HAKE (HAK)

(Merluccius australis)
Tiikati, kehe

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 to 800 m, but some have been found as deep as 1200 m, whereas 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 (WCSI, HAK 7) with the highest catch (17 000 t) recorded in 1977 (Table 1, catches not allocated to Fishstock), immediately before the establishment of the EEZ. The WCSI hake fishery has generally consisted of bycatch in the much larger hoki fishery, but it has undergone several changes over time (Dunn et al in prep). These include changes to the TACCs of both hake and hoki, and 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 2000 t of hake were taken in this target fishery during September 1993 (Ballara 2018). High bycatch levels of hake early in the fishing season have also occurred in some years (Ballara 2018). From 1 October 2005 the TACC for HAK 7 was increased to 7700 t (Table 2) within an overall TAC of 7777 t. The TACC was reduced to 5064 t in 2017–18 and then again to 2272 t in 2019–20 (out of a total TACC for the EEZ of 7783 t) in response to changes in estimated stock status.

On the Chatham Rise and in the Sub-Antarctic, hake have been caught mainly as bycatch by trawlers targeting hoki (Ballara 2018). However, significant targeting for hake has occurred in both areas, particularly in Statistical Area 404 (HAK 4), and around the Norwegian Hole between the Stewart-Snares shelf and the Auckland Islands Shelf in the Sub-Antarctic. Increases in TACCs from 2610 t to 3500 t in HAK 1 and from 1000 t to 3500 t in HAK 4 from 1991–92 allowed the fleet to increase their reported landings of hake from these fish stocks. TACCs were further increased to 3632 t in 1994–95 and to 3701 t in HAK 1 in 2001–02 and have remained at that level since. Reported catches rose over several years to the level of the new TACCs in both HAK 1 and HAK 4. In HAK 1, annual catches remained relatively steady (generally between 3000 t and 4000 t) up to 2004–05 but were generally less than 3000 t from 2005–06 until 2009–10, and generally less than 2000 t since. The reduction in catch of hake in the Sub-Antarctic has coincided with a reduction in targeting of hake and reduced spatial extent of the hoki fishery in the Sub-Antarctic from about 2004–05.

From 2004–05, the TACC for HAK 4 was reduced from 3500 t to 1800 t. Landings from HAK 4 have declined from over 3000 t in 1998–99 to between about 130–300 t 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 2000 t of hake were caught from that area. In previous years, catches from this area have typically been between 100 t and 800 t. These unusually high catches on the western Chatham Rise 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 present and actual TACCs (t) for 1986–87 to present. FSU data from 1984–1986; QMS data from 1986 to the present. [Continued on next page]

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	3 429	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

Table 2 [Continued]:

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
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	1 350	3 701	267	1 800	3 086	5 064	0	10	4 702	10 575
2018–19	896	3 701	183	1 800	1 563	5 064	0	10	2 642	10 575
2019–20	1 062	3 701	137	1 800	2 063	2 272	0	10	3 262	7 783
2020–21	1 503	3 701	207	1 800	1 368	2 272	0	10	3 077	7 783

[1] FSU data

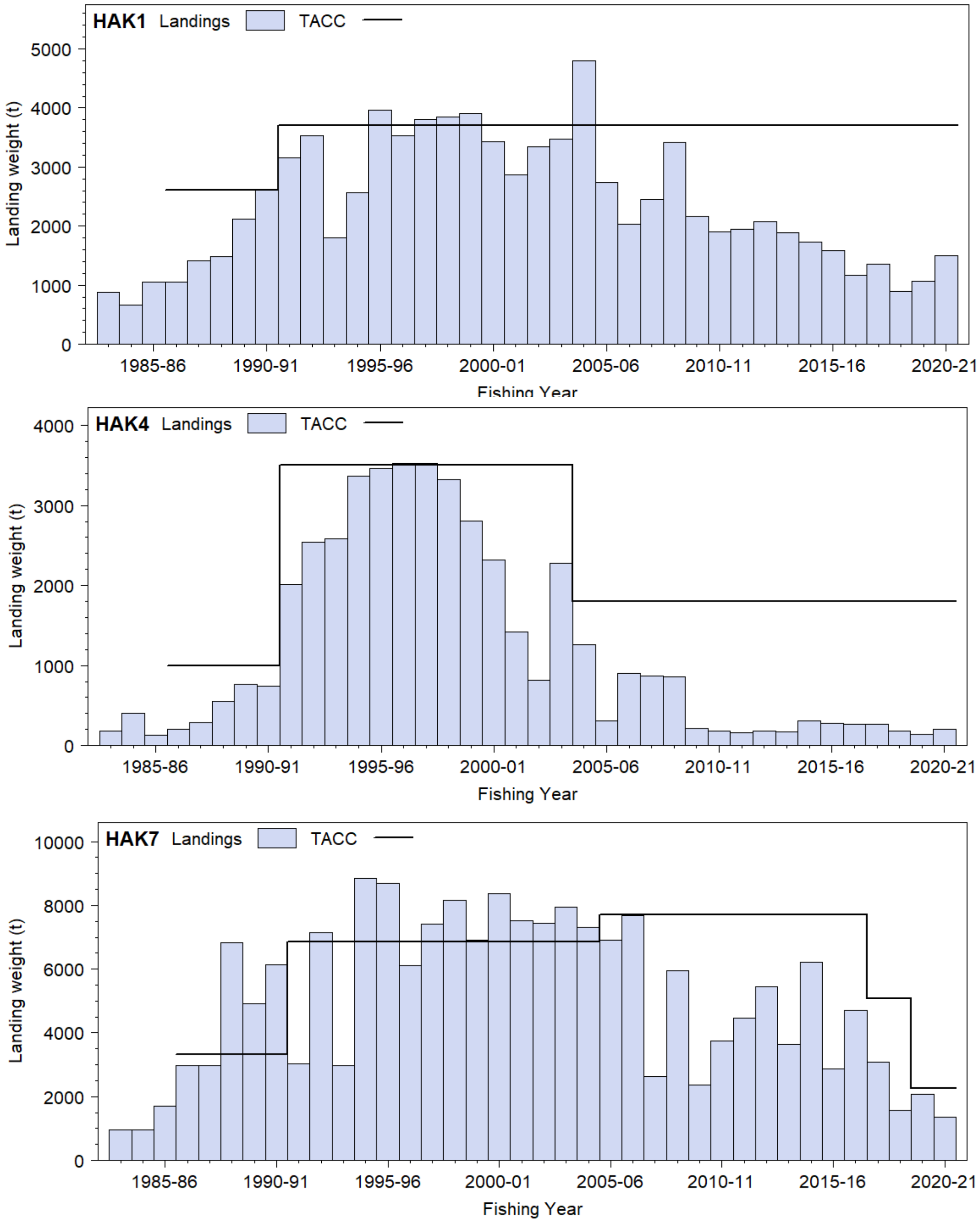


Figure 1: Reported commercial landings and TACC for the three main HAK stocks. From top: HAK 1 (Sub-Antarctic and part of Chatham Rise), HAK 4 (eastern Chatham Rise), and HAK 7 (Challenger).

1.2 Recreational fisheries
The recreational fishery for hake is negligible.

1.3 Customary non-commercial fisheries
The amount of hake caught by Māori is not known but is likely 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 off 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 (Ballara 2018).

In earlier years, before the introduction of higher TACCs in 1991–92, there is some evidence to suggest that catches of hake were not always fully reported. Comparison of catches from vessels carrying observers with those not carrying observers, particularly in HAK 7 from 1988–89 to 1990–91, suggested that actual catches were probably considerably higher than reported catches. For these years, the ratio of hake to hoki in the catch of vessels carrying observers was significantly higher than in the catch of vessels not carrying observers (Colman & Vignaux 1992). The actual hake catch in HAK 7 for these years was estimated by multiplying the total hoki catch (which was assumed to be correctly reported by vessels both with and without observers) by the ratio of hake to hoki in the catch of vessels carrying observers. Reported and estimated catches for 1988–89 were respectively 6835 t and 8696 t; for 1989–90, 4903 t reported and 8741 t estimated; and for 1990–91, 6189 t reported and 8246 t estimated. More recently, the level of such misreporting has not been estimated and is not known. No such corrections have been applied to either the HAK 1 or HAK 4 fishery.

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

The fisheries in the Sub-Antarctic and on the Chatham Rise largely take place in September and October and catch histories used in the assessment models adjust the fishing year to reflect this (see Tables 7 and 13).

1.5 Other sources of mortality
There is likely to be some mortality associated with escapement from trawl nets, mostly from small fish that can escape through the trawl mesh. The mortality of hake associated with escapement is not known. In the Sub-Antarctic, the catch and effort records for hake suggest that small hake are uncommon in areas where the hoki/hake/ling fishery occurs with only very low proportions of small hake recorded by observers. Hence the level of mortality of hake associated with escapement is likely to be low over the history of the fishery and is assumed to be negligible.

Table 3: Revised landings for Sub-Antarctic and Chatham Rise stocks and the West Coast South Island for 1975 to present fishing years. Note, these relate to biological fish stocks, not QMA Fishstocks.

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	1 827	804
1989–90[1]	8 741	2 366	950
1990–91[1]	8 246	2 749	931
1991–92	3 010	3 265	2 418
1992–93	7 059	1 452	2 798
1993–94	2 971	1 844	2 934
1994–95	9 535	2 888	3 271
1995–96	9 082	2 273	3 959
1996–97	6 838	2 599	3 890
1997–98	7 674	2 789	4 074
1998–99	8 742	2 789	3 589
1999–00	7 031	3 011	3 174
2000–01	8 346	2 787	2 962
2001–02	7 498	2 510	1 770
2002–03	7 404	2 741	1 401
2003–04	7 939	3 251	2 465
2004–05	7 298	2 530	3 518
2005–06	6 892	2 555	489
2006–07	7 660	1 812	1 081
2007–08	2 583	2 204	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	1 893	194
2012–13	5 171	1 883	344
2013–14	3 387	1 832	187
2014–15	5 966	1 639	348
2015–16	2 733	1 504	355
2016–17	4 701	1 037	406
2017–18	3 085	1 205	412
2018–19	1 562	636	443
2019–20	2 063	930	318
2020–21	1 367	1 355	355

[1] West Coast South Island revised estimates for 1989–90 and 1990–91 were from Colman & Vignaux (1992) who corrected for under-reporting in 1989–90 and 1990–91, and not Dunn (2003) who ignored such under-reporting.
[2] Estimates from 2019 to 2021 were from Dunn et al (2021a) using a minor redefinition of statistical area for the Sub-Antarctic.

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 estimated von Bertalanffy growth curves. Growth parameters were updated for all stocks by Horn (2008) using both the von Bertalanffy and Schnute growth models, with the Schnute model found to better fit the data. More recently, growth parameters for the Sub-Antarctic (Dunn et al 2021a) and the WCSI (Dunn et al in prep) using a Bayesian von Bertalanffy growth model provided a better fit than the previous Schnute model.

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 by 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) and 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 Shelf, 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 TL at one year old, and about 35 cm TL 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 was 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 = $a(\text{length})^b$ (Weight in t, length in cm)							
Sub-Antarctic	Males	$a = 2.34 \times 10^{-9}$	$b = 3.258$				(Dunn et al 2021a)
	Females	$a = 1.86 \times 10^{-9}$	$b = 3.310$				(Dunn et al 2021a)
	Both sexes	$a = 1.50 \times 10^{-9}$	$b = 3.262$				(Dunn et al 2021a)
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	$a = 3.34 \times 10^{-9}$	$b = 3.175$				(Dunn et al in prep)
	Females	$a = 3.48 \times 10^{-9}$	$b = 3.177$				(Dunn et al in prep)
	Both sexes	$a = 3.02 \times 10^{-9}$	$b = 3.204$				(Dunn et al in prep)
3. von Bertalanffy growth parameters							
Sub-Antarctic	Males	$k = 0.260$	$t_0 = -0.71$	$L_\infty = 89.3$		cv = 0.07	(Dunn et al 2021a)
	Females	$k = 0.160$	$t_0 = -1.33$	$L_\infty = 115.5$		cv = 0.08	(Dunn et al 2021a)
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	$k = 0.329$	$t_0 = -0.43$	$L_\infty = 83.1$		cv = 0.07	(Dunn et al in prep)
	Females	$k = 0.192$	$t_0 = -0.98$	$L_\infty = 107.0$		cv = 0.10	(Dunn et al in prep)
4. Schnute growth parameters ($\tau_1 = 1$ and $\tau_2 = 20$ for all stocks)							
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)

5. Maturity ogives (proportion mature at age) (Horn 2013a)

	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 exist in the EEZ.

Analysis of morphometric data (Colman unpublished data) shows little difference between hake from the Chatham Rise and hake from off the east coast of the North Island but shows highly significant differences between these fish and those from the Sub-Antarctic, Puysegur, and off 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 off 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 Fishstock (with no recorded landings) exists for the Kermadec FMA (HAK 10).

4. STOCK ASSESSMENT

The stock assessments reported here were completed in 2022 for the west coast South Island stock (Dunn et al in prep), 2021 for the Sub-Antarctic stock (Dunn et al 2021b) and in 2020 for the Chatham Rise stock (Holmes 2021). In stock assessment modelling, the Chatham Rise stock was considered to include the whole of the Chatham Rise (including the western end currently forming part of the HAK 1 management area). The Sub-Antarctic stock was considered to 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 2021 stock assessment (Dunn et al 2021b) was carried out with data up to the end of the 2020 calendar 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 2020), 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 an age-structured two-sex model partitioned into age groups 1–30 with the last age group considered a plus group. Maturity-at-age was assumed using estimates made outside the model. The annual cycle assumed is given in Table 5.

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 1974–2016. 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 (Table 6). 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 using a von Bertalanffy growth model. Natural mortality was estimated as a constant over all age classes and years. Year class strengths for the period 1974–2016 were estimated, and otherwise assumed to be 1.0.

Model parameters were estimated using Bayesian estimation implemented using the CASAL software (Bull et al 2012). Initial models were estimated to MAP, and, for final model runs, the full posterior distribution was sampled using Markov chain Monte Carlo (MCMC) methods, based on the Metropolis-Hastings algorithm.

Table 5: Annual cycle of the stock model, showing the processes taking place at each time step, their sequence within each time step, and the available observations. Fishing and natural mortality that occur within a time step occur after all other processes, with half of the natural mortality for that time step occurring before and half after the fishing mortality.

					Observations	
Step	**Period**	**Processes**	***M******	**Age†**	**Description**	**%*Z*‡**
1	August-Mar	Ageing	0.58	0.2	Commercial catch-at-age	0.5
		Recruitment			Trawl catch-at-age	0.5
		Summer trawl fishery (~78%)			Trawl survey (November)	0.5
		Maturation and spawning			CPUE (sensitivity)	0.5
2	Apr-July	Winter trawl fishery (~22%)	0.42	0.5	Trawl survey (April)	0.0

* *M* is the proportion of natural mortality that was assumed to have occurred in that time step.
† Age is the age fraction, used for determining length-at-age, that was assumed to occur in that time step.
‡ %*Z* is the percentage of the total mortality in the step that was assumed to have taken place at the time each observation was made.

Table 6: Summary of the relative abundance series applied in the models.

Data series	**Model years**
Trawl survey biomass (*Tangaroa*, November)	1992–94, 2001–10, 2012–13, 2015, 2017, 2019, 2021
Trawl survey proportion-at-age (*Tangaroa*, November)	1992–94, 2001–10, 2012–13, 2015, 2019, 2021
Trawl survey biomass (*Tangaroa*, April)	1992–93, 1996, 1998
Trawl survey proportion-at-age (*Tangaroa*, April)	1992–93, 1996, 1998
CPUE	1991–2020
Commercial trawl proportion-at-age	1990, 1992–1994, 1996, 1998–2020

4.1.2 Fixed biological parameters and observations

There were five main data sources: the catch history; research trawl survey biomass indices for November–December 1992–2021 (November series) and for April–May 1992–98 (April series), with the September 1992 biomass index used as a sensitivity only; catch-at-age estimates from the research surveys; catch-at-age estimates from the commercial fishery 1990–2020; and a commercial CPUE biomass index from daily processed data of trawls targeting hoki, hake, or ling from 1991–2020 (sensitivity run only).

Catch history

To align with the season of the fishery more closely (specifically between 1990 and 1998), the model year was set as September to August, rather than the fishing year (October to September). The catch history was modified accordingly (Table 7). The catch history includes the revised estimates of catch reported by Dunn (2003). The catch for the most recent year (2021) is not yet known and is assumed to be equal to the mean of the most recent 5 years (1066 t).

The effect of possible incidental mortality associated with escapement from trawl nets and potential unreported catch from before the introduction of the QMS was evaluated in a sensitivity model. Discards from the hoki/hake/ling target fishery were likely to be very low (< 0.5%, Anderson et al 2019). Incidental mortality of small fish associated with escapement was also assumed to be low because the hake fishery occurs in areas away from locations where small hake are found. Unreported catch prior to the introduction of the QMS is not known but assumed to be low due to the high commercial value of hake at that time. A sensitivity model assumed 5% additional fishery mortality for years before the introduction of the QMS (1986) and 2% thereafter (labelled the reference+ model).

Biological parameters

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

Growth was assumed to be von Bertalanffy and constant over time (Table 4). *M* was constant over ages and time and estimated with an informed prior (Table 8). A Beverton-Holt stock recruitment relationship was used with an assumed steepness *h* of 0.8. Year class strengths were estimated for the period 1974–2016, following the Haist parameterisation, with a lognormal prior with CV of 1.1. All other estimated parameters assumed non-informative priors, either uniform log (CPUE *q* where used) or uniform. Ageing error was assumed (with CV = 0.08). All mature fish were assumed to spawn every year.

Table 7: Commercial catch history (t) for the Sub-Antarctic stock. Note that totals by model year from 1990 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 for 2021 assume catch to be the same as mean for the previous 5 years.

Model year	Total	Model year	Total	Model year	Total	Model year	Total
1975	120	1987	713	1999	2 871	2011	1 319
1976	281	1988	1 095	2000	3 100	2012	1 902
1977	372	1989	1 237	2001	2 816	2013	1 878
1978	762	1990	718	2002	2 444	2014	1 840
1979	364	1991	2 318	2003	2 780	2015	1 608
1980	350	1992	2 806	2004	3 228	2016	1 470
1981	272	1993	3 919	2005	2 591	2017	1 042
1982	179	1994	1 620	2006	2 538	2018	1 175
1983	448	1995	1 982	2007	1 706	2019	662
1984	722	1996	2 789	2008	2 330	2020	983
1985	525	1997	1 919	2009	2 445	2021	1 066*
1986	818	1998	2 944	2010	1 927		

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 (μ, cv)	1.0	1.1	0.01	100
Trawl survey q*	Lognormal (μ, cv)	0.16	0.79	0.01	0.40
CPUE q	Uniform-log	–	–	1e-8	1e-3
Selectivities	Uniform	–	–	1	25–200†
M	Normal (μ, sd)	0.19	0.05	0.05	0.40

* The trawl survey q values were estimated independently, but all had the same priors.

† A range of maximum values was used for the upper bound, depending on the parameter.

Research trawl surveys

The biomass estimates from the research trawl surveys are given in Table 9.

Table 9: Research survey indices (and associated CVs) for the Sub-Antarctic stock.

Fishing Year	Vessel	November series†		April series‡		September series‡	
		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*	1 885	0.24				
2013	*Tangaroa*	2 428	0.23				
2015	*Tangaroa*	1 477	0.25				
2017§	*Tangaroa*	1 373	0.34				
2019	*Tangaroa*	1 675	0.25				
2021	*Tangaroa*	1 572	0.20				

* Not used in the reported assessment.

† Series based on indices from 300–800 m core strata, including the 800–1000 m strata in Puysegur, but excluding Bounty Plateau.

‡ Series based on the biomass indices from 300–800 m core strata, excluding the 800–1000 m strata in Puysegur and the Bounty Plateau.

§ 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 2018).

The priors for survey qs 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 8). 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 qs 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. For the biomass indices, no additional process error was added to the trawl survey indices, but a process error CV of 0.20 was added to the CPUE indices (where used).

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 10).

Table 10: Catch-at-age data for the Sub-Antarctic stock, giving the multinomial effective sample sizes assumed for each sample in the stock assessment model. The effective sample size is proportional to the weight given to the data in the model fit.

	Research surveys		
Fishing year	November	April	Commercial catch-at-age
1990	13		13
1991			
1992	14	17	34
1993	20	17	27
1994	25		9
1995			
1996		13	10
1997			
1998		14	16
1999			31
2000			49
2001	40		28
2002	31		41
2003	36		19
2004	36		36
2005	21		12
2006	27		41
2007	27		12
2008	33		32
2009	40		35
2010	40		61
2011			48
2012	34		83
2013	41		52
2014			47
2015	15		36
2016			31
2017			31
2018			38
2019	14		48
2020			27
2021	18		

4.1.3 Model estimation

In the reference model, the main parameters estimated were: pre-exploitation (unfished, equilibrium) biomass (B_0), trawl survey selectivities, fishery selectivity, natural mortality rate, and year class strengths (YCS) from 1974 to 2016.

A wide range of sensitivity models to the reference model were run. Sensitivity models reported here were run to investigate the effect of fixing M at a low (M=0.15 y^{-1}) or high (M=0.23 y^{-1}) value, the sensitivity of the model to the inclusion of the CPUE index; and sensitivity to the inclusion of incidental mortality and unreported catch before the introduction of the QMS.

The fits to the biomass indices were acceptable (Figure 2). Fits to the commercial catch-at-age were generally good (Figure 3), as were the fits to the research survey catch-at-age (Figure 4).

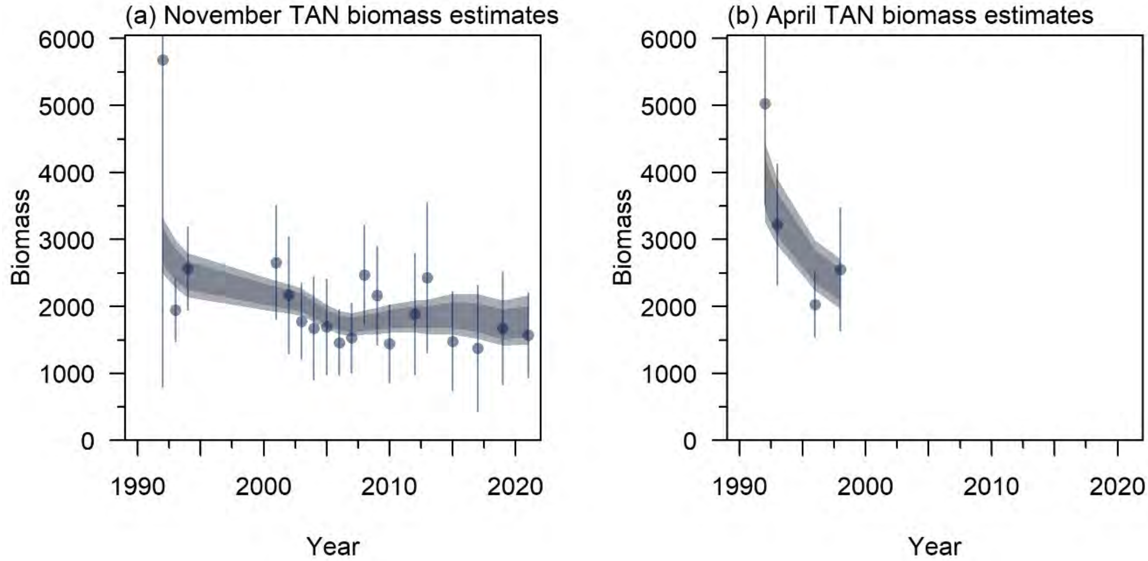


Figure 2: MCMC observed (points) and expected values for the reference model for the Sub-Antarctic stock to the (a) November and (b) April research trawl biomass indices. Dark shaded areas represent the 80% CIs, and light shaded areas the 95% CIs.

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 survey at age 4–5, by the April survey at age 12, and by the fishery at about age 9.

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 2016 (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.

Biomass estimates for the stock appeared well above the target (40% B_0), with estimated current biomass from the base model at about 62% B_0 (95% CIs 50–75% B_0) (Figure 7, Table 11). Annual exploitation rates (catch over vulnerable biomass) were low in all years because of the high estimated stock size relative to the level of catches.

A wide range of sensitivity runs was conducted, and these produced similar estimates of stock size and status. The 2021 assessment model structure was different to the previous (2018) model in (a) correcting the time series of survey biomass estimates used and (b) modifying the annual cycle to more accurately align the observations with their timing in the model. The biomass estimates from the reference model and the 2018 model were similar, albeit the current estimates were more optimistic due to the correction in the time series of biomass estimates used. The sensitivity run using the commercial fishery CPUE index did not allow the observer catch-at-age to be better fitted and was considered to be less plausible than the model fitted to the trawl survey series only. The CPUE model did not converge at MCMC but gave comparable estimates to the reference model. In addition to what is shown in Figure 5, the Deepwater Working Group noted there may be additional uncertainty in the strength of the early age classes, and the resulting trajectory of the assessment. Sensitivity models carried out suggested that the model conclusions were robust to choices of the early strength of year classes. The inclusion of estimates of incidental mortality and pre-QMS unreported catch resulted in a very similar status, and similar estimates of current biomass.

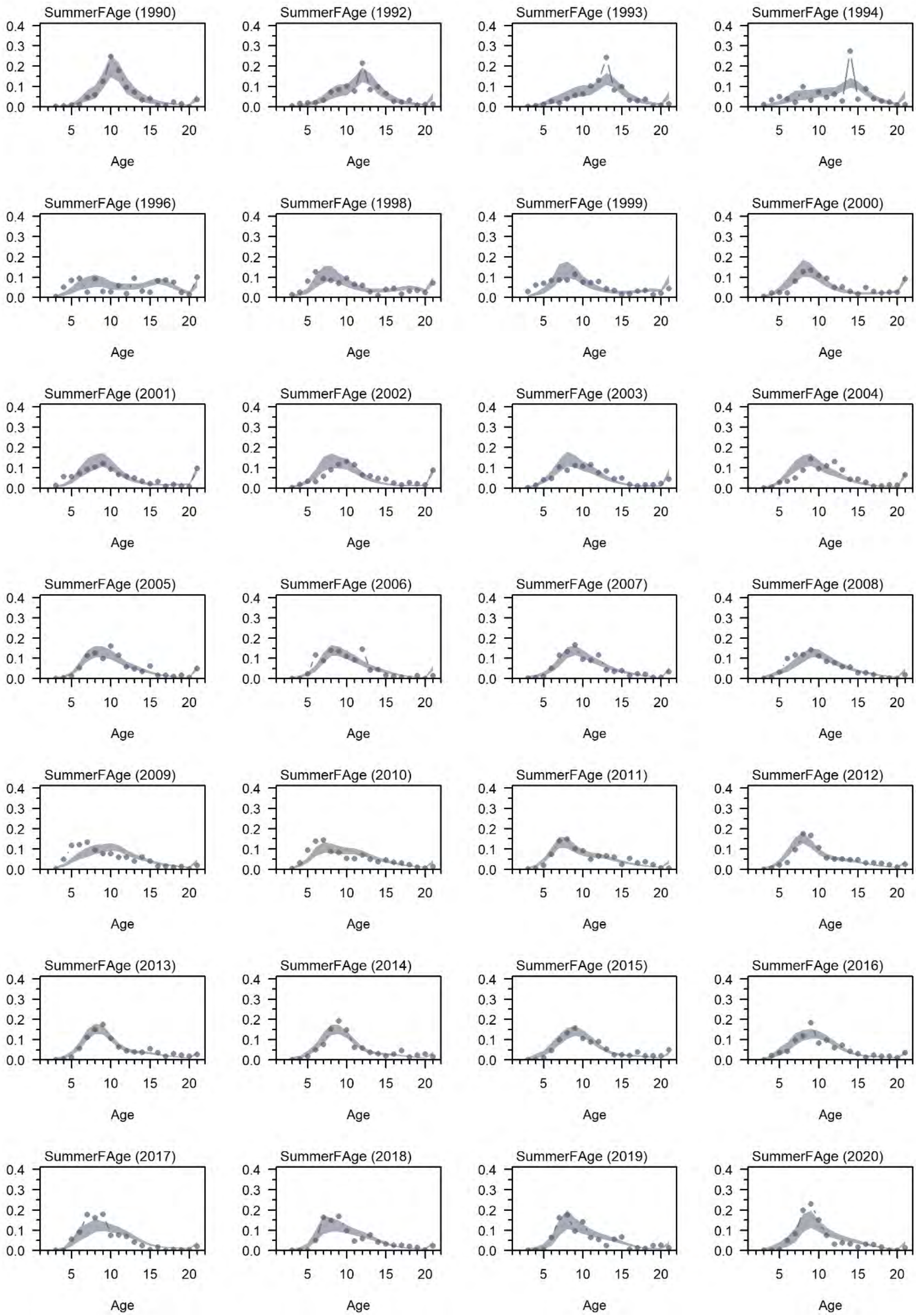


Figure 3: MCMC observed (points) and expected values for reference model for the commercial fishery catch-at-age data.

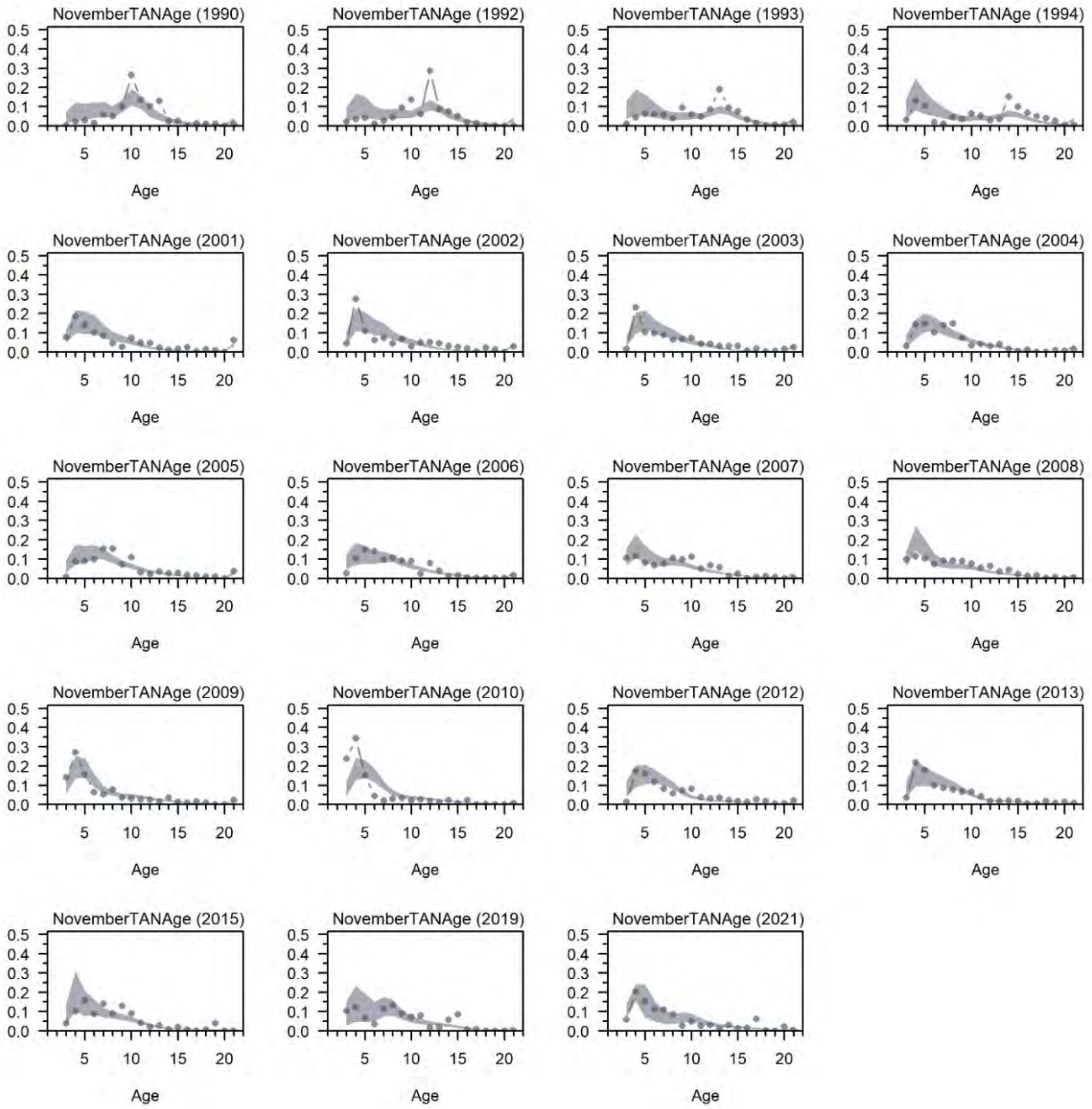


Figure 4: MCMC observed (points) and expected values for reference model for the November research survey catch-at-age data.

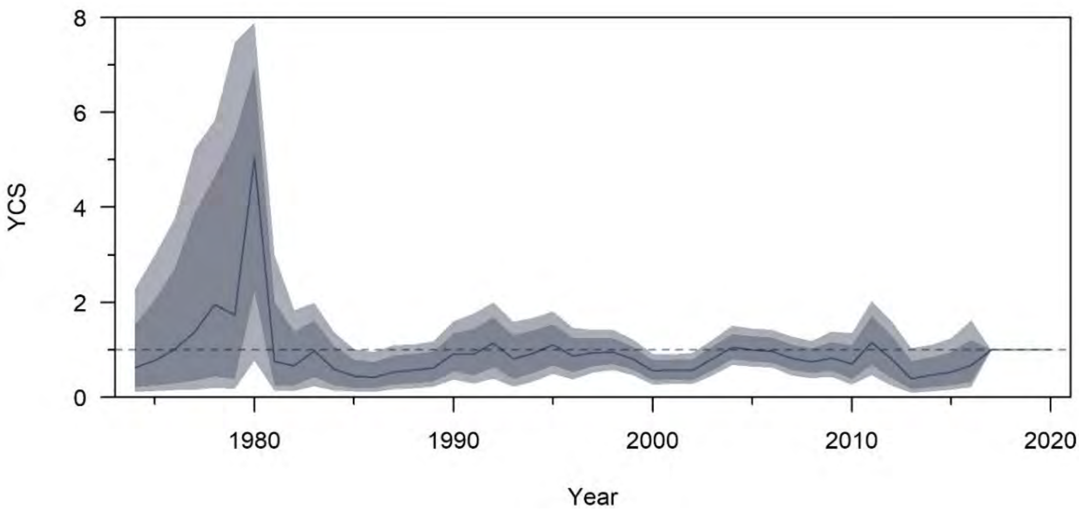


Figure 5: Estimated posterior distributions of year class strengths for the reference case for the Sub-Antarctic stock. The dashed horizontal line indicates a year class strength of one. Dark shaded areas represent the 80% CIs, and light shaded areas the 95% CIs.

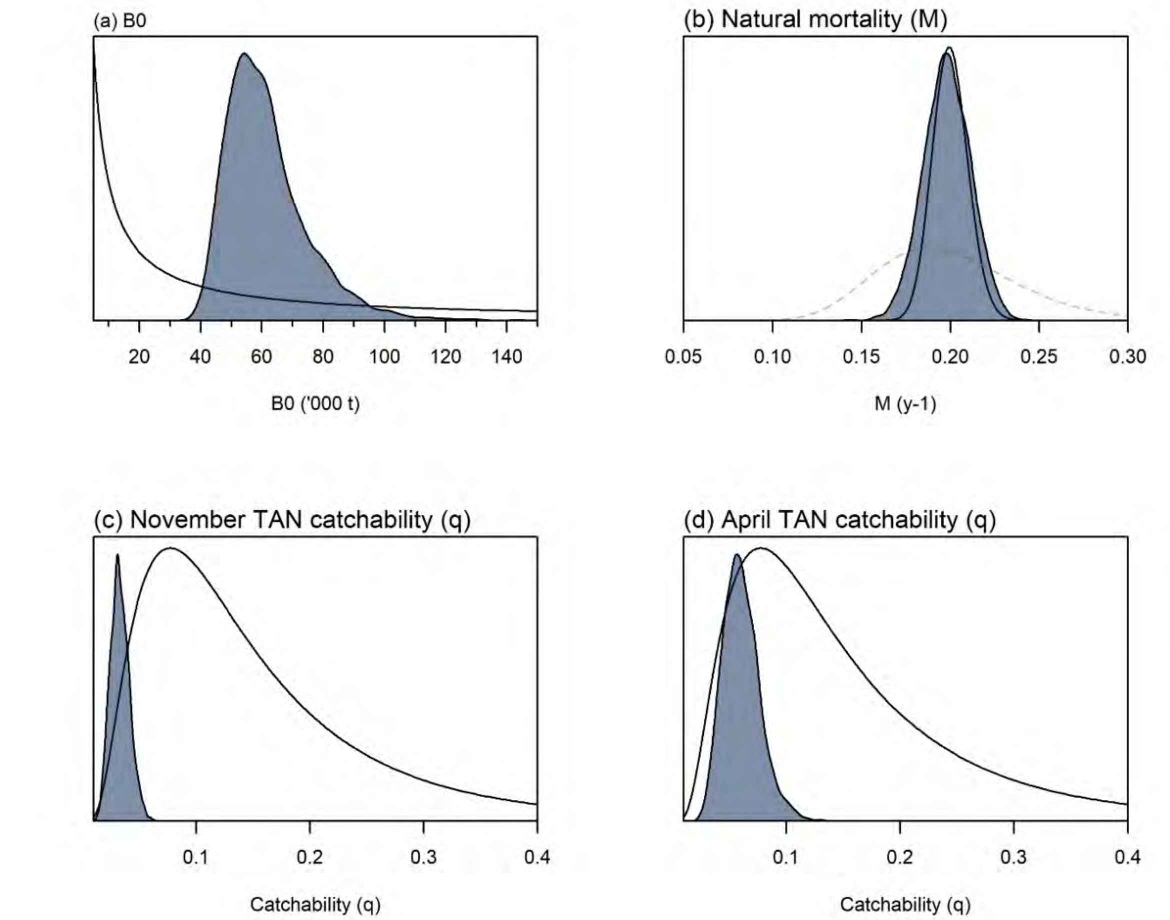


Figure 6: **Reference model estimated prior (lines) and posterior distributions (shaded region) of (a) B_0, (b) natural mortality, (c) catchability for the November research surveys, and (d) catchability for the April research surveys.**

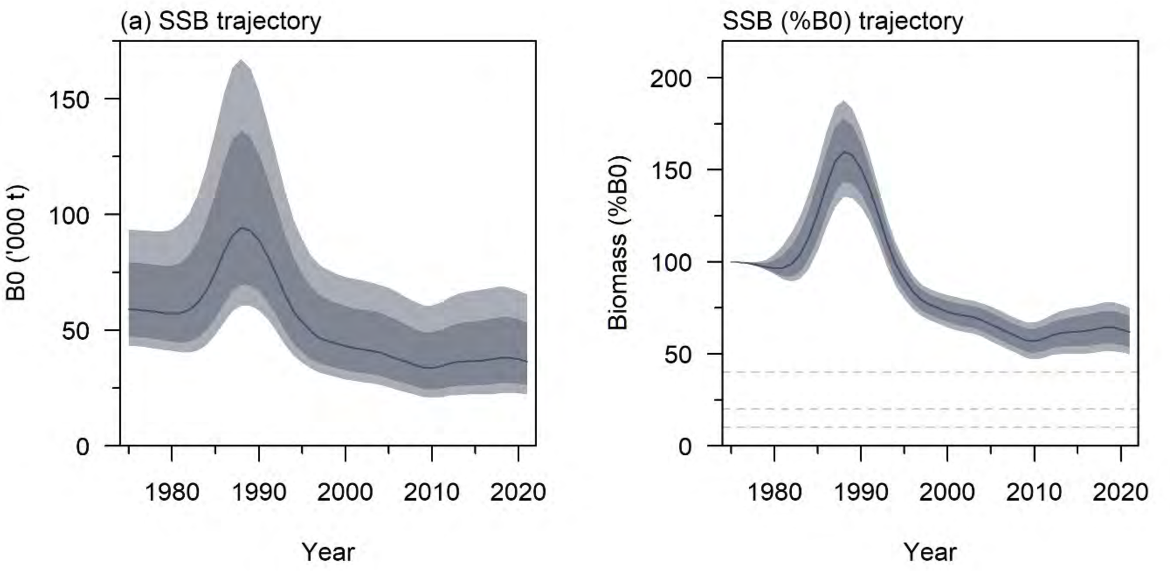


Figure 7: **Reference model MCMC trajectories for absolute spawning stock biomass and spawning stock biomass as a percentage of B_0. Dark shaded areas represent the 80% CIs, and light shaded areas the 95% CIs. The management target (40% B_0, upper dotted horizontal line), soft limit (20% B_0, middle dotted horizontal line), and hard limit (10% B_0, lower dotted horizontal line) are shown on the right-hand panel.**

Table 11: MCMC median (95% credible intervals) of B_0, B_{2021}, B_{2021} as a percent of B_0, and the probability of B_{2021} being above the target (40% B_0), for the reference model and sensitivity runs.

Model run	B_0	B_{2021}	B_{2021} (% B_0)	P(B_{2021} > 0.4 B_0)
Reference model	59 000 (43 220–93 600)	36 490 (22 250–65 510)	62 (50–75)	1.00
Fixed M=0.15 y^{-1}	40 440 (36 050–46 170)	20 990 (14 970–28 760)	52 (41–64)	0.98
Fixed M=0.23 y^{-1}	75 130 (55 310–110 190)	51 700 (33 480–85 480)	68 (55–84)	1.00

Projections

Five-year biomass projections were made for the Base model run assuming future annual catch in the Sub-Antarctic to be an average of the catch from the last five years (1066 t), or the TACC (3701 t). For each projection scenario, future recruitment variability was sampled from actual estimates between 1974 and 2016 (all YCS) or from the most recent ten years (2007–2016, most recent YCS).

At the current catch (1066 t), *SSB* is predicted to remain stable over the next five years (Table 12). At a catch of the TACC (3701 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 about 1% or less using both all YCS or just more recent YCS.

Table 12: HAK 1 Bayesian median (t) and 95% credible intervals (t, in parentheses) of projected B_{2026}, B_{2026} as a percentage of B_0, and B_{2026}/B_{2021} (%) for the reference model.

Model run	Catch (t)	B_{2026}	B_{2026} (% B_0)	B_{2026}/B_{2021} (%)	p(B_{2026} > 0.4 B_0)	p(B_{2026} < 0.2 B_0)	p(B_{2026} < 0.1 B_0)
Reference model	1 066	34 410 (19 950–64 740)	58 (42–78)	94 (76–117)	0.99	0.00	0.00
with recent YCS	3 701	26 240 (11 620–56 700)	44 (25–66)	72 (47–96)	0.66	0.01	0.00
Reference model	1 066	38 070 (21 960–78 930)	63 (46–111)	102 (80–176)	1.00	0.00	0.00
with all YCS	3 701	29 950 (13 590–71 460)	49 (30–97)	80 (54–155)	0.82	0.00	0.00

4.2 Chatham Rise stock (HAK 4 and HAK 1 north of Otago peninsula)

The 2020 stock assessment was carried out up to the end of 2020 using data up to the end of the 2018–19 fishing year and an assumed catch of 436 t for the 2019–20 year (Holmes 2021). The assessment used research time series of abundance indices (trawl surveys of the Chatham Rise from 1992 to 2020), 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.

To align with the seasons of the fishery more closely, the model year was set as September to August, rather than the fishing year (October to September). The catch history was modified accordingly (Table 13). The catch history includes the revised estimates of catch reported by Dunn (2003).

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 1975–2017. Commercial fishing was split into two fisheries, east and west (split at latitude 178.1° E). Double-normal selectivity-at-age ogives were used for the west commercial fishing selectivity and a survey selectivity for the Chatham Rise January trawl survey series. In a change to the previous assessment base case, a logistic selectivity-at-age ogive was used for the east commercial fishing selectivity. 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.

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 from observer data for commercial trawl fisheries on the eastern and western Chatham Rise in some years. The catch histories assumed in all model runs (Table 13) include the revised estimates of catch reported by Dunn (2003). Resource survey abundance indices are given in Table 14.

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 retained from the previous assessment (process error estimated from an MPD run was very similar). A process error CV of 0.20 for the CPUE series estimated following Francis (2011) was also retained from the previous assessment. 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 13: Commercial catch history (t) by fishery (West and East) and total, for the Chatham Rise 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	West	East	Total	Model year	West	East	Total
1975	80	111	191	1998	1 424	1 124	2 547
1976	152	336	488	1999	1 169	3 339	4 509
1977	74	1 214	1 288	2000	1 155	2 130	3 285
1978	28	6	34	2001	1 208	1 700	2 908
1979	103	506	609	2002	454	1 058	1 512
1980	481	269	750	2003	497	718	1 215
1981	914	83	997	2004	687	1 983	2 671
1982	393	203	596	2005	2 585	1 434	4 019
1983	154	148	302	2006	184	255	440
1984	224	120	344	2007	270	683	953
1985	232	312	544	2008	259	901	1 159
1986	282	80	362	2009	1 084	838	1 922
1987	387	122	509	2010	275	134	409
1988	385	189	574	2011	777	165	942
1989	386	418	804	2012	108	101	209
1990	309	689	998	2013	249	117	366
1991	409	503	912	2014	109	96	205
1992	718	1 087	1 805	2015	139	83	222
1993	656	1 996	2 652	2016	249	209	458
1994	368	2 912	3 280	2017	302	124	426
1995	597	2 903	3 500	2018	228	173	401
1996	1 353	2 483	3 836	2019	364	93	457
1997	1 475	1 820	3 295	2020*	286	150	436

* 2020 values are means of the 2016–2019 values for each area.

Year class strengths were assumed known (and equal to one) for years before 1975 and after 2017, 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 a minimum of the next 5×10^6 iterations (i.e., a final sample of at least length 1000 was taken from the Bayesian posterior).

Table 14: 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	0.19
2018	*Tangaroa*	1 660	0.34
2020	*Tangaroa*	1 037	0.20

* Not used in the reported assessment.

4.2.4 Prior distributions and penalty functions

The assumed prior distributions used in the assessment are given in Table 15. 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.

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 15: 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
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	25–200
M	Normal	0.19	0.2	0.1	0.35

4.2.5 Model estimates

Estimates of biomass were produced for an agreed base case run (research survey abundance series, constant M, logistic selectivity for the eastern fishery) using the biological parameters and model input parameters described in section 4.1.2. Sensitivity models were run to investigate the effects of estimating:

- 'High M': A higher fixed constant M (M raised from 0.19 to 0.23) (MPD only).
- 'Low M': A lower fixed constant M (M lowered from 0.19 to 0.15) (MPD only).

- 'All double normal': Selectivities for the survey and both fisheries were modelled as double normal.
- 'CPUE': the eastern CPUE series was included. The CPUE analysis for Chatham Rise hake investigated three CPUE series. The first used catch and effort data from the whole Chatham Rise. Two more were based on the catch and effort of the western and eastern fisheries data, respectively. During the characterisation work for the stock, it was concluded the Eastern CPUE demonstrated least conflict in abundance signal with the survey series.

Stock status from these four models was not markedly different to the base case. For all runs, MPD fits were obtained and qualitatively evaluated. MCMC runs were performed of the base case and all double normal and CPUE models. 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 8) and biomass (Figure 9). 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 and 2011). Consequently, biomass increased slightly during the late 1980s, then declined to about 2006. The growth of the strong 2002 year class resulted in an upturn in biomass from about 2007, followed by a further upturn from 2016 as the 2011 year class began to recruit. Current stock biomass was estimated at about 55% of B_0 (see Figure 9 and Table 16). 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 10).

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. For the eastern fishery, fitting the selectivity as logistic (as in the base case) resulted in wide bounds up to and beyond age of full selectivity which was not until age 14 or 15; this is logical given that the eastern fishery concentrates more on the spawning (i.e., older) biomass. If fitted as double normal the eastern fishery ogive was again essentially logistic.

Base case projections

Five-year biomass projections were made assuming future catches on the Chatham Rise were much higher (and assumed equal to the HAK 4 TACC of 1800 t) or the mean annual catch over the last six years (362 t). For the projections, estimated future recruitment variability was sampled in two ways: the first from actual estimates between 1975 and 2017, a period including the full range of recruitment successes; the second from actual estimates between 2008 and 2017 only. Restricting sampling to the more recent year class strengths was in response to estimated YCS indicating a declining long-term trend in YCS decadal means.

Base case model projections assuming a future annual catch of 1800 t suggest that biomass will decline between 2021 and 2025 (Table 17). The rate of decline depends on whether recruitments are some combination of those from all estimated years or whether they remain at the level of the last decade. In either recruitment scenario 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 362 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 Chatham Rise was taken). Under the assumption there has been no long-term decline in recruitment, future catches of 362 t per year will allow further stock rebuilding. If it is assumed recruitment will remain at the level of the last decade, future catches of 362 t per year are predicted to see *SSB* essentially unchanged over the next 5 years.

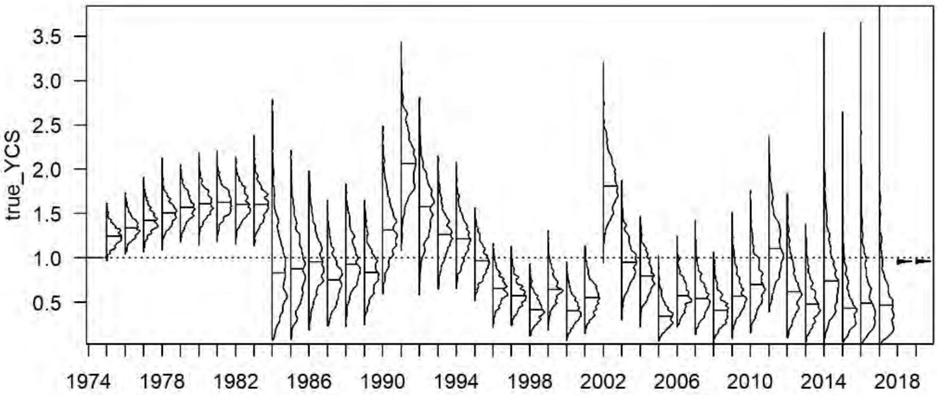


Figure 8: Estimated posterior distributions of year class strengths for the Chatham Rise base case. The dashed horizontal line indicates a year class strength of one. Individual distributions show the marginal posterior distribution, with horizontal lines indicating the median.

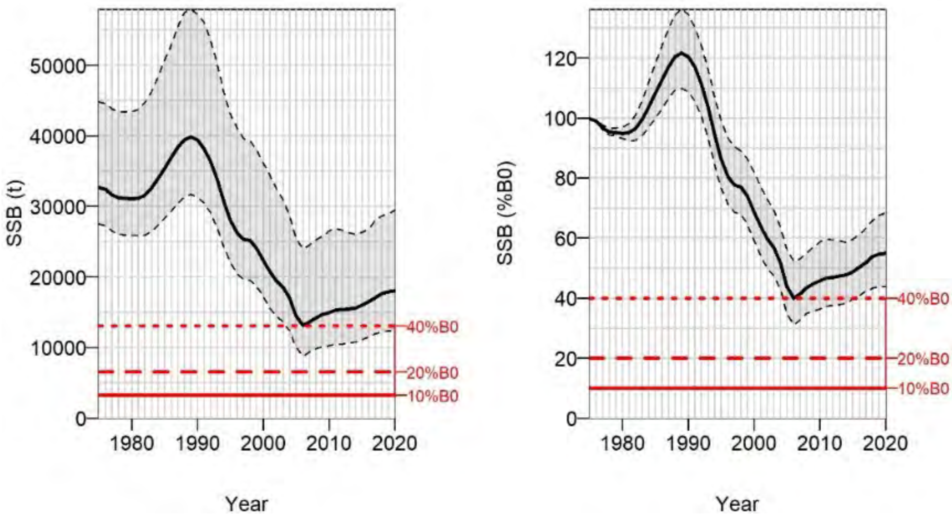


Figure 9: Estimated median trajectories (with 95% credible intervals shown as dashed lines) for the Chatham Rise base case model for absolute biomass and stock status (biomass as a percentage of B_0).

Table 16: Bayesian median and 95% credible intervals of B_0, B_{2020} and B_{2020} as a percentage of B_0 for the Chatham Rise model runs.

Model run	B_0	B_{2020}	B_{2020} (% B_0)	P(B_{2020} > 0.4 B_0)
Base case	32 838 (28 280–42 721)	18 150 (13 204–27 258)	55.1 (45.7–65.9)	0.99
Double normal	32 859 (27 998–43 444)	18 237 (13 175–27 659)	55.4 (45.4–66.8)	0.996
CPUE	34 367 (29 504–44 113)	20 035 (15 096–28 979)	58.0 (49.6–68.1)	1.0

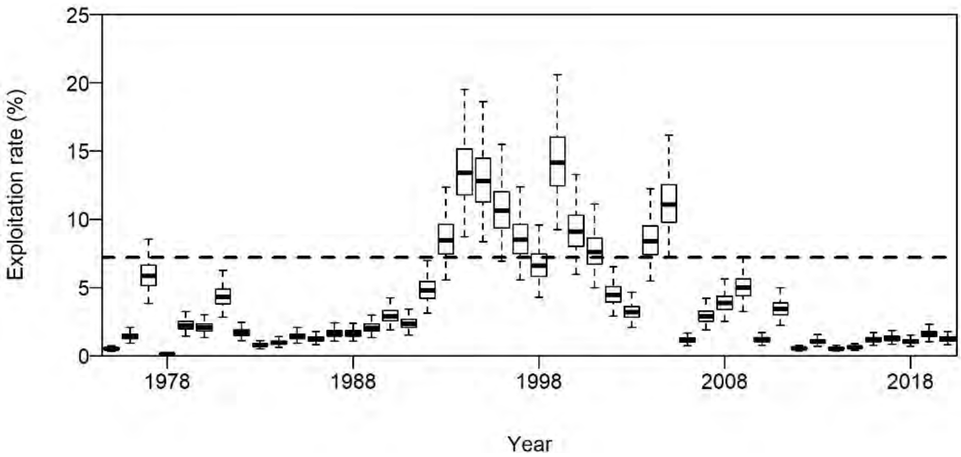


Figure 10: Exploitation rates (catch over vulnerable biomass) for the Chatham Rise stock base case model. Overall exploitation rate uses a catch weighted average of the component fishery exploitations.

Table 17: Chatham Rise base model: Bayesian median and 95% credible intervals of projected biomass, probability (%) of being above target (40% B_0) and below soft limit (20% B_0) or hard limit (10% B_0) in each year to 2025.

Recruitment	Future catch (t)	Year	B	B (% B_0)	p(B > 0.4 B_0)	p(B < 0.2 B_0)	p(B < 0.1 B_0)
All YCS	1 800	2021	17 600 (11 700–29 200)	53.5 (42.0–68.4)	0.992	0	0
		2022	16 400 (10 700–28 100)	50.2 (37.6–66.8)	0.937	0	0
		2023	15 700 (9 800–27 800)	47.6 (34.1–65.6)	0.844	0	0
		2024	15 100 (8 900–27 700)	45.9 (31.2–66.1)	0.762	0	0
		2025	15 000 (8 400–27 500)	45.0 (29.1–66.8)	0.717	0.001	0
All YCS	362	2021	18 100 (12 300–29 800)	55.1 (43.9–69.6)	0.997	0	0
		2022	18 100 (12 300–29 800)	55.2 (43.4–71.2)	0.995	0	0
		2023	18 300 (12 600–30 500)	55.7 (43.2–73.0)	0.992	0	0
		2024	18 800 (12 600–31 500)	57.0 (43.4–76.0)	0.993	0	0
		2025	19 600 (13 000–32 400)	59.3 (44.1–79.8)	0.997	0	0
Recent YCS	1 800	2021	17 500 (11 700–29 100)	53.3 (41.8–68.2)	0.991	0	0
		2022	16 200 (10 400–27 900)	49.7 (36.7–66.4)	0.918	0	0
		2023	15 100 (9 200–27 800)	45.9 (32.1–66.2)	0.769	0	0
		2024	13 900 (8 000–27 400)	42.5 (27.7–65.9)	0.607	0.001	0
		2025	13 000 (6 900–27 000)	39.5 (23.0–65.5)	0.484	0.007	0
Recent YCS	362	2021	18 100 (12 200–29 700)	54.9 (43.7–69.6)	0.996	0	0
		2022	17 900 (12 100–29 500)	54.8 (42.7–71.2)	0.994	0	0
		2023	17 800 (11 900–30 600)	54.3 (41.4–74.1)	0.987	0	0
		2024	17 800 (11 800–31 300)	54.1 (40.0–75.5)	0.975	0	0
		2025	17 800 (11 500–32 000)	53.9 (39.1–77.7)	0.969	0	0

4.3 HAK 7 (West Coast, South Island)

The stock assessment for HAK 7 was updated in 2022 by Dunn et al (in prep). While historical assessments used standardised Catch Per Unit Effort (CPUE) as an index of abundance (Dunn 1998), more recent assessments did not use CPUE because it was not considered to be a reliable index of abundance. Research survey data from the deepwater west coast South Island survey by the RV *Tangaroa* collected over the period 2000–2021 (Table 18) showed that the trends in abundance from CPUE and the survey had diverged to the point that they could not be reconciled within a single stock assessment model (Horn 2017). The 2022 assessment used only the survey indices.

The assessment modelled the fishery from 1974–75 to 2021–22, using catches (Table 19) and catch age composition data from the commercial trawl fishery and the *Tangaroa* research survey biomass indices and age composition data for the core strata (300–650 m) from 2000 to 2021 (Table 18).

4.3.1 Model structure

The model assumed two sexes (male and females) for ages 1–30, with the last age assumed to be a plus group. Natural mortality was assumed constant at M=0.19 per year. The model assumed two time steps: the first representing the period between October and April when recruitment occurred; and the second May to September, when the fishery and the survey took place. Selectivity ogives were assumed to follow logistic ogives for both the commercial fishery and the research survey. Models were explored using double-normal ogives for the commercial fishery and/or the survey, 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 by Horn (2013a). The relation between spawning stock biomass and recruitment was assumed to follow a Beverton-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.

Commercial fishery catch-at-age observations were available from observers from 1989–90 to 2020–21 (Figure 11) and were modelled as three separate fisheries based on the fishery stratification by Horn (2013b).

The research survey off the west coast of the South Island has been conducted since 2000. This survey initially covered an area from 300 m to 650 m depths north of Hokitika Canyon ('core area'). From 2012, the survey was extended into both shallower and deeper water to cover the distribution of a number of species more adequately, including hake (covering an area referred to as 'all areas'). The survey was initially extended to 200–800 m. An additional 800–1000 m deep stratum was added in 2016, to further investigate hake distributions and to better monitor shovelnose dogfish and ribaldo. However, the survey remains north of Hokitika Canyon and consequently does not monitor hake that occur in the canyon and south of the Hokitika Canyon.

Due to variable estimates in the numbers of hake of length less than about 67 cm in both the *Tangaroa* research survey and commercial length frequency data, ages for hake of less than 5 years were excluded from the commercial catch-at-age data, and the survey biomass and age data used in the model. Analyses showed that the amount of catch associated with these size classes was low, made up a negligible proportion of the total catch, and did not appear represent a consistent index of juvenile hake in either the *Tangaroa* research survey or the commercial catch data over time.

The representativeness of the *Tangaroa* research survey of the hake population on the WCSI is not well known. The survey may index a changing proportion of the population over time because it does not monitor areas either in or south of the Hokitika Canyon that are known to support hake in substantial numbers.

Because of concerns about changing fishing behaviour, including targeting and avoidance, advances in gear technology, and changes in fleet structure, the Working Group did not consider CPUE to be a reliable index of abundance.

Table 18: *Tangaroa* research survey indices of abundance (biomass in tonnes) and associated CVs (in parentheses) for the 'core' research survey (300-650 m).

Year	Core	Year	Core
2000	803 (0.13)	2016	221 (0.25)
2012	582 (0.13)	2018	229 (0.33)
2013	330 (0.17)	2021	507 (0.34)

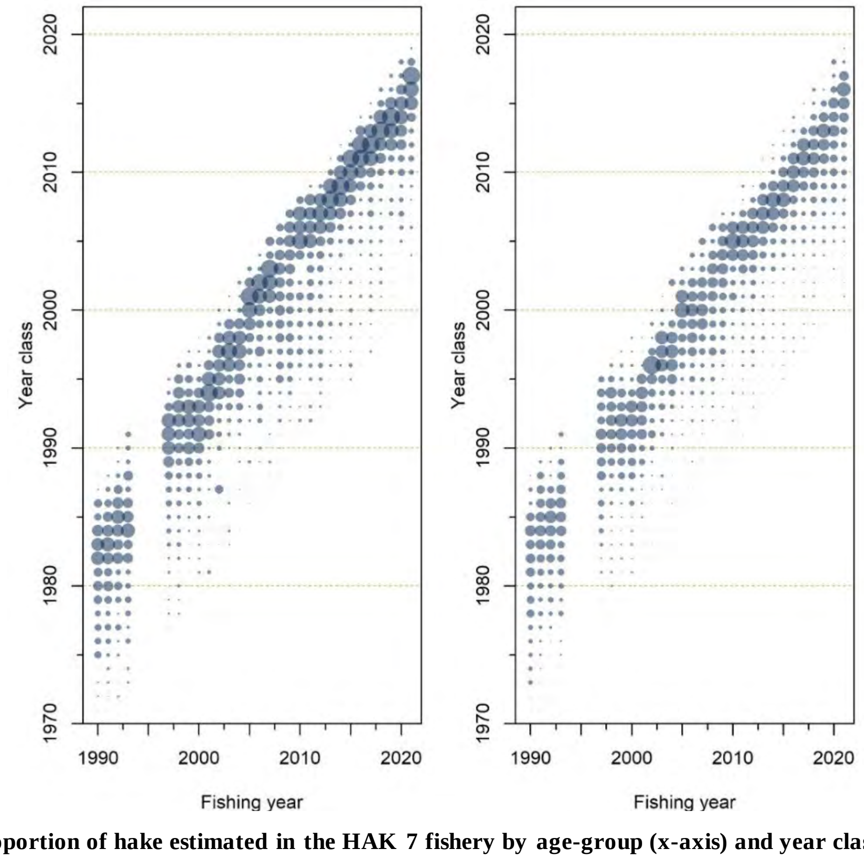


Figure 11: Proportion of hake estimated in the HAK 7 fishery by age-group (x-axis) and year class (y-axis) for data collected from 1990 to -2021.

Table 19: Revised landings (t) from fishing years 1975 to 2022 for the WCSI. Note, these relate to biological stocks, not QMAs.

Fishing year	West Coast S.I.	Fishing year	West Coast S.I.	Fishing year	West Coast S.I.
1974–75	71	1990–91	8 246	2006–07	7 696
1975–76	5 005	1991–92	3 026	2007–08	2 617
1976–77	17 806	1992–93	7 131	2008–09	5 952
1977–78	498	1993–94	2 974	2009–10	2 346
1978–79	4 737	1994–95	9 373	2010–11	3 586
1979–80	3 600	1995–96	9 937	2011–12	4 459
1980–81	2 565	1996–97	8 022	2012–13	5 434
1981–82	1 625	1997–98	7 882	2013–14	3 641
1982–83	745	1998–99	9 098	2014–15	6 219
1983–84	945	1999–00	7 446	2015–16	2 863
1984–85	965	2000–01	9 344	2016–17	4 701
1985–86	1 918	2001–02	7 519	2017–18	3 085
1986–87	3 755	2002–03	7 432	2018–19	1 562
1987–88	3 009	2003–04	7 943	2019–20	2 063
1988–89	8 696	2004–05	7 315	2020–21	1 367
1989–90[1]	8 741	2005–06	6 906	2021–22	2 272*

* Catch for 2021–22 was assumed to be equal to the TACC.

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 likelihood, and to the survey abundance index using a lognormal likelihood. The multinomial observation error effective sample sizes for the at-age data were adjusted using the reweighting procedure of Francis (2011). No additional process error was assumed for the *Tangaroa* research survey as the Francis reweighting estimated no additional process error. 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 and after 2015, 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 average to one.

4.3.4 Prior distributions and penalty functions

The assumed prior distributions used in the assessment are given in Table 20. The priors for B_0 and selectivities were relatively uninformed and had wide bounds. Priors for the year class strengths were assumed to be relatively uninformed with lognormal priors with mu = 1.0 and CV = 1.1. The prior for the survey q was informative and was estimated using the hake survey priors from other areas 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., $0.16 \times 0.54 = 0.09$). Bounds were assumed to be wide and were 0.001–1.0.

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 20: 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	–	–	25 000	250 000
Year class strengths	Lognormal	1.0	1.1	0.01	100
Trawl survey q	Lognormal	0.09	0.79	0.01	1.00
Selectivities	Uniform	–	–	0	50

4.3.5 Model sensitivities

Three main model sensitivity models were developed: (i) assuming year classes before 1985 were fixed at one, (2) and a low M (0.15 y^{-1}), and (3) high M (0.23 y^{-1}) assumption.

Additional sensitivities (not shown) explored the exclusion of the 2000 survey index, the use of the RV *Kaharoa* WCSI inshore research survey biomass and length frequency data as an index of juvenile abundance, the choice of domed selectivities for the fishery and the RV *Tangaroa* survey, introducing a time split in the south shallow fishery after 2006, upweighting and downweighting the *Tangaroa* survey index, and assuming a lower steepness (h=0.7) for the stock. These sensitivities did not significantly change the initial or current status of the model nor estimates of future status under the projection assumptions.

The fixed 1984 YCS sensitivity was to explore the effect of fixing the early and uncertain, year classes in the model. This sensitivity suggested that the fixing of early year classes resulted in a higher stock status than the base case. The low M and high M sensitivities suggested similar initial biomass (B_0) but lower status for the low M sensitivity (31% B_0) and higher status for the high M sensitivity (45% B_0).

The remaining sensitivities also gave similar outcomes to the base case with status ranging between 30% B_0 when the *Kaharoa* biomass and length frequencies were included and 41% B_0 when the south shallow fishery was split into two time periods (up to 2006, and 2007 onwards).

Estimates of the status in 2019 (the time that the previous stock assessment was carried out) gave similar, but slightly higher estimates of status for 2019, with the base case giving a status in 2019 of 25% B_0 (95% CIs 18–36 % B_0) compared with an estimate of 17% from the 2019 assessment.

4.3.6 Model estimates

Results from the base case assessment model and the three main sensitivity models are presented here. For all models, MPD fits were obtained and qualitatively evaluated; MCMC estimates of the median posterior and 95% percentile credible intervals were determined for current and virgin biomass; and projected state calculated under assumptions of recent year classes (i.e., assuming future year class strengths were equal to the period 2006–2015) and all year class strengths (i.e., the period 1975–2015).

The base case stock assessment model estimated spawning stock biomass declined throughout the late 1970s (see Figure 15) 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 because of the higher levels of exploitation and below-average recruitment between 2000–01 and 2014–15 (Figure 12). The stock followed the general trend shown by the trawl survey index (Table 13).

The sensitivity models produced similar trends in the biomass trajectory and in the pattern of year class strength. The base case model estimated the status in 2018–19 to be 25.0% B_0 (95% CIs 18–35%) of initial biomass (B_0), and the current status (2022) to be 39 % B_0 (95% CIs 30–52%) (Table 21). Because of uncertainty in the early YCS, a sensitivity that fixed early YCS to 1984 at one was run. This showed that the assumptions of early YCS being forced to have a lower average had considerable impact on current status. This sensitivity gave a less credible estimate of current status and was much higher than the status estimated for the base case.

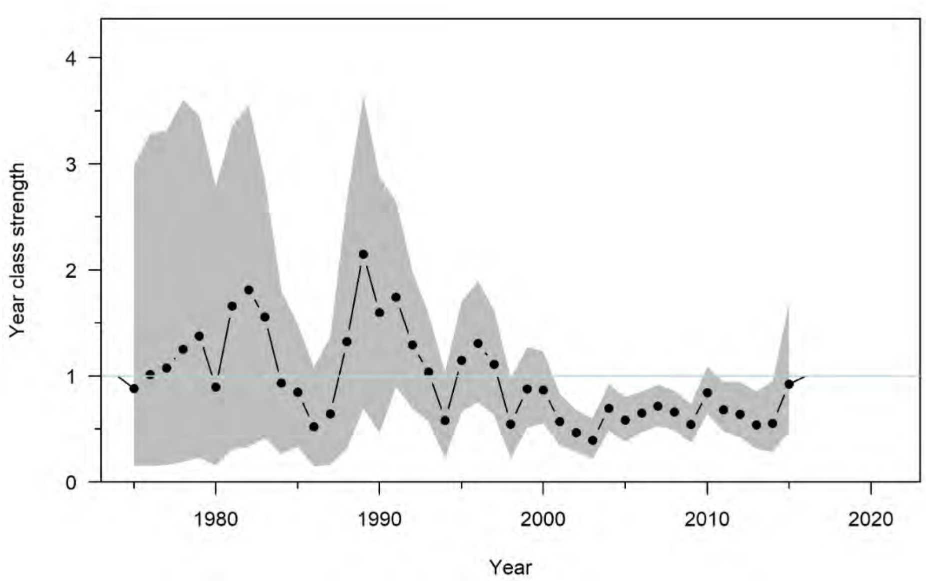


Figure 12: MCMC estimates of year class strengths for the base case model with median (line and individual points) and 95% credible interval (grey band).

Table 21: Bayesian median (95% credible intervals) (MCMC) of B_0 and SSB_{2022} (t), and SSB_{2022} as a percentage of B_0 for the WCSI models. The run with the 1984 fixed YCS was considered by the Plenary to not be credible.

Model run	B_0	SSB_{2022}	SSB_{2022} (% B_0)
Base case	78 870 (74 140–84 810)	30 350 (22 450–43 390)	38.6 (29.5–52.2)
Fixed 1984 YCS*	81 680 (74 440–92 170)	54 080 (35 390–80 350)	66.1 (47.5–87.4)
Low M	80 020 (76 550–84 670)	25 140 (18 080–36 640)	31.4 (23.3–43.5)
High M	85 650 (78 710–94 600)	38 580 (29 070–53 920)	45.1 (35.3–59.4)

* Deemed not to be a credible run.

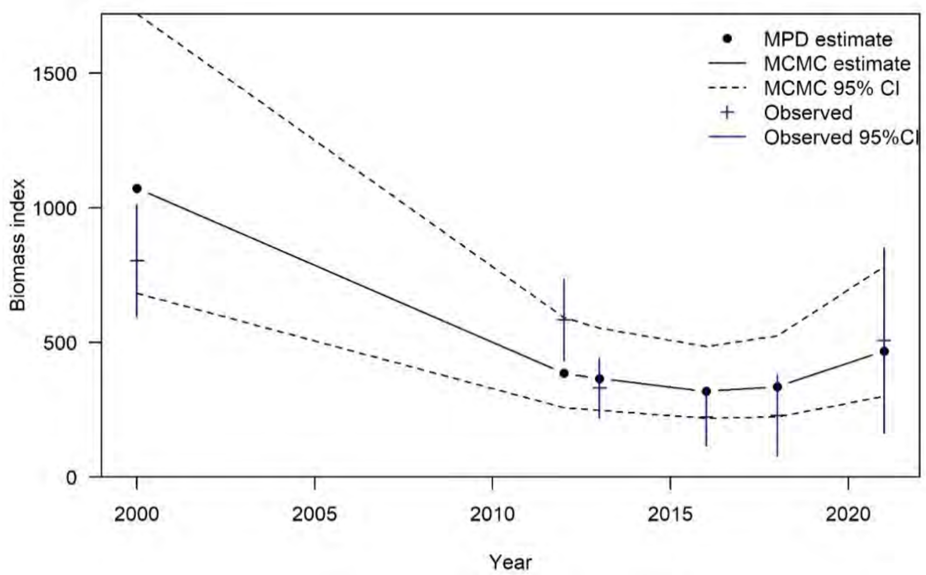


Figure 13: Fit of the base case model to the survey index of abundance from *Tangaroa* research survey for the core strata.

Base case MPD estimates indicated that hake were fully selected by about age 7, similar to the age of maturity and that the three fisheries had similar selectivity by age, but different selectivities by sex (Figure 14).

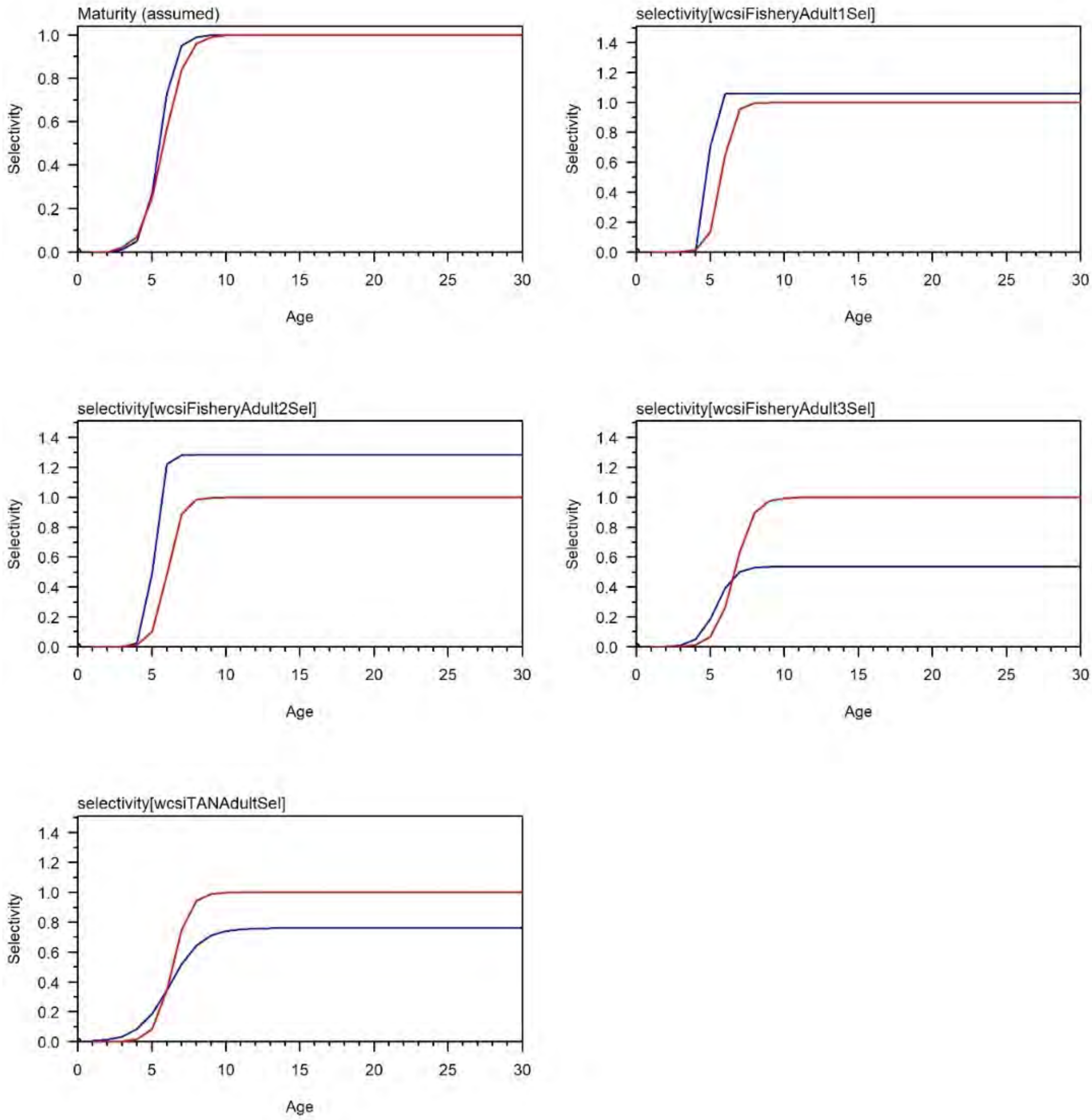


Figure 14: Assumed maturity ogive (top left) and the MPD estimated selectivities for the base case model for the three fisheries and the *Tangaroa* research survey.

4.3.8 Yield estimates and projections

The status of HAK 7 was projected for 5 years (2023–2027), assuming two scenarios for the future catch: (1) catches remaining at the average of 2019–2021 levels (1664 t), and (2) catches at the TACC limit (2272 t). For each projection scenario, future recruitment deviates were sampled from either all years (1974–2015) or for the most recent ten years (2006–2015). Note that the RV *Tangaroa* survey in 2018 and 2021 suggested that the 2016 year class may be near the long-term average but above the recent (2006–2015) average, but these observations were not used in the projections.

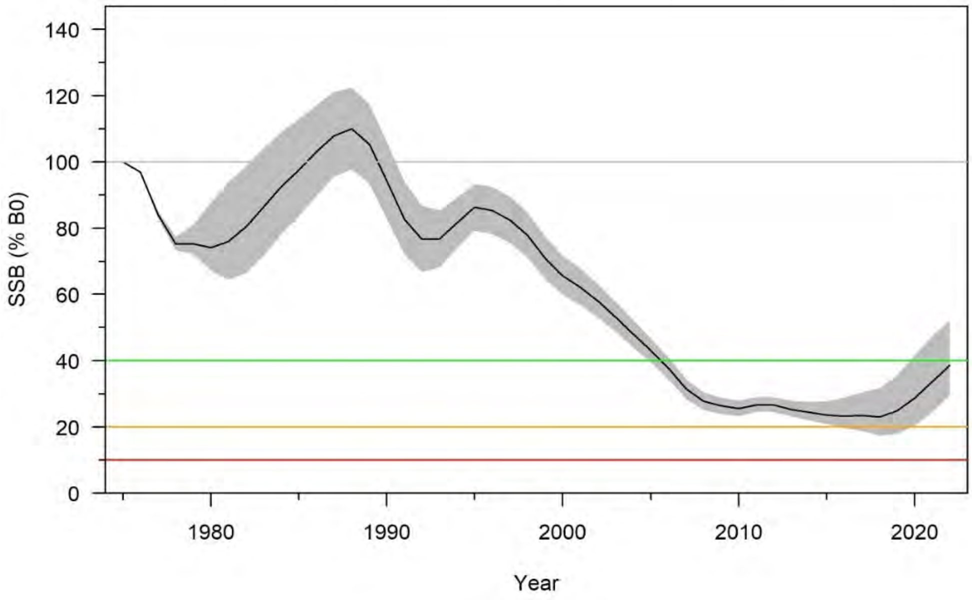


Figure 15: Estimated median spawning stock biomass trajectories for the WCSI stock base case (with 95% credible intervals shown as grey band) for biomass as a percentage of B_0. The red horizontal line at 10% B_0 represents the hard limit, the orange line at 20% B_0 is the soft limit, and the green line is the % B_0 target (40% B_0).

Projections with the base case model using the 2006–2015 recruitment series indicated that spawning biomass will continue to rebuild towards the target biomass for both the current catch (Figure 16) and if catches were at the TACC (Figure 17). If recruitments increased to earlier levels, the biomass is likely to exceed the target (Table 22, Figure 16, Figure 17). The projected stock status in relation to the limits and target are presented in Table 23.

Table 22: Bayesian median (t) and 95% credible intervals of projected B_{2027}, B_{2027} as a percentage of B_0, and B_{2027}/B_{2022} (%) for the base case under two future annual catch scenarios and two future recruitment scenarios.

Future catch (t)	Future YCS	B_{2022}	B_{2027}	B_{2027} (%B_0)	B_{2027}/B_{2022} (%)
Base case					
1664	2006–2015	25 820 (16 770–41 850)	31 650 (20 450–50 130)	40.2 (26.8–60.5)	122.4 (105.1–142.3)
2772		25 820 (16 770–41 850)	29 580 (18 350–48 060)	37.5 (24.0–58.0)	114.1 (97.3–133.7)
1664	1974–2015	30 150 (18 920–47 970)	45 520 (27 840–71 030)	57.7 (36.1–88.5)	148.1 (103.7–230.4)
2772		30 150 (18 920–47 970)	43 420 (25 740–68 920)	55.0 (33.4–85.8)	141.1 (98.1–222.8)

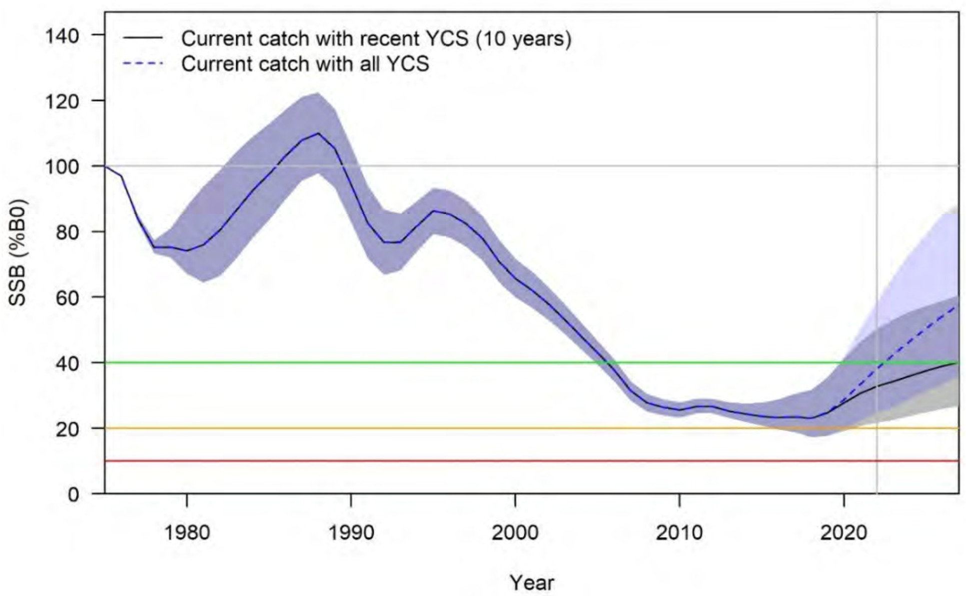


Figure 16: Spawning stock biomass (*SSB*) trajectories including projections from 2023 to 2027 for the base model, projected with catch of 1664 t, with YCS sampled from all years or most recent estimated 10 years (with 95% credible intervals shown as blue band for the long-term recruitments and grey band for the recent recruitments) for biomass as a percentage of B_0. The red horizontal line at 10% B_0 represents the hard limit, the orange line at 20% B_0 is the soft limit, and the green line is the % B_0 target (40% B_0).

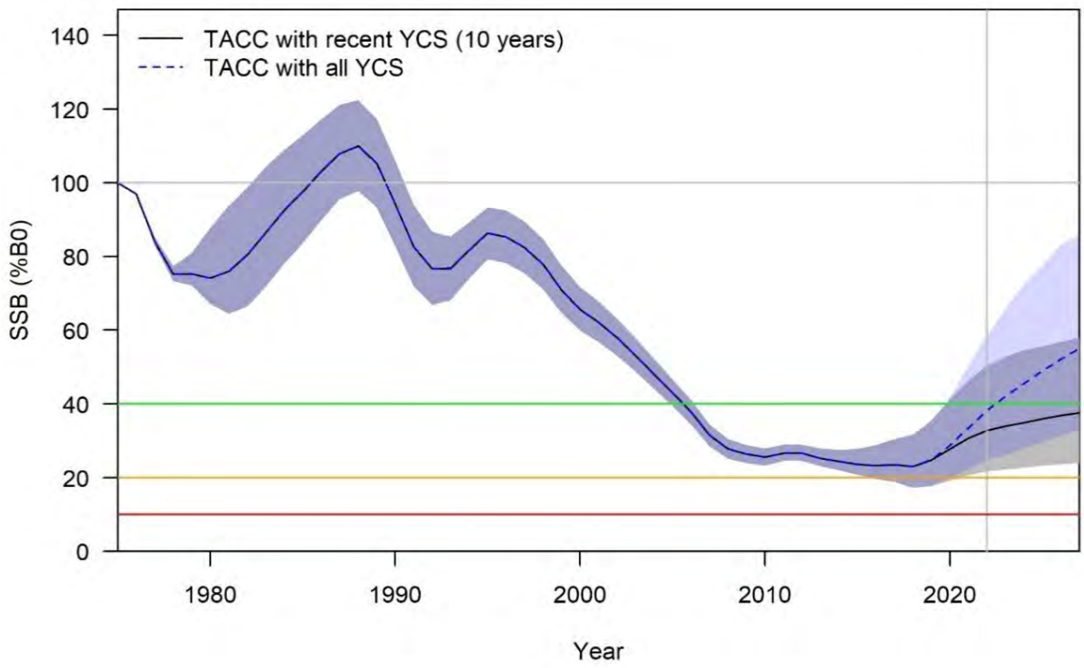


Figure 17: Spawning Stock Biomass (*SSB*) trajectories including projections from 2023 to 2027 for the base model, projected with catch equal to the TACC (2772 t), with YCS sampled from all years or most recent estimated 10 years (with 95% credible intervals shown as blue band for the long-term recruitment and grey band for the recent recruitments) for biomass as a percentage of SSB_0. The red horizontal line at 10% SSB_0 represents the hard limit, the orange line at 20% SSB_0 is the soft limit, and the green line is the % B_0 target (40% SSB_0).

Table 23: Probability of the stock being less than 10% and 20% SSB_0 and greater than 40% SSB_0 for the base case in 2027 with either current catch (1664 t) or TACC (2772 t).

Future catch (t)	Future YCS	P(> 40%)	P(< 20%)	P(< 10%)
Base case				
1664	2006–2015	0.51	0.00	0.00
2772		0.39	0.00	0.00
1664	1974–2015	0.93	0.00	0.00
2772		0.89	0.00	0.00

5. FUTURE RESEARCH CONSIDERATIONS

All HAK stocks

- Review historical ageing of hake to address the uncertainty seen in the1990s.

HAK 1

- Review the age and length data for Sub-Antarctic hake in HAK1 and verify the estimated proportions at age for the commercial data, specifically for periods up to 2000, before further assessments are conducted for this stock.
- Explore the spatial-temporal structure of Sub-Antarctic hake in HAK1 refine the best possible definitions of fisheries for this stock.
- Consider exclusion of the 2017 *Tangaroa* Sub-Antarctic trawl survey biomass estimate from future stock assessments of HAK 1, given that making adjustments to correct this estimate will introduce some undefinable uncertainty.

HAK 7

- Explore the linkage between HAK 7 and HAK 1, particularly the linkage to Puysegur.
- Consider novel options to address concerns regarding the WCSI trawl survey coverage in relation to the HAK 7 stock, particularly the region south of the survey area where much of the commercial fishery takes place. Increasing coverage using bottom trawls is not possible given the topography of this area. Tagging and acoustics have also been previously considered and could be revisited if the stock continues to increase.

- Determine the optimal frequency or periodicity of *RV Tangaroa* surveys to monitor biomass and detect recruitment patterns (e.g., two consecutive surveys every 5 years, or one survey every 3 years), considering both costs and potential benefits.
- Continue development of spatio-temporal analyses to understand the length, age and sex structure of the WCSI hake survey and commercial data using alternative spatial analyses (juveniles, sub-adults and adults) with consideration of seasonal spawning cycles and the timing of surveys.
- Investigate whether juveniles from *RV Tangaroa* (and possibly *RV Kaharoa*) surveys could provide an index of recruitment for the projections.
- Consider development of spatial age-length relationships and the value of additional age data. Further evaluate ageing “outliers”.
- Explore potential climate impacts on spatial and temporal population dynamics and recruitment to the stock.
- Continue spatio-temporal analyses of fisheries CPUE data with consideration of seasonal variability.

6. STATUS OF THE STOCKS

Stock Structure Assumptions

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

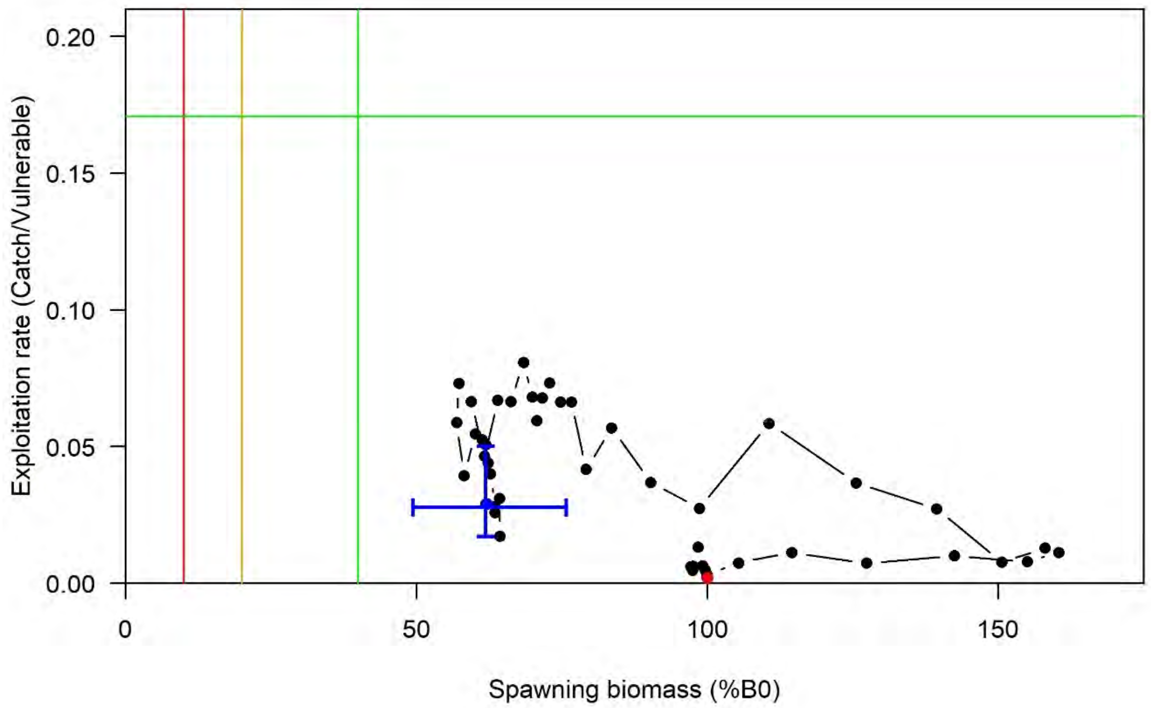
The HAK 1 Fishstock includes all the Sub-Antarctic biological stock, part of the Chatham Rise biological stock, and all hake around the North Island (which are more likely part of either the WCSI or Chatham Rise stocks). The Sub-Antarctic stock is defined as all of Fishstock HAK 1 south of the Otago 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	2021
Assessment Runs Presented	Reference 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_{2021} was estimated at 62% B_0; Very Likely (> 90%) to be at or above the target
Status in relation to Limits	B_{2021} 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 (albeit slightly larger decline) in the biomass trend in 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 Sub-Antarctic stock reference model from the start of the assessment period in 1974 (represented by a red point), to 2021 (blue cross). 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}= 0.17 calculated using CASAL CAY calculation). Biomass and exploitation rate estimates are medians from MCMC results.

Projections and Prognosis	
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 slowly 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: 2021	Next assessment: 2024
Overall assessment quality rank	1 – High Quality	
Main data inputs (rank)	- Research time series of abundance indices (trawl survey: summer, autumn)	1 – High Quality
	- Proportions-at-age data from the commercial fisheries and trawl surveys	1 – High Quality
	- Estimates of biological parameters	1 – High Quality
Data not used (rank)	- Commercial CPUE (used in sensitivity run only)	2 – Medium Quality: potentially biased owing to changes in

		spatial extent and fishing practices
Changes to Model Structure and Assumptions	-Revisions to annual cycle -Removal of the September *Tangaroa* biomass index	
Major Sources of Uncertainty	- The summer trawl survey series estimates are variable and catchability may vary 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. - There is concern that there may be spatial structure that is not adequately captured in the model	

Qualifying Comments
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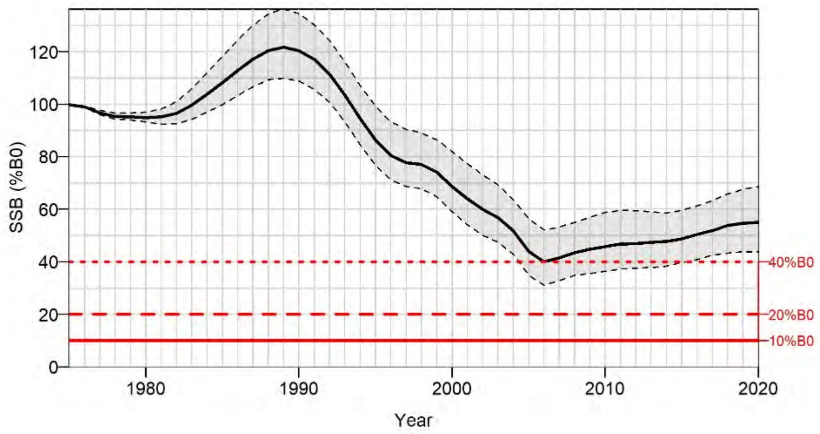
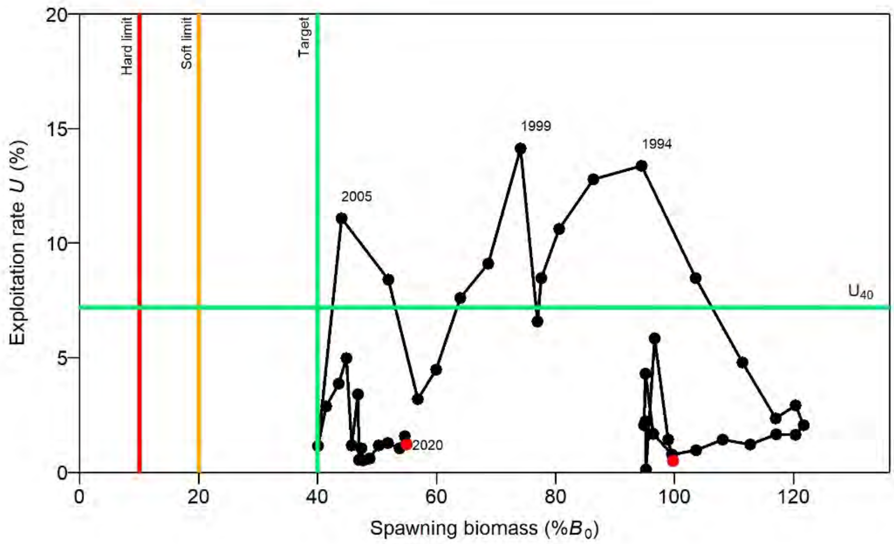
Fishery Interactions
Hake are often taken as a bycatch in hoki target fisheries. Some target fisheries for hake do exist, with the main bycatch species being hoki, ling, silver warehou, and spiny dogfish. Hake are a key predator of hoki. Incidental interactions and associated mortality have been recorded 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	2020
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_{2020} was estimated to be about 55% B_0; Very Likely (> 90%) to be at or above target
Status in relation to Limits	B_{2020} 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 (% 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 2020 (the final assessment year). The management target (40% B_0, short dash horizontal line) and soft limit (20% B_0, dashed horizontal line) and hard limit (solid line) are shown. Years on the x-axis indicate fishing year with "2005" representing the 2004–05 fishing year. Biomass estimates are based on MCMC results.**  **Trajectory over time of exploitation rate (U) and spawning biomass (% B_0), for the HAK 4 stock base model from the start of the assessment period in 1975 (represented by a red point), to 2020 (red and labelled). 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	Median estimates of biomass fell to 40% B_0 in 2006, 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 fishing pressure in most years from 1994 to 2005).
Other Abundance Indices	The CPUE index for the eastern Chatham Rise has been increasing since 2012.
Trends in Other Relevant Indicators or Variables	Recruitment (1996–2013, but excluding 2002 and 2011) is estimated to be lower than the long-term average for this stock.

Projections and Prognosis	
Stock Projections or Prognosis	Expectations for the biomass of the Chatham Rise stock over the next 5 years depends on whether recruitment is assumed able to increase to levels from throughout the time series or

	assumed to be restricted to levels seen recently. If the former, then catch levels equivalent to those from recent years (i.e., about 360 t annually) are expected to result in an increase in SSB, but if recruitments are restricted to the levels of recent years SSB is expected to remain more or less constant. If future catches increase to the level of the full HAK 4 TACC of 1800 t, biomass is expected to decline under both recruitment scenarios with the median estimate reaching 40% B_0 in 2025 under the more pessimistic recruitment assumption.
Probability of Current Catch or TACC causing Biomass to remain below or to decline below Limits	Assuming recent recruitment and current catch (362 t): Soft Limit: Exceptionally Unlikely (< 1%) Hard Limit: Exceptionally Unlikely (< 1%) Assuming recent recruitment and future catches at 1800 t (based on the HAK 4 TACC): Soft Limit: Very Unlikely (< 10%) Hard Limit: Exceptionally Unlikely (< 1%)
Probability of Current Catch or TACC causing Overfishing to continue or to commence	Assuming recent recruitment and future catches at the level of the current catch: Very Unlikely (< 10%) Assuming recent recruitment and future catches at 1800 t (based on 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: 2020	Next assessment: 2023
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	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	- Selectivity for the commercial fishery to the east of the Chatham Rise is modelled as logistic (double normal previously) - Catch history revised from 2009 onwards	
Major Sources of Uncertainty	- Catch at age information from the commercial catch has not been available since 2016 due to declining catches - 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
- In October 2004, large catches were taken in the western deep fishery (i.e., near the Mernoo Bank). This was 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.

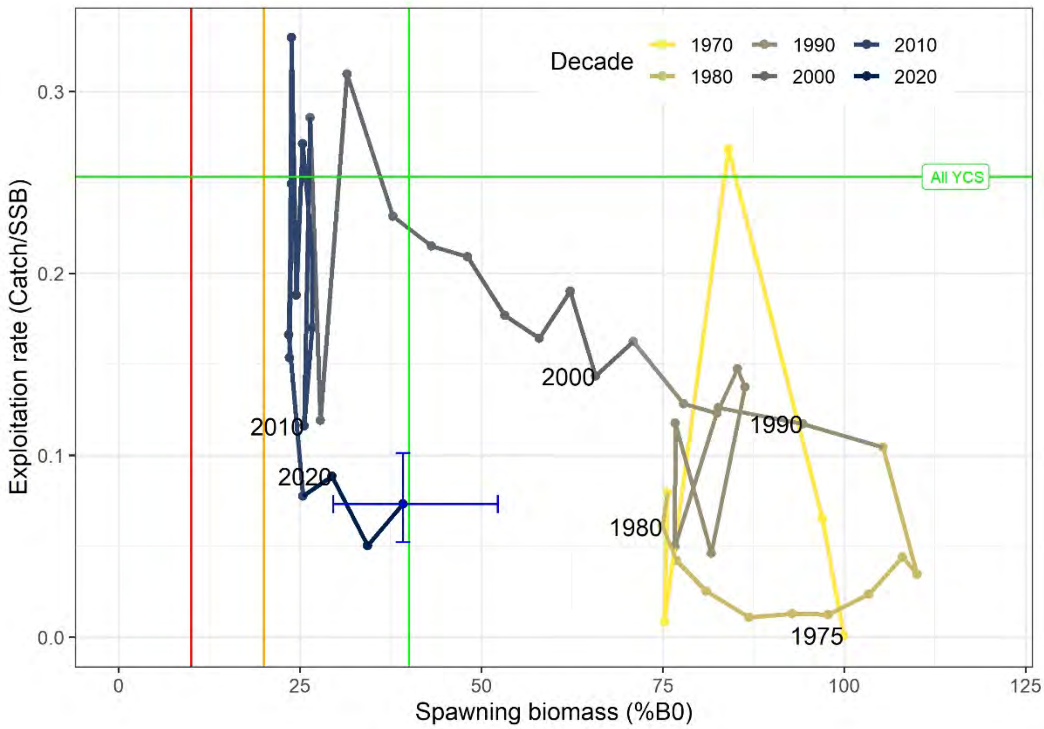
- A pronounced reduction in average recruitment over 40 years may indicate a decline in the productivity of this stock.

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	2022
Assessment Runs Presented	Base case
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_{2022} was estimated to be 39% B_0; About as Likely as Not (40–60%) to be at or above the target
Status in relation to Limits	B_{2022} was Unlikely (< 40%) to be below the Soft Limit and Very Unlikely (< 10%) to be below the hard Limit
Status in relation to Overfishing	Overfishing in 2022 was Unlikely (< 40%) 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 case model, from the start of the assessment period in 1975 (represented by a yellow point), to 2022. The red vertical line at 10% SSB_0 represents the hard limit, the orange line at 20% SSB_0 is the soft limit, and green lines are the %SSB_0 target (40% SSB_0) and the corresponding exploitation rate (U_{40} = 0.25 based on all YCS, calculated using CASAL CAY calculation. Biomass and exploitation rate estimates are medians from MCMC results.

Fishery and Stock Trends	
Recent Trend in Biomass or Proxy	- Biomass has increased substantially since 2019

Recent Trend in Fishing Intensity or Proxy	- The exploitation rate was estimated to have been low from 2019 to 2021.
Other Abundance Indices	
Trends in Other Relevant Indicators or Variables	- Recruitment from 2006–2014 was estimated to be lower than the long-term average. The 2021 survey found a high abundance of juveniles suggesting that recruitment in 2015 and 2016 is likely to be higher than in 2006–2014.

Projections and Prognosis	
Stock Projections or Prognosis	- The biomass of the WCSI stock is expected to increase under both recent recruitment and long-term recruitment, for both the current catch and the TACC
Probability of Current Catch or TACC causing Biomass to remain below or to decline below Limits	- Using recent average recruitment: Current catch: Soft Limit: Very Unlikely (< 10%) Hard Limit: Very Unlikely (< 10%) TACC: Soft Limit: Very Unlikely (< 10%) Hard Limit: Very Unlikely (< 10%)
Probability of Current Catch or TACC causing Overfishing to continue or to commence	Using recent average recruitment: Current catch: Very Unlikely (< 10%) 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: 2022	2025
Overall assessment quality rank	1 – High Quality	
Main data inputs (rank)	- RV *Tangaroa* research trawl surveys (2000-2021 for core area)	1 – High Quality
	- Proportions-at-age data from the commercial fishery and research surveys	1 – High Quality
	- Estimates of fixed biological parameters	1 – High Quality
Data not used (rank)	- RV *Kaharoa* WCSI inshore trawl survey	- Does not monitor the adult stock and may not monitor juvenile abundance
	- RV *Tangaroa* survey estimates from outside the core area	- Time series not long enough
	- Commercial fishery CPUE	- May not track stock biomass
Changes to Model Structure and Assumptions	- New model assumes three fleets-as-areas fisheries selectivities rather than two period based selectivities - Base case model updated to use the core strata survey series (and included the 2000 survey estimate) rather than all strata series	
Major sources of Uncertainty	- Uncertainty about the size of recent year classes affects current stock status and the reliability of stock projections	

	- The spatial and temporal representativeness of the RV *Tangaroa* research 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

Qualifying Comments
-

Fishery Interactions
- The main bycatch species of hoki-hake-ling-silver warehou-white warehou target fisheries are rattails, javelin fish, and spiny dogfish. Hake are a key predator of hoki. Incidental interactions and associated mortality have been recorded for protected species, including New Zealand fur seals and seabirds.

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