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Tini a Tangaroa

Stock assessment of hake (*Merluccius australis*) on the west coast of South Island (HAK 7) for the 2018–19 fishing year

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EXECUTIVE SUMMARY

Kienzle M.; McGregor, V.; Dunn, M.R. (2019). Stock assessment of hake (*Merluccius australis*) on the west coast of South Island (HAK 7) for the 2018–19 fishing year.

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This report summarises the stock assessment for the 2018–19 fishing year for hake on the West Coast South Island (WCSI; Quota Management Area HAK 7). An updated Bayesian assessment was conducted using the general-purpose stock assessment program CASAL v2.30. The assessment incorporated all relevant biological parameters, the commercial catch histories, commercial catch per unit effort (CPUE) and research trawl surveys as relative biomass indices, and time series of proportion-at-age data from the commercial trawl fisheries and research surveys. The analysis included data up to the end of the 2017–18 fishing year.

The stock assessment was updated using a base model assuming one sex (without sex in the partition) and using the research trawl survey indices of abundance collected between 2000 and 2018 as the biomass index. The model indicated that the stock was steadily fished down for 20 years from about 1989–90, and that the spawning stock was currently at about 17% of the pre-fishery level (B_0). Projections indicated that continued fishing at recent catch levels with average future recruitment would keep the biomass of this stock at a similar level. Increases in catches, or continued poor recruitment, would probably cause further stock decline. Three sensitivity analyses to the base model indicated that the assessment was most sensitive to the choice of the index of abundance used (survey or commercial CPUE).

1. INTRODUCTION

This report outlines the stock assessment of hake (*Merluccius australis*) on the West Coast South Island (WCSI; Quota Management Area (QMA) HAK 7) including data up to the end of the 2017–18 fishing year. The current stock hypothesis for hake suggests that there are three separate stocks (Colman 1998); the west coast South Island stock (WCSI, the area of HAK 7 on the west coast South Island), the Sub-Antarctic stock (the area of HAK 1 that encompasses the Southern Plateau), and the Chatham Rise stock (HAK 4 and the area of HAK 1 on the western Chatham Rise).

Until 2011, HAK 7 assessments had been problematic because there were no reliable indices of relative abundance (Dunn 2004a, Horn 2011). While commercial fishery catch per unit effort (CPUE) series have been produced previously (e.g., Ballara & Horn 2011) the trends in these series were generally not considered plausible, and it was concluded that catch rates of hake off WCSI were influenced more by fisher behaviour than by abundance of the species. Consequently, using the available CPUE series in the model would probably be misleading (Horn 2011). Several 'one-off' research surveys of hoki and hake have been conducted by different vessels off WCSI, but these provided no useful relative biomass series. A long-running trawl survey series of inshore waters off WCSI by RV *Kaharoa* did not provide a useful index of hake biomass, as it surveys no deeper than 400 m (Stevenson & Hanchet 2000). Consequently, a HAK 7 assessment by Horn (2011) included only biological parameters, a catch history, and proportion-at-age data from the commercial fishery since 1990 and the *Wesermünde* survey in 1979. While catch-at-age data can provide information on exploitation rate and therefore biomass, they are likely to be much more informative when tuned using a relative abundance series. The HAK 7 assessment by Horn (2011) was considered too unreliable to be reported in the 2011 Plenary Document.

A subsequent assessment (Horn 2013b) differed significantly from the 2011 assessment in two respects. First, it included a CPUE series that was considered by the Deepwater Fisheries Assessment Working Group to be reliable. That series commenced when the deemed value scheme was introduced (2001), and so was believed to be less biased by changes in fishing practice and catch reporting behaviour that had confounded longer CPUE series. Second, the assessment included two comparable trawl biomass indices from surveys that had covered a large proportion of the likely hake habitat off WCSI. The base case model indicated that the WCSI spawning stock was at about 58% B_0, and that continued fishing at the most recent catch level was likely to allow stock size to increase slowly. That assessment was accepted by the Working Group, the first time this had occurred since 2004.

By 2017, two additional points had been added to the research survey series. It then became apparent, however, that there was a conflict between the two relative abundance indices. The trawl survey indicated a recent declining biomass with current biomass being lower than in 2000, whereas the CPUE indicated a recent increase in biomass and a current level similar to that in 2000. The Working Group was unable to determine which of the two series was most likely to index the biomass of the stock, as both had known drawbacks. The trawl survey series was still relatively sparse and it did not survey the entire area off WCSI where hake were known to be relatively abundant. The CPUE series had already been truncated (at 2001) because earlier data were considered unreliable and biased (Ballara 2013), but there may still have been biases in the series since 2001 relating to changes in fishing technology and in the commercial (economic) desirability of hake that were not captured in the QMS effort statistics, and so could not be standardised for in any CPUE model. Consequently, results from two alternative models (Survey, and CPUE) were reported in the 2017 Plenary report.

The stock assessment presented in this report builds on knowledge from previous assessments. It fulfils objective 2 of project HAK2018-01 "To carry out a stock assessment of the west coast South Island hake stock including estimates of current biomass, the status of the stock in relation to management reference points, and future projections of stock status as required to support management.", funded by the Ministry for Primary Industries. Revised catch histories are reported here, as are new model input data and research results. Although some of these data are not relevant to the assessment as reported here, they are included to provide a broader view on the available knowledge and literature about hake in New Zealand waters.

1.1 Description of the fishery

Hake are widely distributed through the middle depths of the New Zealand Exclusive Economic Zone (EEZ) mostly south of latitude 40° S (Anderson et al. 1998). Adults are mainly distributed in depths from 250 to 800 m although some have been found as deep as 1200 m, while juveniles (age 0+) are found in shallower inshore regions under 250 m (Hurst et al. 2000). Hake are taken almost exclusively by trawl, and predominantly by large demersal trawlers — often as bycatch in fisheries targeting other species such as hoki and southern blue whiting, although target fisheries also exist (Devine 2009, Ballara 2018). There is a small reported catch of hake from the bottom longline fishery targeting ling. Present management divides the fishery into three main fish stocks: (a) the Challenger Quota Management Area (QMA) (HAK 7), (b) the Southeast (Chatham Rise) QMA (HAK 4), and (c) the remainder of the EEZ comprising the Auckland, Central, Southeast (Coast), Southland, and Sub-Antarctic QMAs (HAK 1). An administrative fish stock exists in the Kermadec QMA (HAK 10) although there are no recorded landings from this area. The hake QMAs are shown in Figure 1.

The largest fishery has been off the west coast of the South Island (HAK 7) with the highest catch (17 000 t) recorded in 1977, immediately before the establishment of the EEZ. In 2018–19, the TACC for HAK 7 is the largest among the HAK QMAs, at 5 064 t out of a total for the EEZ of 10 575 t (Fisheries Infosite, https://fs.fish.govt.nz, accessed on 4th June 2019). The WCSI hake fishery has generally consisted of bycatch in the much larger hoki trawl fishery, but it has undergone a number of changes since about 2000 (Devine 2009, Ballara 2013). These include changes to the TACCs of both hake and hoki, and also changes in fishing practices such as gear used, tow duration, and strategies to limit hake bycatch. In some years, notably in 1992, 1993, 2006, and 2009 there has been a hake target fishery in September after the peak of the hoki fishery is over (Ballara 2013).

Dunn (2003a) found that area misreporting between the WCSI and the Chatham Rise fisheries occurred from 1994–95 to 2000–01. He estimated that between 16 and 23% (700–1000 t annually) of WCSI landings were misreported as deriving from Chatham Rise, predominantly in June, July, and September. Levels of misreporting before 1994–95 and after 2000–01, and between WCSI and Sub-Antarctic, were estimated as negligible, and there is no evidence of significant misreporting since 2001–02 (Ballara 2013).

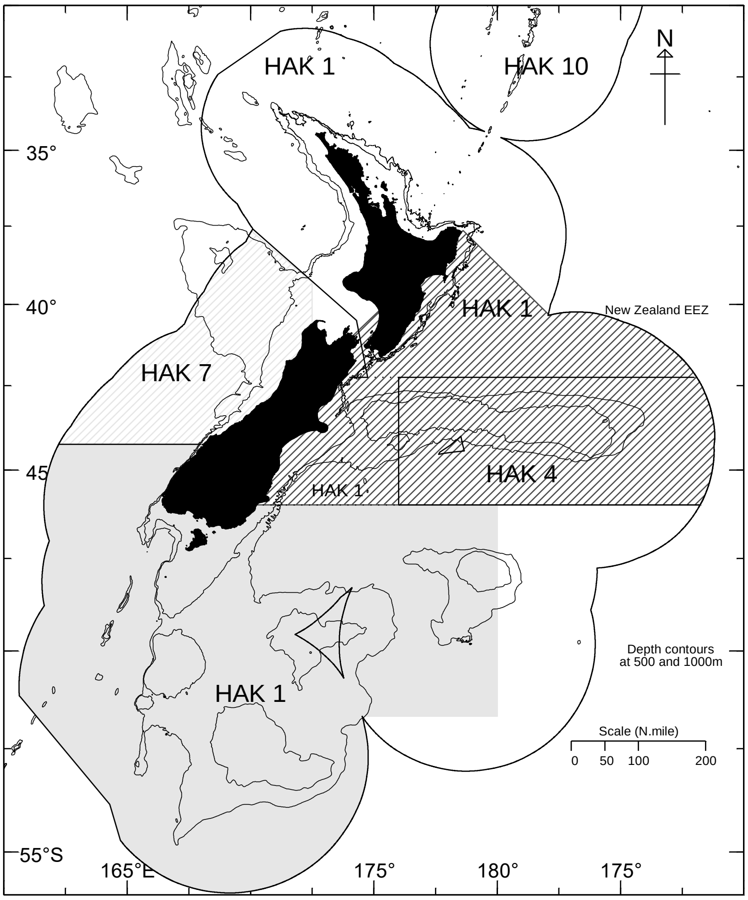

Figure 1: Quota Management Areas (QMAs) HAK 1, 4, 7, & 10; and the west coast South Island (light shading), Chatham Rise (dark shading), and Sub-Antarctic (medium shading) hake stock boundaries assumed in this report.

1.2 Literature review

Previous assessments of hake, by fishing year, are as follows: 1991–92 (Colman et al. 1991), 1992–93 (Colman & Vignaux 1992), 1997–98 (Colman 1997), 1998–99 (Dunn 1998), 1999–2000 (Dunn et al. 2000), 2000–01 (Dunn 2001), 2002–03 (Dunn 2003b), 2003–04 (Dunn 2004a, 2004b), 2004–05 (Dunn et al. 2006), 2005–06 (Dunn 2006), 2006–07 (Horn & Dunn 2007), 2007–08 (Horn 2008), 2009–10 (Horn & Francis 2010), 2010–11 (Horn 2011), 2011–12 (Horn 2013a), 2012–13 (Horn 2013b) and 2016–17 (Horn, 2017). The Bayesian stock assessment software CASAL (Bull et al. 2012) has been used for all assessments since 2002–03. The most recent assessments by stock for WCSI are in Horn (2017).

Since 2000, a trawl and acoustic survey of hoki and middle depth fish abundance on the WCSI has been carried out multiple times from R.V. *Tangaroa* (O'Driscoll & Ballara, 2019). It provides biomass estimates for hake in 2000, 2012, 2014, 2016 and 2018. Appendix A gives more details about the surveys.

An alternative index of abundance has been made available by standardizing commercial Catch Per Unit Effort (CPUE). This index was updated to the 2010–11 fishing year for the WCSI and Chatham Rise stocks only by Ballara (2013). An updated descriptive analysis of all stocks to 2015–16, and CPUE for WCSI and Chatham Rise only, was completed by Ballara (2018) and Finucci (2019).

A book on hakes of the world includes a chapter on the biology and fisheries of *Merluccius australis* in New Zealand waters (Horn 2015).

2. REVIEW OF THE FISHERY

2.1 TACCs, catch, landings, and effort data

Reported catches from 1975 to 1987–88 are shown in Table 1, and reported landings for each QMA since 1983–84 and TACCs since 1986–87 are shown in Table 2. Revised estimates of landings by QMA for 1989–90 to 2010–11 (Table 3) were derived by examining the reported tow-by-tow catches of hake and correcting for possible misreporting, using the method of Dunn (2003a).

Revised landings by biological stock are given in Table 4. The derivation of the catch from 1974–75 to 1988–89 was described for the Chatham Rise and Sub-Antarctic stocks by Dunn et al. (2000) and for WCSI by Dunn (2004b). Landings since 1989–90 from Chatham Rise and Sub-Antarctic and since 1991–92 for WCSI were obtained from the corrected data used to produce Table 3, but this time summing the landings reported in each of the three shaded areas shown on Figure 1. WCSI revised estimates for 1988–89 to 1990–91 are from Colman & Vignaux (1992), who estimated the actual hake catch in HAK 7 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.

Table 1: Reported hake catches (t) from 1975 to 1987–88. Data from 1975 to 1983 from Ministry of Agriculture & Fisheries (Fisheries); data from 1983–84 to 1985–86 from Fisheries Statistics Unit; data from 1986–87 to 1987–88 from Quota Management System (QMS).

	New Zealand vessels			Foreign licensed vessels				
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. 1 April to 31 March; 3. 1 April to 30 September; 4. 1 October to 30 September

Table 2: Reported landings (t) of hake by QMA from 1983–84 to 2010–11 and actual TACCs (t) for 1986–87 to 2015–16. Data from 1983–84 to 1985–86 from Fisheries Statistics Unit; data from 1986–87 to 2015–16 from Quota Management System (– indicates that the data are unavailable).

QMA	HAK 1		HAK 4		HAK 7		HAK 10		Total	
	Landings	TACC	Landings	TACC	Landings	TACC	Landings	TACC	Landings	TACC
1983–84	886	–	180	–	945	–	0	–	2 011	–
1984–85	670	–	399	–	965	–	0	–	2 034	–
1985–86	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	7 783	6 930
1990–91	2 603	2 610	743	1 000	6 148	3 310	0	10	9 567	6 930
1991–92	3 156	3 500	2 013	3 500	3 026	6 770	0	10	8 196	13 780
1992–93	3 525	3 501	2 546	3 500	7 154	6 835	0	10	13 224	13 846
1993–94	1 803	3 501	2 587	3 500	2 974	6 835	0	10	7 363	13 847
1994–95	2 572	3 632	3 369	3 500	8 841	6 855	0	10	14 781	13 997
1995–96	3 956	3 632	3 465	3 500	8 678	6 855	0	10	16 082	13 997
1996–97	3 534	3 632	3 524	3 500	6 118	6 855	0	10	13 176	13 997
1997–98	3 809	3 632	3 523	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	15 333	13 997
1999–00	3 899	3 632	2 803	3 500	6 898	6 855	0	10	13 600	13 997
2000–01	3 504	3 632	2 472	3 500	8 134	6 855	0	10	14 110	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	11 581	14 066
2003–04	3 461	3 701	2 272	3 500	7 943	6 855	0	10	13 686	14 066
2004–05	4 797	3 701	1 266	1 800	7 316	6 855	0	10	13 377	12 366
2005–06	2 743	3 701	305	1 800	6 906	7 700	0	10	9 955	13 211
2006–07	2 025	3 701	900	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	2 351	7 700	0	10	4 715	13 211
2010–11	1 904	3 701	179	1 800	3 754	7 700	0	10	5 838	13 211
2011–12	1 948	3 701	161	1 800	4 459	7 700	0	10	6 568	13 211
2012–13	2 079	3 701	177	1 800	5 434	7 700	0	10	7 690	13 211
2013–14	1 883	3 701	168	1 800	3 642	7 700	0	10	5 693	13 211
2014–15	1 725	3 701	304	1 800	6 219	7 700	0	10	8 248	13 211
2015–16	1 584	3 701	274	1 800	2 864	7 700	0	10	4 722	13 211
2016–17	1 175	3 701	268	1 800	4 701	7 700	0	10	6 144	13 211
2017–18	1 349	3 701	267	1 800	3 086	5 064	0	10	4702	10 575

Table 3: Revised reported landings (t) by QMA 1989–90 to 2014–15 (from Ballara 2018).

Fishing			QMA	Total
Year	HAK 1	HAK 4	HAK 7	
1989–90	2 115	763	4 903	7 781
1990–91	2 592	726	6 175	9 494
1991–92	3 141	2 007	3 048	8 196
1992–93	3 522	2 546	7 157	13 225
1993–94	1 787	2 587	2 990	7 364
1994–95	2 263	2 855	9 659	14 780
1995–96	3 805	3 028	9 153	15 987
1996–97	3 285	2 865	6 950	13 100
1997–98	3 659	3 237	7 686	14 581
1998–99	3 702	2 882	8 929	15 513
1999–00	3 747	2 447	7 086	13 280
2000–01	3 429	2 321	8 351	14 101
2001–02	2 865	1 420	7 499	11 784
2002–03	3 334	805	7 406	11 545
2003–04	3 455	2 254	7 943	13 652
2004–05	4 795	1 260	7 302	13 357
2005–06	2 742	305	6 897	9 944
2006–07	2 006	900	7 660	10 566
2007–08	2 442	865	2 615	5 922
2008–09	3 409	854	5 945	10 208
2009–10	2 156	208	2 340	4 704
2010–11	1 904	179	3 716	5 799
2011–12	1 948	161	4 428	6 537
2012–13	2 056	177	5 426	7 659
2013–14	1 883	168	3 620	5 671
2014–15	1 721	280	6 195	8 196

2.2 Recreational and Maori customary fisheries

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

2.3 Other sources of fishing mortality

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

3. BIOLOGY, STOCK STRUCTURE, AND ABUNDANCE INDICES

3.1 Biology

Data collected by observers on commercial trawlers and from resource 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, possibly 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 fish have also been recorded occasionally near the Mernoo Bank on the western Chatham Rise. Spawning on the Campbell Plateau, primarily to the northeast of the Auckland Islands, may occur from September to February with a peak in September–October. Spawning fish have also been recorded occasionally on the Puysegur Bank, with a seasonality that appears similar to that on the Campbell Plateau (Colman 1998).

Table 4: Estimated landings (t) from fishing years 1974–75 to 2014–15 for the Sub-Antarctic (Sub-A), Chatham Rise (Chat), and west coast South Island (WCSI) biological stocks (areas as defined in Figure 1).

Fishing yr	Sub-A	Chat	WCSI	Fishing yr	Sub-A	Chat	WCSI
1974–75	120	191	71	1995–96	2 873	4 028	9 082
1975–76	281	488	5 005	1996–97	2 262	4 234	6 838
1976–77	372	1 288	17 806	1997–98	2 606	4 252	7 674
1977–78	762	34	498	1998–99	2 796	3 669	8 742
1978–79	364	609	4 737	1999–00	3 020	3 517	7 031
1979–80	350	750	3 600	2000–01	2 790	2 962	8 346
1980–81	272	997	2 565	2001–02	2 510	1 770	7 498
1981–82	179	596	1 625	2002–03	2 738	1 401	7 404
1982–83	448	302	745	2003–04	3 245	2 465	7 939
1983–84	722	344	945	2004–05	2 531	3 526	7 298
1984–85	525	544	965	2005–06	2 557	489	6 892
1985–86	818	362	1 918	2006–07	1 818	1 081	7 660
1986–87	713	509	3 755	2007–08	2 202	1 096	2 583
1987–88	1 095	574	3 009	2008–09	2 427	1 825	5 912
1988–89	1 237	804	8 696	2009–10	1 958	391	2 282
1989–90	1 927	950	8 741	2010–11	1 288	951	3 462
1990–91	2 370	931	8 246	2011–12	1 892	194	4 299
1991–92	2 750	2 418	3 001	2012–13	1 863	344	5 171
1992–93	3 269	2 798	7 059	2013–14	1 830	187	3 387
1993–94	1 453	2 934	2 971	2014–15	1 630	348	5 966
1994–95	1 852	3 387	9 535				

Horn (1997) validated the use of otoliths to age hake. New Zealand hake reach a maximum age of at least 25 years. Males, which rarely exceed 100 cm total length, do not grow as large as females, which can grow to 120 cm total length or more. Readings of otoliths from hake have been used as age-length keys to scale up length frequency distributions for hake collected on resource surveys and from commercial fisheries on the Chatham Rise, Sub-Antarctic, and west coast South Island. The resulting age frequency distributions were reported by Horn & Sutton (2019).

Colman (1998) found that hake reach sexual maturity between 6 and 10 years of age, at total lengths of about 67–75 cm (males) and 75–85 cm (females); he concluded that hake reached 50% maturity at between 6 and 8 years in HAK 1, and 7–8 years in HAK 4. In assessments before 2005, the maturity ogive for the Chatham Rise and Sub-Antarctic was assumed from a combination of the estimates of Colman (1998) and model fits to the west coast South Island data presented by Dunn (1998).

From 2005 to 2007, maturity ogives for the Chatham Rise and Sub-Antarctic stocks were fitted within the assessment model to data derived from resource survey samples, including information on the gonosomatic index, gonad stage, and age (Horn & Dunn 2007, Horn 2008). Individual hake were classified as either immature or mature at sex and age, where maturity was determined from the gonad stage and gonosomatic index (GSI, the ratio of the gonad weight to body weight). Fish identified as stage 1 were classified as immature. Stage 2 fish were classified as immature or mature depending on the GSI index, using the definitions of Colman (1998) — i.e., classified as immature if GSI < 0.005 (males) or GSI < 0.015 (females), or mature if GSI ≥ 0.005 (males) or GSI ≥ 0.015 (females). Fish identified as stages 3–7 were classified as mature. From 2009 to 2011, fixed ogives as derived from the previously described model fitting procedure were used in the assessment models. In 2012, fixed ogives for all stocks were updated by fitting a logistic curve (from Bull et al. 2012) to the proportion mature at age data, by sex, with the fish classified as mature or immature as described above (Horn 2013b). The analysed data were derived from resource surveys over the following periods corresponding with likely spawning activity: Sub-Antarctic, October–February; Chatham Rise, November–January; WCSI, July–September. The proportions mature are listed in Table 5, with ogives plotted in Figure 2; values for combined sexes maturity were taken as the mean of the male and female values. 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.

Von Bertalanffy growth model parameters were previously estimated using data up to 1997 (Horn 1998). The parameters for all three stocks were updated using all data available at February 2007 (Horn 2008). Plots of the fitted curves on the raw data indicated that the von Bertalanffy model tended to underestimate the age of large fish. Consequently, the growth model of Schnute (1981) was fitted to the data sets (Table 5). This model appeared to better describe the growth of larger hake (Horn 2008), and the resulting parameters can be used in the CASAL stock assessment software. Most aged hake have been 3 years or older. However, younger juvenile hake have been taken in coastal waters on both sides of the South Island and on the Campbell Plateau. It is known that hake reach a total length of about 15–20 cm at 1 year old, and about 35 cm total length at 2 years (Horn 1997).

Estimates of natural mortality rate (M) and the associated methodology were given by Dunn et al. (2000); M was estimated as 0.18 y^{-1} for females and 0.20 y^{-1} for males. Colman et al. (1991) estimated M as 0.20 y^{-1} for females and 0.22 y^{-1} for males using the maximum age method of Hoenig (1983) (where they defined the maximum ages at which 1% of the population survives in an unexploited stock as 23 years for females and 21 years for males). These are similar to the values proposed by Horn (1997), who determined the age of hake by counting zones in sectioned otoliths and concluded from that study that it was likely that M was in the range 0.20–0.25 y^{-1}. Up to 2011, constant values of M were used in stock assessment models (i.e., 0.18 y^{-1} for females and 0.20 y^{-1} for males, or 0.19 y^{-1} for sexes combined). However, because true M is likely to vary with age, the assessments in 2012 (Sub-Antarctic, Horn 2013a), 2013 (Chatham Rise and WCSI, Horn 2013b) and 2017 (Horn 2017) allowed the estimation of age-dependent ogives for M within the models. This parameterisation of the model was not investigated during the assessment working group meetings due to focusing on other aspects of the model: the assessments for hake on the WCSI reported below fixed M at 0.19 y^{-1} for both sexes (an average of the two similar male and female estimates above).

Dunn et al. (2010) and Horn & Dunn (2010) found that the diet of hake on the Chatham Rise was dominated by teleost fishes, in particular Macrouridae. Macrouridae accounted for about half 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 more than a third of prey weight. Squids and crustacean prey, which were predominantly natant decapods, were also found. No hake were recorded in the diets of 25 other sympatric demersal species (M.Dunn, pers. comm.).

Length-weight relationships for hake from the Sub-Antarctic and Chatham Rise stocks were revised by Horn (2013a, 2013b) using all available length-weight data collected during trawl surveys since 1989. Following a trawl survey off WCSI in July-August 2012, parameters for hake from that stock were also revised. Parameters were calculated for males, females, and both sexes combined (Table 5). Sample sizes were large (2165 males, 1828 females) and all r^2 values were greater than 0.97.

Table 5: Estimates of biological parameters for the three hake stocks.

		Estimate				Source
Natural mortality						
	Males	$M = 0.20$				(Dunn et al. 2000)
	Females	$M = 0.18$				(Dunn et al. 2000)
	Both sexes	$M = 0.19$				
Weight = $a \cdot (length)^b$ (Weight in t, length in cm)						
Sub-Antarctic	Males	$a = 2.13 \times 10^{-9}$	$b = 3.281$			(Horn 2013a)
	Females	$a = 1.83 \times 10^{-9}$	$b = 3.314$			(Horn 2013a)
	Both sexes	$a = 1.95 \times 10^{-9}$	$b = 3.301$			(Horn 2013a)
Chatham Rise	Males	$a = 2.56 \times 10^{-9}$	$b = 3.228$			(Horn 2013a)
	Females	$a = 1.88 \times 10^{-9}$	$b = 3.305$			(Horn 2013a)
	Both sexes	$a = 2.00 \times 10^{-9}$	$b = 3.288$			(Horn 2013a)
WCSI	Males	$a = 2.85 \times 10^{-9}$	$b = 3.209$			(Horn 2013b)
	Females	$a = 1.94 \times 10^{-9}$	$b = 3.307$			(Horn 2013b)
	Both sexes	$a = 2.01 \times 10^{-9}$	$b = 3.294$			(Horn 2013b)
von Bertalanffy growth parameters						
Sub-Antarctic	Males		$k = 0.295$	$t_0 = 0.06$	$L_\infty = 88.8$	(Horn 2008)
	Females		$k = 0.220$	$t_0 = 0.01$	$L_\infty = 107.3$	(Horn 2008)
Chatham Rise	Males		$k = 0.330$	$t_0 = 0.09$	$L_\infty = 85.3$	(Horn 2008)
	Females		$k = 0.229$	$t_0 = 0.01$	$L_\infty = 106.5$	(Horn 2008)
WCSI	Males		$k = 0.357$	$t_0 = 0.11$	$L_\infty = 82.3$	(Horn 2008)
	Females		$k = 0.280$	$t_0 = 0.08$	$L_\infty = 99.6$	(Horn 2008)
Schnute growth parameters ($\tau_1 = 1$ and $\tau_2 = 20$ for all stocks)						
Sub-Antarctic	Males	$y_1 = 22.3$	$y_2 = 89.8$	$a = 0.249$	$b = 1.243$	(Horn 2008)
	Females	$y_1 = 22.9$	$y_2 = 109.9$	$a = 0.147$	$b = 1.457$	(Horn 2008)
	Both sexes	$y_1 = 22.8$	$y_2 = 101.8$	$a = 0.179$	$b = 1.350$	(Horn 2013a)
Chatham Rise	Males	$y_1 = 24.6$	$y_2 = 90.1$	$a = 0.184$	$b = 1.742$	(Horn 2008)
	Females	$y_1 = 24.4$	$y_2 = 114.5$	$a = 0.098$	$b = 1.764$	(Horn 2008)
	Both sexes	$y_1 = 24.5$	$y_2 = 104.8$	$a = 0.131$	$b = 1.700$	(Horn & Francis 2010)
WCSI	Males	$y_1 = 23.7$	$y_2 = 83.9$	$a = 0.278$	$b = 1.380$	(Horn 2008)
	Females	$y_1 = 24.5$	$y_2 = 103.6$	$a = 0.182$	$b = 1.510$	(Horn 2008)
	Both sexes	$y_1 = 24.5$	$y_2 = 98.5$	$a = 0.214$	$b = 1.570$	(Horn 2011)

Maturity ogives (proportion mature at age)

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

Miscellaneous parameters

Steepness (Beverton & Holt stock-recruitment relationship)	0.84
Proportion spawning	1.0
Proportion of recruits that are male	0.5
Ageing error CV	0.08
Maximum exploitation rate (U_{max})	0.7

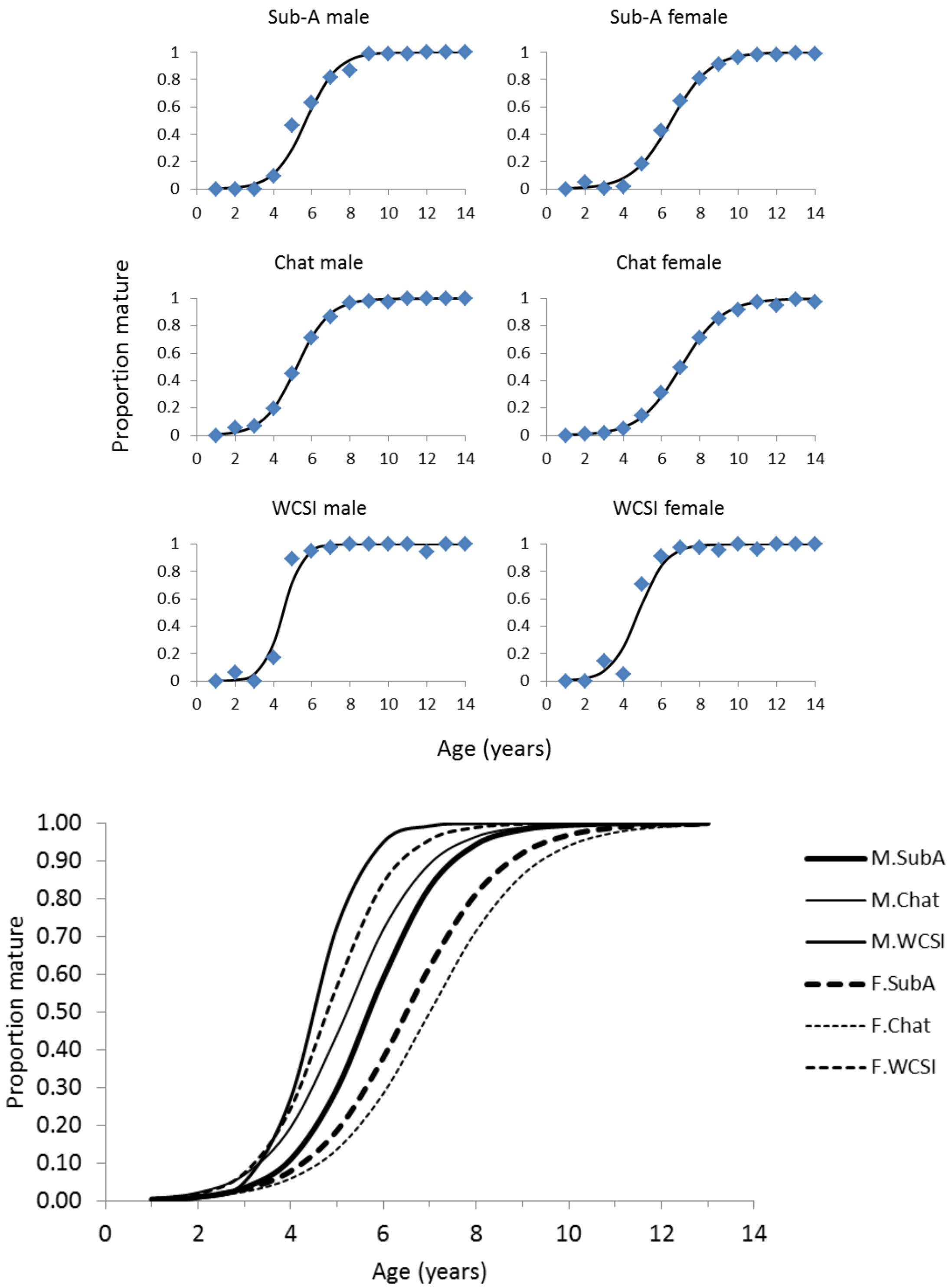

Figure 2: Raw proportion mature at age data with fitted logistic ogives (upper panel), and a comparison plot (lower panel) of all estimated ogives by stock for male (M, solid lines) and female (F, broken lines) hake (reproduced from Horn 2017).

3.2 Stock structure

There are at least three hake spawning areas: off the west coast of the South Island, on the Chatham Rise, and on the Campbell Plateau (Colman 1998). Juvenile hake are found in all three areas, there are differences in size frequency of hake between the west coast and other areas, and differences in growth parameters between all three areas (Horn 1997). There is reason, therefore, to believe that at least three separate stocks can be assumed for the EEZ.

Analysis of morphometric data (J.A. Colman, NIWA, unpublished data) showed little difference between hake from the Chatham Rise and from the east coast of the North Island, but highly significant differences between these fish and those from the Sub-Antarctic, Puysegur, and on the west coast. The Puysegur fish were most similar to those from the west coast South Island, although, depending on which variables were used, they could not always be distinguished from the Sub-Antarctic hake. However, the data were not unequivocal, so the stock affinity is uncertain.

For stock assessment models, the Chatham Rise stock was considered to include the whole of the Chatham Rise (HAK 4 and the western end of the Chatham Rise that forms part of the HAK 1 management area). The Sub-Antarctic stock was considered to contain hake in the remaining Puysegur, Southland, and Sub-Antarctic regions of the HAK 1 management area. The stock areas assumed for this report are shown earlier, in Figure 1.

3.3 Resource surveys

In the Sub-Antarctic, three resource surveys were carried out by *Tangaroa* with the same gear and similar survey designs in November–December 1991, 1992, and 1993, but the series was then terminated as there was evidence that hake, in particular, might be aggregated for spawning at that time of the year and that spawning aggregations had a high probability of being missed during a survey. However, research interest in hoki in the Sub-Antarctic resulted in a return to the November–December survey annually in 2000–2009, 2011, 2012, 2014 and 2016. Surveys by *Tangaroa* in April 1992, May 1993, April 1996, and April 1998 formed the basis for a second series, with hake appearing to be more evenly distributed through the survey area at that time of year. A single survey in September 1992 by *Tangaroa* was also completed. The biomass estimates from the Sub-Antarctic *Tangaroa* and 1989 *Amaltal Explorer* surveys are shown in Table 6 with further details given in Appendix A.

Sub-Antarctic surveys were conducted by *Shinkai Maru* (March–May 1982 and October–November 1983) and *Amaltal Explorer* (October–November 1989, July–August 1990, and November–December 1990). However, these vessels used different gear and had different performance characteristics (Livingston et al. 2002), so cannot be used as part of a consistent time series.

The resource surveys carried out at depths of 200–800 m on the Chatham Rise annually from 1992 to 2014 and in 2016 by *Tangaroa* had the same gear and similar survey designs (see Appendix A). While the survey designs since 1992 were similar, there was a reduction in the number of stations surveyed between 1996 and 1999, and some strata in the survey design used between 1996 and 1999 were merged (see Bull & Bagley 1999). The surveys since 2000 used a revised design, with some strata being split and additional stations added. Since 2000 some of the *Tangaroa* surveys included deepwater strata (i.e., 800–1300 m) on the Chatham Rise, although data from these strata were excluded from the present analysis to maintain consistency in the time series.

Chatham Rise surveys were conducted by *Shinkai Maru* (March 1983 and June–July 1986) and *Amaltal Explorer* (November–December 1989). However, as in the Sub-Antarctic, these surveys used a range of gear, survey methodologies, and survey designs (Livingston et al. 2002), and cannot be used as a consistent time series. The biomass estimates from Chatham Rise resource surveys are shown in Table

7 with further details in Appendix A. Catch distributions from these surveys are plotted by Stevens et al. (2011).

Table 6: Research survey indices (and associated CVs) for the Sub-Antarctic stock. The Nov–Dec series is based on indices from 300–800 m core strata, including the 800–1000 m strata in Puysegur, but excluding Bounty Platform. The other series are based on the biomass indices from 300–800 m core strata, excluding the 800–1000 m strata in Puysegur and the Bounty Platform.

Fishing	**Vessel**	**Nov–Dec series[1]**		**Apr–May series[2]**		**Sep series[2]**	
Year		Biomass (t)	CV	Biomass (t)	CV	Biomass (t)	CV
1989	*Amaltal*	2 660	0.21				
1992	*Tangaroa*	5 686	0.43	5 028	0.15	3 760	0.15
1993	*Tangaroa*	1 944	0.12	3 221	0.14		
1994	*Tangaroa*	2 567	0.12				
1996	*Tangaroa*			2 026	0.12		
1998	*Tangaroa*			2 554	0.18		
2001	*Tangaroa*	2 657	0.16				
2002	*Tangaroa*	2 170	0.20				
2003	*Tangaroa*	1 777	0.16				
2004	*Tangaroa*	1 672	0.23				
2005	*Tangaroa*	1 694	0.21				
2006	*Tangaroa*	1 459	0.17				
2007	*Tangaroa*	1 530	0.17				
2008	*Tangaroa*	2 470	0.15				
2009	*Tangaroa*	2 162	0.17				
2010	*Tangaroa*	1 442	0.20				
2012	*Tangaroa*	2 004	0.23				
2013	*Tangaroa*	1 943	0.25				
2015	*Tangaroa*	1 477	0.25				
2017	*Tangaroa*	1 000	0.25				

Research surveys of hoki and hake have been conducted periodically off WCSI, but these have generally been 'one-off' surveys by different vessels (i.e., *Shinkai Maru* in 1976, *James Cook* in 1978–79, *Wesermünde* in 1979, and *Giljanes* in 1990) so any biomass estimates from them are not useful model inputs. However, a combined trawl and acoustic survey by *Tangaroa* in 2000 (O'Driscoll et al. 2004) was replicated (with some modifications) in the winters of 2012, 2013, 2016 and 2018 (O'Driscoll & Ballara 2019) providing five comparable biomass estimates for the core areas and 4 for all areas (Table 7). A long-running trawl survey series of inshore waters off WCSI by *Kaharoa* has not provided a useful index of hake biomass as it surveys no deeper than 400 m (Stevenson & Hanchet 2000). Age data, and consequently estimates of proportion-at-age, are available for *Tangaroa* surveys. Proportion-at-age data are also available from the 1979 *Wesermünde* survey; these data are included in the assessment model with the WCSI commercial trawl fishery data set as the selectivity ogive for this vessel is likely to be more similar to the commercial fleet than to the *Tangaroa* survey gear (N. Bagley, NIWA, pers. comm.).

Table 7: Research survey indices (and associated CVs) for the Chatham Rise and WCSI stocks. The indices relate to the core survey strata only, i.e. 200–800 m for Chatham Rise and to core and all area for WCSI.

		Chatham rise			WCSI			
		Core areas			Core areas		All areas	
Year	**Vessel**	**Biomass (t)**	**CV**	**Vessel**	**Biomass (t)**	**CV**	**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	0.1					
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	*Tangaroa*	802	0.13		
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	*Tangaroa*	579	0.13	1096	0.13
2013	*Tangaroa*	1 877	0.15	*Tangaroa*	328	0.17	740	0.22
2014	*Tangaroa*	1 377	0.15					
2015	No survey	–						
2016	*Tangaroa*	1 299	0.14	*Tangaroa*	208	0.25	316	0.18
2018				*Tangaroa*	227	0.33	549	0.18

3.4 Observer age samples

The fishery off WCSI was stratified using a tree-based regression on mean lengths of hake in tows where observers had measured five or more hake (Horn & Dunn 2007). A single catch-at-age distribution was estimated for each year with the otoliths used to construct the age-length key being sampled from across the entire fishery (spatially and temporally). Catch-at-age distributions from the WCSI trawl fishery are available from 1978–79 and all years from 1989–90 to 2017–18 (Horn & Sutton 2019).

The age composition of hake caught by the WCSI trawl fishery has shown a higher proportion of younger fish over the years. The data from *Wesermünde* collected in 1979 (see ahead to Figure 8) shows a widespread distribution of age with a large proportion of fish age 10 years old or more. However, these older age-groups disappeared from the catch over the years. The mean age in the catch steadily declined (see ahead to Figure 9) from around 12 years old in 1979, to below 10 years old from 1994 to between 7 and 8 years old since 2013. In recent years, the mean age of hake caught in the fishery has been in the lower range of the distribution of mean ages observed since 1979. The distributions of proportion at age in the fishery do not clearly show a year class progression. The catch in most years since 2011 was dominated by fish aged 5–7 years old. A characteristic of most of the WCSI distributions was that numbers of fish aged 3 and 4 years were generally very low. Fish of this age may be much less vulnerable or available to the trawl during the winter months of the fishery than younger or older hake (Horn & Sutton, 2019).

3.5 CPUE index of abundance

Commercial data to standardize Catch Per Unit Effort (CPUE) in the WCSI hake fishery are available from the 1989–90 to 2017–18 fishing years. In the previous assessment, the WG selected the standardized CPUE series using observer tow-by-tow estimated catches starting from 2001.These data were believed to be less biased by changes in fishing behaviour and catch as they start after the establishment of the deemed value system (Ballara 2013).

Table 8: Hake CPUE indices (and associated CVs) used in WCSI hake stocks (from Finucci 2019).

	WCSI observer	
Year	Index	CV
1989–90	–	–
1990–91	–	–
1991–92	–	–
1992–93	–	–
1993–94	–	–
1994–95	–	–
1995–96	–	–
1996–97	–	–
1997–98	–	–
1998–99	–	–
1999–00	–	–
2000–01	0.91	0.04
2001–02	2.56	0.03
2002–03	0.47	0.07
2003–04	1.2	0.03
2004–05	0.92	0.03
2005–06	1.03	0.03
2006–07	0.86	0.06
2007–08	0.39	0.05
2008–09	0.23	0.06
2009–10	0.46	0.06
2010–11	0.75	0.05
2011–12	0.82	0.05
2012–13	1.36	0.03
2013–14	0.88	0.03
2014–15	0.92	0.03
2015–16	0.89	0.03
2016–17	1.04	0.03
2017–18	1.34	0.03

The CPUE index of abundance (Table 8) was updated in 2019 (Finucci 2019) and estimated broadly a decline between 2000–01 and 2008–09 followed by an increase in abundance (Figure 3 – left hand side). By contrast, the survey estimated hake abundance trending down between 2000 and 2018 (Figure 3 – right hand side).

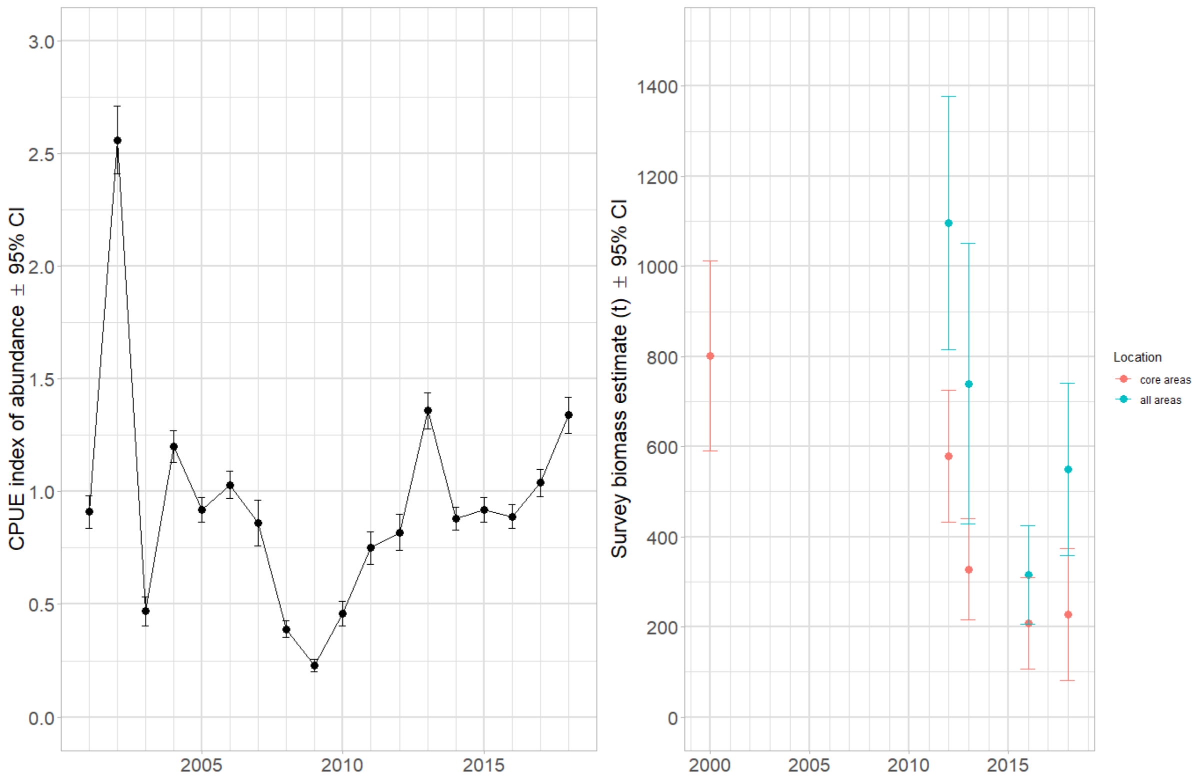

Figure 3: Relative indices of abundance of hake in the WCSI fishery: on the left, from standardizing CPUE; on the right, from scientific survey. The vertical bars indicate the 95% confidence interval of the abundance estimates.

This conflicting signal between two indices of abundance became problematic only in recent assessments. Earlier stock assessments relied only on standardized Catch Per Unit Effort (CPUE) as an index of abundance (Dunn, 1998). Later, CPUE was included in the model in combination with a biomass index from a scientific survey, conducted by RV *Tangaroa* (Horn 2011, 2013b). As additional survey data were collected over the period 2012–16 (Table 6), the trends in abundance provided by the CPUE and survey indices diverged to the point that they could not be reconciled within a single stock assessment model. Horn (2017) fitted two models, one using CPUE and the other using survey abundance estimates, leading to very different stock status: B_{2016}/B_0 at 50.3% and 25.7% respectively. In 2019, the WG decided to use the survey indices in the base case stock assessment model. The results of using CPUE as an index of abundance are presented as a sensitivity run.

4. MODEL STRUCTURE, INPUTS, AND ESTIMATION

Updated assessments of the hake stock on the west coast South Island (WCSI) are presented here. As in the most recent previous assessments of this stock (Horn & Francis 2010, Horn 2011, 2013b, 2017) the assessment models partitioned the population into age groups 1–30, with the last age class considered a plus group. Sex was not in the partition. For WCSI, the model's annual cycle was based on a year beginning on 1 November and divided into two steps (Table 9). The fishing year is not used in this assessment because landings peaks tend to occur from June to October, so it is logical to include the October catch with landings from the four months immediately preceding it, rather than with catches taken about eight months later. Note that model references to "year" within this document are labelled as the most recent calendar year, e.g., the year 1 November 1998 to 31 October 1999 is referred to as "1999".

Table 9: Annual structure used to model the dynamics of hake on the WCSI: processes taking place each year in 2 time steps are described together with 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.

WCSI					Observations	
Step	Period	Processes	% *M*[1]	Age[2]	Description	%*Z*[3]
1	Nov–May	Recruitment	0.42	0.50		
2	Jun–Oct	Fishing, spawning & increment age	0.58	0.00	Proportions-at-age Winter trawl survey	50

1. Natural mortality (M) was fixed to 0.19 per year for both sexes. % *M* is the fraction of natural mortality that was assumed to have occurred in that time step.
2. Age is the age fraction, used for determining length-at-age, that was assumed to occur in that time step.
3. %*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.

For all models discussed below, assumed values of fixed biological parameters are given in Table 5. A Beverton-Holt stock-recruitment relationship, with steepness 0.84, was assumed (Shertzer & Conn 2012). Variability in length at age around the Schnute age-length relationship was assumed to be lognormal with a constant CV of 0.1.

The maximum exploitation rate was assumed to be 0.7 for the stock. The choice of the maximum exploitation rate has the effect of determining the minimum possible virgin biomass allowed by the model, given the observed catch history. This value was set relatively high as there was little external information from which to determine it. A penalty was included to penalise any model run that prevented the observed catch history from being taken, and an examination of the model outputs showed that this maximum exploitation rate was never achieved (and therefore no penalty ever incurred).

Biomass estimates from the resource surveys were used as relative biomass indices, with associated CVs estimated from the survey analysis (Table 7). The survey catchability constant (q) was assumed to be constant across all years in the survey series. Catch-at-age observations were available for each research survey, from commercial observer data for the fishery, and from the research voyage by *Wesermünde* in 1979. The error distributions assumed were multinomial for the proportions-at-age and lognormal for all other data. An additional process error CV of 0.1 was added to the WCSI trawl survey biomass index following Francis et al. (2001). Process error CVs for the CPUE series were estimated following Francis (2011) to equal 0.30. The multinomial observation error effective sample sizes for the at-age data were adjusted using the reweighting procedure of Francis (2011); effective and adjusted sample sizes for each of the age distributions are listed in Table 10. Ageing error was assumed to occur for the observed proportions-at-age data, by assuming a discrete normally distributed error with a CV of 0.08.

Year class strengths were assumed known (and equal to one) for years 1973, 2016 and 2017 when inadequate or no catch-at-age data were available. Otherwise, year class strengths were estimated under the assumption that the estimates from the model must average one (the "Haist parameterisation" for year class strength multipliers; Bull et al. 2012).

Table 10: Initial sample sizes (N_{init}) and adjusted sample sizes (N_{adj}) for each of the fishery and trawl survey age distributions. N_{adj} is the effective sample size assumed in all model final runs. 'Factor' is the value used to determine N_{adj} from N_{init}.

	Fishery				Survey			
	Core strata		All strata		Core strata		All strata	
Year	N_{init}	N_{adj}	N_{init}	N_{adj}	N_{init}	N_{adj}	N_{init}	N_{adj}
1978–79	317	22	317	22				
1989–90	286	20	286	20				
1990–91	474	32	474	33				
1991–92	287	20	287	20				
1992–93	212	15	212	15				
1993–94	186	13	186	13				
1994–95	245	17	245	17				
1995–96	359	25	359	25				
1996–97	326	22	326	23				
1997–98	349	24	349	24				
1998–99	637	44	637	45				
1999–00	440	30	440	31	255	23		
2000–01	319	22	319	22				
2001–02	358	24	358	25				
2002–03	439	30	439	31				
2003–04	416	28	416	29				
2004–05	276	14	276	14				
2005–06	479	24	479	25				
2006–07	508	26	508	26				
2007–08	509	26	509	26				
2008–09	398	20	398	20				
2009–10	218	11	218	11				
2010–11	491	25	491	25				
2011–12	739	38	739	38	332	30	433	47
2012–13	753	38	753	39	371	33	457	48
2013–14	784	40	784	40				
2014–15	780	40	780	40				
2015–16	728	37	728	37	210	19	129	14
2016–17	754	38	754	39				
2017–18	699	36	699	36	277	25	151	16

The catch history assumed in all model runs is as estimated for the WCSI section of HAK 7 by fishing year up to 1990–91, and by the 12-month period commencing 1 November from 1991–92 (Table 11).

Table 11: Reported catch (t) from FMA 7 and estimated catch from the WCSI biological stock (area as defined in Figure 1), by fishing year, model year and estimated catch (t).

Fishing year	Model year	Catch
1974–75	1975	71
1975–76	1976	5 005
1976–77	1977	17 806
1977–78	1978	498
1978–79	1979	4 737
1979–80	1980	3 600
1980–81	1981	2 565
1981–82	1982	1 625
1982–83	1983	745
1983–84	1984	945
1984–85	1985	965
1985–86	1986	1 918
1986–87	1987	3 755
1987–88	1988	3 009
1988–89	1989	8 696
1989–90	1990	8 741
1990–91	1991	8 246
1991–92	1992	3 030
1992–93	1993	7 152
1993–94	1994	3 003
1994–95	1995	9 812
1995–96	1996	9 047
1996–97	1997	6 879
1997–98	1998	7 851
1998–99	1999	8 717
1999–00	2000	6 915
2000–01	2001	8 279
2001–02	2002	7 591
2002–03	2003	7 591
2003–04	2004	7 915
2004–05	2005	7 336
2005–06	2006	6 663
2006–07	2007	7 664
2007–08	2008	2 557
2008–09	2009	5 946
2009–10	2010	2 451
2010–11	2011	3 428
2011–12	2012	4 402
2012–13	2013	5 422
2013–14	2014	3 628
2014–15	2015	6 187
2015–16	2016	2 733
2016–17	2017	4 599
2017–18	2018	2 968
2018–19	2019	2 968

4.1 Prior distributions and penalty functions

The prior distributions used in the assessment are given in Table 12.

The priors for B_0 and year class strengths were intended to be relatively uninformative, and had wide bounds. Priors for all selectivity parameters were assumed to be uniform.

The prior for the survey *q* was informative and was estimated using the Chatham Rise hake survey prior as a starting point because the survey series in both areas used the same vessel and fishing gear. The Chatham Rise hake survey catchability (*q*) prior is 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). However, the Chatham Rise hake survey prior was modified for the WCSI hake assessment as follows: 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 covers only 54% of the known WCSI hake habitat, the mean of the Chatham Rise prior was modified accordingly (i.e., $0.16 \times 0.54 = 0.09$), and the bounds were also reduced from [0.01, 0.40] to [0.01, 0.25]. The same prior was used for the 'core area'.

The prior on the year class strength was lognormal (Table 12).

Table 12: Prior distributions for key parameters. 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.

Stock	Parameter	Distribution	Parameters		Bounds	
WCSI	B_0	Uniform-log	–	–	5 000	250 000
	YCS	Lognormal	1.0	1.1	0.01	100
	Survey *q*	Lognormal	0.09	0.79	0.01	0.25
	Selectivity	Uniform	–	–	1	25–200*

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

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

5. MODEL ESTIMATES FOR WCSI HAKE

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

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.

5.1 Point estimates

5.1.1 Base case assessment

The base case assessment models the fishery from 1974–75 to 2018–19. It used catches and catch age composition data from the commercial trawl fishery, research trawl survey biomass index and age composition data collected in an extended region (referred to as ‘all areas’), and biological parameters available in the scientific literature.

Evidence of change in selectivity in the commercial fishery

The selectivity of the trawl fishery in the base case model was allowed to change in 2005 based on the observation that the most frequently caught hake age-groups in the fishery were between 6 and 12 years old before 2005, and between 5 and 9 years old from 2005 (Figure 4).

Fit to data

The fit of the base case model estimated B_0 at 69 000 tonnes (Figure 5). The profile log-likelihood indicates that the age data from the survey (wcsiTANage) and the commercial fishery (wcsiTRLagePre2005 and wcsiTRLageFrom2005) provide consistent signals regarding the pre-exploited biomass (B_0). The survey biomass exhibits a local minimum between 60 000 and 80 000 tonnes and an absolute minimum close to 50 000 tonnes, suggesting that taken on their own survey biomass indices would estimate B_0 to be lower than 69 000 tonnes.

Estimates of the logistic selectivity ogives (Figure 6) indicated that 8% of age five and 50% of age seven hake were retained by the commercial trawl before 2005. The base case assessment models an increase in retention of younger hake by the commercial fishery after 2005 with the proportion of 5 year olds retained by the trawl nets increasing to 42% and 96% at age seven. A model with a single selectivity estimated an intermediate logistic selectivity, with 55% retention at age six. Allowing the base case model to fit two selectivities improved the fit to the commercial proportion at age by 22.8 units on the log-likelihood scale from 474.3 for a single selectivity to 451.5 for a two selectivities model, providing support to the hypothesis that selectivity changed around 2005.

The base case model fitted the declining abundance of hake observed during surveys between 2012 and 2018 (Figure 7) but gave a poor fit to the lowest abundance observed in 2016.

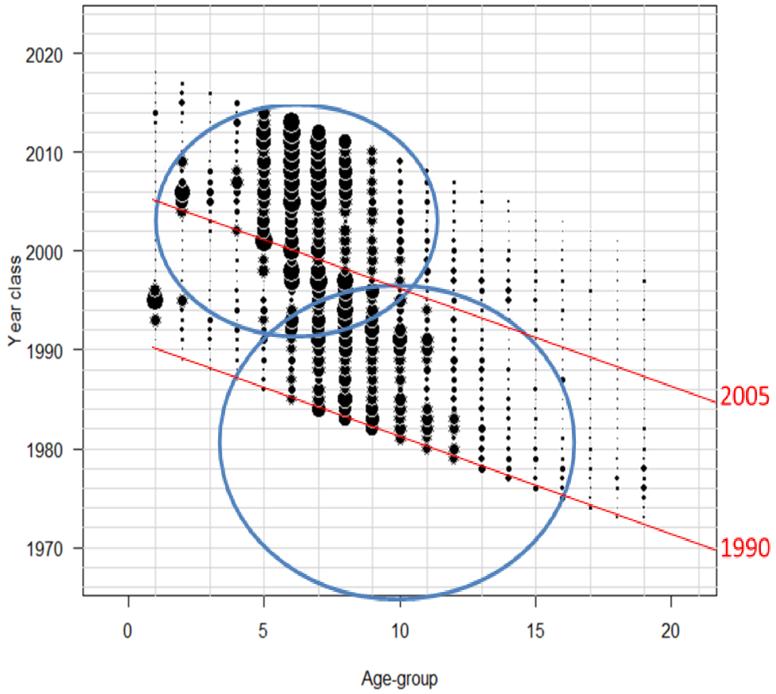

Figure 4: Proportion of hake estimated in the HAK 7 commercial trawl fishery by age-group (x-axis) and year class (y-axis) for data collected from 1990–2018.

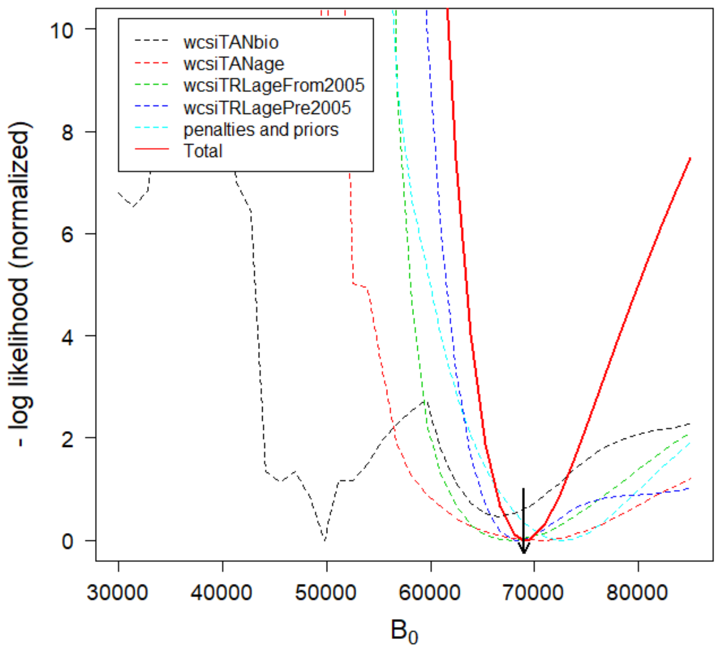

Figure 5: Profile log-likelihood of the base case model.

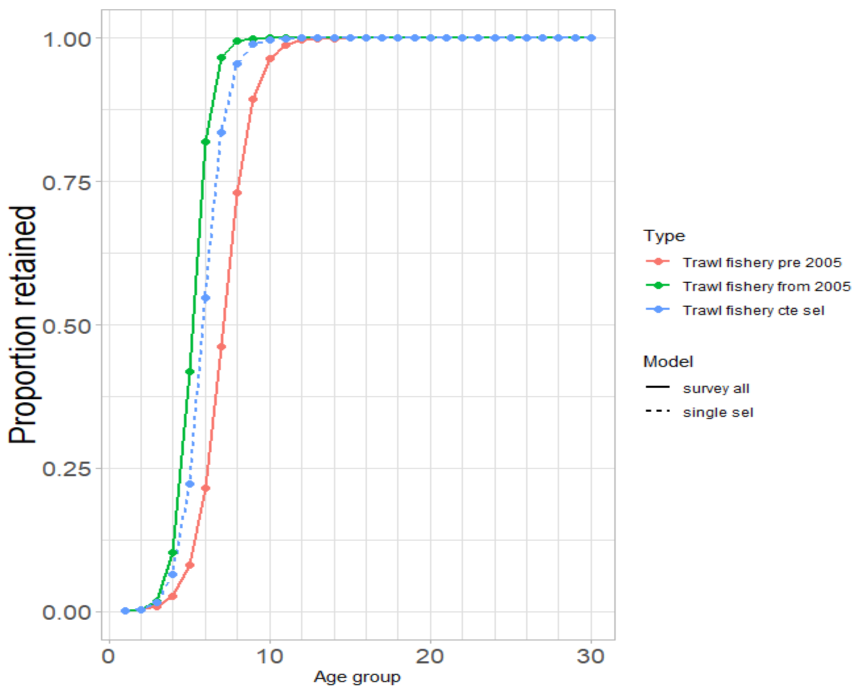

Figure 6: Comparison between estimates of commercial trawl selectivities between a model assuming a change in selectivity in 2005 (base case model) and a model assuming a single constant selectivity throughout the entire time series

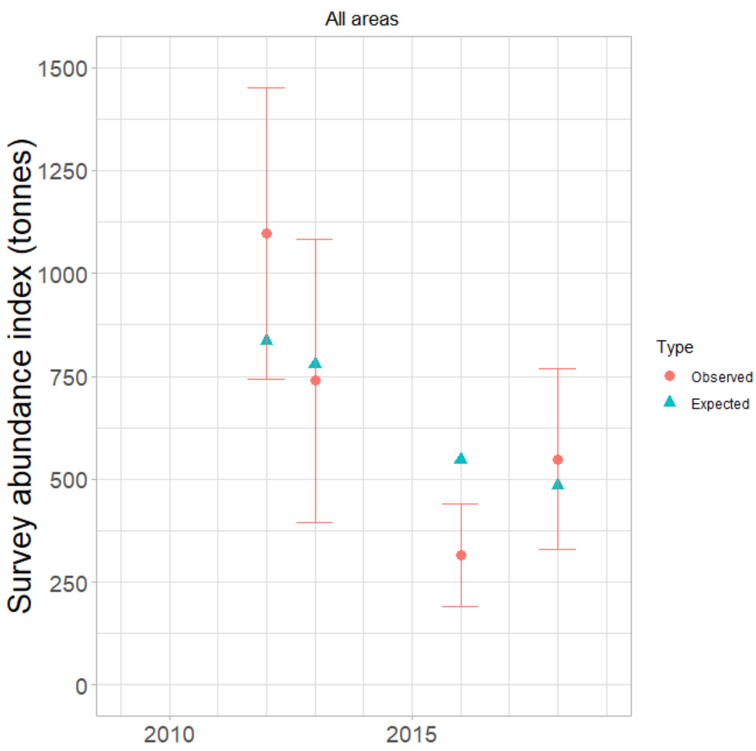

Figure 7: Base case model fit to survey index of abundance.

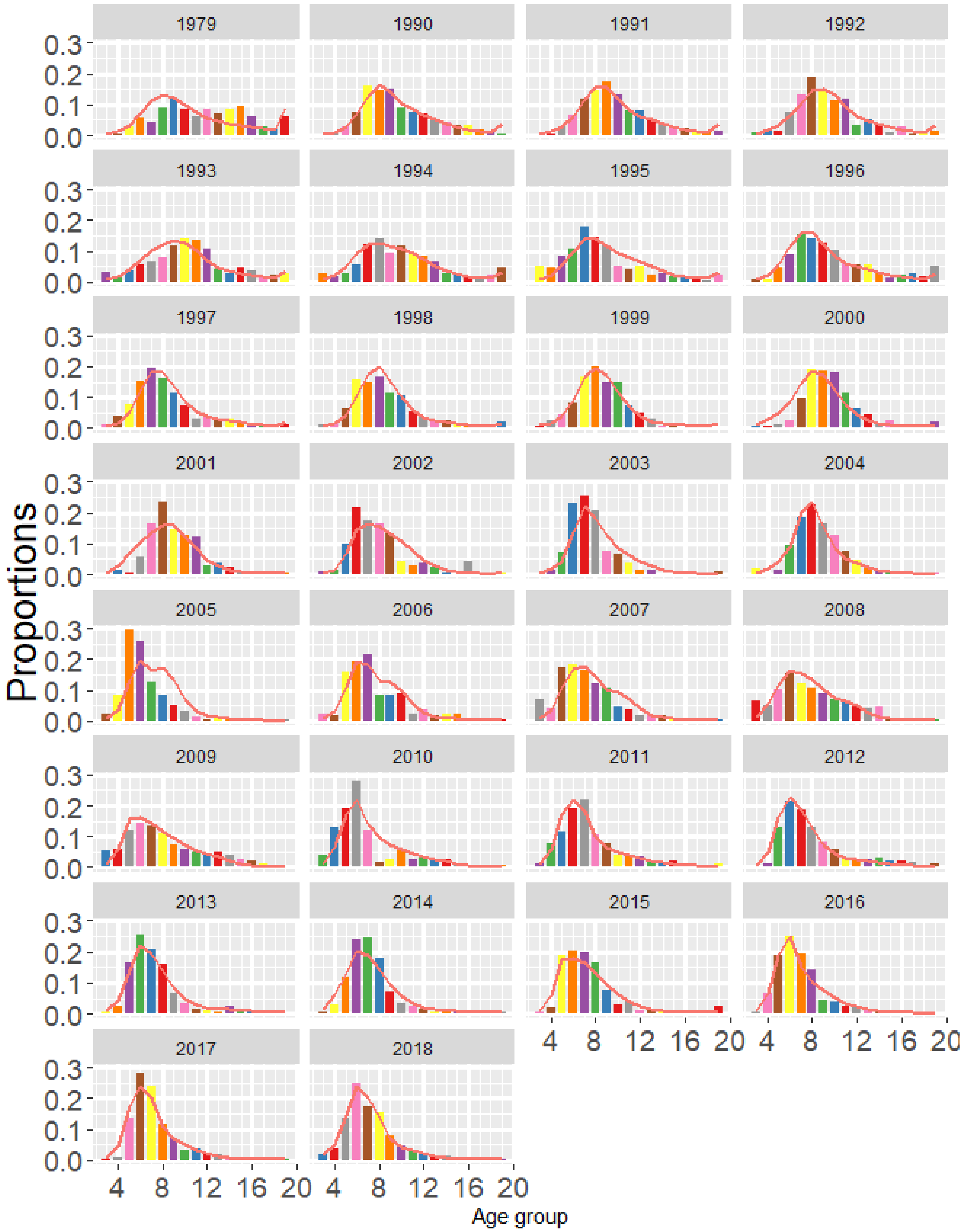

Figure 8: Histograms of age distribution in the fishery overlaid with the fit from the base case model (line).

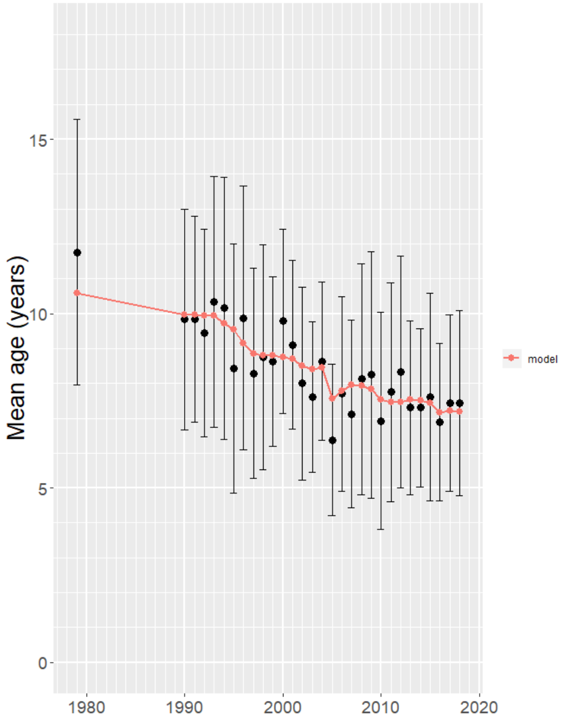

Figure 9: Trends in mean age of hake caught in the fishery (± 1 s.d.) overlaid with mean estimated by the base case model.

The base case model gave good fits to the age composition of hake caught in the fishery (Figure 8) and the trends in mean age (Figure 9). Residuals were well within two standard deviations of observations and Pearson residuals showed no noticeable trends by year or by age-group (Figure 10).

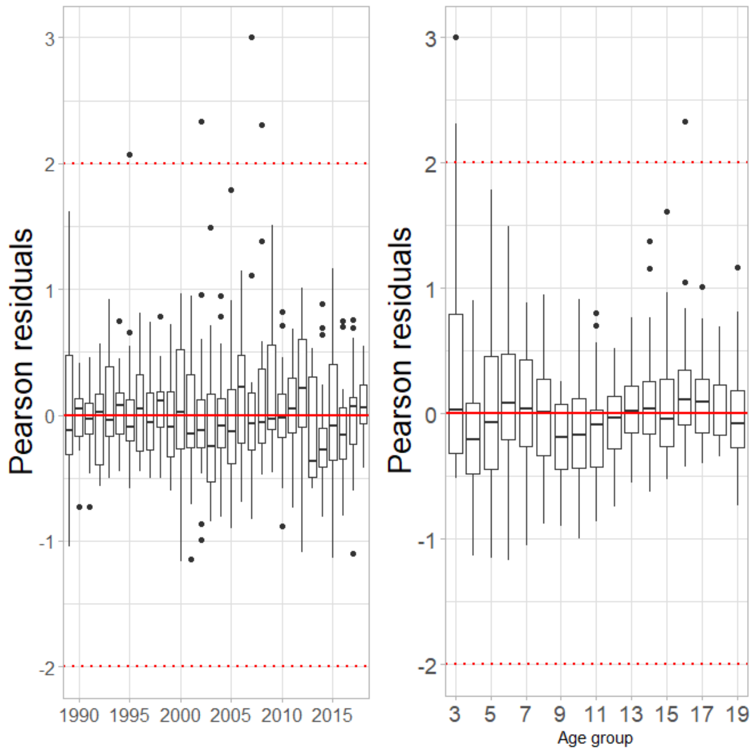

Figure 10: Pearson residuals of the fit of the base case model to proportions at age in the fishery, (left hand side) by year and (right hand side) by age-group.

Estimated population trends

The base case stock assessment model estimated that spawning stock biomass declined throughout the late 1970s (Figure 11) when there were relatively high catch levels. The biomass then increased through the mid-1980s, after which it steadily declined to a low point in 2018–19 owing to higher levels of exploitation and below-average recruitment from 1998 (Figure 11). The stock dropped below the target limit (40% B_0) in 2006 and below the soft limit (20% B_0) in 2016. The base case model estimated the SSB in 2018–19 to be 17.0% of virgin biomass (B_0), with a 95% credible interval ranging from 9.7% to 28.5%.

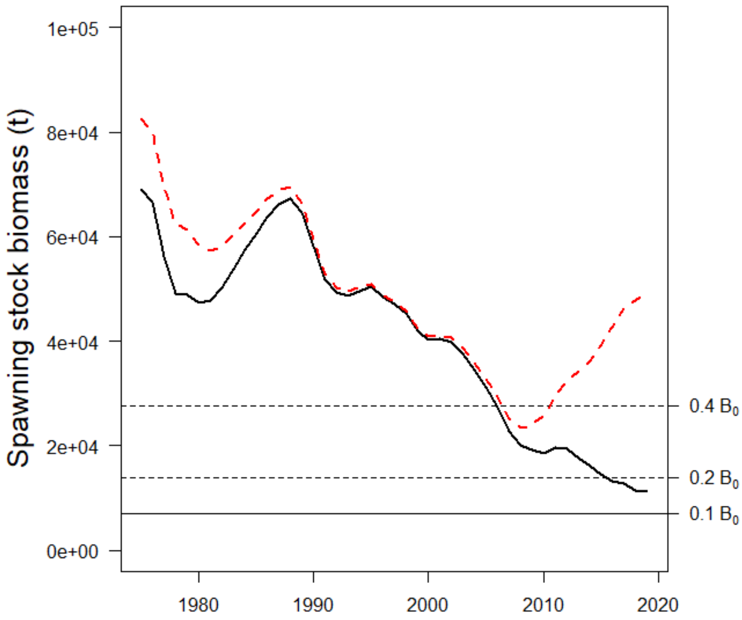

Figure 11: Estimated trend in spawning stock biomass by the base case model (solid line) and the CPUE sensitivity (dashed line). Horizontal lines locate three reference points: the target biomass (40% of B_0); the soft limit (20% of B_0) and the hard limit (10% of B_0).

5.1.2 Sensitivity runs

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

The CPUE sensitivity run estimated a substantially different trend in SSB (Figure 11), which increased after 2007–08 to an SSB2019/B0 of 62.0% (CI 40.5–90.8%).

The survey core sensitivity run produced a better fit to the survey biomass index (Figure 12), and estimated stock status to be 1% greater than the base case run, with wider credibility bounds (Table 13).

The model YCS prior with CV=0.8 produced similar trends in year class strength (Figure 13), and estimated SSB_{2019}/B_0 to be 19.1%, 2% higher than the base case model (Table 13).

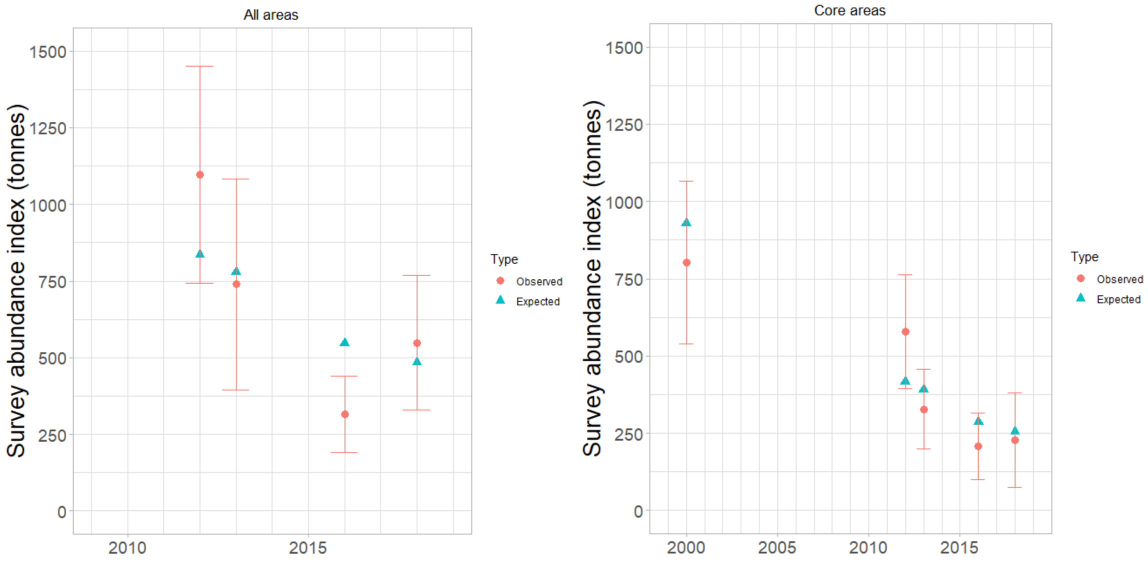

Figure 12: Fit of the base case model to the survey index of abundance from all areas (left) and fit of the sensitivity model to core survey area (right).

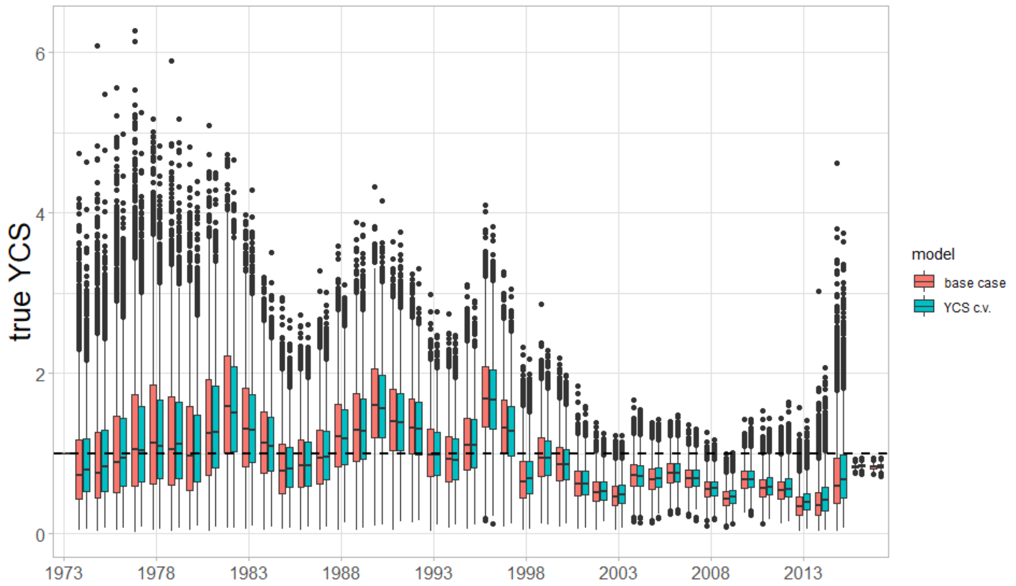

Figure 13: MCMC estimates of year class strength for the base case model and the sensitivity model investigating a narrower prior distribution (YCS CV=0.8 instead of 1.1).

5.2 Posterior distributions of parameters and model quantities

Posterior distributions of parameters and model quantities were estimated using the Bayesian approach implemented in CASAL (Bull et al. 2012). For final runs, the full posterior distribution was sampled using Monte Carlo Markov Chain (MCMC) methods, based on the Metropolis-Hastings algorithm. MCMCs were estimated using 10^7 iterations and with every 2500 sample kept (i.e., a final sample of length 4000 was taken from the Bayesian posterior).

The MCMC chains for estimates of B_0 and B_{2019} from the survey model showed no strong signs of non-convergence (Figure 14).

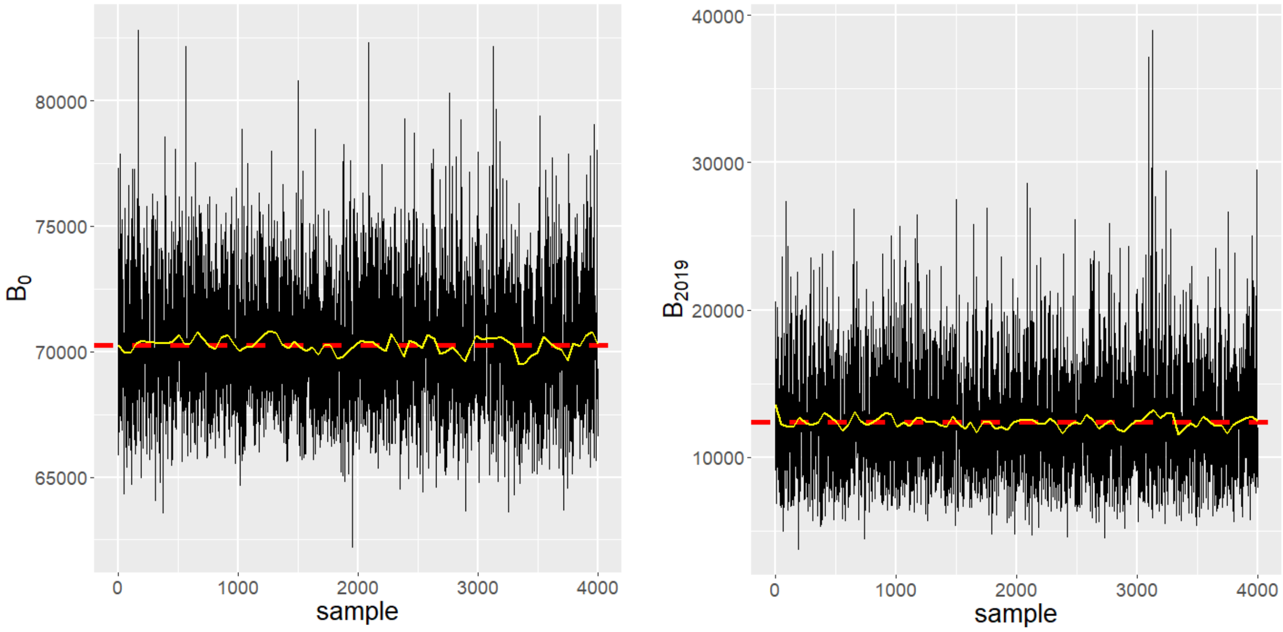

Figure 14: MCMC chains to estimate the posterior distribution of B_0 and SSB_{2019} using the base case model.

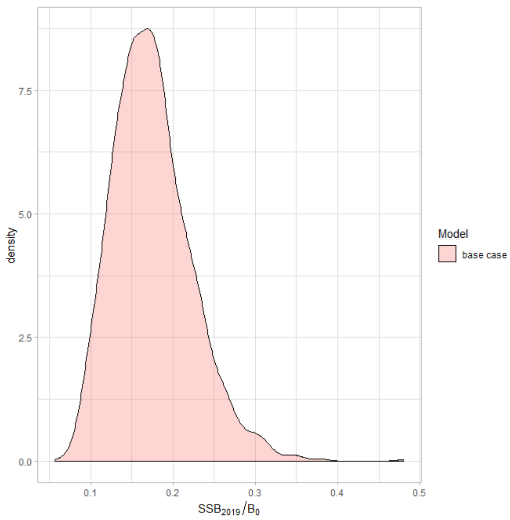

Figure 15: Posterior distribution of SSB_{2019}/ B_0 calculated using the base case model.

The posterior distribution of the unexploited biomass (B_0), biomass in 2019 and the ratio of the two from the base case model (Figure 15) and three sensitivity runs are summarised in Table 13 using the median posterior and 95% percentile credible intervals. The soft limit (20% B_0) falls within the credible interval of the ratio of SSB_{2019}/ B_0 for the base case model (survey all) and all sensitivity runs except the CPUE model, which suggests that HAK 7 SSB in 2019 is between 40.5 and 90.8% of B_0.

Table 13: Bayesian median (95% credible intervals) (MCMC) of SS*B₀*, SS*B₂₀₁₉*, and SS*B₂₀₁₉* as a percentage of *B₀* for the WCSI models.

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

Variation in year class strength did not appear to be great (Figure 13); virtually all median estimates were between 0.5 and 2. The last 12 estimated year class strengths (1998–2015) were all lower than average. The effect of reducing the standard deviation of the lognormal recruitment prior from 1.1 to 0.8 (sensitivity YCS CV) was to reduce slightly the range of recruitment estimates and move them closer to the mean of 1.

For the base model, the exploitation rate was estimated to have first exceeded consistently the exploitation rate that would result in the target biomass ($U_{40\%}$) in 1986–87, and then remained higher than $U_{40\%}$ thereafter (Figure 16). $U_{40\%}$ was estimated at 9% for the base model, but would be 12% if future fishery selectivity returned to that estimated before 2004–05.

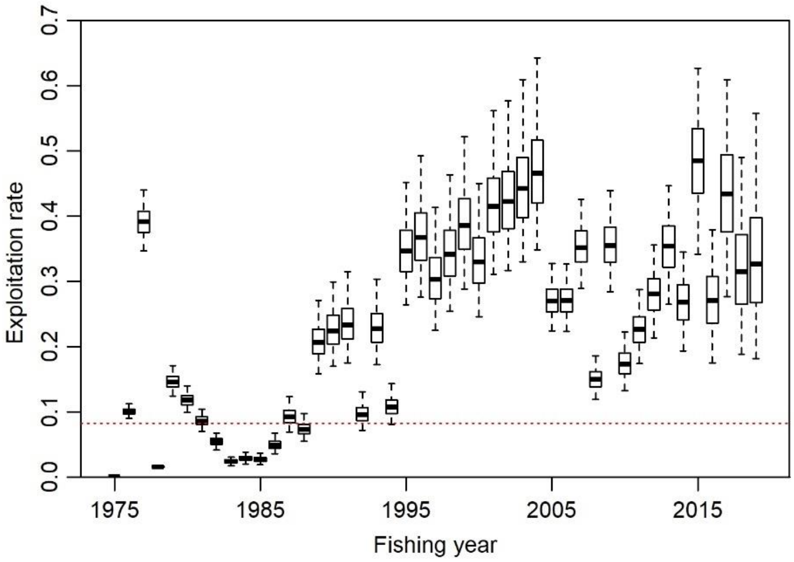

Figure 16: Exploitation rates (catch over vulnerable biomass) for the WCSI 'survey all' model. The horizontal broken line indicates the exploitation rate at 40% B_0 (U_{40}; median derived from MCMC samples).

5.3 Yield estimates and projections

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

Projections with the base case model ('survey all') using the 2006–2015 recruitment series, which is below average, indicated that spawning biomass will remain below 20% B_0 with catches equal to 2968 t (Table 14, Figure 17). If catches were to increase to the current TACC, the SSB in 2024 would drop to 8.8% B_0 (4.3–33.5%). When projections are made from average recruitment (1974–2015), the SSB is expected to increase at the current level of catches and stay at a similar level if the TACC were to be caught.

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

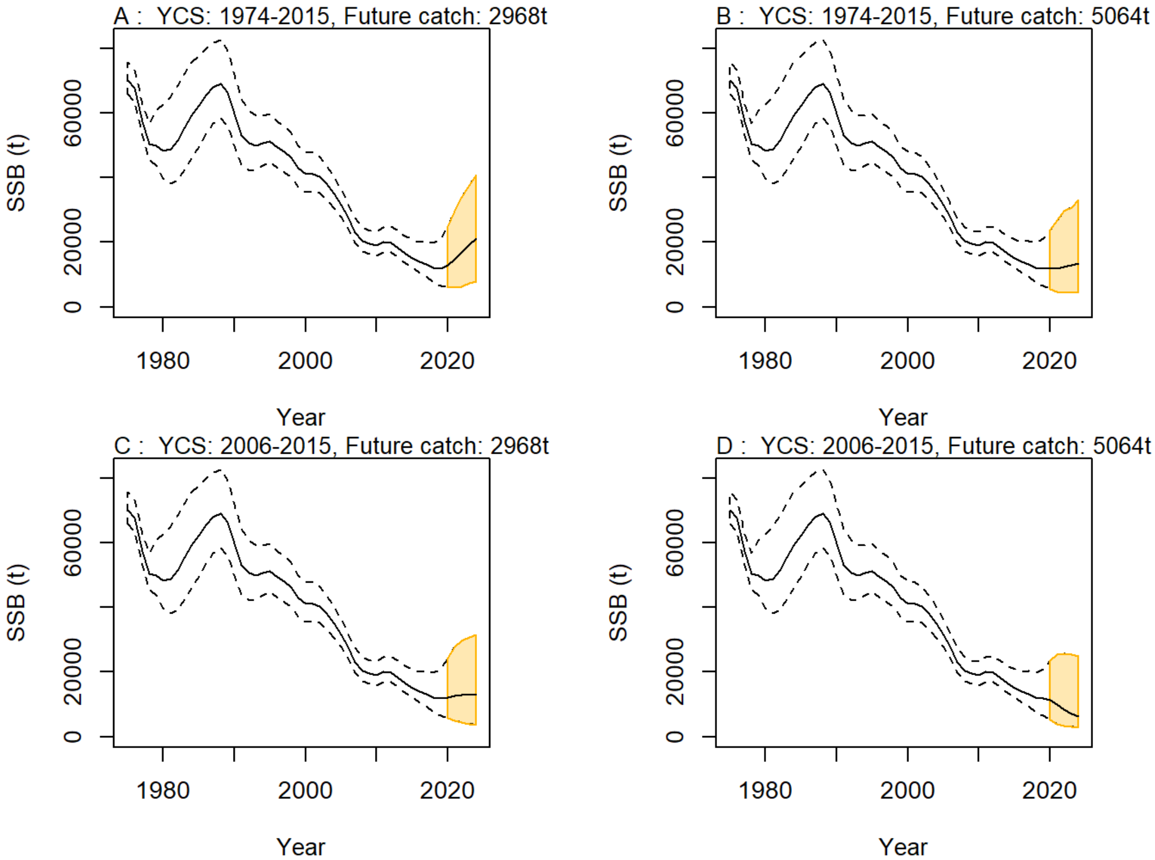

Figure 17: Spawning Stock Biomass (SSB) trajectories including projections from 2020–2024 for the Base model (Survey all), projected with catch of 2968 t (A, C) or TACC catch (B, D), with YCS sampled from all years (A, B) or most recent estimated 10 years (C, D).

Table 14: Bayesian median and 95% credible intervals of projected B_{2024}, B_{2024} as a percentage of B_0, and B_{2024}/B_{2019} (%) for the 'survey' and 'CPUE' models, under two future annual catch scenarios and two future recruitment scenarios.

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

6. DISCUSSION

The previous HAK 7 stock assessment identified that the conflict between the biomass index from CPUE and survey could not be resolved within the stock assessment (Horn, 2017). In 2017, the Deepwater Working Group opted to present two assessments, each using one of the indices of abundance, to present the implications of uncertainty about which abundance index to use on the dynamics of this fishery.

In 2019, the DWWG re-evaluated the status of the stock in the light of new evidence, in particular the data from a new scientific survey conducted in 2018. This estimate of abundance was one of the lowest observed and followed the lowest survey biomass measured in 2016. Hake proportion at age in the catch have also declined since 1979 and have remained in recent years in the lower range of their distribution providing a trend inconsistent with the biomass trajectory of the stock portrayed by the model using CPUE in which abundance is estimated to have increased since 2009, to abundance levels comparable to those in the mid-90s. The WG decided after careful consideration of various alternatives for a base case model to use the index of abundance from the survey that best sampled hake habitat on the WCSI and relegate the CPUE index to use in a sensitivity run only. Problems with deriving an index of abundance from standardizing CPUE were investigated by Horn & Ballara (2018): they concluded that none of the new CPUE series matched well with the research biomass series. Lack of consistent trends with the survey are attributed to the paucity of information regarding fishing power creep over the time period of the assessment that has seen, for example, the adoption by the fishing fleet of new technologies that have improved fishing efficiency. Without such information it becomes difficult to disentangle changes in hake abundance from changes in fishing efficiency during a CPUE standardization (Bishop et al., 2008).

The survey model indicated that the WCSI spawning stock is below the soft limit, at 17% (9.7—28.5%) of B_0. and that continued fishing at recent catch levels or higher are likely to leave the stock below the soft limit if recruitment stays as low as those observed in the last 10 years. Recruitment since 2001 was estimated to be below average. The steepness of the Beverton and Holt stock recruitment was fixed to 0.84. This parameter is possibly quite influential in determining the magnitude of recruitment when the stock is low. A sensitivity analysis of the effect of the magnitude of steepness on the outcome of the assessment might be valuable to perform.

7. ACKNOWLEDGMENTS

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APPENDIX A: RESOURCE SURVEY BIOMASS INDICES FOR HAKE IN HAK 1, HAK 4 AND HAK 7

Table A1: Biomass indices (t) and coefficients of variation (CV) for hake from resource surveys of the Sub-Antarctic. (These estimates assume that the areal availability, vertical availability, and vulnerability are equal to one.)

Vessel	Date	Trip code	Depth	Biomass	CV	Reference
Wesermünde	Mar–May 1979		– [1]	–	–	Kerstan & Sahrhage 1980
Wesermünde	Oct–Dec 1979		– [1]	–	–	Kerstan & Sahrhage 1980
Shinkai Maru	Mar–Apr 1982	SHI8201	200–800	6 045	0.15	N.W. Bagley, Fisheries New Zealand, unpublished data
Shinkai Maru	Oct–Nov 1983	SHI8303	200–800	11 282	0.22	N.W. Bagley, Fisheries New Zealand, unpublished data
Amaltal Explorer	Oct–Nov 1989	AEX8902	200–800	2 660	0.21	Livingston & Schofield 1993
Amaltal Explorer	Jul–Aug 1990	AEX9001	300–800	4 343	0.19	Hurst & Schofield 1995
Amaltal Explorer	Nov–Dec 1990	AEX9002	300–800	2 460	0.16	N.W. Bagley, NIWA, pers. comm.
Tangaroa	Nov–Dec 1991	TAN9105	Reported [2]	5 686	0.43	Chatterton & Hanchet 1994
			300–800 [3]	5 553	0.44	O'Driscoll & Bagley 2001
			1991 area [4]	5 686	0.43	O'Driscoll & Bagley 2001
			1996 area [5]	–	–	
Tangaroa	Apr–May 1992	TAN9204	Reported [2]	5 028	0.15	Schofield & Livingston 1994a
			300–800 [3]	5 028	0.15	O'Driscoll & Bagley 2001
			1991 area [4]	–	–	
			1996 area [5]	–	–	
Tangaroa	Sep–Oct 1992	TAN9209	Reported [2]	3 762	0.15	Schofield & Livingston 1994b
			300–800 [3, 7]	3 760	0.15	O'Driscoll & Bagley 2001
			1991 area [4]	–	–	
			1996 area [5]	–	–	
Tangaroa	Nov–Dec 1992	TAN9211	Reported [2]	1 944	0.12	Ingerson et al. 1995
			300–800 [3]	1 822	0.12	O'Driscoll & Bagley 2001
			1991 area [4]	1 944	0.12	O'Driscoll & Bagley 2001
			1996 area [5]	–	–	
Tangaroa	May–Jun 1993	TAN9304[6]	Reported [2]	3 602	0.14	Schofield & Livingston 1994c
			300–800 [3]	3 221	0.14	O'Driscoll & Bagley 2001
			1991 area [4]	–	–	
			1996 area [5]	–	–	

Table A1 ctd.

Vessel	Date	Trip code	Depth		Biomass	CV	Reference
Tangaroa	Nov–Dec 1993	TAN9310	Reported	2	2 572	0.12	Ingerson & Hanchet 1995
			300–800	3	2 286	0.12	O'Driscoll & Bagley 2001
			1991 area	4	2 567	0.12	O'Driscoll & Bagley 2001
			1996 area	5	–	–	
Tangaroa	Mar–Apr 1996	TAN9605	Reported	2	3 946	0.16	Colman 1996
			300–800	3	2 026	0.12	O'Driscoll & Bagley 2001
			1991 area	4	2 281	0.17	O'Driscoll & Bagley 2001
			1996 area	5	2 825	0.12	O'Driscoll & Bagley 2001
Tangaroa	Apr–May 1998	TAN9805	Reported	2	2 554	0.18	Bagley & McMillan 1999
			300–800	3	2 554	0.18	O'Driscoll & Bagley 2001
			1991 area	4	2 643	0.17	O'Driscoll & Bagley 2001
			1996 area	5	3 898	0.16	O'Driscoll & Bagley 2001
Tangaroa	Nov–Dec 2000	TAN0012	300–800	3	2 194	0.17	O'Driscoll et al. 2002
			1991 area	4	2 657	0.16	O'Driscoll et al. 2002
			1996 area	5	3 103	0.14	O'Driscoll et al. 2002
Tangaroa	Nov–Dec 2001	TAN0118	300–800	3	1 831	0.24	O'Driscoll & Bagley 2003a
			1991 area	4	2 170	0.20	O'Driscoll & Bagley 2003a
			1996 area	5	2 360	0.19	O'Driscoll & Bagley 2003a
Tangaroa	Nov–Dec 2002	TAN0219	300–800	3	1 283	0.20	O'Driscoll & Bagley 2003b
			1991 area	4	1 777	0.16	O'Driscoll & Bagley 2003b
			1996 area	5	2 037	0.16	O'Driscoll & Bagley 2003b
Tangaroa	Nov–Dec 2003	TAN0317	300–800	3	1 335	0.24	O'Driscoll & Bagley 2004
			1991 area	4	1 672	0.23	O'Driscoll & Bagley 2004
			1996 area	7	1 898	0.21	O'Driscoll & Bagley 2004
Tangaroa	Nov–Dec 2004	TAN0414	300–800	3	1 250	0.27	O'Driscoll & Bagley 2006a
			1991 area	4	1 694	0.21	O'Driscoll & Bagley 2006a
			1996 area	7	1 774	0.20	O'Driscoll & Bagley 2006a
Tangaroa	Nov–Dec 2005	TAN0515	300–800	3	1 133	0.20	O'Driscoll & Bagley 2006b
			1991 area	4	1 459	0.17	O'Driscoll & Bagley 2006b
			1996 area	7	1 624	0.17	O'Driscoll & Bagley 2006b

Table A1 ctd.

Vessel	Date	Trip code	Depth		Biomass	CV	Reference
Tangaroa	Nov–Dec 2006	TAN0617	300–800	3	998	0.22	O'Driscoll & Bagley 2008
			1991 area	4	1 530	0.17	O'Driscoll & Bagley 2008
			1996 area	7	1 588	0.16	O'Driscoll & Bagley 2008
Tangaroa	Nov–Dec 2007	TAN0714	300–800	3	2 188	0.17	Bagley et al. 2009
			1991 area	4	2 470	0.15	Bagley et al. 2009
			1996 area	7	2 622	0.15	Bagley et al. 2009
Tangaroa	Nov–Dec 2008	TAN0813	300–800	3	1 074	0.23	O'Driscoll & Bagley 2009
			1991 area	4	2 162	0.17	O'Driscoll & Bagley 2009
			1996 area	7	2 355	0.16	O'Driscoll & Bagley 2009
Tangaroa	Nov–Dec 2009	TAN0911	300–800	3	992	0.22	Bagley & O'Driscoll 2012
			1991 area	4	1 442	0.20	Bagley & O'Driscoll 2012
			1996 area	7	1 602	0.18	Bagley & O'Driscoll 2012
Tangaroa	Nov–Dec 2011	TAN1117	300–800	3	1 434	0.30	Bagley et al. 2013
			1991 area	4	1 885	0.24	Bagley et al. 2013
			1996 area	7	2 004	0.23	Bagley et al. 2013
Tangaroa	Nov–Dec 2012	TAN1215	300–800	3	1 943	0.23	Bagley et al. 2014
			1991 area	4	2 428	0.23	Bagley et al. 2014
			1996 area	7	2 443	0.22	Bagley et al. 2014
Tangaroa	Nov–Dec 2014	TAN1412	300–800	3	1 101	0.32	Bagley et al. 2017
			1991 area	4	1 477	0.25	Bagley et al. 2017
			1996 area	7	1 485	0.25	Bagley et al. 2017
Tangaroa	Nov–Dec 2016	TAN1614	300–800	3	1 000	0.25	O'Driscoll et al. 2018
			1991 area	4	–	–	O'Driscoll et al. 2018
			1996 area	7	–	–	O'Driscoll et al. 2018

1. Although surveys by *Wesermünde* were carried out in the Sub-Antarctic in 1979, biomass estimates for hake were not calculated.
2. The depth range, biomass and CV in the original report.
3. The biomass and CV calculated from source records using the equivalent 1991 region, but excluding both the 800–1000 m strata in Puysegur region and the Bounty Platform strata.
4. The biomass and CV calculated from source records using the equivalent 1991 region, which includes the 800–1000 m strata in Puysegur region but excludes the Bounty Platform strata.
5. The biomass and CV calculated from source records using the equivalent 1996 region, which includes the 800–1000 m strata in Puysegur region but excludes the Bounty Platform strata. (The 1996 region added additional 800–1000 m strata to the north and to the south of the Sub-Antarctic to the 1991 region).
6. Doorspread data not recorded for this survey. Analysis of source data with average of all other survey doorspread estimates resulted in a new estimate of biomass.
7. The biomass and CV calculated from source records using the equivalent 1996 region, which includes the 800–1000 m strata in Puysegur region but excludes the Bounty Platform strata. (The 1996 region added additional 800–1000 m strata to the north and to the south of the Sub-Antarctic to the 1991 region). However, in 2003, stratum 26 (the most southern 800–1000 m strata) was not surveyed. In previous years this stratum yielded either a very low or zero hake biomass. The yield in 2003 from stratum 26 was assumed to be zero.

Table A2: Biomass indices (t) and coefficients of variation (CV) for hake from resource surveys of the Chatham Rise. (These estimates assume that the areal availability, vertical availability, and vulnerability are equal to one.)

Vessel	Date	Trip code	Depth	Biomass	CV	Reference
Wesermünde	Mar–May 1979		– [1]	–	–	Kerstan & Sahrhage 1980
Wesermünde	Oct Dec 1979		– [1]	–	–	Kerstan & Sahrhage 1980
Shinkai Maru	Mar 1983	SHI8301	200–800	11 327	0.12	N.W. Bagley, NIWA, pers. comm.
Shinkai Maru	Nov–Dec 1983	SHI8304	200–800 [2]	8 160	0.12	N.W. Bagley, NIWA, pers. comm.
Shinkai Maru	Jul 1986	SHI8602	200–800	7 630	0.13	N.W. Bagley, NIWA, pers. comm.
Amaltal Explorer	Nov–Dec 1989	AEX8903	200–800	3 576	0.19	N.W. Bagley, NIWA, pers. comm.
Tangaroa	Jan 1992	TAN9106	200–800	4 180	0.15	Horn 1994a
Tangaroa	Jan 1993	TAN9212	200–800	2 950	0.17	Horn 1994b
Tangaroa	Jan 1994	TAN9401	200–800	3 353	0.10	Schofield & Horn 1994
Tangaroa	Jan 1995	TAN9501	200–800	3 303	0.23	Schofield & Livingston 1995
Tangaroa	Jan 1996	TAN9601	200–800	2 457	0.13	Schofield & Livingston 1996
Tangaroa	Jan 1997	TAN9701	200–800	2 811	0.17	Schofield & Livingston 1997
Tangaroa	Jan 1998	TAN9801	200–800	2 873	0.18	Bagley & Hurst 1998
Tangaroa	Jan 1999	TAN9901	200–800	2 302	0.12	Bagley & Livingston 2000
Tangaroa	Jan 2000	TAN0001	200–800	2 090	0.09	Stevens et al. 2001
			200–1000	2 152	0.09	Stevens et al. 2001
Tangaroa	Jan 2001	TAN0101	200–800	1 589	0.13	Stevens et al. 2002
Tangaroa	Jan 2002	TAN0201	200–800	1 567	0.15	Stevens & Livingston 2003
			200–1000	1 905	0.13	Stevens & Livingston 2003
Tangaroa	Jan 2003	TAN0301	200–800	888	0.16	Livingston et al. 2004
Tangaroa	Jan 2004	TAN0401	200–800	1 547	0.17	Livingston & Stevens 2005
Tangaroa	Jan 2005	TAN0501	200–800	1 048	0.18	Stevens & O'Driscoll 2006
Tangaroa	Jan 2006	TAN0601	200–800	1 384	0.19	Stevens & O'Driscoll 2007
Tangaroa	Jan 2007	TAN0701	200–800	1 824	0.12	Stevens et al. 2008
			200–1000	1 976	0.12	Stevens et al. 2008
Tangaroa	Jan 2008	TAN0801	200–800	1 257	0.13	Stevens et al. 2009a
			200–1000	1 323	0.13	Stevens et al. 2009a
Tangaroa	Jan 2009	TAN0901	200–800	2 419	0.21	Stevens et al. 2009b
Tangaroa	Jan 2010	TAN1001	200–800	1 701	0.25	Stevens et al. 2011
			200–1300	1 862	0.25	Stevens et al. 2011

Table A2 ctd.

Tangaroa	Jan 2011	TAN1101	200–800	1 099	0.15	Stevens et al. 2012
			200–1300	1 201	0.14	Stevens et al. 2012
Tangaroa	Jan 2012	TAN1201	200–800	1 292	0.15	Stevens et al. 2013
			200–1300	1 493	0.13	Stevens et al. 2013
Tangaroa	Jan 2013	TAN1301	200–800	1 793	0.15	Stevens et al. 2014
			200–1300	1 874	0.15	Stevens et al. 2014
Tangaroa	Jan 2014	TAN1401	200–800	1 377	0.15	Stevens et al. 2015
			200–1300	1 510	0.14	Stevens et al. 2015
Tangaroa	Jan 2016	TAN1601	200–800	1 299	0.19	Stevens et al. 2017
			200–1300	1 512	0.16	Stevens et al. 2017

1. Although surveys by *Wesermünde* were carried out on the Chatham Rise in 1979, biomass estimates for hake were not calculated.
2. East of 176º E only.

Table A3: Biomass indices (t) and coefficients of variation (CV) for hake from comparable resource surveys off WCSI. (These estimates assume that the areal availability, vertical availability, and vulnerability are equal to one.)

Vessel	Date	Trip code	Depth	Biomass	CV	Reference
Tangaroa	Jul–Aug 2000	TAN0007	300–650	803	0.13	O’Driscoll & Ballara 2018
Tangaroa	Jul–Aug 2012	TAN1210	300–650	583	0.13	O’Driscoll & Ballara 2018
			200–800	1 103	0.13	O’Driscoll & Ballara 2018
Tangaroa	Jul–Aug 2013	TAN1308	300–650	331	0.17	O’Driscoll & Ballara 2018
			200–800	747	0.21	O’Driscoll & Ballara 2018
Tangaroa	Jul–Aug 2016	TAN1609	300–650	221	0.24	O’Driscoll & Ballara 2018
			200–800	355	0.16	O’Driscoll & Ballara 2018
			200–1000	502	0.13	O’Driscoll & Ballara 2018
Tangaroa	Jul–Aug 2018	TAN1807	300–650	229	0.33	O’Driscoll & Ballara (2019)
			200–800	559	0.18	O’Driscoll & Ballara (2019)
			200–1000	899	0.14	O’Driscoll & Ballara (2019)