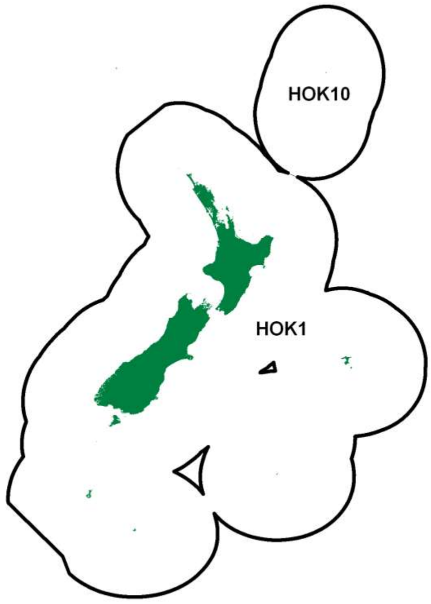
HOKI (HOK)

(*Macruronus novaezelandiae*)
Hoki



1. FISHERY SUMMARY

1.1 Commercial fisheries

Historically, the main fishery for hoki operated from mid-July to late August off the west coast of the South Island (WCSI) where hoki aggregate to spawn. The spawning aggregations begin to concentrate in depths of 300–700 m around the Hokitika Canyon from late June, and further north off Westport later in the season. Fishing in these areas continues into September in some years. Starting in 1988, another major fishery developed in Cook Strait, where separate spawning aggregations of hoki occur. The spawning season in Cook Strait runs from late June to mid-September, peaking in July and August. Small catches of spawning hoki are taken from other spawning grounds off the east coast South Island (ECSI) and late in the season at Puysegur Bank.

Outside the spawning season, when hoki disperse to their feeding grounds, substantial fisheries have developed since the early 1990s on the Chatham Rise and in the Sub-Antarctic. These fisheries usually operate in depths of 300–800 m. The Chatham Rise fishery generally has similar catches over all months except in July-September, when catches are lower due to the fishery moving to the spawning grounds. In the Sub-Antarctic, catches have typically peaked in April-June. Out-of-season catches are also taken from Cook Strait and the east coast of the North Island, but these are small by comparison.

The hoki fishery was developed by Japanese and Soviet vessels in the early 1970s. Catches peaked at 100 000 t in 1977 but dropped to less than 20 000 t in 1978 when the EEZ was declared and quota limits were introduced (Table 1). From 1979 on, the hoki catch increased to about 50 000 t until an increase in the TACC from 1986 to 1990 saw the fishery expand to a maximum catch in 1987–88 of about 255 000 t (Table 2).

From 1986 to 1990, surimi vessels dominated the catches and took about 60% of the annual WCSI catch. However, after 1991, the surimi component of catches decreased and processing to head and gut, or to fillet product increased, as did “fresher” catch for shore processing. The hoki fishery now operates throughout the year, producing high quality fillet product from both spawning and non-spawning fisheries. No surimi has been produced from hoki since 2002. Since 1998, twin-trawl rigs have operated in some hoki fisheries, and trawls made of spectra twine (a high strength twine with reduced diameter resulting in reduced drag and improved fuel efficiencies) were introduced to some vessels in 2007–08.

Between 2012–13 and 2017, Precision Seafood Harvest (PSH) technology was tested in the hoki fishery. This included a prototype trawl system called a Modular Harvest System (MHS) that aimed to target specific species and fish size, as well as enabling fish to be landed in much better condition than traditional trawls. Approval to use MHS gear in the hoki, hake, and ling fisheries was granted in 2018. During the 2017–18 fishing year, seven vessels used the gear to target hoki and caught 9595 t (7% of the total hoki catch). The MHS catch increased to 17 127 t (14% of the total catch) in 2018–19 but has subsequently decreased due to a change in preference of product from fillet to block. In 2020–21, only 2453 t (2.4 % of the total catch) was taken with MHS.

Table 1: Reported trawl catches (t) by fleet from 1969 to 1987–88, 1969–1983 by calendar year, 1983–84 to 1987–88 by fishing year (Oct-Sept). Source - FSU data.

				New Zealand		
Year	**USSR**	**Japan**	**South Korea**	**Domestic**	**Chartered**	**Total**
1969	–	95	–	–	–	95
1970	–	414	–	–	–	414
1971	–	411	–	–	–	411
1972	7 300	1 636	–	–	–	8 936
1973	3 900	4 758	–	–	–	8 658
1974	13 700	2 160	–	125	–	15 985
1975	36 300	4 748	–	62	–	41 110
1976	41 800	24 830	–	142	–	66 772
1977	33 500	54 168	9 865	217	–	97 750
1978*	†2 028	1 296	4 580	678	–	8 581
1979	4 007	8 550	1 178	2 395	7 970	24 100
1980	2 516	6 554	–	2 658	16 042	27 770
1981	2 718	9 141	2	5 284	15 657	32 802
1982	2 251	7 591	–	6 982	15 192	32 018
1983	3 853	7 748	137	7 706	20 697	40 141
1983–84	4 520	7 897	93	9 229	28 668	50 407
1984–85	1 547	6 807	35	7 213	28 068	43 670
1985–86	4 056	6 413	499	8 280	80 375	99 623
1986–87	1 845	4 107	6	8 091	153 222	167 271
1987–88	2 412	4 159	10	7 078	216 680	230 339

* Catches for foreign licensed and New Zealand chartered vessels from 1978 to 1984 are based on estimated catches from vessel logbooks. Few data are available for the first 3 months of 1978 because these vessels did not begin completing these logbooks until 1 April 1978.

† Soviet hoki catches are taken from the estimated catch records and differ from official MAF statistics. Estimated catches are used because of the large amount of hoki converted to meal and not recorded as processed fish.

Annual catches ranged between 175 000 t and 215 000 t from 1988–89 to 1995–96, increasing to 246 000 t in 1996–97, and peaking at 269 000 t in 1997–98, when the TACC was over-caught by 19 000 t. Catches declined, tracking the TACC as it was reduced to address poor stock status, reaching a low of 89 000 t in 2008–09, then increasing again up to 161 500 t in 2014–15 following increases in the TACC as stock status improved (Table 2). The TACC was reduced to 150 000 t in 2015–16 and catches in the next four years were below this level (Table 2). The fishing industry voluntarily shelved 20 000 t of western ACE in 2018–19, leading to an effective lowering of the western catch limit in that year to 70 000 t. The TACC was further reduced to 115 000 t in 2019–20 when the annual catch was 107 700 t. In 2020–21, the TACC remained the same, but available ACE (allowing for shelving and carry-forward) was 52 984 t in the west and 60 899 t for the east, with an annual catch of 100 817 t. The TACC for 2021–22 was reduced to 110 000 t with agreed catch limits of 45 000 t for the western stock and 65 000 t for the eastern stock and there was also an agreement that in the 2021–22 fishing year, catches would be limited to 100 000 t (plus any carryover) with a catch split of 45 000 t from the western stock areas and 55 000 t for the eastern stock areas.

The pattern of fishing has changed markedly since 1988–89 when over 90% of the total catch was taken in the WCSI spawning fishery. This has been due to a combination of TACC changes and redistribution of fishing effort. The WCSI fishery accounted for about 35% of the total hoki catch in 2020–21 and was the second largest hoki fishery in New Zealand behind the Chatham Rise (CR) (Table 3). Cook Strait (CS) catches peaked at 67 000 t in 1995–96 but have been relatively stable in the range from 12 500 t to 21 500 t in the past 14 years. The Chatham Rise was the largest hoki fishery in 2020–21 and contributed about 38% of the total catch. Catches from the Sub-Antarctic (SA) peaked at over 30 000 t from 1999–2000 to 2001–02 but have been variable since, ranging between 6600 t and 19 900 t over the past 14 years (Table 3). Catches from other areas remained at relatively low levels (Table 3).

Table 2: Reported catch (t) from QMS, estimated catch (t), and TACC (t) for HOK 1 from 1986–87 to 2020–21. Reported catches are from the QMR and MHR systems. Estimated catches include TCEPR and CELR data (from 1989–90), LCER data (from 2003–04), NCELR data (from 2006–07), TCER, and LTCER data (from 2007–08), and ERS-trawl data (from 2017–18). Catches from 1986–87 to 1999–00 are rounded to the nearest 500 t.

Year	Reported catch	Estimated catch	TACC
1986–87	158 000	175 000	250 000
1987–88	216 000	255 000	250 000
1988–89	208 500	210 000	250 000
1989–90	210 000	210 000	251 884
1990–91	215 000	210 000	201 897
1991–92	215 000	215 000	201 897
1992–93	195 000	215 000	202 156
1993–94	191 000	195 000	202 156
1994–95	174 000	190 000	220 350
1995–96	210 000	168 000	240 000
1996–97	246 000	194 000	250 000
1997–98	269 000	230 000	250 000
1998–99	244 500	234 000	250 000
1999–00	242 000	237 000	250 000
2000–01	230 625	229 858	250 000
2001–02	200 054	195 492	200 000
2002–03	182 560	184 659	200 000
2003–04	133 764	135 784	180 000
2004–05	102 885	104 364	100 000
2005–06	101 984	104 385	100 000
2006–07	97 790	101 009	100 000
2007–08	87 815	89 318	90 000
2008–09	87 598	88 805	90 000
2009–10	105 105	107 209	110 000
2010–11	115 782	118 805	120 000
2011–12	126 184	130 108	130 000
2012–13	127 962	131575	130 000
2013–14	143 705	146 344	150 000
2014–15	156 471	161 528	160 000
2015–16	136 087	136 719	150 000
2016–17	138 555	141 567	150 000
2017–18	131 504	135 418	150 000
2018–19	116 700	122 459	150 000
2019–20	102 586	107 737	115 000
2020–21	97 513	100 819	115 000

Note: Discrepancies between QMS data and actual catches from 1986 to 1990 arose from incorrect surimi conversion factors. The estimated catch in those years has been corrected from conversion factors measured each year by Scientific Observers on the WCSI fishery. Since 1990 the new conversion factor of 5.8 has been used, and the total catch reported to the QMS is considered to be more representative of the true level of catch.
In 2018–19, 20 000 t of western ACE was voluntarily shelved by the fishing industry so the effective TACC was 130 000 t. In 2020–21, 20 000 t of western ACE was voluntarily shelved by the fishing industry so the effective TACC was 95 000 t.

Since the 2020–21 stock assessment, fisheries were defined, within which the exploitation patterns were more consistent, following the review work of Langley (2020). The main regions (WCSI, Chatham Rise, Sub-Antarctic, and Cook Strait) were split into fisheries, with estimation of length and age frequencies produced for each fishery. The WCSI region was split into three fisheries spatially: WC_north, WC_south, and WC_inside (Figure 1), where 'inside' relates to inside the 25 nm limit. The WCSI WC_north sub-fishery has been the largest WCSI fishery in most years, with most of the recent declines in catch occurring in this fishery. Fish size is smaller in the north, and substantially larger fish are caught inside the 25 nm line. The Sub-Antarctic region was structured spatially as SA_auck (Auckland Islands), SA_snares (the Stewart-Snares shelf), and SA_suba (the remaining SA area) (Figure 1) based on fish size. The SA_snares sub-fishery is the largest Sub-Antarctic fishery in most years. The smallest hoki are on the Stewart-Snares shelf, medium sized fish are around the Auckland Islands, and most of the catch in the rest of the Sub-Antarctic comprises large females. The Chatham Rise region was structured using depth, with effort depth greater than or equal to 475 m defined as CR_deep, and shallower than 475 m as CR_shallow, because larger fish are predominantly found in deeper water. The CR_deep sub-fishery makes up most of the Chatham Rise catch in each year. Puysegur was defined as its own spawning fishery for catches from June to September; catches from Puysegur outside these spawning months were included in the SA_snares fishery. Cook Strait and ECSI catches from spawning months (June-September) made up the CS fishery, and catches from these areas outside the spawning months were included in the CR fisheries. A table of catches by fishing year and fishery as defined for the 2020–21 stock assessment is presented under the Stock Assessment section of this report (see Table 20).

Table 3: Estimated total catch (t) (scaled to reported QMR or MHR) of hoki by area 1988–89 to 2020–21. Catches from 1988–89 to 1997–98 are rounded to the nearest 500 t and catches from 1998–99 to 2020–21 are rounded to the nearest t. Unrep. is catch with no location information.

Fishing	Spawning fisheries				Non-spawning fisheries			Total		
year	WCSI	Puysegur	Cook Strait	ECSI	Sub-Antarctic	Chatham and ECSI	ECNI	WCNI	Unrep.	Catch
1988-89	188 000	3 500	7 000	-	5 000	5 000	-	-	-	208 500
1989-90	165 000	8 000	14 000	-	10 000	13 000	-	-	-	210 000
1990-91	154 000	4 000	26 500	1 000	18 000	11 500	-	-	-	215 000
1991-92	105 000	5 000	25 000	500	34 000	45 500	-	-	-	215 000
1992-93	98 000	2 000	21 000	-	26 000	43 000	2 000	-	3 000	195 000
1993-94	113 000	2 000	37 000	-	12 000	24 000	2 000	-	1 000	191 000
1994-95	80 000	1 000	40 000	-	13 000	39 000	1 000	-	-	174 000
1995-96	73 000	3 000	67 000	1 000	12 000	49 000	3 000	-	2 000	210 000
1996-97	91 000	5 000	61 000	1 500	25 000	56 500	5 000	-	1 000	246 000
1997-98	107 000	2 000	53 000	1 000	24 000	75 000	4 000	-	3 000	269 000
1998-99	94 565	2 874	45 240	1 977	23 780	73 593	2 315	62	134	244 540
2099-00	102 723	2 880	43 192	2 351	33 772	56 014	1 387	98	4	242 421
2000-01	102 235	6 798	36 298	2 411	30 076	49 847	2 035	147	-	229 847
2001-02	92 720	5 322	23 976	2 971	30 175	39 151	1 147	39	-	195 501
2002-03	73 860	5 948	36 713	7 382	20 199	39 091	929	532	8	184 662
2003-04	45 112	1 158	41 034	2 140	11 635	33 650	880	126	-	135 735
2004-05	33 111	5 548	24 833	3 244	6 244	30 673	522	37	-	104 212
2005-06	38 989	1 437	21 803	665	6 732	34 058	686	8	-	104 378
2006-07	33 328	408	20 113	1 006	7 661	37 813	667	8	-	101 004
2007-08	20 931	308	18 470	2 323	8 708	37 920	640	17	-	89 317
2008-09	20 548	233	17 535	1 054	9 807	39 011	588	25	-	88 801
2009-10	36 349	272	17 880	669	12 275	39 138	618	7	-	107 208
2010-11	48 373	1 176	14 937	1 625	12 655	38 447	1 588	2	-	118 803
2011-12	54 532	1 308	15 859	2 531	15 743	39 246	858	31	-	130 108
2012-13	56 219	955	19 396	3 311	14 098	36 536	1 051	9	-	131 575
2013-14	69 400	778	18 400	2 750	19 927	33 752	1 326	9	-	146 342
2014-15	78 705	1 875	20 100	3 624	16 378	40 071	766	11	5	161 535
2015-16	68 877	1 056	18 378	4 126	6 639	36 714	888	20	-	136 698
2016-17	65 962	1 209	16 084	4 405	13 157	39 919	826	6	-	141 568
2017-18	55 533	1 133	21 473	3 569	15 431	37 134	1 141	4	-	135 418
2018-19	46 464	1 268	20 349	3 674	9 061	40 462	1 177	4	-	122 459
2019-20	43 927	349	16 909	4 722	8 039	32 939	844	6	-	107 735
2020-21	35 141	448	12 524	4 064	9 136	38 751	746	7	-	100 817

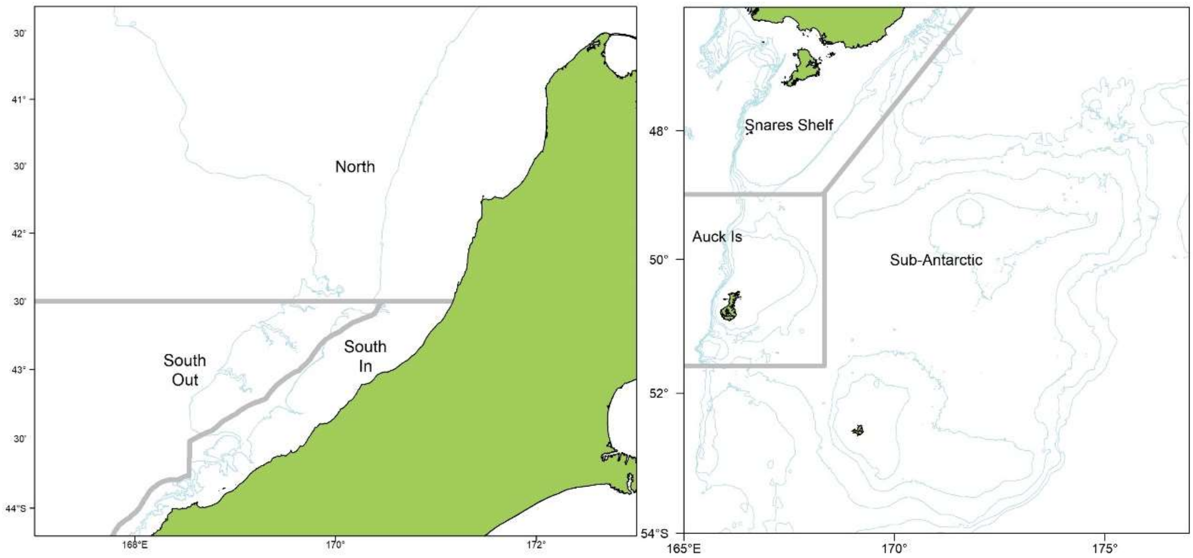


Figure 1: Spatial definitions for WC fisheries (left) and SA (Sub-Antarctic) fisheries (right) as defined for the 2020–21 stock assessment. North: WC_north; South Out: WC_south; South In: WC_inside; Stewart-Snares (Snares) shelf: SA_snares; Auck Is: SA_auck; Sub-Antarctic: SA_suba.

From 1999–2000 to 2001–02, there was a redistribution in catch from eastern stock areas (Chatham Rise, ECSI, east coast North Island (ECNI), and Cook Strait) to western stock areas (WCSI, Puysegur, and Sub-Antarctic) (Table 4). This was initially due to industry initiatives to reduce the catch of small fish in the area of the Mernoo Bank but, from 1 October 2001, was part of an informal agreement with the Minister responsible for fisheries that 65% of the catch should be taken from the western fisheries to reduce pressure on the eastern stock. This arrangement ended following the 2003 hoki assessment in 2002–03, which indicated that the eastern hoki stock was less depleted than the western stock and effort was shifted back into eastern areas, particularly Cook Strait. Since 2004–05 there have been a series of agreements, including limiting catch below the TACC and voluntary catch splits between western and eastern fishing grounds (Table 5). The split between eastern and western catches has been close to the agreed catches in most years. In 2020–21, eastern and western catches (including carry forward) were below catch limits for both eastern and western stock areas. Figure 2a shows the reported landings and TACC for HOK 1, and Figure 2b shows the eastern and western catch components of this stock since 1988–89.

Table 4: Proportions of total catch for different fisheries.

Fishing	Spawning fisheries		Non-spawning fisheries	
Year	West	East	West	East
1988–89	92%	3%	2%	3%
1989–90	82%	7%	5%	6%
1990–91	74%	13%	8%	5%
1991–92	51%	12%	16%	21%
1992–93	51%	11%	14%	24%
1993–94	60%	19%	7%	14%
1994–95	47%	23%	7%	23%
1995–96	36%	33%	6%	25%
1996–97	39%	26%	10%	25%
1997–98	41%	20%	9%	30%
1998–99	38%	20%	10%	32%
1999–00	43%	19%	14%	24%
2000–01	47%	15%	13%	24%
2001–02	50%	13%	15%	22%
2002–03	43%	23%	11%	23%
2003–04	34%	30%	9%	27%
2004–05	37%	25%	6%	32%
2005–06	39%	20%	6%	35%
2006–07	33%	19%	8%	40%
2007–08	24%	20%	10%	46%
2008–09	23%	18%	11%	48%
2009–10	34%	15%	11%	39%
2010–11	42%	11%	11%	36%
2011–12	43%	12%	12%	33%
2012–13	43%	14%	11%	32%
2013–14	48%	12%	14%	27%
2014–15	50%	12%	10%	28%
2015–16	51%	14%	5%	30%
2016–17	47%	12%	9%	31%
2017–18	42%	16%	11%	31%
2018–19	39%	20%	7%	34%
2019–20	41%	18%	8%	33%
2020–21	35%	17%	9%	39%

Table 5: Total available ACE (total catch available) including voluntary catch splits and industry shelving agreements by year. Values are in tonnes.

Year	TACC	Eastern catch limit	Western catch limit	Total available HOK 1 ACE	Industry shelving of ACE
2001–02	200 000	70 000	130 000	199 402	–
2002–03	200 000	70 000	130 000	203 943	–
2003–04	180 000	70 000	110 000	180 000	–
2004–05	100 000	60 000	40 000	100 000	–
2005–06	100 000	60 000	40 000	100 251	–
2006–07	100 000	60 000	40 000	100 493	–
2007–08	90 000	65 000	25 000	90 000	–
2008–09	90 000	65 000	25 000	90 682	–
2009–10	110 000	60 000	50 000	111 872	–
2010–11	120 000	60 000	60 000	124 666	–
2011–12	130 000	60 000	70 000	135 770	–
2012–13	130 000	60 000	70 000	135 650	–
2013–14	150 000	60 000	90 000	153 959	–
2014–15	160 000	60 000	100 000	167 572	–
2015–16	150 000	60 000	90 000	150 000	–
2016–17	150 000	60 000	90 000	161 205	–
2017–18	150 000	60 000	90 000	166 075	–
2018–19	150 000	60 000	90 000	164 730	20 000 (from West)
2019–20	115 000	60 000	55 000	115 000	–
2020–21	115 000	60 000	55 000	122 259	20 000 (split evenly East/West)
2021–22	110 000	65 000	45 000	110 000	10 000 (from East)

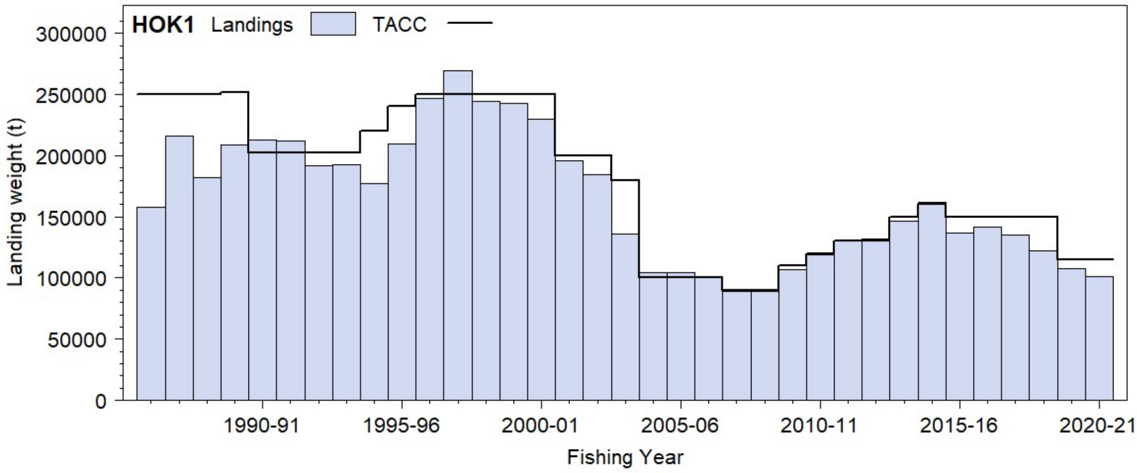


Figure 2a: Reported commercial landings and TACCs for HOK 1 since 1986–87. Note that this graph does not show data prior to entry into the QMS.

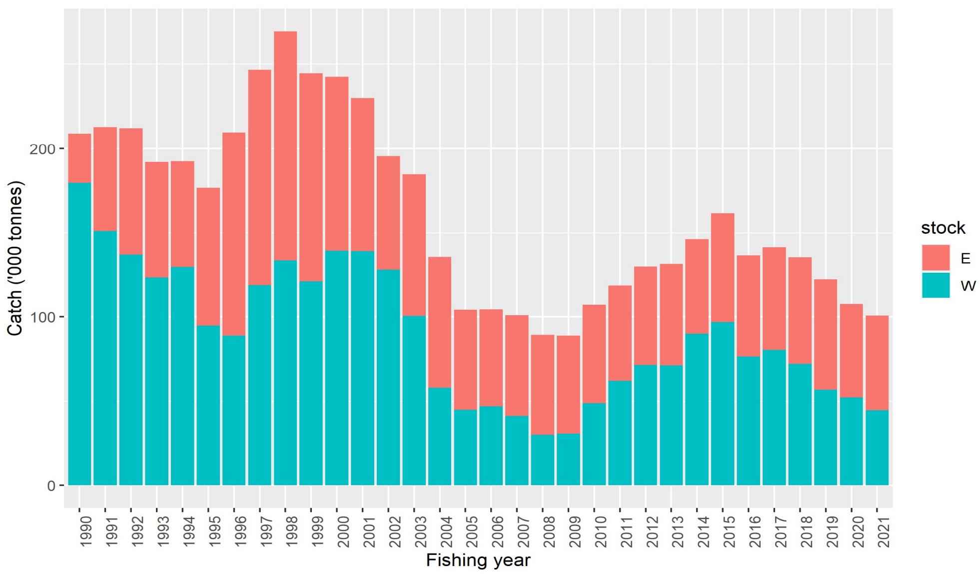


Figure 2b: The eastern and western components of the total HOK 1 landings since 1988–89. Note that these figures do not show data prior to entry into the QMS.

Total Allowable Commercial Catch (TACC) and area restrictions
In the 2020–21 fishing year, the TACC for HOK 1 was 115 000 t. This TACC applied to all areas of the EEZ (except the Kermadec FMA which had a TACC of 10 t). With the allowance for other mortality at 1500 t and 20 t allowances for customary and recreational catch, the 2020–21 TAC was 116 540 t, but available ACE (allowing for shelving and carry-forward) was 52 984 t in the west and 60 899 t for the east. From 1 October 2021 the TACC for HOK 1 decreased to 110 000 t, with a voluntary catch split arrangement of 65 000 t from eastern stock areas and 45 000 t from western stock areas. There was also an agreement that in the 2021–22 fishing year, catches would be limited to 100 000 t (plus any carryover) with a catch split of 45 000 t from the western stock areas and 55 000 t for the eastern stock areas (Table 5).

Vessels larger than 46 m in overall length may not fish inside the 12 nautical mile (nm) Territorial Sea, and there are other various vessel size restrictions around some parts of the coast. On the WCSI, a 25-nm line closes much of the hoki spawning area in the Hokitika Canyon, and most of the area south to the Cook Canyon, to vessels larger than 46 m overall length. In Cook Strait, the whole spawning area is closed to vessels over 46 m overall length. In November 2007 the Government closed 17 Benthic Protection Areas to bottom trawling and dredging, representing about 30% of the EEZ and including depths that are outside the depth range of hoki.

The fishing industry introduced a Code of Practice (COP) for hoki target trawling in 2001 with the aim to protect small fish (less than 60 cm). The main components of this COP were: 1) a restriction on fishing in waters shallower than 450 m; 2) a rule requiring vessels to 'move on' if there are more than 10% small hoki in the catch; and 3) seasonal and area closures in spawning fisheries. The COP was superseded by Operational Procedures for Hoki Fisheries, also introduced by the fishing industry from 1 October 2009. The Operational Procedures aim to manage and monitor fishing effort within four industry Hoki Management areas where there are thought to be high abundances of juvenile hoki (Narrows Basin of Cook Strait, Canterbury Banks, Mernoo Bank, and Puysegur). These areas are closed to trawlers over 28 m targeting hoki, with increased monitoring when targeting species other than hoki. There is also a general recommendation that vessels move from areas where catches of juvenile hoki (now defined as less than 55 cm total length) comprise more than 20% of the hoki catch by number.

From 2018–19 to 2020–21 there was agreement from industry to close certain fishing grounds to target fishing for hoki to allow spawning to occur undisturbed at peak times (Operational Procedures version 18). Seasonal spawning closures were:

- WCSI inside the 25-nm line: between 0000 h 18 July and 2400 h 24 July.
- WCSI outside the 25-nm closure, shallower than 800 m, between Kahurangi Point in the north and the boundary between FMAs 5 and 7 in the south: between 0000 h 25 July and 2400 h 31 July.
- Cook Strait: Entire fishery between 0000 h 1 August and 2400 h 7 August.
- Pegasus: between 0000 h 1 September and 2400 h 7 September.

2020–21 hoki fishery
The overall reported catch of 100 817 t was about 6900 t lower than the catch in 2019–20, and about 14 200 t lower than the TACC of 115 000 t (Table 3). Total available ACE was 122 259 t with 20 000 t shelved (Table 5) giving an agreed catch of 102 259 t. Relative to 2019–20, catches in 2020–21 decreased in most areas (WCSI, Cook Strait, ECSI, Sub-Antarctic, Puysegur, and ECNI) and increased on the Chatham Rise.

The WCSI catch decreased by 8700 t, to 35 141 t in 2021 (2020–21). Catches from inside the 25-nm line made up 28% of the total WCSI catch in 2021, a decrease in proportion from 2020, but still lower than the peak of 41% of the catch taken from inside-the-line in 2004. From 2011 to 2019, fishing off the WCSI began in May (with most pre-June catch from inside the 25-nm line) and continued into September; but in 2020 and 2021 very little catch was taken in May. Most (66%) of the WCSI catch in 2021 was taken by midwater trawl. Twin trawls accounted for about 27% of the bottom trawl catch and 7% of the WCSI catch overall. Unstandardised catch rates increased slightly from 2020, with a median catch rate in all midwater tows targeting hoki of 4.4 t per hour in 2021. The WCSI catch in 2021 was dominated by fish from 60 to 110 cm total length (TL) from the 2011 to 2018 year classes (ages 3–10). Previous comparisons showed fishing inside the 25-nm line catches a higher proportion of larger fish (greater than 70 cm) than fisheries outside the line. This was seen again in 2021; the observer and land-based sampling data from the WC_inside sub-fishery had very few fish less than 80 cm, but many fish smaller than 80 cm were caught in the WC_north and WC_south sub-fisheries. The WC_north fishery had the highest proportion of small fish, especially males, with 19% of hoki less than 65 cm. From 2000 to 2004, the sex ratio of the WCSI catch was highly skewed, with many more females caught than males. In 2005 to 2011, as the catch of younger fish increased, the sex ratio reversed with more males than females caught. The sex ratio of the WCSI catch in 2021 was 54% females in WC_inside, and 63–65% females in WC_north and WC_south. The mean length-at-age for hoki off the WCSI increased from the start of the fishery to the mid-2000s but has since decreased.

The Chatham Rise fishery caught 38 751 t in 2020–21, an increase of 5812 t from 2019–20, and overtaking the WCSI as the largest New Zealand hoki fishery. The Chatham Rise fishery now occurs all year around, with catches throughout the winter spawning period. Over 93% of the 2020–21 Chatham Rise catch was taken in bottom trawls. There was an increase in catch from twin trawls, with this method accounting for 43% of the bottom trawl catch in 2020–21. The median unstandardised catch rate in bottom trawls targeting hoki was 2.0 t per hour, which was higher than in 2019–20 (1.7 t per hour). There was a large decrease in the Chatham Rise catch taken using the Modular Harvest System (MHS) (treated as a separate method to bottom trawls) from 6280 t in 2019–20 to 1990 t in 2020–21. Less than 2% of the Chatham Rise catch was taken by midwater trawls. The length frequency distributions in the CR_shallow and CR_deep sub-fisheries for both male and female hoki had modes at 40–80 cm, corresponding to fish from the 2019, 2018, 2014, and 2015 year classes. The CR_shallow sub-fishery has proportionally more small fish by number, with about 49% of the CR_shallow catch less than 65 cm, compared with 38% of the CR_deep catch.

The catch from Cook Strait in 2021 (2020–21) was 12 524 t, a decrease of 4385 t from that in 2020. Peak catches were from mid-July to mid-September. Most catch (99%) is taken by midwater trawls. Unstandardised catch rates in Cook Strait continued to be high; the median catch rate in midwater tows targeting hoki increased from 18.8 t in 2020 to 20.6 t per hour in 2021. A broad size range of hoki was caught in 2021, with the main modes at ages 2–12 (2009 to 2019 year classes) for females, and ages 2–9 (2012 to 2019 year classes) for males. About 20% of the Cook Strait catch was of fish less than 65 cm. As for the WCSI, the mean length-at-age in the Cook Strait fishery increased until the mid-2000s and has subsequently declined, although there was an increase in mean length-at-age for most year classes from 2019–20 to 2020–21.

The catch from the Sub-Antarctic increased by 1097 t from 2019–20 to 9136 t in 2020–21. Over 99% of the catch was taken in bottom trawls, of which 29% was from twin trawls. There was no MHS catch. The median unstandardised catch rate in bottom trawls targeting hoki was lower than that on the Chatham Rise, at 1.2 t per hour in 2020–21. The 2020–21 SA_snares and SA_auck sub-fishery observed catches had a large peak of fish at about 75 cm, with most fish from the 2014 to 2016 year classes. The SA_suba sub-fishery had proportionally more old fish, with the modal age of 7 (2013 year class) for males and 9 (2011 year class) for females. About 36%, 35%, and 2% of the SA_snares, SA_auck, and SA_suba sub-fishery catch was of fish less than 65 cm, respectively.

Catches from ECSI and ECNI decreased to 4064 t and 746 t, respectively, and catches from Puysegur increased slightly to 448 t in 2020–21.

1.2 Recreational fisheries
Recreational fishing for hoki is negligible.

1.3 Customary non-commercial fisheries
The level of this fishery is believed to be negligible.

1.4 Illegal catch
No information is available about illegal catch, but it is believed to be negligible.

1.5 Other sources of fishing mortality

There are a number of potential sources of additional fishing mortality in the hoki fishery. In the years just prior to the introduction of the EEZ, when large catches were first reported, and following the increases of the TACC in the mid-1980s, it is likely that high catch rates from the west coast South Island spawning fishery resulted in burst bags, loss of catch, and some mortality. Although burst bags were recorded by some scientific observers, the extent of fish loss has not been estimated; however, the occurrence was at a sufficient level to result in the introduction of a code of practice to minimise losses in this way. Based on observer records from the period 2000–01 to 2006–07, Ballara et al (2010) and Anderson et al (2019) found that fish lost from the net during landing accounted for 0–14.5% of the non-retained catch each year in the hoki, hake, and ling fishery.

- The use of escape panels or windows part way along the net (developed to avoid burst bags) may also in itself result in some mortality of fish that pass through the window. It is believed that such devices are not currently used in the fishery.
- The development of the fishery on younger hoki (2 years and over) on the Chatham Rise from the mid-1990s, and the prevalence of small hoki in catches off the WCSI in some years, may have resulted in some unreported mortality of small fish.
- Overseas studies indicate that large proportions of small fish can escape through trawl meshes during commercial fishing and that the mortality of escapees can be high, particularly among species with deciduous scales (scales that shed easily) such as hoki. Selectivity experiments in the 1970s indicated that the 50% selection length for hoki for a 100-mm mesh cod-end is about 57–65 cm total length (Fisher 1978, as reported by Massey & Hore 1987). Research using a twin-rig trawler in June 2007 estimated that the 50% selection length was somewhat lower at 41.5 cm with a selection range (length range between 25% and 75% retention) of 14.3 cm (Haist et al 2007). Applying the estimated retention curve to scaled length frequency data for the Chatham Rise fishery suggested that between 47 t (in 1997–98) and 4287 t (in 1995–96) of hoki may have escaped commercial fishing gear each year. More recent research comparing the selectivity of 100 mm and MHS cod-ends in June 2017 suggested similar mean 50% selection lengths of about 48–49 cm for both gears, but with the MHS gear having a narrower selection range (11.7 cm compared with 14.8 cm for a 100-mm cod-end) (O'Driscoll & Millar 2017). Net-damaged adult hoki have been recorded in the WCSI fishery in some years indicating that there may be some survival of escapees. The extent of damage and resulting mortality of fish passing through the net is unknown.

These sources of additional fishing mortality are not incorporated in the current stock assessment.

2. BIOLOGY

Hoki are widely distributed throughout New Zealand waters from 34° S to 54° S, from depths of 10 m to over 900 m, with greatest abundance between 200 m and 600 m. Large adult hoki are generally found deeper than 400 m, whereas juveniles are more abundant in shallower water. In the January 2003 Chatham Rise trawl survey, exploratory tows with midwater gear over a hill complex east of the survey area found low density concentrations of hoki in midwater at 650 m over depths of 900 m or greater (Livingston et al 2004). The proportion of larger hoki outside the survey grounds is unknown. Commercial data also indicate that larger hoki have been targeted over other hill complexes outside the survey areas of both the Chatham Rise and Sub-Antarctic (Dunn & Livingston 2004) and have also been caught as bycatch by tuna fishers over very deep water (Bull & Livingston 2000).

The two main spawning grounds on the WCSI and in Cook Strait are considered to comprise fish from separate stocks, based on the geographical separation of these spawning grounds and a number of other factors (see Section 3 "Stocks and areas" below).

Hoki migrate to spawning grounds in Cook Strait, WCSI, Puysegur, and ECSI areas in the winter months. Throughout the rest of the year the adults are dispersed around the edge of the Stewart-Snares shelf, over large areas of the Sub-Antarctic and Chatham Rise, and to a lesser extent around the North Island. Juvenile fish (2–4 y) are found on the Chatham Rise throughout the year.

Hoki spawn from late June to mid-September, releasing multiple batches of eggs. In recent years, spawning has occurred in early June off the WCSI. They have moderately high fecundity with a female of 90 cm TL spawning over 1 million eggs in a season (Schofield & Livingston 1998). Not all hoki within the adult size range spawn in a given year. Winter surveys of both the Chatham Rise and Sub-Antarctic have found notable numbers of large hoki with no gonad development, at times when spawning is occurring in other areas. Histological studies of female hoki from the Sub-Antarctic in May 1992 and 1993 estimated that 67% of hoki aged 7 years and older on the Sub-Antarctic would spawn in winter 1992, and 82% in winter 1993 (Livingston et al 1997). A similar study repeated in April 1998 found that a much lower proportion (40%) of fish aged 7 and older was developing to spawn (Livingston & Bull 2000). Reanalysis of the 1998 data has shown that there is a correlation between stratum and oocyte development (Francis 2009). A method, developed to estimate proportion spawning from summer samples of post-spawner hoki in the Sub-Antarctic, indicated that approximately 85% of the hoki aged 4 years and older from 2003 and 2004 had spawned (Grimes & O'Driscoll 2006, Parker et al 2009).

The main spawning grounds are centred on the Hokitika Canyon off the WCSI and in Cook Strait Canyon. The planktonic eggs and larvae move inshore by advection or upwelling (Murdoch et al 1990, Murdoch 1992) and are widely dispersed north and south with the result that 0+ and 1-year-old fish can be found in most coastal areas off the South Island and parts of the North Island. The major nursery ground for juvenile hoki aged 2–4 years is along the Chatham Rise, in depths of 200 to 600 m. The older fish disperse to deeper water and are widely distributed in the Sub-Antarctic and on the Chatham Rise. Analyses of trawl survey (1991–2002) and commercial data suggest that a significant proportion of hoki move from the Chatham Rise to the Sub-Antarctic as they approach maturity, with most movement between ages 3 and 7 years (Bull & Livingston 2000, Livingston et al 2002). Based on a comparison of RV *Tangaroa* trawl survey data, on a proportional basis (assuming equal catchability between areas), 80% or more of hoki aged 1–2 years occur on the Chatham Rise. Between ages 3 and 7, this drops to 60–80%. By age 8, 35% or fewer fish are found on the Chatham Rise compared with 65% or more in the Sub-Antarctic. A study of the observed sex ratios of hoki in the two spawning and two non-spawning fisheries found that in all areas, the proportion of male hoki declines with age (Livingston et al 2000). There is little information at present to determine the season of movement, the exact route followed, or the length of time required, for fish to move from the Chatham Rise to the Sub-Antarctic. Bycatch of hoki from tuna vessels following tuna migrations from the Sub-Antarctic showed a northward shift in the incidence of hoki towards the WCSI in May-June (Bull & Livingston 2000). The capture of net-damaged fish on Pukaki Rise following the WCSI spawning season where there had been intense fishing effort in 1989 also provides circumstantial evidence that hoki migrate from the WCSI back to the Sub-Antarctic post-spawning (Jones 1993).

Growth is fairly rapid with juveniles reaching about 27–35 cm TL at the end of the first year. There is evidence for changing growth rates over time. In the past, hoki reached about 45, 55, and 60–65 cm TL at ages 2, 3, and 4, respectively, but in the mid-2000s length modes were centred at 50, 60, and 70 cm TL for ages 2, 3, and 4. Recently growth has slowed and is intermediate between these two levels. Although smaller spawning fish are taken on the spawning grounds, males appear to mature mainly from 60–65 cm TL after 3–5 years, whereas females mature at 65–70 cm TL. From the age of maturity, the growth of males and females differs. Males grow up to about 115 cm TL, whereas females grow to a maximum of 130 cm TL and up to 7 kg weight. Horn & Sullivan (1996) estimated growth parameters for the two stocks separately (Table 6). Fish from the eastern stock sampled in Cook Strait are smaller on average at all ages than fish from the WCSI. Maximum age is from 20 to 25 years, and the instantaneous rate of natural mortality in adults is about 0.25 to 0.30 per year.

Ageing error may cause problems in the estimation of year class strength. For example, the 1989 year class appeared as an important component in the catch-at-age data at older ages, yet this year class is believed to have been extremely weak in comparison with the preceding 1988 and 1987 year classes. An improved ageing protocol was developed to increase the consistency of hoki age estimation, and this has been applied to the survey data from 2000 onwards and to catch samples from 2001 (Francis 2001). Data from earlier samples, however, are still based on the original ageing methodology.

Estimates of biological parameters relevant to stock assessment are shown in Table 6.

Table 6: Estimates of fixed biological parameters.

Fishstock							**Estimate**	**Source**
1. Natural mortality (M)								
				Females			Males	
HOK 1				0.25			0.30	Sullivan & Coombs (1989)
2. Weight = a (length)^b (Weight in g, length in cm total length)								
							Both stocks	
				a			b	
HOK 1				0.00479			2.89	Francis (2003)
3. von Bertalanffy growth parameters								
	Females			Males				
	K	t_0	L_∞	K	t_0	L_∞		
HOK 1 (Western Stock)	0.213	-0.60	104.0	0.261	-0.50	92.6		Horn & Sullivan (1996)
HOK 1 (Eastern Stock)	0.161	-2.18	101.8	0.232	-1.23	89.5		Horn & Sullivan (1996)

3. STOCKS AND AREAS

Morphometric and ageing studies have found consistent differences between adult hoki taken from the two main dispersion areas (Chatham Rise and Sub-Antarctic), and from the two main spawning grounds in Cook Strait and WCSI (Livingston et al 1992, Livingston & Schofield 1996b, Horn & Sullivan 1996). These differences demonstrate that there are possibly two sub-populations of hoki. Whether or not they reflect genetic differences between the two sub-populations, or they are just the result of environmental differences between the Chatham Rise and Sub-Antarctic, is not known. No genetic differences have been detected with selectively neutral markers (Smith et al 1981, 1996), but a low exchange rate between stocks could reduce genetic differentiation. Results of an ongoing genetics study indicate that there appears to be little genetic differentiation between hoki within the New Zealand EEZ although differences were detected between New Zealand and Tasmanian hoki (Koot et al 2021).

Two pilot studies appeared to provide support for the hypothesis of spawning stock fidelity for the Cook Strait and WCSI spawning areas. Smith et al (2001) found significant differences in gill raker counts, and Hicks & Gilbert (2002) found significant differences in measurements of otolith rings, between samples of 3-year-old hoki from the 1997 year class caught off the WCSI and in Cook Strait. However, when additional year classes were sampled, differences were not always detected (Hicks et al 2003). If there are differences in the mean number of gill rakers and otolith measurements between stocks, due to high variation, large sample sizes would be needed to statistically detect these (Hicks et al 2003). Francis et al (2011) carried out a pilot study to determine whether analyses of stable isotopes and trace elements in otoliths could be useful in testing stock structure hypotheses and the question of natal fidelity. However, none of the six trace elements or two stable isotopes considered provided evidence of unambiguously differentiated stocks.

The DWWG has assessed the two spawning groups as separate stock units (Figure 3). The west coast of the North Island and South Island and the area south of New Zealand including Puysegur, Stewart-Snares shelf, and the Sub-Antarctic has been taken as one stock unit (the 'western stock'). The area of the ECSI, Mernoo Bank, Chatham Rise, Cook Strait, and the ECNI up to North Cape has been taken as the other stock unit (the 'eastern stock'). The two stocks are assumed to mix as juveniles on Chatham Rise.

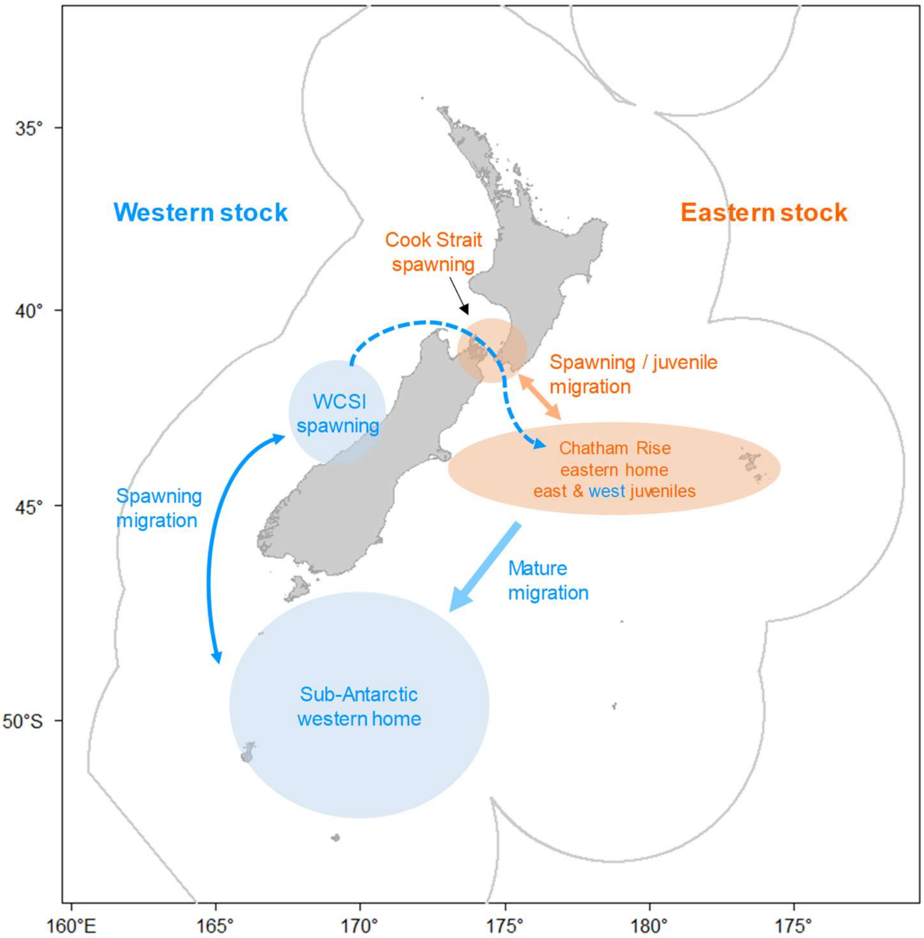


Figure 3: Hoki juvenile nurseries, spawning grounds, and assumed migration routes for the eastern and western stocks.

4. ENVIRONMENTAL AND ECOSYSTEM CONSIDERATIONS

This section was developed and reviewed by the Aquatic Environment Working Group for the May 2012 Fisheries Assessment Plenary and has been updated annually with more recent data, where available, and minor corrections made to reflect the updates. This summary is from the perspective of the hoki fishery; a more comprehensive review from an issue-by-issue perspective is available in the Aquatic Environment and Biodiversity Annual Review 2021 (Fisheries New Zealand 2021), online at https://www.mpi.govt.nz/dmsdocument/51472-Aquatic-Environment-and-Biodiversity-Annual-Review-AEBAR-2021-A-summary-of-environmental-interactions-between-the-seafood-sector-and-the-aquatic-environment.

4.1 Role in the ecosystem

Hoki is the species with the highest biomass in the bottom fish community of the upper slope (200–800 m), particularly around the South Island (Francis et al 2002) and is considered to be a key biological component of the upper slope ecosystem. Understanding the predator-prey relationships between hoki and other species in the slope community is important, particularly because substantial changes in the biomass of hoki have taken place since the fishery began (Horn & Dunn 2010). Other metrics such as ecosystem indicators may also provide insight into fishery interactions with target and non-target fish populations (e.g., Tuck et al 2014). For example, changes in growth rate can be indicative of density-dependent compensatory mechanisms in response to changes in population density.

4.1.1 Trophic interactions

On the Chatham Rise, hoki is a benthopelagic and mesopelagic forager preying primarily on lantern fishes and other midwater fishes and natant decapods with little seasonal variation (Clark 1985a, b, Dunn et al 2009a, Connell et al 2010, Stevens et al 2011). Hoki show ontogenetic shifts in their feeding preferences. Larger hoki (over 80 cm) consume proportionately more fish and squid than smaller hoki (Dunn et al 2009a, Connell et al 2010). The diet of hoki overlaps with that of alfonsino, arrow squid, hake, javelinfish, Ray's bream, and shovelnose dogfish (Dunn et al 2009a). Hoki are prey to several piscivores, particularly hake but also stargazers, smooth skates, several deepwater shark species, and ling (Dunn et al 2009a). The proportion of hoki in the diet of hake averages 38% by weight and declined from 1992 to 2008, possibly because of a decline in the relative abundance of hoki on the Chatham Rise between 1991 and 2007 (Dunn & Horn 2010). There is little information about the size of hoki eaten by predators (i.e., specifically whether the hoki are large enough to have recruited to the fishery or not), but this could be an important factor in understanding the interaction with the fishery.

4.1.2 Ecosystem Indicators

Tuck et al (2009) used data from the Sub-Antarctic and Chatham Rise trawl survey series to derive fish-based ecosystem indicators using diversity, fish size, and trophic level. Species-based indicators appeared the most useful in identifying changes in the marine ecosystem correlated with fishing intensity; Pielou's evenness appears the most consistent, but the Shannon-Wiener index, species richness, and Hill's N1 and N2 also showed some promise (Tuck et al 2009). Trends in diversity in relation to fishing are not necessarily downward and depend on the nature of the community. Size-based indicators did not appear as useful for New Zealand trawl survey series as they have been overseas, and this may be related to the requirement to consider only measured species. In New Zealand, routine measurement of all fish species in trawl surveys was implemented in 2008 and this may increase the utility of size-based indicators in the future.

Between 1992 and 1999 the growth rates of all year classes of hoki increased by 10% in all four fishery areas, but it is unclear whether this was a result of reduced competition for food within and among cohorts or some other factor (Bull & Livingston 2000). The abundance of mesopelagic fish, a major prey item for hoki, has the potential to be an indicator of food availability. Recent research using acoustic backscatter data collected during trawl surveys has shown no clear temporal trend in mesopelagic fish biomass on the Chatham Rise between 2001 and 2009, but a decline in the Sub-Antarctic area from 2001 to 2007, followed by an increase in 2008 and 2009. The abundance of mesopelagic fish is consistently much higher on the Chatham Rise than in the Sub-Antarctic, with highest densities observed on the western Chatham Rise and lowest densities on the eastern Campbell Plateau (O'Driscoll et al 2011a). Spatial patterns in mesopelagic fish abundance closely matched the distribution of hoki. O'Driscoll et al (2011a) hypothesise that prey availability influences hoki distribution, but that hoki abundance is being driven by other factors such as recruitment variability and fishing. There was no evidence for a link between hoki condition and mesopelagic prey abundance and there were no obvious correlations between mesopelagic fish abundance and environmental indices.

4.2 Bycatch (fish and invertebrates)

Hoki, hake, and ling made up 84%, 2%, and 3%, respectively, of the observed catch in target hoki trawls Hoki, hake, ling, silver warehou, and white warehou are frequently caught together, and trawl fisheries targeting these species are, as of 2018, considered one combined trawl fishery. The total catch weight of the main bycatch species caught in this combined fishery was estimated from a model which used observer and fisher-reported data (Anderson et al 2019). Based on this model the total non-target fish and invertebrate catch in the combined hoki, hake, ling, silver warehou, and white warehou fishery fluctuated between 17 t and 49 000 t per year in the period between 1990–91 and 2016–17 (Anderson et al 2019). Between 1 October 2002 and 30 September 2017, the five target species combined accounted for 90.14% of the total estimated catch from all observed target trawls in this fishery (Table 8). Hoki was the main catch species (73%), followed by hake (6.7%), ling (5.2%), silver warehou (3.9%), and white warehou (1.3%). The main non-target species caught in the combined fishery off the west coast South Island, on Chatham Rise, and in the Sub-Antarctic are rattails, javelinfish, and spiny dogfish. In Cook Strait, the main non-target species caught is spiny dogfish. The hoki, hake, ling, silver warehou, and white warehou fishery is complex, and changes in fishing practice are likely to have contributed to variability between years (Ballara & O'Driscoll 2015b).
between 2013–14 and 2017–18 (Table 7).

Table 7: Percentage of total observed catch weight of species taken in hoki target trawls for the 2013–14 to 2017–18 fishing years. Only species with an observed annual catch of over 20 t for any of the five years are listed. Data were last updated in 2019 from the Centralised Observer Database (Anderson et al 2019).

Species	2013–14	2014–15	2015–16	2016–17	2017–18
Hoki	85.9	87.7	86.2	83.9	78.7
Ling	2.8	2.4	3.2	2.8	4.6
Hake	2.1	1.8	1.8	2.7	3.2
Javelinfish	1.3	1.4	1.8	2.2	2.9
Rattails	1.2	1.1	1.5	2.3	1.8
Spiny dogfish	1.1	0.8	0.7	1.2	1.3
Silver warehou	1.1	0.9	1	0.5	1.7
Black oreo	0.7	<0.1	0.1	0.4	0.1
Frostfish	0.5	0.6	0.7	0.3	0.6
White warehou	0.3	0.1	0.1	0.3	0.3
Pale ghost shark	0.3	0.2	0.2	0.3	0.4
Lookdown dory	0.2	0.2	0.2	0.2	0.2
Arrow squid	0.2	0.1	0.2	0.2	0.2
Gemfish	0.2	0.1	0.1	0.3	0.3
Ribaldo	0.2	0.1	0.1	0.1	0.2
Southern blue whiting	0.1	0.1	0.1	0.1	0.2
Sea perch	0.1	0.2	0.2	0.2	0.3
Baxter's lantern dogfish	0.1	<0.1	0.1	0.1	0.1
Shovelnose dogfish	0.1	<0.1	0.2	0.1	0.2
Smooth skate	0.1	0.1	0.1	0.2	0.1
Stargazer	0.1	0.1	0.1	0.1	0.1
Ray's bream	0.1	0.1	<0.1	<0.1	<0.1
Alfonsino	0.1	0.3	0.1	0.1	<0.1
Redbait	0.1	0.1	<0.1	0.1	0.1
Leafscale gulper shark	0.1	<0.1	0.1	<0.1	0.1
Long-nosed chimaera	0.1	<0.1	<0.1	<0.1	<0.1
Scabbardfish	0.1	<0.1	0.1	<0.1	0.1
Dark ghost shark	<0.1	0.1	0.1	0.1	0.1
Smooth oreo	<0.1	<0.1	<0.1	<0.1	<0.1
Conger eel	<0.1	<0.1	<0.1	<0.1	<0.1
Seal shark	<0.1	<0.1	<0.1	<0.1	<0.1
Silverside	<0.1	<0.1	<0.1	0.1	0.1
Warty squid	<0.1	<0.1	<0.1	<0.1	0.1
Banded bellowsfish	<0.1	<0.1	<0.1	<0.1	0.1
Barracouta	<0.1	0.3	<0.1	0.3	0.4
Swollenhead conger	<0.1	<0.1	<0.1	<0.1	<0.1
Deepsea flathead	<0.1	<0.1	<0.1	0.1	0.1
Silver roughy	<0.1	<0.1	<0.1	<0.1	<0.1
Silver dory	<0.1	<0.1	0.1	<0.1	<0.1
Northern spiny dogfish	<0.1	<0.1	<0.1	<0.1	<0.1
Cardinalfish	<0.1	<0.1	<0.1	<0.1	0.2
Jack mackerel	<0.1	0.1	0.1	0.1	0.2
Common warehou	<0.1	<0.1	<0.1	<0.1	0.2
Others	0.5	0.5	0.5	0.5	0.5

Table 8: Modelled annual bycatch estimates (t) for main bycatch species in the combined hoki, hake, ling, silver warehou, and white warehou trawl fishery from the 2012–13 to the 2016–17 fishing years, and percentage of total observed catch for the target trawl fishery from 1 Oct 2002 to 30 Sep 2017, in decreasing order (Anderson et al 2019). [Continued on next page]

	Model-based estimates of total catch					% of observed
Species	2012–13	2013–14	2014–15	2015–16	2016–17	2002–03 to 2016–
Combined target species (5 species)	148 525	160 402	178 661	149 150	156 636	90.14
Javelinfish	4 807	4 099	7 443	7 138	7 483	1.87
Rattails (excl. Javelinfish)	5 656	3 914	7 068	6 067	7 116	1.55
Spiny dogfish	1 957	3 841	3 596	2 114	3 764	1.41
Arrow squid	563	604	1 117	722	815	0.51
Barracuda	639	624	509	320	1 290	0.47
Morid cods	615	1 004	1 161	711	806	0.42
Pale ghostshark	747	1 084	1 151	1 298	923	0.32
Ribaldo	378	591	981	415	486	0.28
Sea perch	672	399	975	846	582	0.27
Dark ghostshark	418	477	581	842	560	0.24
Lookdown dory	551	555	833	681	664	0.23
Black oreo	673	1517	593	343	733	0.21
Southern blue whiting	28	232	175	135	143	0.17
Giant stargazer	283	314	619	371	327	0.16
Red cod	172	275	164	227	251	0.14
Shovelnose dogfish	274	338	211	346	217	0.13

Table 8 [continued]

Species	2012–	2013–	2014–15	2015–16	2016–	% of observed 2002–03 to
	Model-based estimates of total catch					
Gemfish	164	236	173	281	689	0.12
Jack mackerel	21	14	62	45	29	0.08
Alfonsino	25	50	118	33	75	0.03
Orange roughy	8	8	9	11	6	0.02
Slickheads	6	13	14	11	13	0.01

4.3 Incidental capture of protected species (mammals, seabirds, and protected fish)

For protected species, capture estimates presented here include all animals recovered to the deck (alive, injured, or dead) of fishing vessels but do not include any cryptic mortality (e.g., seabirds struck by a warp but not brought on board the vessel, Middleton & Abraham 2007).

4.3.1 Marine mammal captures

New Zealand fur seal captures

The New Zealand fur seal was classified in 2008 as 'Least Concern' by the International Union for Conservation of Nature (IUCN) and in 2010 as 'Not Threatened' under the New Zealand Threat Classification System (Baker et al 2019).

Vessels targeting hoki incidentally catch fur seals (Baird 2005c, Smith & Baird 2009, Thompson & Abraham 2010a, Baird 2011, Abraham et al 2016 & 2021, Abraham & Richard 2019). The lowest capture rates have occurred in the most recent years (Table 9). Observed captures have occurred mostly off the west coast South Island and in the Cook Strait. Estimated captures of New Zealand fur seals in the hoki fishery have accounted for 44% (749 out of 1691) of all fur seals estimated to have been caught by trawling in the EEZ between 2002–03 and 2017–18 for those fisheries modelled.

Table 9: Number of tows (commercial and observed) by fishing year, observed and estimated New Zealand fur seal captures and capture rate in hoki trawl fisheries, 2002–03 to 2019–20 (Abraham et al 2021). Estimates are available online at https://protectedspeciescaptures.nz/PSCv6/released/. Observed and estimated protected species captures in this table derive from the PSC database version PSCV6.

	Fishing effort			Obs. captures		Est. captures		Est. capture rate	
Fishing year	Tows	No. Obs	% obs	Captures	Rate	Mean	95% c.i.	Mean	95% c.i.
2002–03	27 787	2 593	9.3	45	1.74	609	401–912	2.19	1.44–3.28
2003–04	22 522	2 345	10.4	56	2.39	522	343–784	2.32	1.52–3.48
2004–05	14 541	2 134	14.7	120	5.62	1 021	713–1 467	7.02	4.90–10.09
2005–06	11 588	1 775	15.3	62	3.49	535	350–811	4.61	3.02–7.00
2006–07	10 600	1 755	16.6	29	1.65	343	216–527	3.24	2.04–4.97
2007–08	8 783	1 877	21.4	58	3.09	347	235–505	3.95	2.67–5.75
2008–09	8 175	1 661	20.3	37	2.23	226	146–345	2.76	1.79–4.22
2009–10	9 965	2 066	20.7	30	1.45	191	129–276	1.92	1.29–2.77
2010–11	10 407	1 724	16.6	24	1.39	264	151–443	2.54	1.45–4.26
2011–12	11 333	2 694	23.8	34	1.26	221	143–332	1.95	1.26–2.93
2012–13	11 690	4 512	38.6	60	1.33	352	222–554	3.01	1.90–4.74
2013–14	12 948	3 977	30.7	32	0.80	141	95–206	1.09	0.73–1.59
2014–15	13 590	3 614	26.6	42	1.16	261	168–396	1.92	1.24–2.91
2015–16	12 639	3 474	27.5	42	1.21	220	146–324	1.74	1.16–2.56
2016–17	12 952	2 908	22.5	37	1.27	238	156–351	1.84	1.20–2.71
2017–18	13 793	4 767	34.6	41	0.86	190	128–283	1.38	0.93–2.05
2018–19	12 070	3 463	28.7	21	0.61				
2019–20	9 550	3 893	40.8	21	0.54				

New Zealand sea lion captures

The New Zealand (or Hooker's) sea lion was classified in 2008 as 'Vulnerable' by IUCN and in 2019 as 'Nationally Vulnerable' under the New Zealand Threat Classification System (Baker et al 2019) (having formerly been classed 'Nationally Critical' by Baker et al 2016). There are contrasting pup production trends at different breeding colonies. Pup production declined at the main colonies on the Auckland Islands from a peak in 1999 to a low in 2009 and appear to have stabilised thereafter. At Campbell Islands, pup production increased rapidly from low numbers in the early 1990s and appear to have plateaued since around 2010. Newly established breeding populations on Stewart Island and the New Zealand mainland appear to be rapidly increasing.

New Zealand sea lions are rarely captured by vessels trawling for hoki; since 2002–03 there have been three observed captures during fishing seasons with 9–41% of observer coverage (Abraham et al 2016), and all were near the Auckland Islands. The spatial overlap of the fisheries with the foraging distribution of sea lions is low, and observer coverage in these fisheries has been high. The spatial risk assessment model of Large et al (2019) estimated very low capture rates (median 0 per year) of sea lions, with high certainty (upper 95% CI = 1).

Common dolphin captures

Three common dolphins have been observed captured in the hoki trawl fishery since 2002–03 (https://protectedspeciescaptures.nz/PSCv6/released/).

4.3.2 Seabird captures

Vessels targeting hoki incidentally catch seabirds. Information on observed captures is summarised for 1998–99 to 2002–03 by Baird (2005a), for 2003–04 to 2005–06 by Baird & Smith (2007, 2008), for 1989–90 to 2008–09 by Abraham & Thompson (2011) and subsequently by Abraham et al (2016). For species that are sufficiently abundant (and captured sufficiently frequently in hoki fisheries) to enable capture rates to be estimated directly, capture rates are estimated using a hierarchical mixed-effects generalised linear model (GLM), fitted using Bayesian methods (Abraham et al 2016, Abraham & Richard 2017, 2018). Separately, a multi-species seabird risk assessment model applying the SEFRA (spatially explicit fisheries risk assessment) framework is used (Richard et al 2017, 2020) to estimate fisheries impacts across all commercial fisheries for all seabird species and relate the cumulative fisheries impact to an impact threshold that reflects the ability of the species to sustain impacts while still achieving a defined population recovery or stabilisation outcome.

Using the direct captures estimation approach, in the 2018–19 fishing year, there were 80 observed seabird captures in hoki trawl fisheries, and an estimated total of 278 (95% c.i. 224–341) captures (Table 10). In the 2019–20 fishing year, there were 113 observed seabird captures in hoki trawl fisheries, and an estimated total of 239 (95% c.i. 201–286) captures. Annual observed seabird capture rates have ranged between 1.3 and 4 per 100 tows in the hoki fishery over the time period 2002–03 to 2019–20, with little apparent trend. These figures represent summed totals across all seabird species and all methods of capture. To determine changes for particular species of interest or within particular subsets of the hoki fishery, more detailed analysis will be required.

Table 10: Number of tows by fishing year and observed seabird captures in hoki trawl fisheries, 2002–03 to 2019–20. No. obs, number of observed tows; % obs, percentage of tows observed; Rate, number of captures per 100 observed tows. Estimates are based on methods described by Abraham & Richard (2020) and are available online at https://protectedspeciescaptures.nz/PSCv6/released/. Observed and estimated protected species captures in this table derive from the PSC database version PSCV6.

	Fishing effort			Obs. captures		Est. captures		Est. capture rate	
Fishing year	Tows	No. Obs	% obs	Captures	Rate	Mean	95% c.i.	Mean	95% c.i.
2002–03	27 787	2 593	9.3	82	3.16	729	570–931	2.62	2.05–3.35
2003–04	22 522	2 345	10.4	32	1.36	451	343–585	2.00	1.52–2.6
2004–05	14 541	2 134	14.7	45	2.11	384	295–495	2.64	2.03–3.4
2005–06	11 588	1 775	15.3	54	3.04	348	256–465	3.00	2.21–4.01
2006–07	10 600	1 755	16.6	23	1.31	228	160–313	2.15	1.51–2.95
2007–08	8 783	1 877	21.4	28	1.49	190	135–258	2.16	1.54–2.94
2008–09	8 175	1 661	20.3	37	2.23	257	186–344	3.14	2.28–4.21
2009–10	9 965	2 066	20.7	53	2.57	269	204–345	2.70	2.05–3.46
2010–11	10 407	1 724	16.6	55	3.19	337	254–436	3.24	2.44–4.19
2011–12	11 333	2 694	23.8	58	2.15	271	211–343	2.39	1.86–3.03
2012–13	11 690	4 512	38.6	103	2.28	304	249–373	2.60	2.13–3.19
2013–14	12 948	3 977	30.7	159	4.00	418	349–502	3.23	2.7–3.88
2014–15	13 590	3 614	26.6	82	2.27	439	349–551	3.23	2.57–4.05
2015–16	12 639	3 474	27.5	49	1.41	257	201–321	2.04	1.59–2.54
2016–17	12 952	2 908	22.5	59	2.03	299	235–375	2.31	1.81–2.9
2017–18	13 793	4 767	34.6	142	2.98	338	285–400	2.45	2.07–2.9
2018–19	12 070	3 463	28.7	80	2.31	278	224–341	2.30	1.86–2.83
2019–20	9 550	3 893	40.8	113	2.90	239	201–286	2.50	2.1–2.99

Observed seabird captures in hoki fisheries since 2002–03 have been dominated by six species: Salvin's, southern Buller's, and New Zealand white-capped albatrosses make up 45%, 27%, and 22% of the albatrosses captured, respectively; and sooty shearwaters, white-chinned petrels, and cape petrels make up 58%, 23%, and 6% of other birds, respectively (Table 11). The highest proportions of captures have been observed off the east coast of the South Island (50%), on the Stewart-Snares shelf (20%), on the Chatham Rise (11%), and off the west coast of the South Island (9%). These numbers should be regarded as only a general guide on the distribution of captures because observer coverage is not uniform across areas and may not be representative. The spatial risk assessment is designed to correct for potential bias arising from spatially non-representative data.

The seabird risk assessment approach identifies ten at-risk seabird species for which the hoki fishery makes a contribution to the cumulative commercial fisheries risk score (see Table 11). The two species for which the hoki fisheries are responsible for the highest risk are southern Buller's albatross (hoki fishery mean risk score 0.14, i.e., 36% of the cumulative species risk score 0.39) and Salvin's albatross (hoki fishery mean risk score 0.12, i.e., 15% of the cumulative species risk score 0.78).

Table 11: Outputs of the Zealand seabird risk assessment for all at-risk seabirds. Risk ratios are shown for the hoki fishery in isolation and cumulatively for all commercial fisheries. The risk ratio is an estimate of annual fishery related deaths as a proportion of the Population Sustainability Threshold, PST (see Richard et al 2017, 2020). The DOC threat classifications are also shown (Robertson et al 2017 at http://www.doc.govt.nz/documents/science-and-technical/nztcs19entire.pdf).

		Risk ratio			
Species name	**PST(mean)**	**HOK***	**TOTAL**	**Risk category**	**DOC Threat Classification**
Southern Buller's albatross	1 360	0.144	0.37	High	At Risk: Naturally Uncommon
Salvin's albatross	3 460	0.120	0.65	High	Threatened: Nationally Critical
Westland petrel	351	0.068	0.54	High	At Risk: Naturally Uncommon
NZ white-capped albatross	10 800	0.042	0.29	Medium	At Risk: Declining
Northern Buller's albatross	1 640	0.033	0.26	Medium	At Risk: Naturally Uncommon
Northern giant petrel	337	0.030	0.15	Medium	At Risk: Naturally Uncommon
Chatham Island albatross	428	0.015	0.28	High	At Risk: Naturally Uncommon
Campbell black-browed albatross	2 000	0.010	0.06	Low	At Risk: Naturally Uncommon
Black petrel	447	0.009	1.23	Very high	Threatened: Nationally Vulnerable
Flesh-footed shearwater	1 450	0.008	0.49	High	Threatened: Nationally Vulnerable

*Risk ratio HOK comes from Richard et al (2017).

Mitigation methods such as streamer (tori) lines, Brady bird bafflers, warp deflectors, and offal management are used in the hoki trawl fishery. Warp mitigation was voluntarily introduced from about 2004 and made mandatory in April 2006 (Department of Internal Affairs 2006). The 2006 notice mandated that all trawlers over 28 m in length use a seabird scaring device while trawling (being "paired streamer lines", "bird baffler", or "warp deflector" as defined in the notice).

To understand changing fisheries risk over time as affected by changes in mitigation uptake, vessel behaviour, or gear configuration, it will be necessary to disaggregate the seabird risk assessment to examine trends for subsets of the fishery and species of interest. Of particular relevance, the seabird risk assessment includes estimates of cryptic mortality (i.e., deaths that are not counted among observable captures) whereas the captures estimation does not. In trawl fisheries, it is thought that for every observed seabird capture on a trawl warp, there may be several additional cryptic deaths (due to bird carcasses falling off the warps unobserved), but the true multiplier is uncertain. In contrast, seabird captures in the net have a much lower cryptic mortality multiplier, and some birds are released alive. For this reason, even a relatively constant total capture rate (as in Table 10) may conceal substantial changes in total deaths and population level risk at the species level, if the ratio of net captures to warp captures has changed in this period.

4.3.3 Protected fish species captures

Basking shark

The basking shark (*Cetorhinus maximus*) was classified as 'Endangered' by IUCN in 2013 and as 'Threatened – Nationally Vulnerable' in 2016, under the New Zealand Threat Classification System (Duffy et al 2018). Basking shark has been a protected species in New Zealand since 2010, under the Wildlife Act 1953 and is also listed in Appendix II of the CITES convention.

Basking sharks are caught occasionally in hoki trawls (Francis & Duffy 2002, Francis & Smith 2010, Ballara et al 2010). Standardised capture rates from observer data showed that the highest rates and catches occurred in 1989 off the WCSI and in 1987–92 off the ECSI. Smaller peaks in both areas were observed in the late 1990s and early 2000s, but captures have been few since then (Table 12). Most basking sharks have been captured in spring and summer and nearly all came from FMAs 3, 5, 6, and 7. It is not known whether the low numbers of captures in recent decades are a result of different operational methods used by the fleet, a change in regional availability of sharks, or a decline in basking shark abundance (Francis 2017). Of a range of fisheries and environmental factors considered, vessel nationality stood out as a key factor in high catches in the late 1980s and early 1990s (Francis & Sutton 2012). Research to improve the understanding of the interactions between basking sharks and fisheries was reported by Francis & Sutton (2012) and updated by Francis (2017).

Table 12: Total number of tows, number and percentage of observed tows, and number of observed basking shark captures from 1988–89 to 2019–20 in the hoki target trawl fishery, extracted from the Central Observer Database. Observed trawls used bottom trawl (BT) and midwater trawl (MW) fishing methods.

Fishing year	Tows	No. observed	% observed	No. captures	Fishing year	Tows	No. observed	% observed	No. captures
1988–89	8 341	2 213	26.5	10	2004–05	14 554	3 334	22.9	1
1989–90	15 656	2 246	14.3	0	2005–06	11 584	1 773	15.3	0
1990–91	21 859	2 495	11.4	4	2006–07	10 600	1 764	16.6	0
1991–92	21 873	2 246	10.3	2	2007–08	8 779	1 923	21.9	1
1992–93	22 583	2 311	10.2	0	2008–09	8 170	1 671	20.5	1
1993–94	21 704	2 959	13.6	3	2009–10	9 964	2 116	21.2	0
1994–95	26 141	1 550	5.9	2	2010–11	10 398	1 766	17.0	0
1995–96	31 886	2 148	6.7	2	2011–12	11 328	2 709	23.9	2
1996–97	37 263	1 241	3.3	2	2012–13	11 672	4 510	38.6	1
1997–98	38 406	3 159	8.2	14	2013–14	12 941	4 001	30.9	3
1998–99	32 324	3 560	11.0	7	2014–15	13 539	3 618	26.7	0
1999–00	33 070	4 844	14.6	3	2015–16	12 636	3 474	27.5	0
2000–01	32 073	5 716	17.8	4	2016–17	12 897	2 936	22.8	0
2001–02	27 234	6 333	23.3	1	2017–18	13 773	4 789	34.8	0
2002–03	27 792	4 470	16.1	5	2018–19	12 051	3 486	28.9	1
2003–04	22 535	3 594	15.9	2	2019–20	9 503	3 853	40.5	1

4.4 Benthic interactions

The spatial extent of seabed contact by trawl fishing gear in New Zealand's EEZ and Territorial Sea has been estimated and mapped in numerous studies for trawl fisheries targeting deepwater species (Baird et al 2011, Black et al 2013, Black & Tilney 2015, Black & Tilney 2017, Baird & Wood 2018, and Baird & Mules 2019, 2021a, 2021b), species in waters shallower than 250 m (Baird et al. 2015, Baird & Mules 2021a, 2021b), and all trawl fisheries combined (Baird & Mules 2021a, 2021b). The most recent assessment of the deepwater trawl footprint was for the period 1989–90 to 2018–19 (Baird & Mules 2021b).

The only target method of capture in the hoki fishery is trawling using either bottom (demersal) or midwater gear. Baird & Wood (2012) estimated that trawling for hoki accounted for 20–40% of all tows on or near the sea floor reported on TCEPR forms 1989–90 to 2005–06, and Black et al (2013) estimated that hoki trawling has accounted for 30% of all tows reported on TCEPR forms between 1989–90 and 2009–10. Between 2006–07 and 2010–11, 93% of hoki catch was reported on TCEPR forms. In the early years of the hoki fishery, vessels predominantly used midwater trawls because most of the catch was taken from spawning aggregations off the WCSI. Outside the spawning season, bottom trawling is used on the Chatham Rise and Sub-Antarctic fishing grounds (Table 13). Twin trawls were used to catch almost half of the TACC in some years. This gear is substantially wider than single trawl gear and catches more fish per tow than single trawl gear. The relationship between total catch and bottom impact of twin trawls has, however, not been analysed. As year-round fishing increased, vessels increased fishing effort on the Chatham Rise and in the Sub-Antarctic, and the bottom trawl effort increased to a peak between 1997–98 and 2003–04. Effort has declined substantially in all areas since 2005–06, largely as a result of TACC reductions but has increased again with increases in TACCs. Midwater trawling peaked in 1995–96 to 1996–97 in Cook Strait and on the Chatham Rise 1996–97 to 1997–98 but declined in all areas from 1997–98. Overall, midwater trawling has declined by about 90% since the peak in 1997 and bottom trawling by about 70% since the peak in 2000 (Table 13).

Table 13: Summary of number of hoki target trawl tows (TCEPR and ERS-trawl only) in the hoki fishery from fishing years (FY) 1989–90 to 2020–21. (MW, midwater trawl; BT, bottom trawl).

Fishery	WCSI/Puysegur		Cook Strait/ECSI		Sub-Antarctic		Chatham Rise/ECSI				
Season	Spawning		Spawning		Non-spawn		Non-spawn		All areas combined		%
Method	MW	BT	MW	BT	MW	BT	MW	BT	MW	BT	BT
FY											
1989–90	7 849	1 187	1 084	25	36	2 109	28	2 027	8 997	5 348	37
1990–91	7 351	1 678	2 226	26	81	3 927	953	3 492	10 611	9 123	46
1991–92	5 624	1 579	1 772	14	117	5 442	443	5 555	7 956	12 590	61
1992–93	5 488	1 861	1 564	18	442	4 915	1 054	5 266	8 548	12 060	59
1993–94	8 014	1 639	1 852	154	562	2 039	1 331	3 448	11 759	7 280	38
1994–95	7 223	1 501	2 019	258	419	2 329	2 174	6 260	11 835	10 348	47
1995–96	5 698	2 017	3 187	1 439	418	2 506	2 305	7 913	11 608	13 875	54
1996–97	7 428	1 894	3 672	1 350	332	3 423	2 314	9 305	13 746	15 972	54
1997–98	6 979	1 548	2 371	701	165	4 376	3 780	11 456	13 295	18 081	58
1998–99	5 476	2 118	1 992	580	420	3 659	2 428	11 445	10 316	17 802	63
1999–00	5 470	2 275	1 943	370	516	5 943	2 706	9 494	10 635	18 082	63
2000–01	6 229	2 577	1 969	175	667	5 448	912	9 862	9 777	18 062	65
2001–02	4 988	3 095	1 136	173	132	6 449	858	7 820	7 114	17 537	71
2002–03	4 615	2 977	2 117	282	96	4 407	496	9 278	7 324	16 944	70
2003–04	4 274	1 887	1 812	72	78	3 023	385	7 225	6 549	12 207	65
2004–05	2 534	1 308	1 457	111	68	1 428	340	4 996	4 399	7 843	64
2005–06	1 783	1 508	1 020	49	74	719	140	4 822	3 017	7 098	70
2006–07	1 147	752	919	82	25	1 194	57	4 769	2 148	6 797	76
2007–08	813	492	393	386	36	925	75	4 203	1 317	6 006	82
2008–09	689	354	747	148	38	927	11	3 914	1 485	5 343	78
2009–10	1 182	612	799	77	56	1 251	116	4 361	2 153	6 301	75
2010–11	1 581	913	544	63	62	1 245	52	4 075	2 239	6 296	74
2011–12	1 660	1 188	836	81	70	1 202	74	4 397	2 640	6 868	72
2012–13	1 826	1 019	1 022	98	6	1 373	169	4 175	3 023	6 665	69
2013–14	2 318	1 111	1 011	65	12	1 872	131	3 981	3 472	7 029	67
2014–15	2 716	1 244	953	53	89	1 620	209	4 319	3 967	7 236	65
2015–16	2 694	1 529	823	93	10	834	101	4 066	3 628	6 522	64
2016–17	2 366	1 907	729	100	24	1 278	99	4 193	3 218	7 478	70
2017–18	2 102	2 043	833	18	81	1 728	63	3 658	3 080	7 447	71
2018–19	2 978	965	1 327	108	12	830	63	2 705	4 380	4 608	51
2019–20	2 553	714	975	66	5	692	32	2 759	3 565	4 231	54
2020–21	1 764	655	734	94	2	927	75	3 514	2 575	5 190	67

Note: Spawning fisheries include WCSI (Jul–Sep), Cook Strait (Jul–Sep), Puysegur (Jul–Dec), ECSI (Jul–Sep). Non-spawning fisheries include ECSI (Aug–Jun), Chatham Rise (Aug–Jun), Sub-Antarctic (Aug–Jun). TCER, CELR, and North Island tows are excluded.

During 1989–90 to 2018–19, about 434 000 bottom-contacting hoki trawls were reported on TCEPRs, TCERs, and ERS (Baird & Mules 2021b). The total footprint generated from these tows was estimated at about 167 650 km^2. This footprint represented coverage of 4.1% of the seafloor of the combined EEZ and the Territorial Sea areas and 12% of the ‘fishable area’, that is, the seafloor area open to trawling, in depths of less than 1600 m. In the 2018–19 fishing year, almost 8700 hoki tows resulted in a trawl footprint of 24 392 km^2, equivalent to 0.6% of the EEZ and Territorial Sea and 1.8 % of the fishable area (Baird & Mules 2021b).

The overall trawl footprint for hoki (1989–90 to 2018–19) covered 20% of the seafloor in 200–400 m, 28% of 400–600 m seafloor, and 28% of the 600–800 m seafloor (Baird & Mules 2021b). The hoki footprint contacted 1.6%, 6.7%, and 2.7% of those depth ranges in 2018–19, respectively (Baird & Mules 2021b). The Benthic-optimised Marine Environment Classification (BOMEC, Leathwick et al 2012) classes with the highest proportion of area covered by the hoki footprint were classes G (Cook Strait), H (Chatham Rise), I (Chatham Rise slope and shelf edge of the east coast South Island), and L (Southern Plateau waters). In 2018–19, 3% of class G (6342 km^2), 4% of class H (138 551 km^2), 19.7% of class I, and 2.3% of class L were contacted by the hoki footprint (Baird & Mules 2021b).

Bottom trawling for hoki, like trawling for other species, is likely to have effects on benthic community structure and function (e.g., Rice 2006) and there may be consequences for benthic productivity (e.g., Jennings et al 2001, Hermsen et al 2003, Hiddink et al 2006, Reiss et al 2009). These are not considered in detail here but are discussed in the Aquatic Environment and Biodiversity Annual Review 2021 (Fisheries New Zealand 2021).

4.5 Other factors

4.5.1 Spawning disruption

Fishing during spawning may disrupt spawning activity or success. Although there has been no research on the disruption of spawning hoki by fishing in New Zealand, the hoki quota owners voluntarily ceased fishing some defined spawning grounds for certain periods on the WCSI, Pegasus Canyon (ECSI), and Cook Strait as a precautionary measure from the 2004 to 2009 spawning seasons with the intention of assisting stock rebuilding. This closure was lifted in the 2010 spawning season because the biomass of the western stock was estimated to have rebuilt to within the management target range, but seasonal spawning closures were reintroduced from 2018–19 (see Section 1).

4.5.2 Habitat of particular significance to fisheries management

Habitats of particular significance to fisheries management have not been defined for hoki or any other New Zealand fish. Studies of potential relevance have identified areas of importance for spawning and juveniles (O'Driscoll et al 2003). Areas on Puysegur Bank, Canterbury Bight, Mernoo Bank, and Cook Strait have been subject to non-regulatory measures to reduce fishing mortality on juvenile hoki (Deepwater Group 2011).

5. RECRUITMENT, ENVIRONMENTAL VARIABILITY, AND CLIMATE CHANGE

This section was last updated in May 2021.

Recruitment dynamics are challenging to assess or predict because of the many underlying drivers that vary over time and space. Stock size, demographic and trait composition, condition and distribution of spawning fish, and the spatio-temporal dynamics of trophic and environmental interactions all influence recruitment processes. Annual variations in hoki recruitment have considerable impact on this fishery and a better understanding of the influence of environmental variables on recruitment patterns would be very useful for the future projection of stock size under different climate change scenarios and different environmental conditions.

New Zealand waters are becoming warmer and more acidic due to the emission of anthropogenic carbon dioxide (Law et al 2018a, Law et al 2018b) and, as in other parts of the world, some fish distributions will be or already are changing. The link between climate, oceanographic conditions, and hoki recruitment is still not well understood. Analyses by Francis et al (2006) do not support conclusions drawn by Bull & Livingston (2001) that model estimates of recruitment to the western stock are strongly correlated with the southern oscillation index (SOI). Francis et al (2006) noted that there is a correlation of -0.70 between the autumn SOI and annual estimates of recruitment (1+ and 2+ fish) from the Chatham Rise trawl survey but found this difficult to interpret because the survey is considered to be an index of the combined recruitment to both the eastern and western stocks. A more recent analysis supports some climate variable effect on hoki recruitment but remains equivocal about its strength or form (Dunn et al 2009b). Bradford-Grieve & Livingston (2011) collated and reviewed information on the ocean environment off the WCSI in relation to hoki and other spawning fisheries. The authors noted that understanding of the underlying mechanisms and causal links between the WCSI marine environment and hoki recruitment remain elusive.

New Zealand research trawl data indicate small hoki (< 30 cm TL) are absent at bottom temperatures above about 15 °C and occur most frequently at 13–14 °C, whereas adults prefer cooler bottom water temperatures of about 6–10 °C (Dunn et al in prep). Surface water temperature has no clear relationship to hoki occurrence. Gunn et al (1989) hypothesised that hoki spawning and migration off Tasmania was influenced by water temperature, with spawning starting once temperatures dropped to 13–14 °C.

Off Australia, colder water temperatures during winter have been thought to be conducive to higher year class strength (Pecl et al 2014).

A baseline report summarising trends in climatic and oceanographic conditions in New Zealand that are of potential relevance for fisheries and marine ecosystem resource management identified a reciprocal correlation between northern gemfish and hoki year class strength (Hurst et al 2012). An updated chapter on oceanic trends in the Aquatic Environment & Biodiversity Annual Review 2021 (Fisheries New Zealand 2021) examines a recent review of temperature trends in New Zealand waters by Sutton & Bowen (2019). It notes that the effects of recent warmer temperatures (e.g., the high surface temperatures off the WCSI during the 2016 and 2017 spawning seasons, marine heatwaves, and general warming of the Tasman Sea) on fish distribution, growth, or spawning success have yet to be determined.

The state of knowledge of climate change-associated predictions for components of New Zealand's marine environment that are most relevant to fisheries has been documented (Cummings et al 2021). Past and future projected changes in coastal and ocean properties, including temperature, salinity, stratification and water masses, circulation, oxygen, ocean productivity, detrital flux, ocean acidification, coastal erosion and sediment loading, and wind and waves are reviewed. Fish stock responses to climate change effects on these coastal and ocean properties are discussed, as well as their likely impact on the fisheries sector, where known.

A range of decision support tools in use overseas were evaluated with respect to their applicability for dissemination of the state of knowledge on climate change and fisheries. Three species, for which there was a relatively large amount of available information, were chosen for further analysis. These were pāua, snapper, and hoki (shellfish, inshore, and middle-depths/deepwater fisheries, respectively). An evaluation of the sensitivity and exposure of hoki to climate change-associated threats, based on currently available published literature and expert opinion, assessed hoki vulnerability as 'low' (Cummings et al 2021).

Recent work on the growth rate of fish exposed to temperature increases showed that the stochasticity of recruitment and density-dependence overrides the background influence of global warming (Neubauer et al in press). It was concluded that extreme or catastrophic events such as marine heatwaves may have a greater influence on recruitment and biomass than the incremental changes of background warming (Neubauer et al in press).

Another recent study of hoki growth found that fishing and environmental factors initially promote individual fish growth but may then heighten the sensitivity of stocks to environmental change (Morrongiello et al 2021). Regional-scale wind and temperature affected growth of tarakihi and snapper, whereas deepwater hoki and ling growth was sensitive to the Interdecadal Pacific Oscillation (Morrongiello et al 2021).

No substantive changes in hoki spatial occurrence have been reported to date. Models predicting the spatial distribution of hoki at the end of the 21st Century, in response to changes in average water temperature and productivity predicted by the New Zealand Earth Systems Model, suggested some reduction in hoki occurrence on the Chatham Rise, but the overall change in hoki distribution was expected to be negligible in the short to medium term (Dunn et al in prep.).

Brooks (2020) used ecological niche modelling (Maxent) to predict current and future hoki distribution around New Zealand. The models were trained on catch data from the Fisheries New Zealand research trawl database and remote-sensed environmental data. Under more severe climate change scenarios, hoki habitat was predicted to contract to the south Chatham Rise and sub-tropical convergence zone around southern New Zealand and be lost from the west coast South Island. The main predictors of these changes were sea surface temperature and salinity.

The effects of climate change on the temperature of surface waters are reasonably well determined in New Zealand because the data are derived from satellite records (Ministry for the Environment & Stats NZ 2019, Law et al 2018b). However, deriving temperature from hoki fisheries depths 200–800 m below the sea surface is hampered by a lack of data from subsurface waters, and the correlation between surface and bottom temperatures at hoki depths is often weak. This data gap is being addressed in part by the MOANA project by placing thermal sensors on fishing vessels (https://www.moanaproject.org/). Temperature data collected from the NIWA trawl surveys show that marine heatwaves only seem to influence water temperatures above the mixed layer depth (R. O'Driscoll, NIWA, pers. comm.). However, unexplained warming has been detected in the Tasman Sea to 800 m depth off the west coast South Island from XBT profiles (Sutton & Bowen 2019). The effects of marine heatwaves on plankton productivity and knock-on trophic effects on hoki fisheries are not currently understood in New Zealand.

6. STOCK ASSESSMENT

The most recent stock assessment was completed in 2022. The 2022 assessment updated the 2021 assessment which followed a review of input data and model assumptions completed between 2018 and 2020 (Dunn & Langley 2018, Langley 2020). There was no assessment completed in 2020. The 2021 assessment differed substantially from 2019, in having different assumptions for natural mortality, maturation, and migrations, and spatially restructured fisheries dependent data with revised selectivity assumptions. A high-level summary of these changes is presented under the 'Changes to Model Structure and Assumptions' in Section 8 "Status of the Stocks" of this report, and in full detail by Dunn & Langley (2018) and Langley (2020). The general-purpose stock assessment programme, CASAL (Bull et al 2012), was used to perform the analyses.

Recent trends in standardised CPUE have varied by area but are all at or above the long-term average and have been relatively stable on the Chatham Rise for the last 14 years. The WCSI and Sub-Antarctic CPUE remained at similar levels in 2020–21, with WCSI CPUE increasing slightly and Sub-Antarctic CPUE indices decreasing slightly. Standardised CPUE in Cook Strait has increased since 2014. CPUE is not used in the stock assessment because it does not accurately index abundance over the long term.

Survey abundance indices are shown in Table 14. The Chatham Rise trawl survey biomass in January 2022 was 9% higher than that in 2020. The relative biomass of recruited hoki (ages 3+ years and older) on the Chatham Rise in 2022 also increased (by 8%) from that in 2020 and there was an above average estimate for 2+ hoki (2019 year class). The most recent Sub-Antarctic trawl survey estimate in November-December 2020 (2021 fishing year) was similar to that in 2016, and higher than that in 2018. The acoustic survey biomass in Cook Strait in 2021 was 75% higher than the equivalent index from the 2019 survey, reversing the decreasing trend observed in the time series since 2015. The 2018 WCSI acoustic survey was down 47% on 2013 and was the lowest in the time series.

Table 14: Abundance indices ('000 t) used in the stock assessment (* data new to this assessment). Years are fishing years (1990 = 1989–90). – no data. Biomass estimates are for all age classes in core survey area. [Continued on next page]

Year	Acoustic survey WCSI Winter[1]	Trawl survey Sub-Antarctic December[2]	Trawl survey Sub-Antarctic April[3]	Trawl survey Chatham Rise January[4]	Acoustic survey Cook Strait Winter[5]
1988	266	–	–	–	–
1989	165	–	–	–	–
1990	169	–	–	–	–
1991	227	–	–	–	88
1992	229	80	68	122	–
1993	380	87	–	186	283
1994	–	100	–	147	278
1995	–	–	–	121	194
1996	–	–	89	153	92
1997	445	–	–	158	141
1998	–	–	68	87	80
1999	–	–	–	109	114
2000	263	–	–	72	–
2001	–	56	–	60	102
2002	–	38	–	74	145
2003	–	40	–	53	104
2004	–	14	–	53	–
2005	–	18	–	85	59
2006	–	21	–	99	60
2007	–	14	–	71	104
2008	–	46	–	77	82
2009	–	47	–	144	166
2010	–	65	–	98	–

Table 14 [continued]

Year	Acoustic survey WCSI Winter[1]	Trawl survey Sub-Antarctic December[2]	Trawl survey Sub-Antarctic April[3]	Trawl survey Chatham Rise January[4]	Acoustic survey Cook Strait Winter[5]
2011	–	–	–	94	141
2012	283	46	–	88	–
2013	233	56	–	124	168
2014	–	–	–	102	–
2015	–	31	–	–	204
2016	–	–	–	115	–
2017	–	38	–	–	102
2018	123	–	–	122	–
2019	–	31	–	–	91
2020	–	–	–	90	–
2021	–	38*	–	–	159
2022				97*	

1. survey_WC_abundance
2. survey_SA_summer_abundance (truncated at age 3)
3. survey_SA_autumn_abundance
4. survey_CR_summer_abundance (truncated at age 2)
5. survey_CS_spawning_abundance

6.1 Methods

Model structure

The general-purpose stock assessment programme, CASAL (Bull et al 2012), was used to perform the stock assessment modelling. As with previous assessments, the model used in the 2021–22 assessment was a total catch-history age-based model. The model partitioned the population into two sexes, 18 age groups (1 to 17 and a plus group, 18+), two stocks [eastern (E) and western (W)], and four areas (Chatham Rise (CR), West Coast South Island (WC), Sub-Antarctic (SA), and Cook Strait (CS)). It is assumed that the adult fish of the two stocks do not mix: those from the western stock spawn off the west coast South Island and spend the rest of the year in the Sub-Antarctic; the eastern fish move between their spawning ground, Cook Strait, and their home ground, the Chatham Rise. Juvenile fish from both stocks live on Chatham Rise, but natal fidelity is assumed (i.e., all fish spawn in the area in which they were spawned). There is little direct evidence of natal fidelity for hoki, though its life history characteristics would indicate that 100% natal fidelity is unlikely (Horn 2011).

The model is not partitioned into mature and immature fish. The proportion mature was defined using an assumed logistic ogive, set to be the same for both stocks, with a_{50} and a_{to95} parameters of (3, 3) for male and (4, 4) for female. The main reason maturity was assumed rather than estimated is because the observations of mature fish-at-age are different in different sub-fisheries of the spawning fishery, with no overall proportion mature-at-age calculated. There are three autumn observations in the Sub-Antarctic of proportions of females that will spawn that year, but these were not fitted because the proportions mature in the base model were not estimated.

The model's annual cycle divides the fishing year into five time steps and includes four types of migration (Table 15). The first type of migration involves only newly spawned fish, all of which are assumed to move from the spawning grounds (Cook Strait and the west coast South Island) to arrive at the Chatham Rise at time step 2 and approximate age 1.6 y. The second affects only young western fish, some of which are assumed to migrate, at time step 3, from the Chatham Rise to the Sub-Antarctic. The last two types of migrations relate to spawning. Each year fish migrate from their home ground (the Chatham Rise for eastern fish, the Sub-Antarctic for western fish) to their spawning ground (Cook Strait for eastern fish, the west coast South Island for western fish) at time step 4. At time step 1 in the following year all spawners return to their home grounds.

The above describes the two-stock model structure. A one-stock model was also constructed as a sensitivity to the combined predictions of the two-stock model. In the one-stock model there were no migrations, and all fishery and survey selectivity ogives were allowed to be more flexible (default double normal). The data used in both models was the same. In the one-stock model, an absence of older fish (e.g., on Chatham Rise) can be attributed to domed selectivity, whereas in the two-stock model it can be attributed to migration. In general, the one-stock model produced improved fits to composition data, but reduced quality of fits to abundance data. Overall, the model outputs were similar to the two-stock model when presented as combined-stock outputs.

Table 15: Annual cycle of the assessment two stock model, showing the processes taking place at each time step, their sequence within each time step, and the available biomass observations. Any fishing and natural mortality within a time step occurred after all other processes, with half of the natural mortality occurring before and after the fishing mortality. An age fraction of, say, 0.25 for a time step means that a 2+ fish was treated as being of age 2.25 in that time step, etc. The last column ('Prop mort') shows the proportion of that time step's total mortality that was assumed to have taken place when each observation is made.

					Observations	
Step	Approx. months	Process	M fraction	Age fraction	Label	Prop mort
1	Oct-Nov	post-spawning migrations: WC->SA, CS->CR	0.17	0.25	–	
2	Dec-Mar	recruitment at age 1+ to CR (for both stocks)	0.33	0.60	survey_SA_summer_abundance	0.5
		non-spawning fisheries (CR, SA)			survey_CR_summer_abundance	0.6
3	Apr-Jun	migration: CR->SA	0.25	0.90	survey_SA_autumn_abundance	0.1
4	End Jun	spawning migrations: SA->WC, CR->CS	0.00	0.90		
5	Jul-Sep	increment ages	0.25	0.00	survey_CS_spawning_abundance	0.5
		spawning fisheries (WC, CS, PUY)			survey_WC_abundance	0.5

Data and error assumptions

Five series of abundance indices were used in the assessment (Table 14). New data were available from a trawl survey on Chatham Rise in January 2022 (Stevens & Ballara in press) and an acoustic survey of the Cook Strait in July-August 2021 (Escobar-Flores & O'Driscoll in prep). The age data used in the assessment (Table 16) were similar to those used in the 2021 assessment, but with one additional year of data.

The error distributions assumed were multinomial (Bull et al 2012) for the at-age data and lognormal for all other data. The weight assigned to each data set was controlled by the effective sample size for each observation, calculated from the observation error, and a reweighting procedure for the data sets following Francis (2011).

Two alternative sets of CVs were used for the biomass indices. The 'total' CVs represent an estimate of the total uncertainty associated with these data. For the trawl survey indices, these were calculated as the sum of an observation-error CV (which was calculated using the standard formulae for stratified random surveys, e.g., Livingston & Stevens 2002), and an additional 'process' error CV, which was either estimated or set at 0.1 for the Chatham Rise and Sub-Antarctic summer and autumn surveys (note that CVs are added as squares: $CV_{total}^2 = CV_{process}^2 + CV_{observation}^2$). For final model MCMC runs, the process-error CVs were set at 0.1. The CVs of the biomass indices are shown in Table 17.

Table 16: Age data used in the assessment. Years are model years (1990 = 1989–90). All age data from 2021–2022 are new inputs for the 2022 assessment. Age data follow the revised fishery stratification (see Table 18) and so are not directly comparable with previous assessments. Data from Puysegur were first included in 2021.

Area	Label	Data type	Years	Source of age data
PUY	fishery_PUY_spwn_age	Catch-at-age	1990–1992, 1994–1997, 2000–2005	Otoliths
WC	fishery_WC_inside_age	Catch-at-age	2000–2010, 2012–2021	Otoliths
	fishery_WC_north	Catch-at-age	1988–2021	Otoliths
	fishery_WC_south_age	Catch-at-age	1988–2021	Otoliths
SA	fishery_SA_auck_age	Catch-at-age	2001, 2003, 2004, 2006–2021	Otoliths
	fishery_SA_snares_age	Catch-at-age	2001, 2006–2021	Otoliths
	fishery_SA_suba_age	Catch-at-age	2001, 2002, 2003, 2009, 2012, 2016, 2018, 2019, 2021	Otoliths
	survey_SA_summer_age	Trawl survey	1992–94, 2001–10, 2012–13, 2015, 2017, 2019, 2021	Otoliths
	survey_SA_autumn_age	Trawl survey	1992, 1996, 1998	Otoliths
CS	fishery_CS_spwn_age	Catch-at-age	1990–2005, 2007–2010, 2014–2021	Otoliths
CR	fishery_CR_deep_age	Catch-at-age	2001–2021	Otoliths
	fishery_CR_shallow_age	Catch-at-age	1999–2019, 2021	Otoliths
	survey_CR_summer_age	Trawl survey	1992–2014, 2016, 2018, 2020, 2022	Otoliths

Table 17: Coefficients of variation (CVs) used with biomass indices in the assessment. Total CVs include both observation error CVs and process error CVs. Observation error CVs are shown for CR_summer, SA_summer, and SA_autumn, and the process error CVs either estimated or set to 0.1 for MPD (Mode of the Posterior Distribution) runs. Total CVs shown here for CS and WC. Years are fishing years (1990 = 1989–90).

survey_CR_summer_abundance	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
Observation	0.08	0.10	0.10	0.08	0.10	0.08	0.11	0.12	0.12	0.10	0.11	0.09
survey_CR_summer_abundance	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2016	2018
Observation	0.12	0.11	0.08	0.11	0.11	0.15	0.14	0.10	0.15	0.10	0.14	0.16
survey_CR_summer_abundance	2020	2022										
Observation	0.14	0.10										
survey_SA_summer_abundance	1992	1993	1994	2001	2002	2003	2004	2005	2006	2007	2008	2009
Observation	0.07	0.06	0.09	0.13	0.16	0.14	0.13	0.12	0.13	0.11	0.16	0.14
survey_SA_summer_abundance	2012	2013	2015	2017	2019	2021						
Observation	0.15	0.15	0.13	0.17	0.11	0.12						
survey_SA_autumn_abundance	1992	1996	1998									
Observation	0.08	0.09	0.11									
survey_CS_spawning_abundance	1991	1993	1994	1995	1996	1997	1998	1999	2001	2002	2003	2005
Total	0.41	0.52	0.91	0.61	0.57	0.40	0.44	0.36	0.30	0.34	0.34	0.32
Observation	0.12	0.15	0.14	0.12	0.09	0.12	0.10	0.09	0.12	0.12	0.17	0.11
survey_CS_spawning_abundance	2007	2008	2009	2011	2013	2015	2017	2019	2021			
Total	0.46	0.30	0.39	0.35	0.30	0.33	0.36	0.36	0.41			
Observation	0.26	0.06	0.11	0.14	0.15	0.18	0.17	0.12	0.15			
survey_WC_abundance	1988	1989	1990	1991	1992	1993	1997	2000	2012			
Total	0.60	0.38	0.40	0.73	0.49	0.38	0.60	0.28	0.34			
Observation	0.12	0.15	0.06	0.10	0.17	0.07	0.10	0.14	0.15			
survey_WC_abundance	2013	2018										
Total	0.35	0.46										
Observation	0.18	0.15										

For the acoustic indices, the total CVs were calculated using a simulation procedure intended to include all sources of uncertainty (O'Driscoll 2002). The observation-error CVs were calculated using standard formulae for stratified random acoustic surveys (e.g., Coombs & Cordue 1995) and included only the uncertainty associated with between-transect (and within-stratum) variation in total backscatter.

The observation CVs for the otolith-based, at-age data were calculated by a bootstrap procedure, which included an explicit allowance for age estimation error. No observation-error CVs were available for the observer length frequency based data from the non-spawning fisheries, so an ad hoc procedure was used to derive observation errors, which were forced to be higher than those from the spawning fisheries (Francis 2004b). The age ranges used in the model varied amongst data sets (Table 18). In all cases, the last age for these data sets was treated as a plus group.

Table 18: Age ranges used for at-age data sets.

	Age range	
Data set	**Lower**	**Upper**
survey_SA_autumn_age	2	15+
survey_CR_summer_age	2	13+
survey_SA_summer_age	4	15+
survey_CR_SHI_age	2	9+
survey_SA_SHI_age	2	10+
Survey_SA_AEX_age	2	6+
fishery_PUY_spwn_age	2	18+
All other fisheries	1	18+

The catch for each year was divided among the 10 fisheries in the model according to area and month (Table 19). This division was based on estimated catch data from the catch and effort logs, and the resulting values were then scaled up to sum to the HOK 1 MHR total. The method of dividing the catches (Table 19) was similar to that used in the 2021 assessment, except that the definitions of the fisheries were different. The catch totals used in the model (Table 20) were unchanged, except for revisions to the previously assumed catch for 2021.

For the 2021–22 fishing year, catches by fishery were defined using 103 700 tonnes (56 050 tonnes eastern stock; 47 650 tonnes western stock) based on industry advice.

Table 19: The division of annual catches by area and months into the 10 model fisheries. The small amount of catch reported from the west coast North Island and Challenger areas, typically about 100 t per year, has been distributed pro rata across all fisheries.

Fishery	Description	Areas/months
CR_deep	Chatham Rise deep (effort depth ≥475m), non-spawning	CR, CS (Oct-May), ECNI, ECSI (Oct-May)
CR_shallow	Chatham Rise shallow (effort depth <475m), non-spawning	CR, CS (Oct-May), ECNI, ECSI (Oct-May)
CS	Cook Strait spawning	CS (Jun-Sep), ECSI (Jun-Sep)
SA_auck	Sub-Antarctic Auckland Islands, non-spawning	Sub-Antarctic Auckland Islands
SA_snares	Sub-Antarctic Snares shelf, non-spawning	Sub-Antarctic Snares, Puysegur (Oct-May)
SA_suba	Sub-Antarctic excluding Auckland Islands and Snares shelf, non-spawning	Sub-Antarctic
PUY_spn	Puysegur spawning fishery	Puysegur (Jun-Sep)
WC_inside	WCSI south of 42.5 inside the line	West coast inside
WC_north	WCSI north of 42.5 and includes inside the line	West coast north
WC_south	WCSI south of 42.5 outside the line	West coast south

Further assumptions

Two key outputs from the assessment are B_0 — the average spawning stock biomass that would have occurred over the period of the fishery had there been no fishing — and the time series of year class strengths (YCSs). For example, the YCS for 1970 comprised fish spawned in the winter of 1970 that first arrived in the model in area Chatham Rise at age 1.6 y, in about December 1971, which was in model year 1972. Associated with B_0 was an estimated mean recruitment, R_0, which was used, together with a Beverton-Holt stock-recruit function and the YCSs, to calculate the recruitment in each year. The first five YCSs (for years 1970 to 1974) were set equal to 1 (because of the lack of at-age data for the early years), but all remaining YCSs (for 1975 to 2020) were estimated. The model corrects for bias in estimated YCSs arising from ageing error. YCSs were constrained to average to 1 over the years 1975 to 2018, so that R_0 may be thought of as the average recruitment over that period. R_0 and a set of YCSs were estimated separately for each stock. The B_0 for each stock was calculated as the spawning biomass that would occur given no fishing and constant recruitment, R_0, and the initial biomass before fishing (B_{INIT}) was set equal to B_0. The steepness of the stock-recruitment relationship was assumed fixed at 0.75 for both stocks (Francis 2009).

Table 20: Model catch history (t) by fishery and fishing year (1972 means fishing year 1971–72), as used in this assessment. Years are fishing years (1990 = 1989–90). The 2022 catch is assumed, based on industry advice. [Continued on next page]

Year	CR_ deep	CR_ shallow	CS_ spwn	PUY_ spwn	SA_ auck	SA_ snares	SA_ suba	WC_ inside	WC_ north	WC_ south	Total
1972	3 500	500						1 700	3 300	10	9 010
1973	3 500	500						1 700	3 300	10	9 010
1974	5 200	800						1 700	3 300	10	11 010
1975	31 300	4 700						3 400	6 600	10	46 010
1976	32 200	4 800						10 200	19 700	100	67 000
1977	33 100	4 900						20 500	39 400	100	98 000
1978	2 600	400						1 700	3 300	10	8 010
1979	5 200	800						6 100	11 800	10	23 910
1980	7 000	1 000						6 800	13 100	10	27 910
1981	7 000	1 000						8 500	16 400	100	33 000
1982	6 100	900						8 500	16 400	100	32 000
1983	8 700	1 300		10	1 300	1 700	400	9 100	17 400	100	40 010
1984	8 700	1 300		10	1 700	2 300	600	12 100	23 200	100	50 010
1985	8 700	1 300		10	1 500	1 900	500	10 300	19 700	100	44 010
1986	14 800	2 200		100	3 500	4 700	1 100	24 800	47 600	200	99 000
1987	14 800	2 200		200	6 800	9 000	2 200	47 700	91 700	300	174 900
1988	7 100	1 100	7 400	300	10 300	13 700	3 300	72 500	139 300	500	255 500
1989	5 500	800	5 700	200	8 200	11 000	2 600	57 800	111 200	400	203 400
1990	9 395	4 738	14 955	7 249	660	9 646	1 596	1 765	78 955	79 716	208 675
1991	25 377	5 788	30 500	4 849	1 748	8 244	6 798	1 180	72 352	55 711	212 547
1992	36 353	13 237	25 435	4 756	2 496	17 039	11 252	754	64 421	36 356	212 099
1993	35 703	10 424	22 023	1 682	3 635	14 258	7 492	1 039	83 763	11 799	191 818
1994	17 841	8 335	36 115	2 349	865	8 562	2 246	1 647	95 943	18 293	192 196

Table 20 [continued]

Year	CR_ deep	CR_ shallow	CS_ spwn	PUY_ spwn	SA_ auck	SA_ snares	SA_ suba	WC_ inside	WC_ north	WC_ south	Total
1995	34 429	12 212	35 100	795	2 089	7 254	4 376	2 384	54 153	23 839	176 631
1996	39 467	20 683	60 218	2 217	1 665	9 233	2 377	4 249	42 781	25 906	208 796
1997	47 453	22 174	57 506	5 530	6 576	11 468	4 071	7 964	62 161	21 249	246 152
1998	61 925	26 810	46 546	1 691	9 153	10 176	6 269	7 765	71 292	27 217	268 844
1999	53 808	27 733	41 592	2 234	7 985	11 221	5 213	7 220	50 504	36 836	244 346
2000	40 898	20 424	41 623	2 469	13 985	13 821	6 377	14 137	64 632	23 954	242 320
2001	37 837	17 921	34 831	5 752	11 391	12 690	7 040	21 574	43 405	37 257	229 698
2002	31 644	11 011	24 591	4 814	9 018	7 456	14 209	21 825	45 597	25 299	195 464
2003	28 339	14 055	41 721	5 588	7 921	3 485	9 153	16 477	37 983	19 401	184 123
2004	27 932	8 815	40 957	724	4 778	2 604	4 687	18 784	14 334	11 995	135 610
2005	26 339	6 658	26 277	5 446	2 654	2 293	1 399	7 893	15 759	9 459	104 177
2006	24 904	11 806	20 501	1 211	1 232	4 843	883	5 220	17 783	15 985	104 368
2007	34 006	6 791	18 803	250	1 780	5 388	651	3 109	23 678	6 541	100 997
2008	34 170	7 274	17 910	133	2 801	4 557	1 525	914	16 936	3 082	89 302
2009	34 426	7 872	15 890	120	2 201	6 394	1 326	1 151	16 692	2 705	88 777
2010	34 410	7 528	16 366	106	2 527	8 365	1 550	2 933	31 060	2 357	107 202
2011	32 709	10 616	13 272	1 097	3 272	7 805	1 657	7 509	35 453	5 411	118 801
2012	34 901	8 187	15 407	894	2 973	11 195	1 988	8 487	35 554	10 492	130 078
2013	32 250	9 467	18 577	460	4 257	7 819	2 518	6 858	35 180	14 181	131 567
2014	31 033	7 850	17 346	400	5 784	7 406	7 115	10 355	44 026	15 019	146 334
2015	36 486	8 289	19 785	1 296	4 575	9 370	3 013	13 388	49 840	15 478	161 520
2016	29 841	10 707	19 558	928	2 406	2 716	1 644	16 172	37 372	15 333	136 677
2017	34 996	9 115	17 123	926	2 490	6 036	4 914	16 737	32 547	16 678	141 562
2018	31 893	9 814	21 579	947	3 694	4 919	7 011	17 095	18 408	20 054	135 414
2019	36 444	6 561	22 673	1 026	2 440	4 366	2 494	14 987	14 335	17 130	122 456
2020	30 141	5 445	19 818	257	3 013	3 906	1 211	13 725	17 941	12 248	107 705
2021	32 682	5 904	16 818	104	1 216	1 577	489	13 100	17 124	11 690	100 704
2022	35 673	5 564	14 813	243	3 495	3 736	1 350	11 643	14 795	12 388	103 700

In model runs natural mortality (*M*) by sex was assumed to be constant over time, and the same for each stock, with female $M = 0.25\ y^{-1}$ and male $M = 0.30\ y^{-1}$. An alternative model was run with higher M for males to resolve patterns in sex ratio by age class.

The model used 17 selectivity ogives (11 for the eastern and western spawning and non-spawning fisheries and six for the trawl surveys on the Chatham Rise and Sub-Antarctic) and two migration ogives (Chatham Rise to Sub-Antarctic migration, defined separately for males and females).
Prior distributions were assumed for all parameters. Bounds for the acoustic catchability parameters were calculated by O'Driscoll et al (2016) (who called them overall bounds); for YCS, bounds were set at the 0.001 and 0.999 quantiles of their distributions (Table 21). Prior distributions for all other parameters were assumed to be uniform, with bounds that were wide enough so as not to affect point estimation, or, for some ogive parameters, deliberately set to constrain the ogive to a plausible shape.

Table 21: Assumed prior distributions for key parameters. Parameters are bounds for uniform; mean (in natural space) and CV for lognormal; and mean and SD for normal and beta.

Parameter	Description	Distribution	Values		Reference
recruitment[E].YCS	year-class strengths (E)	lognormal	1	0.95	Francis (2004a)
recruitment[W].YCS	year-class strengths (W)	lognormal	1	0.95	Francis (2004a)
q[survey_CS_spawning_q].q	catchability, CS acoustic survey	lognormal	0.55	0.90	O'Driscoll et al (2016)
q[survey_WC_spawning_q].q	catchability, WC acoustic survey	lognormal	0.39	0.77	O'Driscoll et al (2016)

The final models, taken to MCMC, are summarised in Table 22. Models 2022A and 2022B are alternative base models, because they only differ in the assumed natural mortality for males (*M* set at $0.35\ y^{-1}$ for males in Model 2022B).

Table 22: Characteristics for final model runs.

Model	Short name	Main assumptions
2022A	Base2021 with SA selectivity shifts	Two spawning stocks, that spawn on the CS and WC. Recruits from both stocks reside on CR as juveniles. Western-spawned fish migrate to SA (estimated ogive; further testing of this parameterisation required). Mature WC-stock fish migrate from SA to WC to spawn and mature CR-stock fish from CR to CS to spawn. After spawning, all mature fish return (WC to SA and CS to CR).
2022B	Base2021 with M (male) = 0.35	

Bayesian posterior distributions were estimated for models 2022A and 2022B using a Markov chain Monte Carlo (MCMC) approach. For each model, a chain of length 8 million was completed, with adaptive step size allowed during the first 4.5 million samples. The initial 1.5 million samples of each chain were discarded, and the remaining 6.5 million samples were concatenated and thinned to produce a posterior sample of size 6500.

Calculation of fishing intensity and B_{MSY}

Due to complications in calculating fishing intensity (U) when there are multiple fisheries and stocks, a simplified version was calculated as the catch in biomass divided by the estimated spawning stock biomass (*SSB*). For a given stock and run, the corresponding reference fishing intensities were estimated using the same equation (catch/*SSB*), and by running the model to equilibrium using a range of constant future catch levels, until the stock level at equilibrium was sufficiently close to the stock level reference point.

The 2022 assessment was conducted in two steps. First, a set of initial model runs was carried out generating point estimates (which estimate the Mode of the Posterior Distribution). Their purpose was to investigate model structure and assumptions to decide which runs to carry forward as final runs. The final runs used MCMC parameter estimation.

Deterministic B_{MSY} estimates are no longer calculated, for the following reasons. First, it assumes a harvest strategy that is unrealistic in that it involves perfect knowledge (current biomass must be known exactly, to calculate the target catch) and annual changes in TACC (which are unlikely to happen in New Zealand and not desirable for most stakeholders). Second, it assumes perfect knowledge of the stock-recruitment relationship, which is very poorly known (Francis 2009). Third, the closeness of B_{MSY} to the soft limit permits the limit to be breached too easily and too frequently, given, for example, a limited period of low recruitment. Fourth, it would be very difficult with such a low biomass target to avoid the biomass occasionally falling below 20% B_0, the default soft limit according to the Harvest Strategy Standard.

Instead, the target range of 35% B_0 to 50% B_0 is used as a proxy for the likely range of credible B_{MSY} estimates.

6.2 Results

Model estimates are presented for the spawning stock biomass (Table 23), year class strengths (Figure 4), fishing intensity (Figure 5), and biomass trajectories with projections (Figure 6). The current western biomass was estimated to be 28% B_0 (median value for the base two stock model, Model 2022A) and 31% B_0 (Alternative base model, Model 2022B). Current eastern biomass estimates were 51% B_0 (Model 2022A) and 55% B_0 (Model 2022B). The current total biomass was estimated to be 40% B_0 (Model 2022A) and 43% B_0 (Model 2022B).

Table 23: Estimates of spawning biomass (‘000 tonnes) (medians of marginal posterior, with 95% confidence intervals in parentheses). B_{2022} is the biomass in mid-season 2022. See Table 22 for the associated run numbers.

	B_0 (‘000t)			B_{2022} (‘000t)			B_{2022}/B_0	
Eastern	Western	Total	Eastern	Western	Total	Eastern	Western	Total
Model 2022A								
682	1 161	1 843	351	327	678	0.51	0.28	0.40
(622, 747)	(1 107, 1 227)	(1 729, 1 974)	(243, 477)	(242, 442)	(485, 919)	(0.38, 0.65)	(0.22, 0. 36)	(0.30, 0.51)
Model 2022B								
689	1 167	1 856	381	362	743	0.55	0.31	0.43
(626, 757)	(1 110, 1 239)	(1 736, 1 996)	(266, 517)	(270, 481)	(536, 998)	(0.41, 0.70)	(0.24, 0.40)	(0.33, 0.55)

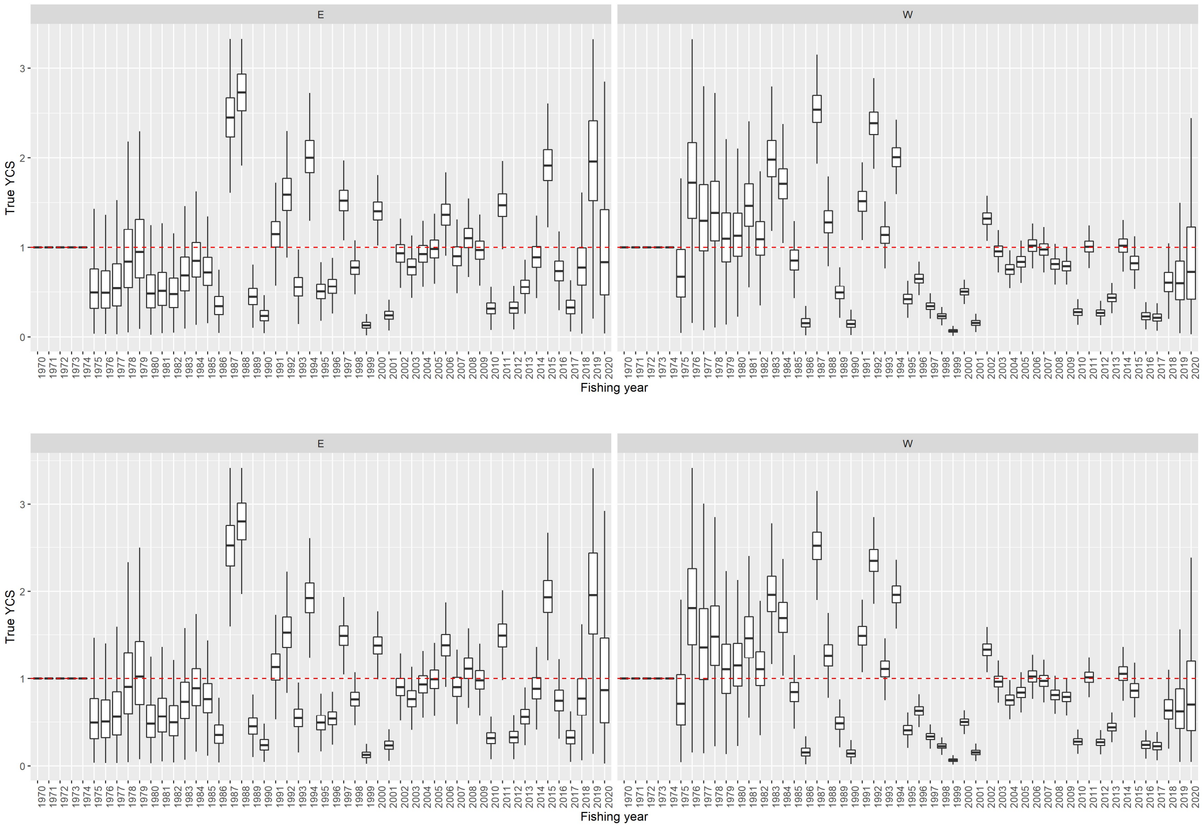


Figure 4: Year class strengths (YCS) for eastern (left) and western (right) stocks from model 2022A (top) and 2022B (bottom) from MCMC samples. Years are model years (1990 = 1989–90).

Fishing intensity for the western stock was estimated to be at or near all-time highs in 2002–2003 and is now substantially lower (Figure 5). For the eastern stock, fishing intensity peaked in 1999 and then again in 2004–2005 and is now lower.

Biomasses of both stocks were at their lowest points from about 2004 to 2006 (lowest values being at about 30% B_0 for the eastern stock and 20% B_0 for the western stock) (see Figure 6), after the western stock experienced seven consecutive years of poor recruitment from 1995 to 2001 inclusive and the eastern stock had below average recruitment over the same period (Figure 4). Both stocks then increased to above the target range of 35–50% B_0, then declined, with the eastern stock towards the top of the management target range and the western stock towards the lower bound of the target range, providing long-term recruitment levels are assumed. Recruitment to the western stock following the 1995–2001 period of poor recruitment remained low for two more years, then was estimated to have been above average for about five years before dropping again, with recruitment below average for 2011–2019. The recruitment patterns were similar for the eastern stock over these years, except for two strong year classes in 2011 and 2015.

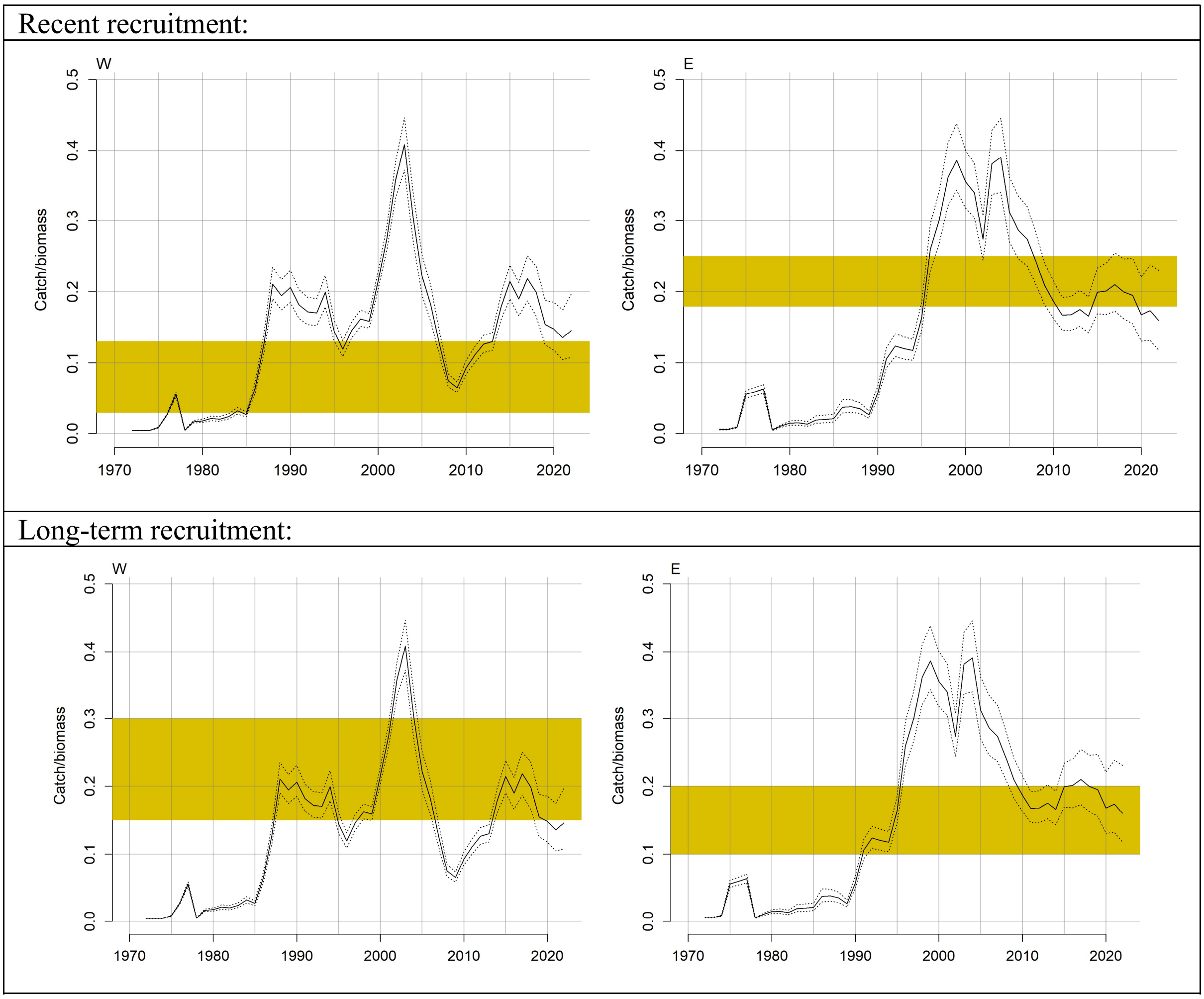


Figure 5: Fishing intensities, *U* (from MCMCs) for model 2022A, plotted by stock. Shown are medians (solid black line) with 95% confidence intervals (dotted lines). Also shown shaded in orange is the management range where the upper bound is the reference level $U_{35\%B_0}$ and the lower bound $U_{50\%B_0}$ which are the fishing intensities that would cause the spawning biomass to tend to 35% B_0 and 50% B_0, respectively, under recent recruitment (top) or long-term recruitment (bottom).

6.3 Sensitivities

A number of sensitivities were conducted at the MPD level. The results are shown in Table 24. The sensitivities that had the largest effect on stock status were the natural mortality sensitivities, with lower natural mortality having the largest effect on status of the eastern stock, and higher natural mortality having the largest effect on status of the western stock.

The single-area single-stock model (Model 2022C) has the least assumptions on movement, timing, and location. In this model, there is only one region and one stock, and selectivity ogives are used as proxies for the other dynamics. This is a useful model to include as a sensitivity if any of the assumptions in the base model are incorrect. The 2021 assessment included MCMC results from this model, but in the 2022 assessment the Fisheries New Zealand Deepwater Working Group decided more work was required on this model for it to be accepted. The MPD results for Model 2022C are still reported here as the concerns of the working group largely related to the performance of the MCMC chains.

Table 24: MPD sensitivities. Biomass estimates are in thousands of tonnes. Total estimates for model 2022A sensitivities are the sum of the estimates for the East and West stocks.

	East			West			Total		
Model description	B_0	B_{2022}	B_{2022}/B_0	B_0	B_{2022}	B_{2022}/B_0	B_0	B_{2022}	B_{2022}/B_0
Base2022A: *M*(male)=0.3, *M*(female)=0.25; *h*=0.75; Maturation: logistic (male)=2,2 (female)=3,3; cv.process_error=0.10; SA selectivity shifts not included	669	300	0.45	1 182	376	0.32	1 851	676	0.37
Base2022: *M*(male)=0.35, *M*(female)=0.25	722	411	0.57	1 182	370	0.31	1 904	781	0.41
Base2022: *M*(male)=0.35, *M*(female)=0.3	775	490	0.65	1 261	430	0.34	2 036	920	0.45
Base2022: *M*(male)=0.25, *M*(female)=0.20	763	307	0.40	1 197	274	0.23	1 960	581	0.30
Base2022: *h*=0.70	703	384	0.55	1 151	333	0.29	1 854	717	0.39
Base2022: *h*=0.80	737	384	0.52	1 193	330	0.28	1 930	714	0.37
Base2022: maturation logistic (male)=1,2; (female)=2,3	749	436	0.58	1 201	347	0.29	1 950	783	0.40
Base2022: maturation logistic (male)=3,2; (female)=4,3	695	324	0.47	1 133	330	0.29	1 828	654	0.36
Model 2022C: single stock model							2 096	925	0.44

6.4 Projections

Five-year projections were carried out for the two model runs. Estimates of recruitment for 2019 and 2020 were based on observations. Future recruitments (2021 onwards) were randomly selected based on two scenarios: (i) recruitments estimated for 2009–2018 (recent recruitment), and (ii) recruitments estimated for 1975–2020 (long-term recruitment). Total future annual catches were assumed to be constant at the TACC of 110 000 tonnes (45000 tonnes western stock; 65 000 tonnes eastern stock). These future catches were apportioned by fishery using average proportions from the 2020 and 2021 fishing years. The projections indicated that the eastern biomass would remain fairly constant over the next 5 years and likely above the top of the target range (see Figure 6, Tables 25, 26a, b). The western biomass is projected to increase under long-term recruitment and remain constant under recent recruitment (see Figure 6, Tables 25, 26a, b).

For both eastern and western stocks, the estimated probability of being less than the soft or the hard limit at the end of the five-year projection period was less than 10% (Tables 26a, b).

Table 25: Projected median *SSB* (% B_0) for 2022 to 2027 from the base model (2022A), assuming future estimated catch levels of 110 000 tonnes (65 000 tonnes eastern stock; 45 000 tonnes western stock), and with recruitment levels randomly selected from: 2009–2018 estimates (recent recruitment); 1975–2020 (long-term recruitment).

Recruitment	Stock	2022	2023	2024	2022	2026	2027
Recent	All	37	40	42	43	42	41
	East	51	57	58	57	54	52
	West	28	30	32	33	33	33
Long-term	All	37	40	43	45	47	49
	East	51	57	59	58	57	56
	West	28	30	33	36	40	44

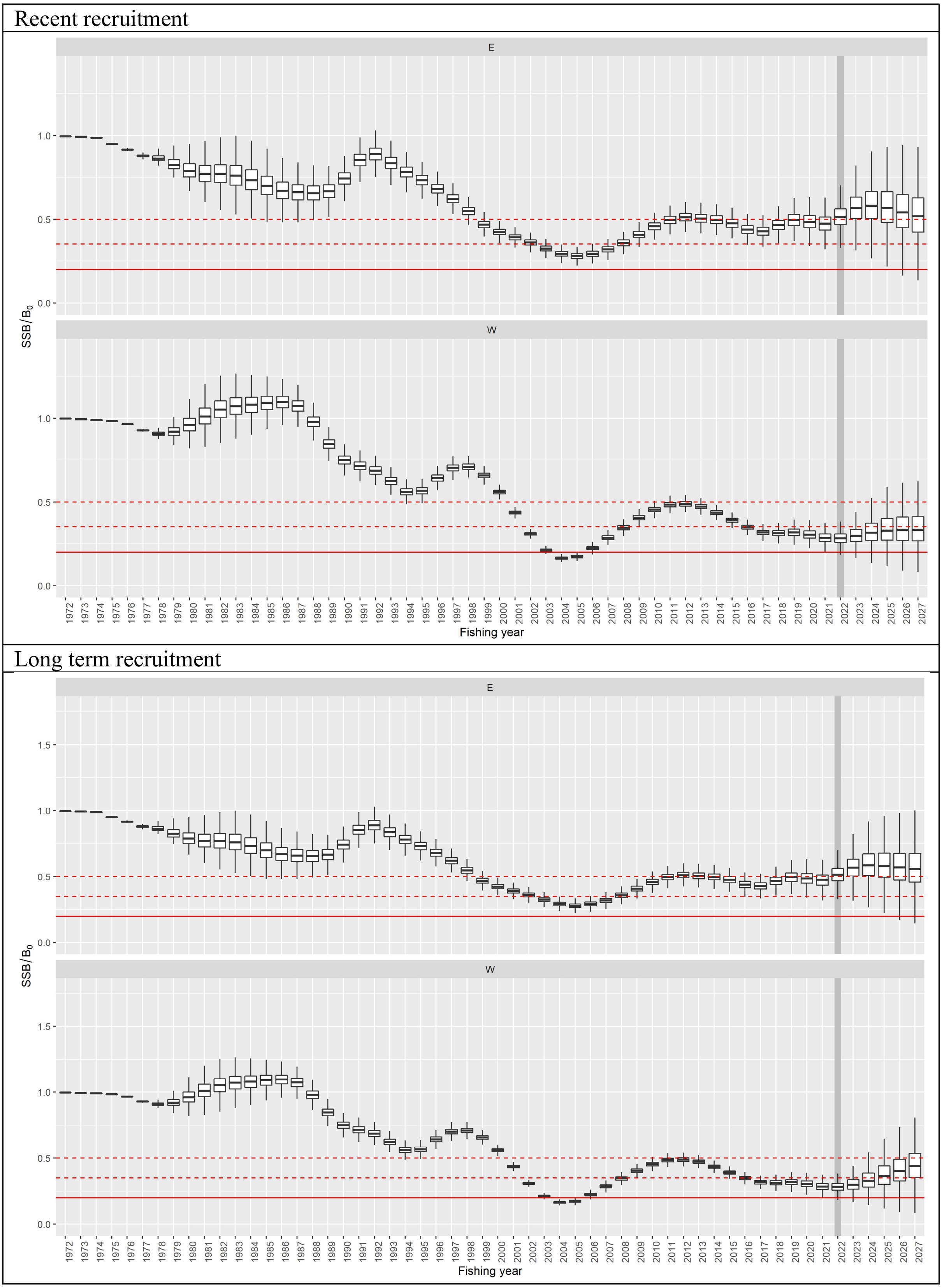


Figure 6: Projected spawning biomass (as % B_0) from the base model (2022A) under two recruitment scenarios: recent (2009–2018) (top block); long-term (1975–2020) (bottom block), for eastern stock (upper plot in each block), western stock (lower plot in each block). The horizontal dashed red lines represent the target management range of 35–50% B_0. The horizontal red solid line shows 20% B_0.

Table 26a: Projected probabilities (to two decimal places) from the base model (2022A) of *SSB* being below, within, or above various levels of % B_0 for 2022 to 2027, assuming future estimated catch levels of 110 000 tonnes (65 000 tonnes eastern stock; 45 000 tonnes western stock) and with recruitment levels randomly selected from 2009–2018 estimates (recent recruitment).

	2022	**2023**	**2024**	**2022**	**2026**	**2027**
EAST 2022A						
P (SSB<10% B_0)	0.00	0.00	0.00	0.00	0.00	0.00
P (SSB<20% B_0)	0.00	0.00	0.00	0.00	0.00	0.00
P (SSB<35% B_0)	0.01	0.01	0.01	0.03	0.06	0.11
P (35≤SSB<50% B_0)	0.41	0.23	0.22	0.27	0.32	0.34
P (SSB≥50% B_0)	0.58	0.76	0.76	0.69	0.62	0.55
WEST 2022A						
P (SSB<10% B_0)	0.00	0.00	0.00	0.00	0.00	0.00
P (SSB<20% B_0)	0.01	0.01	0.02	0.04	0.06	0.07
P (SSB<35% B_0)	0.94	0.82	0.63	0.55	0.51	0.49
P (35≤SSB<50% B_0)	0.05	0.17	0.31	0.33	0.34	0.35
P (SSB≥50% B_0)	0.00	0	0.04	0.08	0.09	0.09
ALL 2022A						
P (SSB<10% B_0)	0.00	0.00	0.00	0.00	0.00	0.00
P (SSB<20%B_0)	0.00	0.01	0.01	0.02	0.03	0.04
P (SSB<35% B_0)	0.48	0.41	0.32	0.29	0.29	0.30
P (35≤SSB<50% B_0)	0.23	0.20	0.26	0.30	0.33	0.34
P (SSB≥50% B_0)	0.29	0.38	0.40	0.39	0.35	0.32

Table 26b: Projected probabilities (to two decimal places) from the base model (2022A) of *SSB* being below, within, or above various levels of % B_0 for 2022 to 2027, assuming future estimated catch levels of 110 000 tonnes (65 000 tonnes eastern stock; 45 000 tonnes western stock) and with recruitment levels randomly selected from 1975–2020 estimates (long-term recruitment).

	2022	**2023**	**2024**	**2022**	**2026**	**2027**
EAST 2022A						
P (SSB<10% B_0)	0.00	0.00	0.00	0.00	0.00	0.00
P (SSB<20% B_0)	0.00	0.00	0.00	0.00	0.00	0.00
P (SSB<35% B_0)	0.01	0.01	0.01	0.03	0.04	0.07
P (35≤SSB<50% B_0)	0.41	0.23	0.21	0.24	0.27	0.28
P (SSB≥50% B_0)	0.58	0.77	0.77	0.73	0.69	0.65
WEST 2022A						
P (SSB<10% B_0)	0.00	0.00	0.00	0.00	0.00	0.00
P (SSB<20% B_0)	0.01	0.01	0.02	0.02	0.02	0.02
P (SSB<35% B_0)	0.94	0.81	0.59	0.42	0.30	0.23
P (35≤SSB<50% B_0)	0.05	0.18	0.35	0.42	0.45	0.42
P (SSB≥50% B_0)	0.00	0.00	0.05	0.14	0.23	0.33
ALL 2022A						
P (SSB<10% B_0)	0.00	0.00	0.00	0.00	0.00	0.00
P (SSB<20% B_0)	0	0.01	0.01	0.01	0.01	0.01
P (SSB<35% B_0)	0.48	0.41	0.3	0.22	0.17	0.15
P (35≤SSB<50% B_0)	0.23	0.2	0.28	0.33	0.36	0.35
P (SSB≥50% B_0)	0.29	0.38	0.41	0.43	0.46	0.49

7. FUTURE RESEARCH CONSIDERATIONS

- The Sub-Antarctic q estimated in the current model is much larger than Chatham Rise q. Understanding why this is happening could help understand the Chatham Rise/Sub-Antarctic dynamic, and by changing selectivities and/or migration the model could estimate relative qs that are more intuitive.
- The migration from the Chatham Rise to the Sub-Antarctic is important for the eastern/western stock dynamic in the model, but it is difficult to estimate due to confounding with selectivities. Combining the Chatham Rise and Sub-Antarctic is one option to avoid the issue. This would mean the Chatham Rise and Sub-Antarctic combined area would consist of all juvenile western and eastern stock fish, which would then migrate to the appropriate spawning grounds, and then return. Alternatively, structuring sensitivities that explore this migration could help highlight plausible dynamics.

- More abundance data including LFs, otoliths, and gonad staging need to be collected from the Pegasus Canyon and surrounding areas to determine the importance or relevance of these areas, including enabling the development of a consistent index of hoki abundance. Any temporal or areal differences in the availability of hoki in the Cook Strait and Pegasus spawning fisheries could then be integrated into the model.
- The single-area single-stock model (Model 2022C) requires further refinement and evaluation.
- Some trends in mean size-at-age (growth rates) are not accounted for in the model. This affects the conversion of catches in tonnes to mortality in numbers.
- Length to weight ratios change when fish are about to spawn, which also affects the conversion of catches in tonnes to mortality in numbers. This is currently not accounted for in the model.
- Currently the Chatham Rise summer survey has knife edge selectivity at 2 years, but there are still patterns in the resulting composition residuals. Because the Chatham Rise is important for the eastern/western stock split dynamics in the model, this could be an important area to resolve.
- There are strong patterns in proportions by sex in spawning fisheries that are still not resolved. This could relate to natural mortality, because a higher natural mortality for males goes some way to resolving the issue. This, along with assumptions about maturation, affects the migration of fish to the spawning grounds (and hence fisheries), but it is not well informed. Both should be further explored.
- The potential impacts on model results of mature fish not spawning every year should be investigated, noting that previous studies have been conducted to estimate the average percentage of mature fish not migrating to spawn.
- Males are assumed to have higher natural mortality than females in the model. The values for these could be explored further by focusing on the composition data, especially in the spawning fisheries.
- The last estimated biomass from the west coast South Island acoustics survey is from 2018, which was a low point, but the model is reliant on the Sub-Antarctic summer survey for the western stock abundance observations after this, and it is flat for the most recent few years. The utility of the west coast South Island acoustics survey should be re-examined.
- Alternative catch histories could be constructed, particularly for the period of operation of surimi vessels off the west coast of the South Island (1986 to the mid-1990s) following the large increase in hoki quota, as these vessels are believed to have under-reported their catches.
- The potential effects of cryptic mortality should be investigated, focusing on years of high juvenile abundance where density-dependent effects may occur.
- Consider making better use of the CPUE data, for example by examining whether it can be used to track young fish when they leave the Chatham Rise and arrive at the Stewart-Snares shelf. The size of fish indexed by the CPUE also needs to be considered.
- Consider expressing fishing intensity as the catch divided by the biomass of hoki of particular age and older rather than as catch/*SSB*.
- Improve knowledge of habitats of particular significance for hoki.
- Evaluate the Chatham Rise trawl survey data to improve knowledge of spatial patterns in hoki length, age, and abundance.
- A Management Strategy Evaluation to investigate the robustness of the current monitoring and assessment regime (including frequency of current surveys, the utility of additional surveys, target reference points, frequency of assessment, etc.) under the current stock paradigm and alternative stock assumptions. The study should also investigate alternative harvest strategies related to spatial distribution of catch between the main fisheries.
- Consider inclusion of CR_deep age and length data for the July-September period for the most recent three years as well as collection of more data in the current year.
- Review the sub-Antarctic stock assessment area boundaries, with consideration of biologically-relevant factors, e.g., temperature or depth.
- Define the appropriate observer coverage to provide consistent annual LF and AF sampling from the Sub-Antarctic fisheries.
- Develop an ALK (age-length-key) for the Sub-Antarctic by sampling in proportion to catch.
- Conduct spatial and temporal analysis of age structure for the hoki fishery.

8. STATUS OF THE STOCKS

Stock Structure Assumptions

Hoki are assessed as two intermixing biological stocks, based on the presence of two main areas where simultaneous spawning takes place (Cook Strait and the WCSI), and observed and inferred migration patterns of adults and juveniles:

- Adults of the western stock occur off the west coast of the North and South islands and the area south of New Zealand including Puysegur, Stewart-Snares shelf, and the Sub-Antarctic;
- Adults of the eastern stock occur off the east coast of the South Island, Cook Strait, and the ECNI up to North Cape;
- Juveniles of both biological stocks occur on the Chatham Rise including Mernoo Bank.

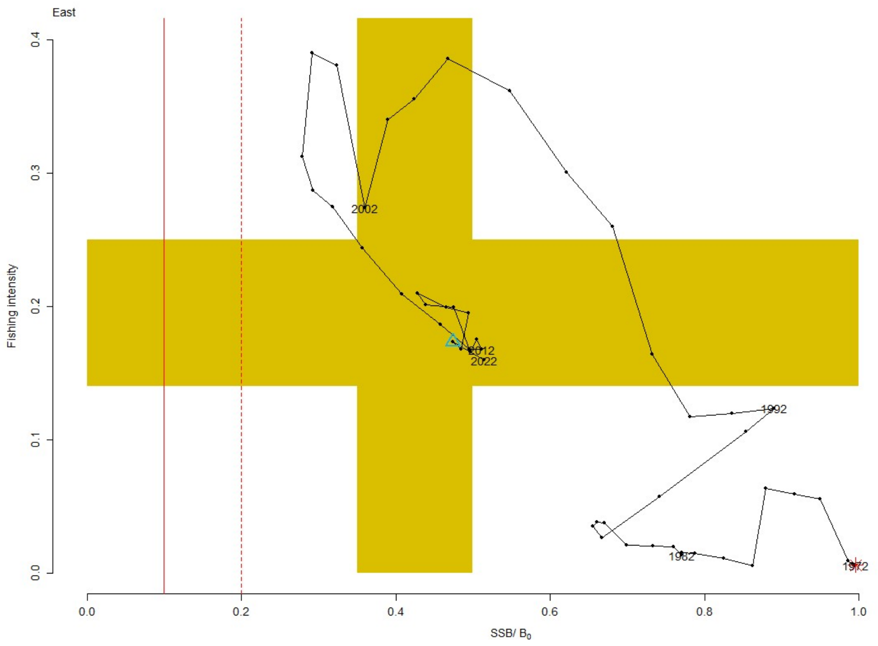
Both of these biological stocks lie within the HOK 1 Fishstock boundaries.

- **Eastern Hoki Stock**

Stock Status	
Year of Most Recent Assessment	2022
Assessment Runs Presented	Two stock (Base case: 2022A)
Reference Points	Target: 35–50% B_0 Soft Limit: 20% B_0 Hard Limit: 10% B_0 Overfishing threshold: $F_{35\%B0}$
Status in relation to Target	B_{2022} was estimated to be 51% B_0. Very Likely (> 90 %) to be above the lower end of the target range About as Likely as Not (40–60%) to be above the upper end of the range
Status in relation to Limits	B_{2022} is Very Unlikely (< 10%) to be below the Soft Limit and Exceptionally Unlikely (< 1%) to be below the Hard Limit
Status in relation to Overfishing	Overfishing is Unlikely (< 40%) to be occurring

Historical Stock Status Trajectory

Recent recruitment:



Trajectory over time of fishing intensity (*U*) and spawning biomass (% B_0), for the eastern hoki stock from the start of the assessment period in 1972 (represented by a red asterisk) to 2022 (blue triangle). The red solid vertical line at 10% B_0 represents the hard limit, the red dashed line at 20% B_0 is the soft limit, and the shaded area represents the management target ranges in biomass and fishing intensity, with fishing intensity estimated using recent recruitment. Biomass and fishing intensity estimates are medians from MCMC results.

Fishery and Stock Trends	
Recent Trend in Biomass or Proxy	Biomass has fluctuated with a slight increase since 2016–17
Recent Trend in Fishing Intensity or Proxy	Declining since 2016–17
Other Abundance Indices	-
Trends in Other Relevant Indicators or Variables	- The trawl surveys of the Chatham Rise in 2022 suggested an above average 2019 year class and a weak 2020 year class, but based on the other datasets in the model, the 2019 year class appeared to be the eastern stock rather than the western stock. Early predictions of the stock split for high year classes are always uncertain. - CPUE indices from the Chatham Rise fishery have remained relatively stable over the last 10 years.

Projections and Prognosis	
Stock Projections or Prognosis	The eastern stock is projected to remain above the target over the next five years.
Probability of Current Catch or TACC causing Biomass to remain below or to decline below Limits	For current catch or agreed catch limit: Soft Limit: Very Unlikely (< 10%) Hard Limit: Exceptionally Unlikely (< 1%)
Probability of Current Catch causing Overfishing to continue or to commence	For current catch: Unlikely (< 40%)

Assessment Methodology and Evaluation		
Assessment Type	Level 1 - Full Quantitative Stock Assessment	
Assessment Method	Age-structured CASAL model with Bayesian estimation of posterior distributions	
Assessment Dates	Latest assessment: 2022	Next assessment: 2023
Overall assessment quality rank	1 – High Quality	
Main data inputs (rank)	- Research time series of abundance indices (trawl and acoustic surveys) - Proportions-at-age data from the commercial fisheries and trawl surveys - Estimates of fixed biological parameters	1 – High Quality 1 – High Quality 1 – High Quality
Data not used (rank)	- Commercial CPUE	3 – Low Quality: does not track stock biomass over the long term
Changes to Model Structure and Assumptions	Changes from the 2021 model: - Selectivity caps free for spawning males - Sub-Antarctic summer survey minimum age extended to 3 years from 4 years - Selectivity shifts as applied to Sub-Antarctic selectivity estimated in the Stock Synthesis model were not applied - West coast north fishery not split at 2000	
Major Sources of Uncertainty	- Stock structure and migration patterns, in particular the migration from the Chatham Rise to the Sub Antarctic - Estimates of *q* for the Chatham Rise trawl survey (relative to the Chatham Rise trawl survey) - The actual split of recruitment between the eastern and western stocks for the three most recent year classes	

Qualifying Comments
Model fits to the Cook Strait composition data are still poor, and this dataset was down-weighted to reduce its effect on the rest of the model.

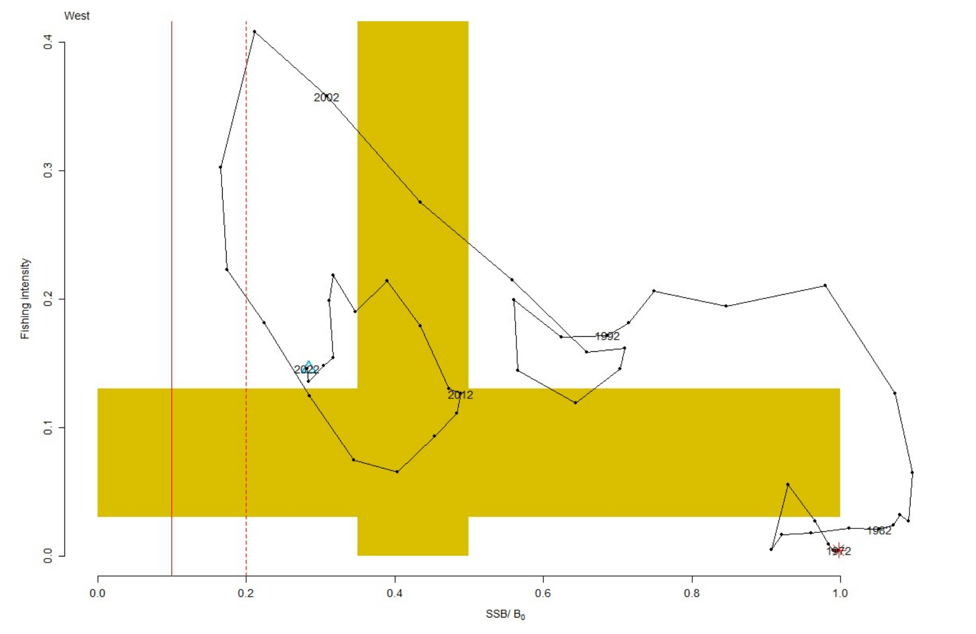
Fishery Interactions
Hoki, hake, ling, silver warehou, and white warehou are frequently caught together, and trawl fisheries targeting these species are, as of 2018, considered one combined trawl fishery. The main non-target species caught in the combined fishery off the west coast South Island and Sub-Antarctic are rattails, javelinfish, and spiny dogfish. Incidental captures of protected species have been recorded for New Zealand fur seals, basking sharks, and seabirds. The only target method of capture in the hoki fishery is trawling using either bottom or midwater gear. Bottom trawling is likely to have effects on benthic community structure and function.

- **Western Hoki Stock**

Stock Status	
Year of Most Recent Assessment	2022
Assessment Runs Presented	Two stock (Base case: 2022A)
Reference Points	Target: 35–50% B_0 Soft Limit: 20% B_0 Hard Limit: 10% B_0 Overfishing threshold: $F_{35\%B0}$
Status in relation to Target	B_{2022} was estimated to be 28% B_0. Unlikely (< 40%) to be above the lower end of the target range Exceptionally Unlikely (< 1%) to be above the upper end of the target range
Status in relation to Limits	B_{2022} is Unlikely (< 40%) to be below the Soft Limit and Very Unlikely (< 10%) to be below the Hard Limit
Status in relation to Overfishing	Overfishing is About as Likely as Not (40–60 %) to be occurring

Historical Stock Status Trajectory

Recent recruitment:



Trajectories over time of fishing intensity (*U*) and spawning biomass (% *B₀*), for the western hoki stock from the start of the assessment period in 1972 (represented by a red asterisk) to 2022 (blue triangle). The red solid vertical line at 10% B_0 represents the hard limit, the red dashed line at 20% B_0 is the soft limit, and the shaded area represents the management target ranges in biomass and fishing intensity, with fishing intensity estimated using recent recruitment. Biomass and fishing intensity estimates are medians from MCMC results.

Fishery and Stock Trends	
Recent Trend in Biomass or Proxy	Biomass has been declining since 2011–12 to 2020–21 but has been similar in the last year.
Recent Trend in Fishing Intensity or Proxy	Declining for the last 5 years but has increased slightly in 2021–22.
Other Abundance Indices	
Trends in Other Relevant Indicators or Variables	- The trawl survey of the Chatham Rise in 2022 suggested an above average 2019 year class and a weak 2020 year class but, based on the other datasets in the model, the 2019 year class appeared to be eastern stock rather than western stock. Early predictions of the stock split for high year classes are always uncertain. - The trawl survey of the WCSI northern area showed an increase in hoki abundance from 2018 to 2021 although there was high uncertainty in the 2021 estimate. - CPUE indices from the WCSI North fishery increased by about 60% in 2019/20–2020/21 from a relatively low level in 2016/17 to 2018/19.

Projections and Prognosis	
Stock Projections or Prognosis	If future recruitment remains similar to recent recruitment, the biomass of the western hoki stock is expected to slowly increase over the next five years at assumed future catch levels.
Probability of Current Catch or TACC causing Biomass to remain below or to decline below Limits	For current catch or agreed catch limit: Soft Limit: Unlikely (< 40%) Hard Limit: Very Unlikely (< 10%)
Probability of Current Catch or TACC causing Overfishing to continue or to commence	For current catch or agreed catch limit: 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: 2022	Next assessment: 2023
Overall assessment quality rank	1 – High Quality	
Main data inputs (rank)	- Research time series of abundance indices (trawl and acoustic surveys) - Proportions at age data from the commercial fisheries and trawl surveys - Estimates of fixed biological parameters	1 – High Quality 1 – High Quality 1 – High Quality
Data not used (rank)	- Commercial CPUE - WCSI trawl survey biomass estimate - Some years of age data	3 – Low Quality: does not track stock biomass 3 – Low Quality: not considered to index spawning biomass 3 – Low quality: currently not used as it was not thought to be representative of the fishery
Changes to Model Structure and Assumptions	Changes from the 2021 model: - Selectivity caps free for spawning males - Sub-Antarctic summer survey minimum age extended to 3 years from 4 years	

	- Selectivity shifts not applied to Sub-Antarctic selectivity - Selectivity of West coast north fishery not split at 2000
Major Sources of Uncertainty	- Stock structure and migration patterns, in particular the migration from the Chatham Rise to the Sub Antarctic - Estimates of q for the Sub-Antarctic trawl survey (relative to the Chatham Rise trawl survey) - The actual split of recruitment between the eastern and western stocks for the three most recent year classes

Qualifying Comments
-

Fishery Interactions
Hoki, hake, ling, silver warehou, and white warehou are frequently caught together, and trawl fisheries targeting these species are, as of 2018, considered one combined trawl fishery. The main non-target species caught in the combined fishery off the west coast South Island and Sub-Antarctic are rattails, javelinfish, and spiny dogfish. Incidental captures of protected species have been recorded for New Zealand fur seals, basking sharks, and seabirds. The only target method of capture in the hoki fishery is trawling using either bottom or midwater gear. Bottom trawling is likely to have effects on benthic community structure and function.

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