	74	1 214	1 288	1998	1 424	1 124	2 547
1978	28	6	34	1999	1 169	3 339	4 509
1979	103	506	609	2000	1 155	2 130	3 285
1980	481	269	750	2001	1 208	1 700	2 908
1981	914	83	997	2002	454	1 058	1 512
1982	393	203	596	2003	497	718	1 215
1983	154	148	302	2004	687	1 983	2 671
1984	224	120	344	2005	2 585	1 434	4 019
1985	232	312	544	2006	184	255	440
1986	282	80	362	2007	270	683	953
1987	387	122	509	2008	259	901	1 159
1988	385	189	574	2009	1 069	832	1 902
1989	386	418	804	2010	231	159	390
1990	309	689	998	2011	822	118	940
1991	409	503	912	2012	70	154	224
1992	718	1 087	1 805	2013	215	164	379
1993	656	1 996	2 652	2014	65	150	215
1994	368	2 912	3 280	2015	62	174	236
1995	597	2 903	3 500	2016	110	230	340

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
2016	*Tangaroa*	1 299	0.14

Year class strengths were assumed known (and equal to one) for years before 1975 and after 2013, 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 3×10^6 iterations, with every 5000th sample taken from the next 5×10^6 iterations (i.e., a final sample of length 1000 was taken from the Bayesian posterior).

4.2.4 Prior distributions and penalty functions

The assumed prior distributions used in the assessment are given in Table 13. 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 4.1.2

above. The prior for M was informative and assumed a normal distribution with a CV of 0.2 around a mean of 0.19.

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 and normal priors, and mean (in natural space) and standard deviation for normal-by-stdev priors.

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*
M	Normal	0.19	0.2	0.1	0.35

* 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 a constant 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. 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 9) and biomass (Figure 10). 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 since then (except for 2002, 2010 and 2011). Consequently, biomass increased slightly during the late 1980s, then declined to about 2005. The growth of the strong 2002 year class resulted in an upturn in biomass from about 2006, followed by a further upturn from 2015 as the 2010 and 2011 year classes began to recruit. Current stock biomass was estimated at about 48% of B_0 (see Figure 10 and Table 14). Annual exploitation rates (catch over vulnerable biomass) were low (less than 0.1) up to 1993 and since 2006, but moderate (although probably less than 0.25) in the intervening period (Figure 11).

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 7 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 remain constant at about 48% of B_0 by 2021 (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 400 t in the last six 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). Future catches of 400 t per year will allow further stock rebuilding.

Table 14: Bayesian median and 95% credible intervals of B_0, B_{2016}, and B_{2016} as a percentage of B_0 for the Chatham Rise model runs.

Model run	B_0	B_{2016}	B_{2016} (% B_0)
Base case	30 080 (26 510–40 090)	14 540 (10 850–22 460)	48.2 (40.0–59.1)
Tight survey prior	32 620 (28 420–39 600)	16 000 (11 770–23 120)	49.4 (40.9–59.8)
Estimate *M*	32 500 (27 440–47 110)	19 020 (13 160–33 220)	58.0 (46.2–74.0)
CPUE	36 910 (30 760–64 230)	20 160 (14 910–40 510)	54.5 (46.8–64.7)

Table 15: Bayesian median and 95% credible intervals of projected B_{2021}, B_{2021} as a percentage of B_0, and B_{2021}/B_{2016} (%) for the Chatham Rise model runs.

Model run	Future catch (t)	B_{2021}	B_{2021} (% B_0)	B_{2021}/B_{2016} (%)
Base	1 800	14 700 (8 850–25 600)	48.3 (32.3–69.6)	100 (75–132)
	400	19 170 (13 620–30 280)	63.7 (48.9–83.4)	132 (108–162)
Tight survey prior	1 800	16 560 (9 980–26 260)	50.3 (33.8–70.1)	101 (77–132)
	400	21 180 (14 810–31 800)	64.9 (49.2–84.1)	130 (107–160)
Estimate *M*	1 800	19 490 (11 570–35 640)	59.5 (39.9–87.0)	102 (78–133)
	400	23 770 (15 570–38 720)	72.5 (53.9–95.9)	124 (99–156)
CPUE	1 800	21 010 (13 240–44 050)	56.6 (40.4–78.2)	103 (79–136)
	400	25 580 (17 920–49 950)	68.7 (54.7–89.3)	126 (104–156)

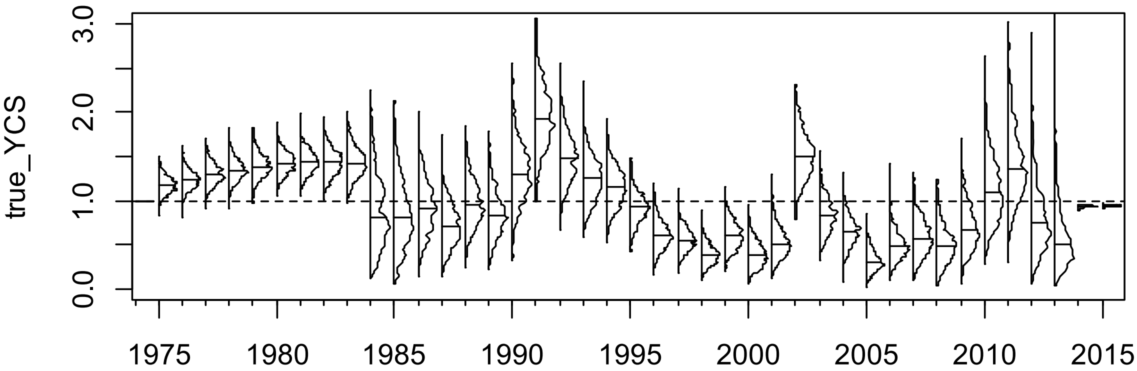


Figure 9: Estimated posterior distributions of year class strengths for the Chatham Rise (HAK 4) base case. The dashed horizontal line indicates a year class strength of one. Individual distributions show the marginal posterior distribution, with horizontal lines indicating the median.

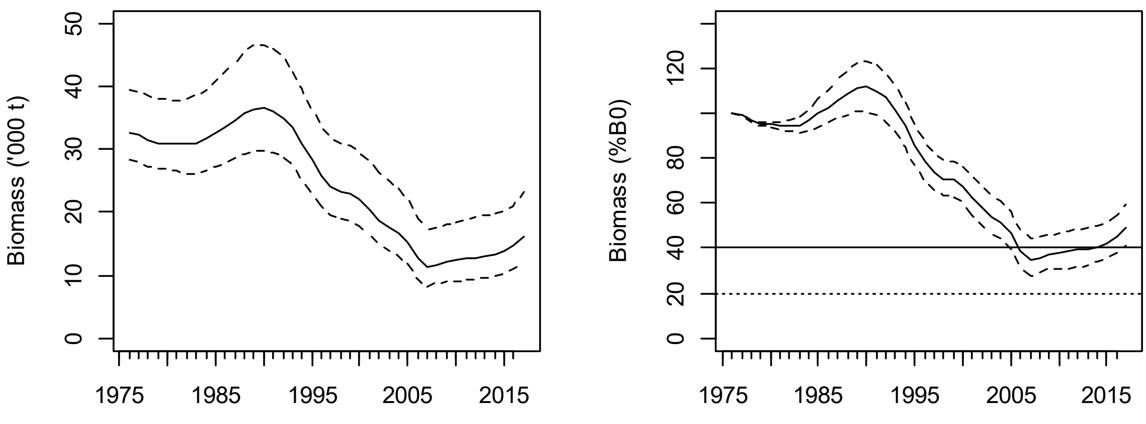


Figure 10: Estimated median trajectories (with 95% credible intervals shown as dashed lines) for the Chatham Rise (HAK 4) base case model for absolute biomass and stock status (biomass as a percentage of B_0).

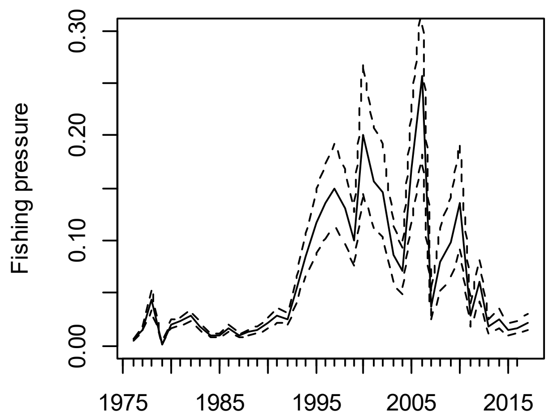


Figure 11: Exploitation rates (catch over vulnerable biomass) for the Chatham Rise stock base case model.

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 stock assessment for HAK 7 was accepted by the working group in 2019, building on previous assessments. Earlier work used standardized Catch Per Unit Effort (CPUE) as an index of abundance (Dunn, 1998). Later, CPUE was included in the model in combination with a biomass index from a scientific survey, conducted by *RV Tangaroa* (Horn 2011, 2013b). As additional survey data were collected over the period 2012–16 (Table 16), the trends in abundance provided by the CPUE and survey indices diverged to the point that they could not be reconciled within a single stock assessment model (Horn, 2017). The 2019 assessment base case used the survey indices only (including the 2018 survey index). Results from the model using the CPUE index in place of the survey abundance index are presented as a sensitivity run.

The present assessment for HAK 7 modelled the fishery from 1974–75 to 2018–19. It used catches and catch age composition data from the commercial trawl fishery, research trawl survey biomass indices and age composition data, and biological parameters available in the scientific literature.

4.3.1 Model structure

The model assumed a single sex (male and females combined), having 30 unsexed age groups, with the last age group being a plus (accumulator) group. Natural mortality was assumed constant at M=0.19 year^{-1}. The model assumed two time-steps: the first representing the period between October and May when recruitment occurred; and the second June to September, when the fishery and the survey took place. Selectivity ogives were assumed to follow logistic ogives for the commercial fishery, and double-normal with an estimated descending right-hand limb for the trawl survey. Models were explored using double-normal ogives for the commercial fishery, and the resulting estimated curves were almost logistic, with little difference to the model fits or results. Hake sexual maturation was set to occur according to an age-specific schedule informed by biological studies. The relation between spawning stock biomass and recruitment was assumed to follow a Beverton and Holt relationship with assumed fixed steepness equal to 0.84. The model was initialised assuming an equilibrium age structure at an unfished equilibrium biomass (B_0) in 1975, i.e., with constant recruitment set equal to the mean of the recruitments over the period 1975 to 2015.

4.3.2 Fixed biological parameters and observations

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

Commercial fishery catch-at-age observations were available for 1979 (fishing by RV *Wesermünde*), and from observers from 1989–90 to 2017–18 (Fig. 12). Until 2005, the most frequently caught age-groups of hake in the fishery were between 6 and 12 years old, and after 2005 between 5 and 9 years old.

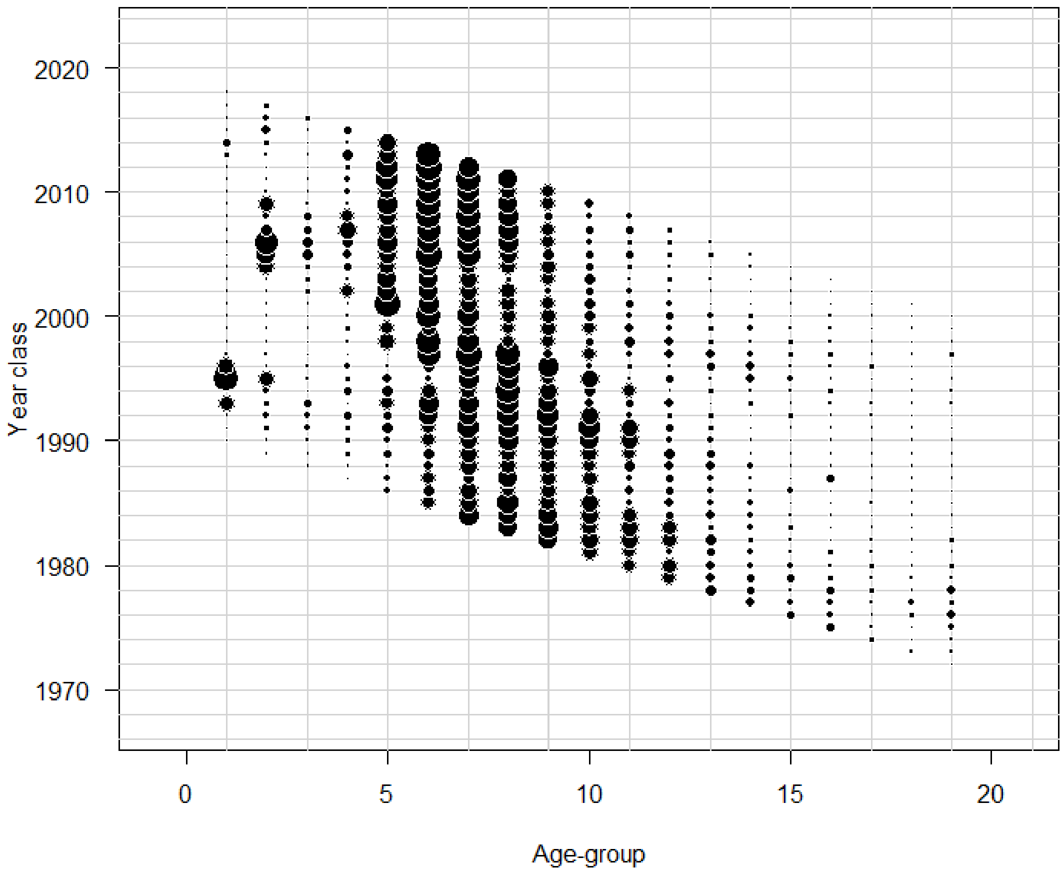


Figure 12: Proportion of hake estimated in the HAK 7 commercial trawl fishery by age-group (x-axis) and year class (y-axis) for data collected from 1990-2018.

The research trawl survey on the west coast of the South Island has been carried out since 2000. This survey initially covered an area from 300 to 650 m depth north of Hokitika Canyon (‘core area’). Since 2012, the survey focus was changed by extending into both shallower and deeper water to more adequately cover the distribution of a number of species, including hake (covering an area referred to as ‘all areas’). The survey was initially extended from 200 to 800 m. An additional 800–1000 m deep stratum was added in 2016, to monitor shovelnose dogfish and ribaldo. However, the survey remains north of Hokitika Canyon and consequently does not monitor populations, including hake, which are in the canyon and south.

Due to variable estimates in the numbers of hake aged 1 and 2 observed in the survey, possibly from the changes in coverage over time, these age classes were excluded from the survey biomass estimates and survey age data used in the model.

The representativeness of the survey (either core or all) of the hake population on the WCSI is not well known and the survey may index a changing proportion of the population over time. This is because this survey does not monitor areas south of the Hokitika Canyon which are known to support hake in reasonable numbers.

Standardised CPUE indices are shown in Table 17. Because of concerns about changing fishing behaviour, including targeting and avoidance, advances in gear technology, and changes in fleet structure, the working group considered the CPUE to be a less reliable index of abundance than the fishery independent survey series.

Table 16: Research survey indices of abundance (biomass in tonnes) and associated CVs (in parentheses) for core and all survey areas.

Year	core	all
2000	803 (0.13)	NA
2012	579 (0.13)	1 096 (0.13)
2013	328 (0.17)	740 (0.22)
2016	208 (0.25)	316 (0.18)
2018	227 (0.33)	549 (0.18)

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

Year	Index	CV
2000–01	0.91	0.04
2001–02	2.56	0.03
2002–03	0.47	0.07
2003–04	1.20	0.03
2004–05	0.92	0.03
2005–06	1.03	0.03
2006–07	0.86	0.06
2007–08	0.39	0.05
2008–09	0.23	0.06
2009–10	0.46	0.06
2010–11	0.75	0.05
2011–12	0.82	0.03
2012–13	1.36	0.03
2013–14	0.88	0.03
2014–15	0.92	0.03
2015–16	0.89	0.03
2016–17	1.04	0.03
2017–18	1.34	0.03

The catch history assumed in the model runs is shown in Table 18.

Table 18: Revised landings (t) from fishing years 1975 to 2018 for the West Coast South Island. Note, these relate to biological stocks, not QMAs.

Fishing year	West Coast S.I.	Fishing year	West Coast S.I.
1974–75	71	1996–97	6 838
1975–76	5 005	1997–98	7 674
1976–77	17 806	1998–99	8 742
1977–78	498	1999–00	7 031
1978–79	4 737	2000–01	8 346
1979–80	3 600	2001–02	7 498
1980–81	2 565	2002–03	7 404
1981–82	1 625	2003–04	7 939
1982–83	745	2004–05	7 298
1983–84	945	2005–06	6 892
1984–85	965	2006–07	7 660
1985–86	1 918	2007–08	2 583
1986–87	3 755	2008–09	5 912
1987–88	3 009	2009–10	2 282
1988–89	8 696	2010–11	3 462
1989–90[1]	8 741	2011–12	4 299
1990–91[1]	8 246	2012–13	5 171
1991–92	3 010	2013–14	3 387
1992–93	7 059	2014–15	5 966
1993–94	2 971	2015–16	2 733
1994–95	9 535	2016–17	4 599
1995–96	9 082	2017–18	2 968

4.3.3 Model estimation

Model parameters were derived using Bayesian estimation, implemented by using the general-purpose stock assessment program CASAL v2.30 (Bull et al 2012). For final model runs, the full posterior distribution was sampled using Markov Chain Monte Carlo (MCMC) methods.

The model was fitted to proportions-at-age using a multinomial probability distribution, and to the survey abundance index using a lognormal distribution. A process error of 0.10 was applied on the biomass index in addition to its measurement uncertainty (CVs in Table 16). A process error CV of 0.30 for the CPUE series was estimated following the recommendations of 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 normally distributed error with a CV of 0.08.

Year class strengths were assumed known (and equal to one) for years before 1974–75 and after 2014–15, 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 to one.

4.3.4 Prior distributions and penalty functions

The assumed prior distributions used in the assessment are given in Table 19. 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 prior as a starting point (see Section 4.1.2) 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 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. Because the biomass survey coverage only includes 54% of the known WCSI hake habitat, the mean of the Chatham Rise prior 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]. The same prior was used for the 'core area'. Priors for all selectivity parameters were assumed to be uniform.

The prior on the year class strength was lognormal with mean equal to 1 and standard deviation (σ_R) equal to 1.1. 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 19: The assumed priors for key distributions (when estimated) for the WCSI stock assessment. The parameters are mean (in natural space) and CV for lognormal and normal priors.

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*

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

4.3.2 Model sensitivities

Three model sensitivity models were developed. The 'CPUE' sensitivity model used CPUE to index abundance in place of the survey. The 'core' sensitivity model used the 'core' survey biomass index in place of the 'all' survey biomass index. The 'YCS c.v.' sensitivity model reduced the coefficient of variance (CV) on Year Class Strength (YCS) estimates from 1.1 as it is in the base model, to 0.8. A fourth sensitivity model assumed a single selectivity function while the base case and the remaining selectivity runs estimated separate selectivity functions before and after 2005 because of the shift in the age composition of the catch described above in Section 4.3.2.

4.3.5 Model estimates

Results from the base case assessment model (model 'survey all'), and four sensitivity models are presented here. The sensitivity models are: (1) the effect of a narrower prior on year class strength (i.e., the CV on the prior was 0.8 instead of 1.1); (2) using core survey areas instead of all survey areas (model 'survey core'); (3) using a single selectivity for the commercial fishery throughout the time series (model 'single sel'); and (4) replacing the survey index of abundance by a standardized CPUE index (model 'CPUE').

For all models, MPD fits were obtained and qualitatively evaluated. For all models except the single selectivity model, MCMC estimates of the median posterior and 95% percentile credible intervals were determined for current and virgin biomass, and projected states. The 'single sel' selectivity run was only run to the MPD level and is not reported in Table 20.

The base case stock assessment model estimated spawning stock biomass declined throughout the late 1970s (Figure 13) when there were relatively high catch levels. The biomass then increased through the mid-1980s, after which it steadily declined to a low point in 2018–19 owing to higher levels of exploitation and below-average recruitment from 2000–01 to 2014–15 (Figure 14).

The model YCS prior with CV=0.8 produced similar trends in year class strength (Figure 14), and estimated SSB_{2019}/B_0 to be 19.1%, 2% higher than the base case model (Table 20). The base case model estimated the SSB in 2018–19 to be 17.0% of virgin biomass (B_0), with a 95% credible interval ranging from 9.7% to 28.5%.

The survey core sensitivity produced a better fit to the survey biomass index (Figure 15), and estimated stock status to be 1% greater than the base case run with wider credibility bounds (Table 19).

Table 20: Bayesian median (95% credible intervals) (MCMC) of SSB_0, SSB_{2019}, and SSB_{2019} as a percentage of B_0 for the WCSI models.

Model run	B_0		SSB_{2019}		SSB_{2019} (%B_0)	
Survey all	70 046	(65 945–75 588)	11 904	(6 636–20 977)	17.0	(9.7–28.5)
Survey core	70 430	(65 930–72 218)	13 068	(6 082–24 929)	18.5	(8.9–33.0)
YCS c.v.	70 586	(66 425–76 419)	13 442	(7 632–23 569)	19.1	(11.2–31.6)
CPUE	84 745	(76 048–99 139)	52 595	(31 309–88 696)	62.0	(40.5–90.8)

4.3.2 Model sensitivities

Three model sensitivity runs were developed. The 'CPUE' sensitivity model used CPUE to index abundance in place of the survey. The 'core' sensitivity model used the 'core' survey biomass index in place of the 'all' survey biomass index. The 'YCS c.v.' sensitivity model reduced the coefficient of variance (CV) on Year Class Strength (YCS) estimations from 1.1 as it is in the base model to 0.8.

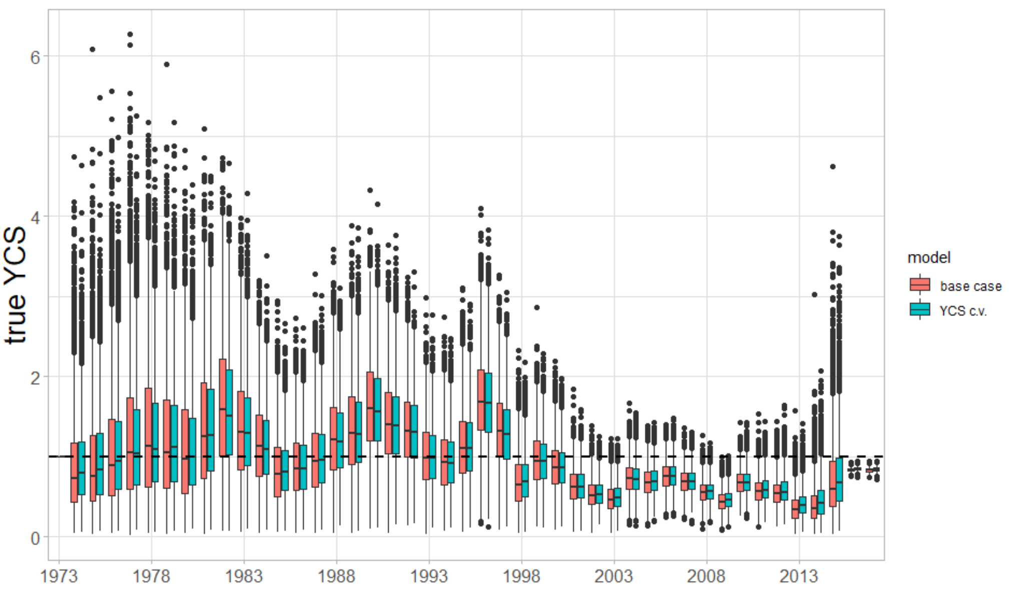


Figure 14: MCMC estimates of year class strength for the base case model and the sensitivity model investigating a narrower prior distribution (YCS c.v.=0.8 instead of 1.1)

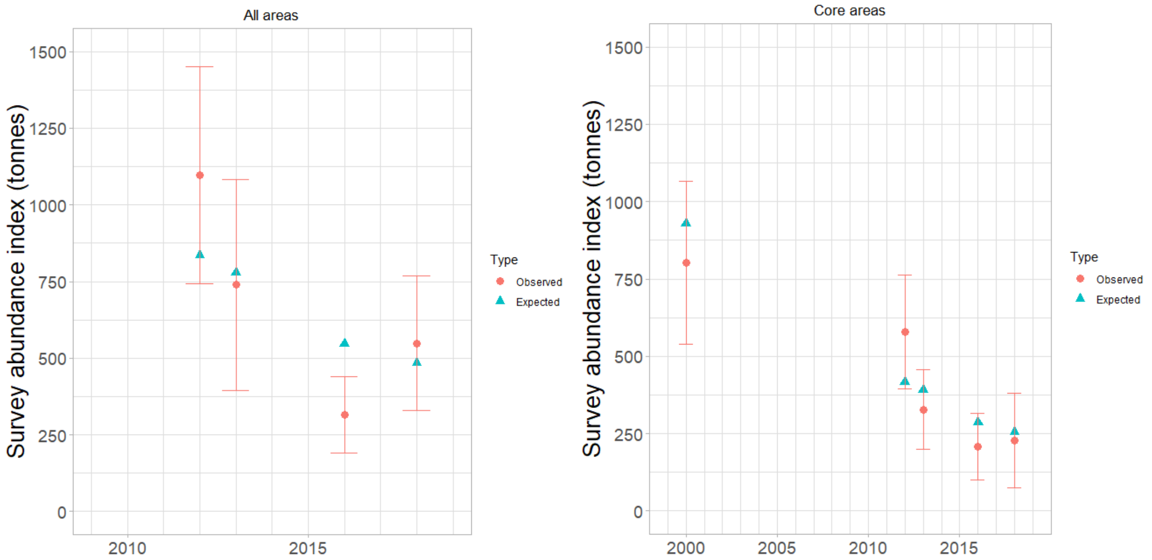


Figure 15: Fit of the base case model to the survey index of abundance from all areas (left) and fit of the sensitivity model to core survey area (right).

Base case MPD estimates from the logistic selectivity ogives (Figure 16) indicated that 8% of age five and 50% of age seven hake were retained by the commercial trawl before 2005. After 2005, the proportion retained increased to 42% at age five and 96% at age seven. The 'single sel' model run estimated a selectivity ogive between these two, with 55% retention at age six. The base case model fitted the proportion-at-age data better than the 'single sel' run, and supports the assumption that selectivity changed around 2005.

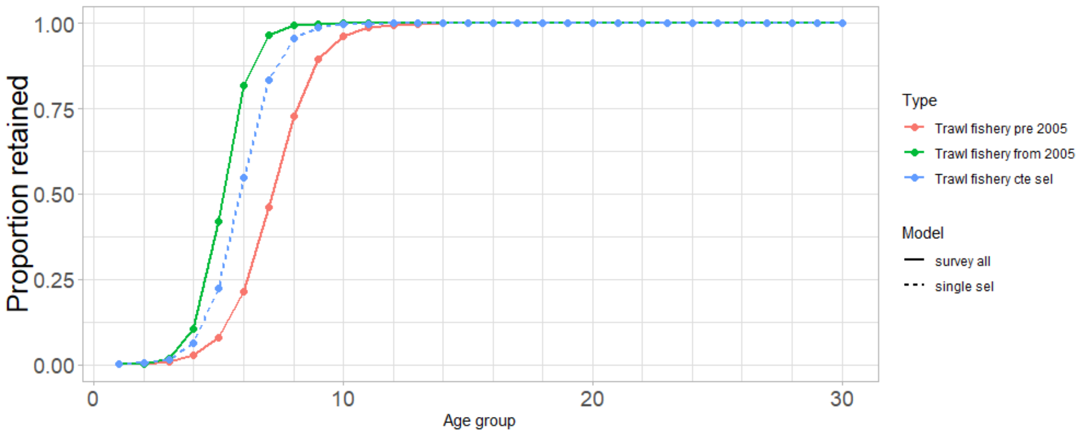


Figure 16: MPD estimated logistic commercial trawl gear selectivity estimated for the base case model (survey all) and the sensitivity model (single sel).

The CPUE sensitivity run estimated a substantially different trend in SSB (Figure 17), which increased after 2007–08 to an SSB_{2019}/B_0 of 62.0% (CI 40.5–90.8%).

For the base model, the exploitation rate was estimated to have first exceeded the exploitation rate that would result in the target biomass ($U_{40\%}$) in 1986–87, and then remained higher than $U_{40\%}$ until 2018–19 (Figure 18). $U_{40\%}$ was estimated at 9% for the base model, but would be 12% if future fishery selectivity returned to that estimated before 2004–05.

4.3.6 Yield estimates and projections

The biomass of HAK 7 was projected five-years into the future (2019–2024), assuming two scenarios for future WCSI catches: (1) catches staying at 2017–18 levels (2968 t annually) and (2) catches at the TACC limit (5064 t annually). For each projection scenario, future recruitment deviates were sampled from two sets of recruitment estimates (1) recruitment estimates between 1973 and 2015 and (2) between 2006 and 2015. Note that the *RV Tangaroa* survey in 2018 and *RV Kaharoa* inshore survey in 2017 suggested that the 2016 year class was above average, but these data were not included in the projections.

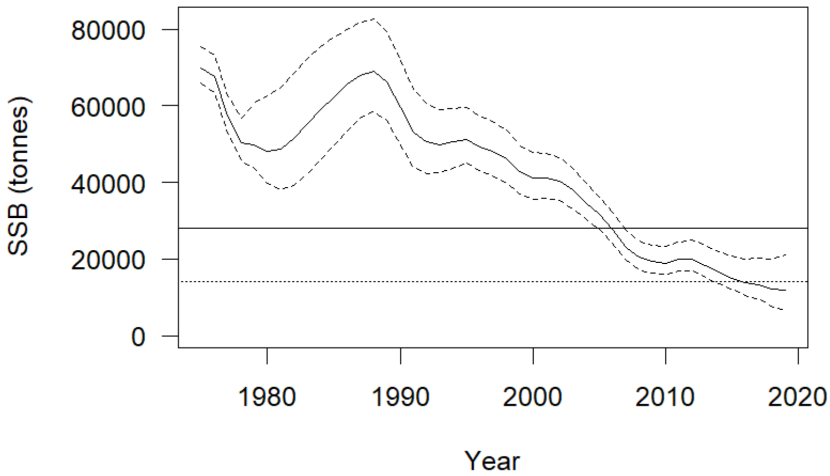


Figure 17: Estimated median trajectories (with 95% credible intervals shown as dashed lines) for the WCSI stock base case. The management target (40% B_0, solid horizontal line) and soft limit (20% B_0, dotted horizontal line) are shown as horizontal solid and dotted lines respectively.

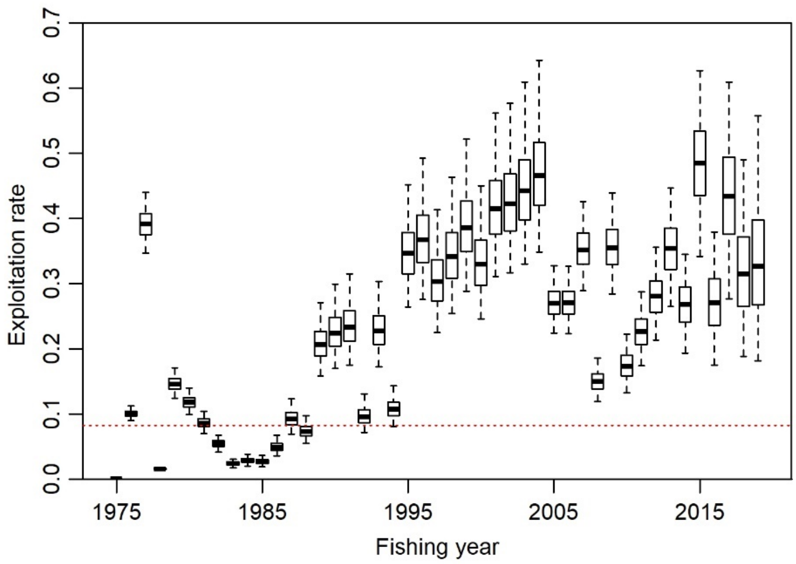


Figure 18: Exploitation rates (catch over vulnerable biomass) for the WCSI 'survey all' model. The horizontal broken line indicates the exploitation rate at 40% B_0 (U_{40}; median derived from MCMC samples).

Projections with the base case model ('survey all') using the 2006–2015 recruitment series, which is below average, indicated that spawning biomass will remain below 20% B_0 with catches equal to 2968 t (Table 21, Figure 19). If catches were to increase to the current TACC, the SSB in 2024 would drop to 8.8% B_0 (4.3–33.5%). When projections Bare made from average recruitment (1974–2015), the SSB is expected to increase at current level of catches and stay at a similar level if the TACC were to be caught.

Projections when assuming a narrower 'recruitment variability (YCS c.v.=0.8 model) estimated 2–4% increases to the projected biomass relative to the base case. The 'core survey' model also projected the stock status to be slightly greater than the base case model (1–3%). The CPUE model projected that the stock will remain above 40% B_0 in all scenarios.

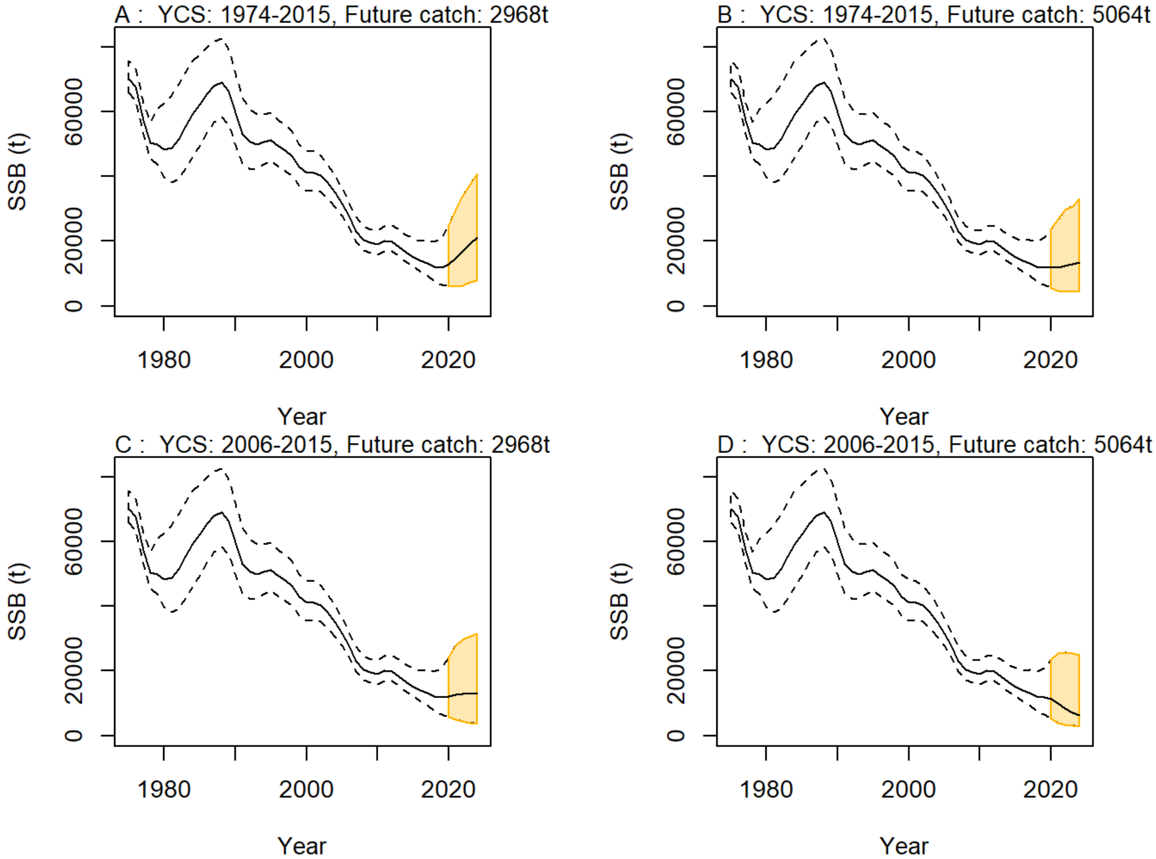


Figure 19: Spawning Stock Biomass (SSB) trajectories including projections from 2020–2024 for the Base model (Survey all), projected with catch of 2968 t (A, C) or TACC catch (B, D), with YCS sampled from all years (A, B) or most recent estimated 10 years (C, D).

Table 21: Bayesian median and 95% credible intervals of projected B_{2024}, B_{2024} as a percentage of B_0, and B_{2024}/B_{2019} (%) for the 'survey' and 'CPUE' models, under two future annual catch scenarios and two future recruitment scenarios.

Future catch (t)	Future YC	B_{2019}		B_{2024}		B_{2024} (%B_0)		B_{2024}/B_{2019} (%)	
Survey all model									
2968	2006-2015	11 815	(6 513–20946)	13 127	(3 695–31 629)	18.7	(5.4–42.8)	110	(49–194)
5064		11 823	(6 499–20934)	6 167	(2947–24 967)	8.8	(4.3–33.5)	57	(32–140)
2968	1974-2015	11 891	(6 604–21 038)	21 271	(7 951–40 903)	30.4	(11.7–56.0)	174	86–320)
5064		11 912	(6 604–21 036)	13 427	(4 362–33 506)	19.0	(6.4–45.1)	110	(44–248)
YCS c.v.=0.8 model									
2968	2006-2015	13 362	(7 519–23 547)	15 846	(5 419–34 506)	22.4	(8.0–46.4)	116	(61–188)
5064		13 364	(7 526–23 547)	7 980	(3 469–26 319)	11.4	(5.1–35.2)	61	(34–134)
2968	1974-2015	13 430	(7 569–23 629)	23 244	(10 318–42 017)	32.9	(15.1–56.9)	166	(97–137)
5064		13 432	(7 629–23 554)	15 477	(5 107–34 909)	21.9	(7.5–47.9)	112	(47–224)
Survey core model									
2968	2006-2015	12 980	(5 954–24 835)	14 972	(3 540–39 555)	21.3	(5.2–51.9)	114	(49–202)
5064		12 972	(5 926–24 844)	7 376	(2 940–31 125)	10.5	(4.4–41.3)	62	(32–150)
2968	1974-2015	13 075	(5 997–24 947)	22 593	(8 253–45 522)	32.0	(12.1–61.0)	168	(90–321)
5064		13 080	(6 018–24 942)	14 839	(4 519–37 125)	21.0	(6.6–49.7)	111	(45–240)
CPUE model									
2968	2006-2015	52 796	(31 037–89 937)	62 224	(34 740–111 194)	73.5	(44.7–115)	118	(92–146)
5064		52 749	(31 106–89 799)	54 692	(27 220–104 575)	64.7	(34.8–109)	104	(76–133)
2968	1974-2015	52 504	(31 248–89 156)	57 544	(34 548–92 927)	67.9	(43.6–97.7)	109	(81–150)
5064		52 536	(31 118–89 203)	50 115	(26 927–84 105)	59.0	(34.5–89.3)	94	(68–133)

Table 22: Probability of the stock being less than 10, 20 and 40% B_0 for the Base, Survey core, YCS c.v. and CPUE models, at 2019 and projected out to 2024 with either current catch (2968 tonnes) or TACC (5064 tonnes).

	2019				2024		
Model	**P(<10%)**	**P(<20%)**	**P(<40%)**		**P(<10%)**	**P(<20%)**	**P(<40%)**
Base	0.038	0.74	1.00	**Current catch**	0.12	0.55	0.97
				TACC	0.58	0.88	0.99
Survey core	0.048	0.60	1.00	**Current catch**	0.11	0.44	0.92
				TACC	0.47	0.79	0.97
YCS c.v.				**Current catch**	0.054	0.39	0.94
	0.0098	0.58	1.00	**TACC**	0.43	0.80	0.99
CPUE	0.00	0.00	0.022	**Current catch**	0.00	0.00	0.011
				TACC	0.00	0.00	0.072

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.

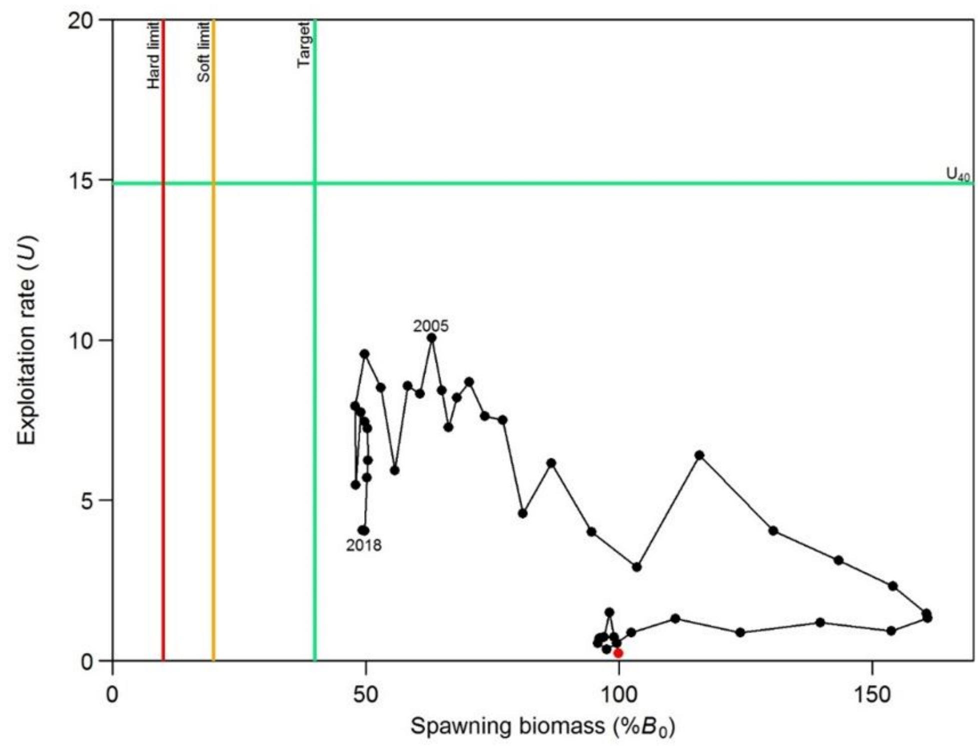
The HAK 1 Fishstock includes all of the Sub-Antarctic biological stock, part of the Chatham Rise biological stock, and all hake around the North Island (which are more likely part of either the WCSI or Chatham Rise stocks). The Sub-Antarctic stock is defined as all of Fishstock HAK 1 south of the Otago 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	2018
Assessment Runs Presented	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_{2018} was estimated at 49% B_0; Likely (> 60%) to be at or above the target
Status in relation to Limits	B_{2018} is Exceptionally Unlikely (< 1%) to be below both the Soft and Hard Limits
Status in relation to Overfishing	Overfishing is Exceptionally Unlikely (< 1%) to be occurring

Fishery and Stock Trends	
Recent Trend in Biomass or Proxy	Biomass is estimated to have been stable since 2010.
Recent Trend in Fishing Mortality or Proxy	Exploitation rate is estimated to have been low throughout the duration of the fishery.
Other Abundance Indices	A CPUE series showed a similar biomass trend to the research surveys.
Trends in Other Relevant Indicators or Variables	Recent year classes (since 2008) have been below average.

Historical Stock Status Trajectory and Current Status



Trajectory over time of exploitation rate (*U*) and spawning biomass (% B_0), for the HAK 1 stock base model from the start of the assessment period in 1974 (represented by a red point), to 2018. The red vertical line at 10% B_0 represents the hard limit, the orange line at 20% B_0 is the soft limit, and green lines are the %B_0 target (40% B_0) and the corresponding exploitation rate (U_{40}). Biomass and exploitation rate estimates are medians from MCMC results.

Projections and Prognosis (2019)	
Stock Projections or Prognosis	The biomass of the Sub-Antarctic stock was expected to remain stable at recent average catch levels. At the TACC, the stock biomass is expected to decline.
Probability of Current Catch or TACC causing Biomass to remain below or to decline below Limits	Soft Limit: Exceptionally Unlikely (< 1%) Hard Limit: Exceptionally Unlikely (< 1%)
Probability of Current Catch or TACC causing Overfishing to continue or to commence	Current catch: Extremely Unlikely (< 1%) TACC: 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: 2018	Next assessment: 2021
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	1 – High Quality 1 – High Quality 1 – High Quality
Data not used (rank)	Commercial CPUE (used in sensitivity run only)	2 – Medium Quality: potentially biased owing to changes in fishing practice and catch reporting

Changes to Model Structure and Assumptions	This assessment now assumes constant *M* (rather than age-specific), and logistic selectivity for the fishery (rather than domed).
Major Sources of Uncertainty	- The summer trawl survey series has shown a 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. - There are patterns in the residuals in the commercial catch-at-age data fitted by the model. - 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.

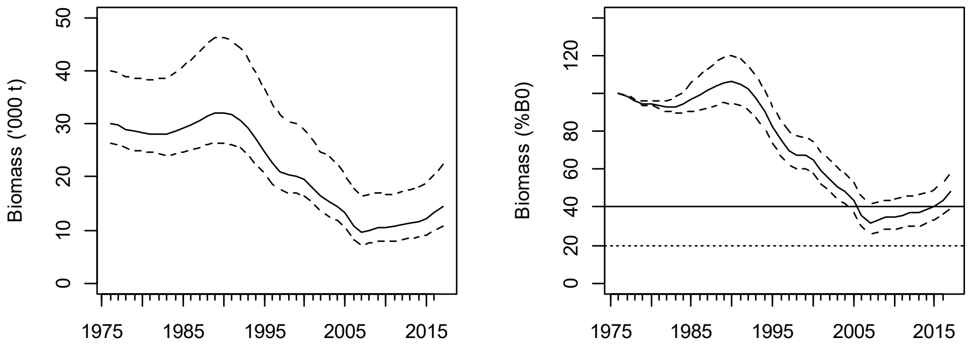
Qualifying Comments
-

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. Hake are a key predator of hoki. Incidental interactions and associated mortality have been recorded for some protected species, including 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	2017
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: $F_{40\%Bo}$
Status in relation to Target	B_{2016} was estimated to be about 48% B_0; Likely (> 60%) to be at or above target
Status in relation to Limits	B_{2016} 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 2016 (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 were below 40% B_0 from 2006 to 2014, but biomass has been slowly increasing since 2007.
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 (1996–2013, but excluding 2002, 2010, and 2011) 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 increase over the next 5 years at catch levels equivalent to those from recent years (i.e., about 400 t annually), but is projected to remain constant 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: Unlikely (< 20%) Hard Limit: Exceptionally unlikely (< 1%)
Probability of Current Catch or TACC causing Overfishing to continue or to commence	Assuming future catches at the HAK 4 TACC: Unlikely (< 40%) Assuming future catches at the level of the current catch: 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: 2017	Next assessment: 2020?
Overall assessment quality rank	1 – High Quality	
Main data inputs (rank)	- Research time series of abundance indices (trawl survey)	1 – High Quality
	- Proportions-at-age data from the commercial fisheries and trawl surveys	1 – High Quality

	- Estimates of biological parameters - New information since the 2013 assessment included two trawl surveys, and updated catch and catch-at-age data.	1 – High Quality 1 – High Quality
Data not used (rank)	Commercial CPUE	2 – Medium or Mixed Quality: does not track stock biomass well, and was used in a sensitivity model
Changes to Model Structure and Assumptions	- The model structure is unchanged from the previous assessment.	
Major Sources of Uncertainty	- 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 fishery selectivity ogives will compensate for some variation in mortality rate with age.	

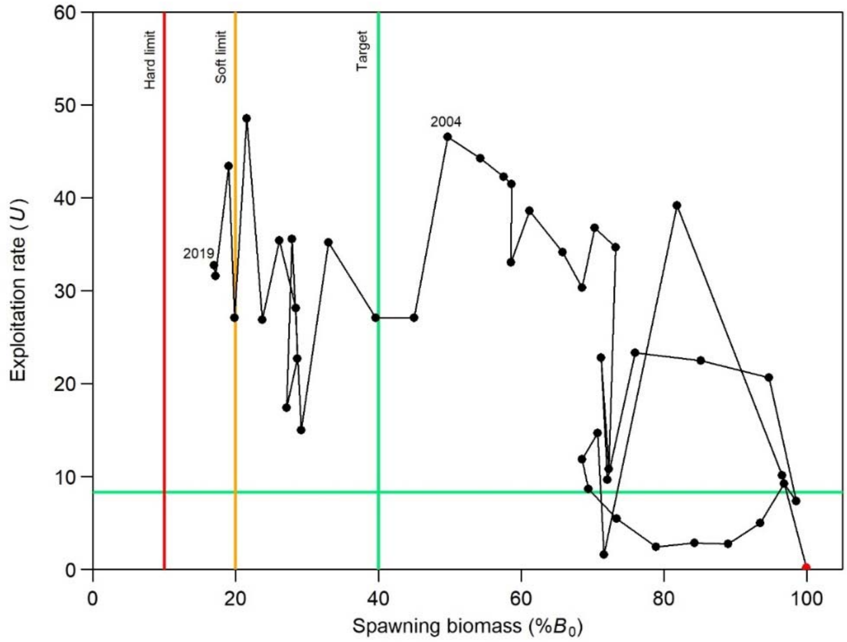
Qualifying Comments
- The assumption of a single Chatham Rise stock independent of hake in all other areas is the most parsimonious interpretation of available information. - The increase in relative abundance seen since 2006 is the result of good recruitment in 2002, 2010, and 2011. - In October 2004, 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 catch in hoki target fisheries. Some target fisheries for hake do exist, with the main bycatch species being hoki, ling, silver warehou and spiny dogfish. Hake are a key predator of hoki. Incidental interactions and associated mortality have been recorded 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	2019
Assessment Runs Presented	One base case, and three sensitivity model runs.
Reference Points	Target: 40% B_0 Soft Limit: 20% B_0 Hard Limit: 10% B_0 Overfishing threshold: $F_{40\%Bo}$
Status in relation to Target	B_{2019} was estimated to be 17% B_0; Exceptionally Unlikely (< 1%) to be at or above the target
Status in relation to Limits	B_{2019} is About as Likely as Not (40–60%) to be below the Soft Limit and Very Unlikely (< 10%) to be below the hard Limit.
Status in relation to Overfishing	Overfishing in 2019 was Likely (> 60%) to be occurring.

Historical Stock Status Trajectory and Current Status



Trajectory over time of exploitation rate (*U*) and spawning biomass (% B_0), for the HAK 7 base model fitted to the survey biomass index, from the start of the assessment period in 1974 (represented by a red point), to 2018. The red vertical line at 10% B_0 represents the hard limit, the orange line at 20% B_0 is the soft limit, and green lines are the %B_0 target (40% B_0) and the corresponding exploitation rate (U_{40}). Biomass and exploitation rate estimates are medians from MCMC results.

Fishery and Stock Trends	
Recent Trend in Biomass or Proxy	- The 'all area' survey series shows a decreasing trend from 2012 until 2016, with the 2018 estimate higher than the 2016 estimate. - The 'core area' survey series shows a decreasing trend from 2000 until 2016, with the 2018 estimate similar to the 2016 estimate.
Recent Trend in Fishing Intensity or Proxy	Exploitation rate was estimated to have been high since 1989.
Other Abundance Indices	The CPUE index indicated an increasing biomass trend, but may not be a reliable index of abundance.
Trends in Other Relevant Indicators or Variables	Recent recruitment (2006–2015) is estimated to be lower than the long-term average for this stock.

Projections and Prognosis	
Stock Projections or Prognosis	The biomass of the WCSI stock is expected to remain constant under recent recruitment and current catch, and to increase under average recruitment and recent catch. Under catches equal to the TACC, the biomass is expected to decline with recent recruitment, and remain constant with average recruitment.
Probability of Current Catch or TACC causing Biomass to remain below or to decline below Limits	For the Base model at current catches and recent average recruitment: Current catch: Soft Limit: About as Likely as Not (40–60%) Hard Limit: Unlikely (< 10%) TACC: Soft Limit: Very Likely (> 90%) Hard Limit: Likely (> 60%)

Probability of Current Catch or TACC causing Overfishing to continue or to commence	For the Base model at current catches and recent average recruitment: Current catch: Likely (> 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: 2019	2022
Overall assessment quality rank	1 – High Quality	
Main data inputs (rank)	- Research trawl surveys (2000-2018 for 'core area', and 2012-2018 for 'all area') - Proportions-at-age data from the commercial fishery and research surveys - Estimates of fixed biological parameters - Trawl fishery CPUE	1 – High Quality 1 – High Quality 1 – High Quality 2 – Medium or Mixed Quality: may not track stock biomass
Data not used (rank)	*RV Kaharoa* WCSI inshore trawl survey	Does not monitor the adult stock
Changes to Model Structure and Assumptions	- The model assumes two fishery selectivities rather than one. - The base case model used the 'all area' survey series.	
Major sources of Uncertainty	- Uncertainty about the size of recent year classes affects the reliability of stock projections. - The spatial and temporal representativeness of the survey of the hake stock on the WCSI is not known - 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 and years.	

Qualifying Comments
- CPUE from this stock has previously been considered too unreliable to be used as an abundance index, but a truncated series from 2001 was previously used as an alternative base run. The fishery-independent abundance series is sparse (at most five comparable trawl surveys) and while we have used the 'all' strata that more accurately samples hake for the base model, we have included the 'core' strata as a sensitivity as this data extends back to include the year 2000. - The estimates of the 2016 year class (which is not included in projections) from the *RV Tangaroa* survey in 2018 and *RV Kaharoa* inshore survey in 2017 suggested that this year class may be above average.

Fishery Interactions
The main bycatch species of hoki-hake-ling-silver warehou-white warehou target fisheries are rattails, javelinfish, and spiny dogfish. Hake are a key predator of hoki. Incidental interactions and associated mortality have been recorded for some protected species, including New Zealand fur seals and seabirds. Additional information about bycatch, protected species captures and benthic interactions can be found in the Environmental and Ecosystem Considerations section of the hoki chapter.

Table 23: Summary of TACCs (t) and reported landings for the most recent fishing year.

Fishstock	QMA	2017–18 actual TACC	2017–18 reported landings
HAK 1	Auckland, Central Southeast, Southland, Sub-Antarctic (FMAs 1, 2, 3, 5, 6, 8, 9)	3 701	1 349
HAK 4	Chatham Rise (FMA 4)	1 800	267
HAK 7	Challenger (FMA 7)	5 064	3 086
HAK 10	Kermadec	10	0
Total		10 575	4 702

6. FOR FURTHER INFORMATION

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