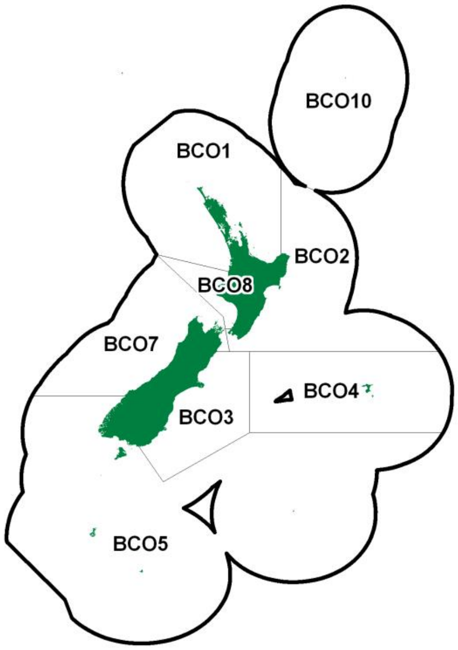
BLUE COD (BCO)

(Parapercis colias)
Rāwaru



1. FISHERY SUMMARY

Allowances, TACCs, and TACs are shown in Table 1.

Table 1: Recreational and Customary non-commercial allowances (t), other mortality (t), TACCs (t), and TACs (t) for blue cod by Fishstock as at 1 October 2021.

Fishstock	Recreational allowance	Customary non-commercial allowance	Other mortality	TACC	TAC
BCO 1	2	2	–	46	50
BCO 2	–	–	–	10	10
BCO 3	83	20	10	130	243
BCO 4	20	10	40	759	829
BCO 5	85	20	20	800	925
BCO 7	–	–	–	70	–
BCO 8	188	2	2	34	226
BCO 10	–	–	–	10	10

1.1 Commercial fisheries

Blue cod is predominantly an inshore domestic fishery with very little deepwater catch. The major commercial blue cod fisheries in New Zealand are off Southland and the Chatham Islands, with smaller but regionally significant fisheries off Otago, Canterbury, the Marlborough Sounds, and Wanganui.

The fishery has had a long history. National landings of up to 2400 t were reported in the 1930s and landings of over 1500 t were sustained for many years in the 1950s and 1960s (see Table 2). Fluctuations in annual landings since the 1930s can be attributed to World War II, the subsequent market for frozen blue cod for a short period of time, and then the development of the rock lobster fishery. Annual landings of blue cod also vary with the success of the rock lobster season. Traditionally many blue cod fishers were primarily rock lobster fishers. Therefore, the amount of effort in the blue cod fishery tended to depend on the success of the rock lobster season, with weather conditions in Southland affecting the number of 'fishable' days.

The commercial catch from the BCO 5 fishery is almost exclusively taken by the target cod pot fishery operating within Foveaux Strait and around Stewart Island (Statistical Areas 025, 027, 029, and 030). Similarly, the BCO 3 commercial catch is dominated by the target pot fishery, although blue cod is also taken as a small bycatch of the inshore trawl fisheries operating within BCO 3. Most of the catch from BCO 3 is taken in the southern area of the Fishstock (Statistical Area 024). Catches from BCO 3 and

BCO 5 peak during autumn and winter and the seasonal nature of the fishery is influenced by the operation of the associated rock lobster fishery.

Total landings averaged 574 t in the 1970s before building up to 1546 t in 1985, the year before the QMS was implemented. Landings then declined to 1989 but have since increased, coinciding with a change in the main fishing method from hand lines to cod pots. Historical landings are given in Table 2, recent reported landings are given in Table 3, and Figure 1 shows the historical landings and TACC values for the five main BCO Fishstocks. FSU landings 1970 to 1983 are given in Table 4.

During the fishing years 1994–95 to 2017–18, total landings exceeded 2000 t annually, peaking at 2501 t in 2003–04. In 2018–19 landings dropped to 1844 t and in 2020–21, when the overall TACC was reduced to 1892 t, 1747 t were landed. Historically, the largest catches of blue cod have been taken in BCO 5 (1556 t in fishing year 2003–04). The total landings from this fishery remained relatively stable from 1982 to 1993 and subsequently increased to approach the level of the TACC in 1995–96. Landings have been declining since 2003–04, and the TACC was lowered to 1239 t in 2011–12. In 2018–19, less than 1000 t of landings were recorded for the first time since 1991–92; 926 t were landed in 2019–20. In 2020–21, the BCO 5 TACC was lowered to 800 t and 788 t were landed.

Table 2: Reported landings (t) for the main QMAs from 1931 to 1982.

Year	BCO 1	BCO 2	BCO 3	BCO 4	BCO 5	BCO 7	BCO 8
1931–32	29	0	55	148	719	4	4
1932–33	12	0	59	111	726	1	5
1933–34	24	5	26	1 055	792	3	2
1934–35	17	5	23	1 306	1057	0	4
1935–36	18	23	34	1 197	284	44	2
1936–37	3	7	27	755	113	61	0
1937–38	2	8	31	793	172	81	0
1938–39	2	3	19	686	94	57	0
1939–40	1	4	33	715	135	68	0
1940–41	3	7	39	320	177	72	0
1941–42	2	5	30	189	128	54	0
1942–43	3	5	20	204	139	65	0
1943–44	4	12	31	212	221	80	0
1944	3	10	38	216	552	88	0
1945	8	6	45	102	634	109	0
1946	11	9	43	175	715	116	2
1947	8	22	81	278	955	153	1
1948	7	24	74	623	852	88	2
1949	37	6	98	390	929	82	3
1950	5	5	66	485	1005	94	1
1951	4	9	51	494	873	74	2
1952	5	7	53	543	889	95	3
1953	7	20	62	682	414	114	2
1954	5	9	84	603	385	112	2
1955	4	8	83	355	405	79	3
1956	1	7	86	636	656	77	2
1957	2	5	63	1185	581	61	2
1958	2	4	57	892	542	71	2
1959	1	2	51	1158	492	71	1
1960	1	4	48	903	757	65	2
1961	1	2	43	871	590	55	3
1962	1	9	37	550	668	65	3
1963	1	12	46	633	621	60	4
1964	1	107	83	495	462	70	3
1965	1	18	55	742	296	59	2
1966	1	395	35	13	337	79	6
1967	1	437	34	0	518	74	5
1968	1	312	69	0	494	105	2
1969	6	232	92	8	361	60	1
1970	0	402	70	39	432	70	8
1971	1	105	81	36	375	44	2
1972	0	137	60	3	194	63	1
1973	1	127	65	4	571	68	11
1974	0	67	61	1	486	61	16
1975	0	5	42	2	232	58	14
1976	0	103	72	17	254	58	17
1977	2	3	21	46	208	87	19
1978	0	9	49	14	197	104	12
1979	0	17	74	13	217	98	16
1980	1	1	89	1	403	62	18
1981	1	2	69	40	494	79	23
1982	7	0	62	13	356	68	34

Table 3: Reported landings (t) of blue cod by Fishstock from 1983 to present and actual TACCs (t) from 1986–87 to present. QMS data from 1986 to present. FSU data cover 1983–1986. [Continued on next page]

Fishstock	BCO 1		BCO 2		BCO 3		BCO 4		BCO 5	
FMA (s)	1 & 9		2		3		4		5 & 6	
	Landings	TACC	Landings	TACC	Landings	TACC	Landings	TACC	Landings	TACC
1983*	23	–	4	–	81	–	192	–	626	–
1984*	39	–	6	–	74	–	273	–	798	–
1985*	21	–	3	–	55	–	274	–	954	–
1986*	19	–	2	–	82	–	337	–	844	–
1986–87	8	30	1	10	84	120	417	600	812	1 190
1987–88	9	40	1	10	148	140	204	647	938	1 355
1988–89	8	42	1	10	136	142	279	647	776	1 447
1989–90	10	45	1	10	121	151	358	749	928	1 491
1990–91	12	45	< 1	10	144	154	409	757	1 096	1 491
1991–92	10	45	1	10	135	154	378	757	873	1 536
1992–93	12	45	4	10	171	156	445	757	1 029	1 536
1993–94	14	45	2	10	142	162	474	757	1 132	1 536
1994–95	13	45	1	10	155	162	565	757	1 218	1 536
1995–96	11	45	2	10	158	162	464	757	1 503	1 536
1996–97	13	45	2	10	156	162	423	757	1 326	1 536
1997–98	16	45	4	10	163	162	575	757	1 364	1 536
1998–99	12	45	2	10	150	162	499	757	1 470	1 536
1999–00	14	45	2	10	168	162	490	757	1 357	1 536
2000–01	15	45	2	10	154	162	627	757	1 470	1 536
2001–02	12	46	2	10	138	163	648	759	1 477	1 548
2002–03	11	46	4	10	169	163	724	759	1 497	1 548
2003–04	9	46	4	10	167	163	710	759	1 556	1 548
2004–05	9	46	5	10	183	163	731	759	1 473	1 548
2005–06	7	46	1	10	183	163	580	759	1 346	1 548
2006–07	6	46	4	10	177	163	747	759	1 382	1 548
2007–08	6	46	3	10	167	163	779	759	1 277	1 548
2008–09	7	46	8	10	158	163	787	759	1 391	1 548
2009–10	8	46	7	10	171	163	691	759	1 210	1 548
2010–11	7	46	8	10	183	163	781	759	1 296	1 548
2011–12	6	46	8	10	166	163	753	759	1 215	1 239
2012–13	9	46	7	10	170	163	739	759	1 207	1 239
2013–14	9	46	8	10	159	163	720	759	1 208	1 239
2014–15	11	46	7	10	175	163	796	759	1 132	1 239
2015–16	9	46	6	10	169	163	758	759	1 099	1 239
2016–17	12	46	10	10	170	163	741	759	1 152	1 239
2017–18	8	46	12	10	174	163	752	759	1 027	1 239
2018–19	9	46	9	10	177	163	744	759	827	1 239
2019–20	8	46	7	10	180	163	732	759	926	1 239
2020–21	8	46	7	10	183	163	703	759	788	800

Fishstock	BCO 7		BCO 8		BCO 10			
FMA (s)	7		8		10		Total	
	Landings	TACC	Landings	TACC	Landings	TACC	Landings	TACC
1983*	91	–	53	–	0	–	1 070	–
1984*	129	–	56	–	0	–	1 375	–
1985*	169	–	70	–	0	–	1 546	–
1986*	83	–	42	–	0	–	1 409	–
1986–87	79	110	22	60	0	10	1 422	2 130
1987–88	78	126	44	72	0	10	1 420	2 400
1988–89	66	131	32	72	0	10	1 298	2 501
1989–90	75	136	34	74	0	10	1 527	2 666
1990–91	63	136	28	74	0	10	1 752	2 667
1991–92	57	136	25	74	0	10	1 480	2 722
1992–93	85	136	32	74	0	10	1 777	2 724
1993–94	67	95	21	74	0	10	1 852	2 689
1994–95	113	95	24	74	0	10	2 089	2 689
1995–96	65	70	31	74	0	10	2 234	2 664
1996–97	71	70	38	74	0	10	2 029	2 664
1997–98	60	70	15	74	0	10	2 197	2 664
1998–99	52	70	35	74	0	10	2 220	2 664
1999–00	28	70	30	74	0	10	2 089	2 664
2000–01	26	70	22	74	0	10	2 316	2 664
2001–02	30	70	17	74	0	10	2 319	2 680
2002–03	39	70	13	74	0	10	2 457	2 680
2003–04	45	70	10	74	0	10	2 501	2 680
2004–05	44	70	7	74	0	10	2 452	2 680
2005–06	50	70	20	74	0	10	2 184	2 680
2006–07	69	70	34	74	0	10	2 413	2 680
2007–08	59	70	22	74	0	10	2 313	2 680
2008–09	58	70	18	74	0	10	2 427	2 680
2009–10	59	70	16	74	0	10	2 162	2 680
2010–11	51	70	16	74	0	10	2 342	2 681
2011–12	54	70	10	34	0	10	2 214	2 332
2012–13	71	70	12	34	0	10	2 215	2 332
2013–14	58	70	12	34	0	10	2 174	2 332
2014–15	68	70	8	34	0	10	2 198	2 332
2015–16	60	70	4	34	0	10	2 096	2 332
2016–17	65	70	5	34	0	10	2 155	2 332

Table 3: [Continued]

Fishstock FMA (s)	BCO 7 7		BCO 8 8		BCO 10 10		Total	
	Landings	TACC	Landings	TACC	Landings	TACC	Landings	TACC
2017–18	71	70	4	34	0	10	2 049	2 332
2018–19	64	70	14	34	0	10	1 844	2 332
2019–20	57	70	3	34	0	10	1 914	2 332
2020–21	55	70	3	34	0	10	1 748	1 893

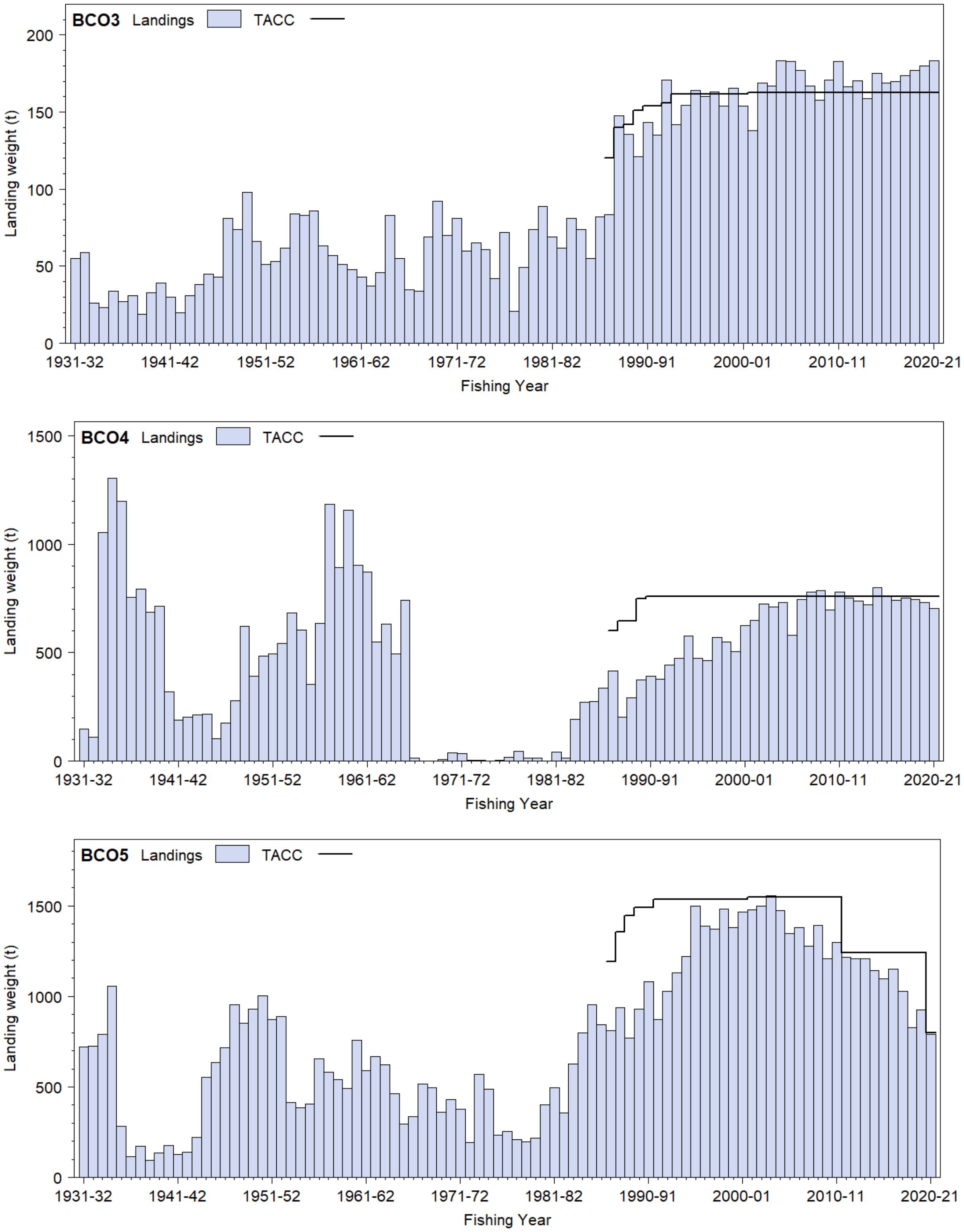
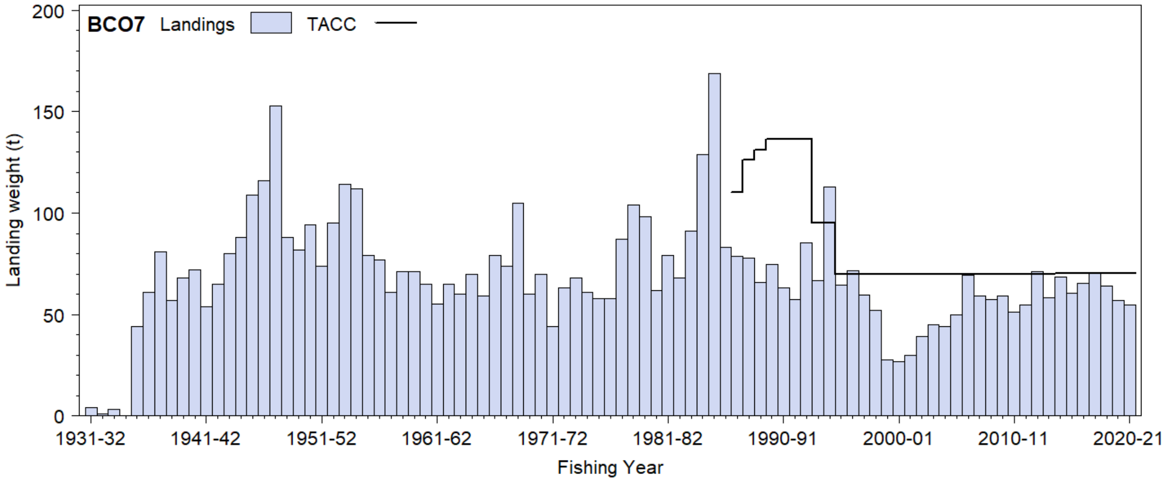


Figure 1: Reported commercial landings and TACC for the five main BCO stocks. From top: BCO 3 (South East Coast), BCO 4 (South East Chatham Rise), and BCO 5 (Southland). **[Continued on next page]**



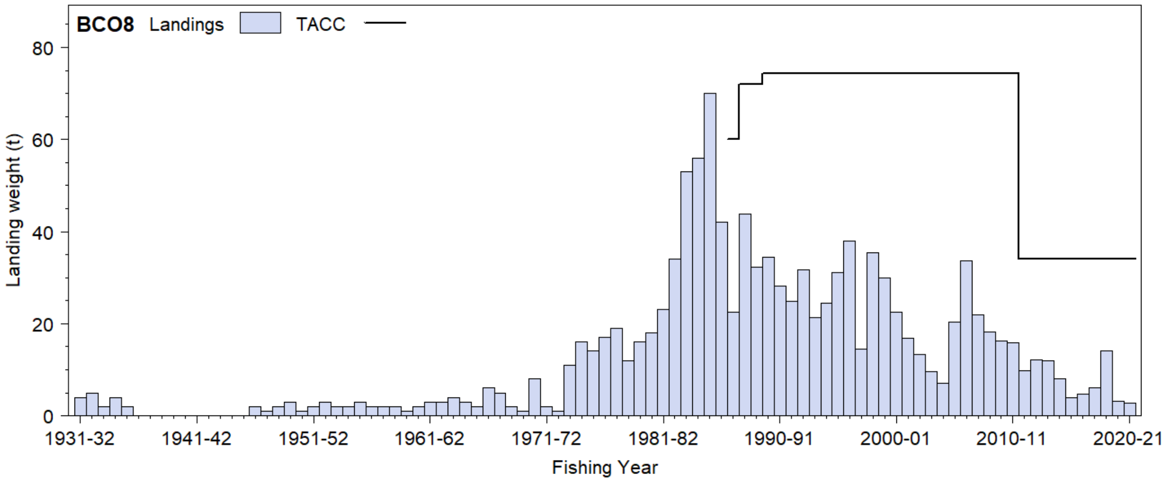


Figure 1: [Continued] Reported commercial landings and TACC for the five main BCO stocks. From top: BCO 7 (Challenger) and BCO 8 (Central Egmont).

Table 4: Reported total New Zealand landings (t) of blue cod for the calendar years 1970 to 1983. Sources MAF and FSU data.

Year	Landings
1970	1 022
1971	644
1972	459
1973	846
1974	696
1975	356
1976	524
1977	383
1978	378
1979	437
1980	536
1981	696
1982	539
1983	1 135

1.2 Recreational fisheries

Blue cod are generally the most important recreational finfish in Marlborough, Otago, Canterbury, Southland, and the Chatham Islands. Blue cod are taken predominantly by line fishing, but also by longlining, set netting, potting, and spearfishing. The current allowances within the TAC for each Fishstock are shown in Table 1.

1.2.1 Management controls

The main methods used to manage recreational harvests of blue cod are minimum legal size (MLS) limits, method restrictions, and daily bag limits. Daily bag limits are specified as either blue cod specific (DL) or a combined species limit (CDL). The main management controls have changed over time and vary by

Fishstock (Table 5). In addition, there have been temporary and seasonal closures in the Marlborough Sounds and several Fiordland sounds.

Table 5: Minimum legal size (MLS in cm), blue cod specific daily bag limit (DL), and combined species daily bag limit (CDL) by Fishstock from 1986 to present. Slot = slot limit (legal size range). * DS = Doubtful Sounds, TS = Thompson Sound, BS = Bradshaw Sound. C = inner sounds closed. # excluding Challenger East. ^bag limit of 6 inside Te Whaka ā Te Wera Mātaitai Reserve. There are two separate areas with different bag limits in each of BCO 3 South East and BCO 5 Southland (see text below for more detail).**

Fishstock	BCO 1		BCO 2		BCO 3		BCO 3		BCO 3		BCO 4	
Area	Auckland		Central (East)		South East (Otago)		North Canterbury		Kaikōura Marine Area		South East (Chatham Is.)	
	MLS	CDL	MLS	CDL	MLS	CDL	MLS	DL	MLS	DL	MLS	CDL
1986	30	30	30	30	30	30	30	30	N/A	N/A	30	30
1993	33	20	33	20	30	30	30	30	N/A	N/A	30	30
1994	33	20	33	20	30	30	30	30	N/A	N/A	30	30
2001	33	20	33	20	30	30	30	10	N/A	N/A	30	30
2008	30	20	33	20	30	30	30	10	N/A	N/A	30	30
2014	30	20	33	20	30	30	30	10	33	6	30	30
2017	30	20	33	20	30	30	30	10	33	6	30	30
2020	30	20	33	20	33	10/15	33	2	33	6	33	15

Fishstock	BCO 5		BCO 5		BCO 5		BCO 5		BCO 7		BCO 7	
Area	Southland & Fiordland (External)		Paterson Inlet ^		Fiordland internal (excl. DS, TS, BS*)		DS, TS, BS*		Challenger West & South		Challenger East (incl. Marlborough Sounds)	
	MLS	CDL	MLS	DL	MLS	DL	MLS	DL	MLS	DL	MLS	DL
1986	30	30	30	30	33	20	33	20	30	30	30	12
1993	33	30	33	30	33	20	33	20	33	20	33	10
1994	33	30	33	15	33	20	33	20	33	20	28	6
2001	33	30	33	15	33	20	33	20	33	20	28	6
2003	33	30	33	15	33	20	33	20	33	20	30	3
2005	33	30	33	15	33	20	C**	C**	33	20	30	3
2008	33	30	33	15	33	20	C**	C**	33	20	C**	C**
2011	33	30	33	15	33	20	C**	C**	33	20	#SLOT 30–35	2
2014	33	20	33	15	33	20	C**	C**	33	20	#SLOT 30–35	2
2015	33	20	33	15	33	3	33	1	33	20	33	2
2017	33	20	33	15	33	3	33	1	33	20	33	2
2020	33	15/10	33	15	33	3	33	1	33	10	33	2

Fishstock	BCO 8		BCO 10	
Area	Central (West)		Kermadec	
	MLS	DL	MLS	CDL
1986	30	30	30	30
1993	33	20	33	20
2014	33	10	33	20
2017	33	10	33	20
2020	33	10	33	20

During 1992–93, the national minimum legal size (MLS) for blue cod increased from 30 cm to 33 cm for both amateur and commercial fishers, with the exception of BCO 3 and BCO 4 (South East management area). However, this was amended to 30 cm in 2008 for BCO 1, in response to a management review of blue cod in the area. Additionally, the Marlborough Sounds Area (part of BCO 7) had several MLS amendments between 1993 and 2015, including a closure in the inner sounds followed by a slot limit of 30–35 cm in response to differing management approaches in the Marlborough Sounds, before changing to an MLS of 33 cm and daily bag limit of 2 in 2015. In 2014, the Kaikōura Marine Area in BCO 3 was established and the MLS of blue cod in this area was set at 33 cm. In 2020, an MLS of 33 cm was adopted for all management areas out to 12 nm, apart from BCO 1 which remains at 30 cm.

In 2001, the recreational daily bag limit (DL) was reduced to 10 fish over the MLS in the North Canterbury area (BCO 3). In 2014, the DL was set at 6 in the newly established Kaikōura Marine Area (BCO 3), and the DL was reduced to 20 in Southland and the external waters of the Fiordland marine area (BCO 5). Before these changes, the DL in Paterson's Inlet (BCO 5) was reduced from 30 to 15 in 1994. In 2005, new commercial and recreational rules were introduced to the internal waters of the Fiordland Marine Area and Doubtful Sound, Thompson Sound, and Bradshaw Sound were closed to all blue cod fishing for 10 years. The closure was lifted in 2015 to allow recreational blue cod fishing and the new DL within Doubtful Sound was set at 1. The DL for the Challenger East area (BCO 7) has reduced from 10 to 2 since 1993 in response to differing management regimes in the area. In 2014, the DL in BCO 8 was reduced from 20 to 10.

On 1 July 2020, the DLs for South Island stocks out to 12 nm were revised (http://www.mpi.govt.nz/bluecod). In BCO 5 there are two areas with DLs of 10 and one with a DL of 15. The restrictions in the fiords and sounds remained unchanged. In BCO 3 the area south of Otago Harbour mouth has a DL of 15 and the area north to Banks Peninsula has a DL of 10. From the southern side of Banks Peninsula to the Conroy River, the DL is 2. North of the Conway River to the Clarence River, the DL is 10 and within the Kaikōura Marine Area the DL is 6. The BCO 7 Tasman area, including the Marlborough Sounds, has a DL of 2, whereas the Kahurangi area has a DL of 10 and the Westland area a DL of 15. The DL for the Chatham Islands is 15.

1.2.2 Estimates of recreational harvest

Recreational harvest estimates are given in Table 6. There are two broad approaches to estimating recreational fisheries harvest: the use of onsite or access point methods where fishers are surveyed or counted at the point of fishing or access to their fishing activity; and offsite methods where some form of post-event interview and/or diary are used to collect data from fishers.

The first estimates of recreational harvest for blue cod were calculated using an offsite approach, the offsite regional telephone and diary survey approach: MAF Fisheries South (1991–92), Central (1992–93), and North (1993–94) regions (Teirney et al 1997). Estimates for 1996 came from a national telephone and diary survey (Bradford 1998). Another national telephone and diary survey was carried out in 2000 (Boyd & Reilly 2004) and a rolling replacement of diarists in 2001 (Boyd et al 2004) allowed estimates for a further year (population scaling ratios and mean weights were not re-estimated in 2001).

The harvest estimates provided by these telephone diary surveys are no longer considered reliable for various reasons. With the early telephone/diary method, fishers were recruited to fill in diaries by way of a telephone survey that also estimated the proportion of the population that was eligible (likely to fish). A 'soft refusal' bias in the eligibility proportion arose if interviewees who did not wish to co-operate falsely stated that they never fished. The proportion of eligible fishers in the population (and, hence, the harvest) was thereby under-estimated. Pilot studies for the 2000 telephone/diary survey suggested that this effect could occur when recreational fishing was established as the subject of the interview at the outset. Another equally serious cause of bias in telephone/diary surveys was that diarists who did not immediately record their day's harvest after a trip sometimes overstated their harvest or the number of trips made. There is some indirect evidence that this may have occurred in all the telephone/diary surveys (Wright et al 2004).

The recreational harvest estimates provided by the 2000 and 2001 telephone diary surveys are thought to be implausibly high, which led to the development of an alternative maximum count aerial-access onsite method that provides a more direct means of estimating recreational harvests for suitable fisheries. The maximum count aerial-access approach combines data collected concurrently from two sources: a creel survey of recreational fishers returning to a subsample of ramps throughout the day; and an aerial survey count of vessels observed to be fishing at the approximate time of peak fishing effort on the same day. The ratio of the aerial count in a particular area to the number of interviewed parties who claimed to have fished in that area at the time of the overflight was used to scale up harvests observed at surveyed ramps, to estimate harvest taken by all fishers returning to all ramps. The methodology is further described by Hartill et al (2007).

This aerial-access method was first employed, optimised for SNA, in the Hauraki Gulf in 2003–04. It was then extended to survey the wider SNA 1 fishery in 2004–05 and to other areas (SNA 8) and other species, including blue cod in BCO 7 in 2005–06 (Davey et al 2008). The estimates for BCO 7 in 2005–06 may not be accurate for two reasons. A large proportion of the fishing effort observed during aerial surveys of the outer Marlborough Sounds was from launches and other vessels that would not have returned to the surveyed boat ramps, because they would have returned to other access points and often on following days. A significant proportion of the boats fishing in the inner Marlborough Sounds may also have returned to a bach/crib rather than a surveyed ramp. For both these situations it was therefore necessary to assume that the catch and effort of these boats would have been the same as that reported by boats returning to surveyed boat ramps on the same day, which may not have been the case. A repeat aerial-access survey was conducted in BCO 7 over the 2015–16 fishing year (Hartill et al 2017) and this was considered by the Marine Amateur Fisheries Working Group to be more reliable than the initial survey because a greater number of days were surveyed in this year, and a pilot survey was undertaken to determine where boats fishing in the inner Marlborough Sounds had originated from, which led to interviews being conducted at two extra high traffic ramps in this area. The recreational harvest from BCO 7 in 2015–16 was about half that in 2005–06 (Table 6), almost with all the decrease being in the Marlborough Sounds.

In response to the cost and scale challenges associated with onsite methods, in particular the difficulties in sampling other than trailer boat fisheries, offsite approaches to estimating recreational fisheries harvest have been revisited. This led to the implementation of a national panel survey during the 2011–12 fishing year (Wynne-Jones et al 2014). The panel survey used face-to-face interviews of a random sample of 30 390 New Zealand households to recruit a panel of fishers and non-fishers for a full year. The panel members were contacted regularly about their fishing activities and harvest information in standardised phone interviews. The national panel survey was repeated during the 2017–18 fishing year using very similar methods to produce directly comparable results (Wynne-Jones et al 2019). Recreational catch estimates from the two national panel surveys are given in Table 6. Note that national panel survey estimates do not include recreational harvest taken under s111 general approvals.

Table 6: Recreational harvest estimates for blue cod stocks. The telephone/diary surveys and aerial-access survey ran from December to November but are denoted by the January calendar year. The national panel surveys ran throughout the October to September fishing years but are denoted by the January calendar year. Mean fish weights were obtained from boat ramp surveys (for the telephone/diary and panel survey harvest estimates).

Stock	Year	Method	Number of fish	Total weight (t)	CV
BCO 1	1996	Telephone/diary	34 000	17	0.11
	2000	Telephone/diary	37 000	23	0.31
	2012	Panel survey	17 463	1	0.20
	2018	Panel survey	13 276	6	0.18
BCO 2	1996	Telephone/diary	145 000	81	0.13
	2000	Telephone/diary	187 000	161	0.25
	2012	Panel survey	53 618	26	0.19
	2018	Panel survey	48 140	28	0.26
BCO 3	1996	Telephone/diary	217 000	151	0.11
	2000	Telephone/diary	1 026 000	752	0.29
	2012	Panel survey	212 184	101	0.20
	2018	Panel survey	202 765	99	0.18
BCO 5	1996	Telephone/diary	171 000	139	0.12
	2000	Telephone/diary	326 000	229	0.28
	2012	Panel survey	72 328	44	0.24
	2018	Panel survey	139 176	67	0.20
BCO 7	1996	Telephone/diary	356 000	239	0.09
	2000	Telephone/diary	542 000	288	0.20
	2006	Aerial-access	–	149	0.16
	2012	Panel survey	176 152	77	0.17
	2016	Aerial-access	–	75	0.15
	2018	Panel survey	129 038	63	0.12
BCO 8	1996	Telephone/diary	159 000	79	0.12
	2000	Telephone/diary	232 000	188	0.32
	2012	Panel survey	88 980	48	0.36
	2018	Panel survey	62 539	31	0.20

1.2.3 Charter vessel harvest

The national marine diary survey of recreational fishing from charter vessels in 1997–98 found blue cod to be the second most frequently landed species nationally and the most frequently landed species in the South Island. Results indicated that recreational harvests from charter vessels (Table 7) follow the same pattern as overall recreational harvest (Table 6). The estimated recreational harvests from charter vessels in BCO 7 exceeded the 1997–98 TACC and the commercial landings in QMA 7.

Table 7: Results of a national marine diary survey of recreational fishers from charter vessels, 1997–98 (November 1997 to October 1998).*

Fishstock	Number caught	CV	Estimated landings (number of fish killed)	Point Estimate (t)
BCO 1	430	0.18	2 500	2.4
BCO 2	34	0.50	300	0.2
BCO 3	17 272	0.29	72 000	58
BCO 5	16 750	0.36	63 000	51
BCO 7	32 026	0.13	110 000	76
BCO 8	2	–	–	0

*Estimated number of blue cod harvested by recreational fishers on charter vessels by Fishstock and the corresponding harvest tonnage. The mean weights used to convert numbers to harvest weight were considered the best available at the time (James & Unwin 2000).

1.3 Customary non-commercial fisheries

No quantitative data on historical or current blue cod customary non-commercial catch are available. However, bones found in middens show that blue cod was a significant species in the traditional Māori take of pre-European times.

1.4 Illegal catch

No quantitative data on the levels of illegal blue cod catch are available.

1.5 Other sources of mortality

Blue cod have in the past been used for bait within the rock lobster fishery. Pots are either set specifically to target blue cod or have a bycatch of blue cod that is used for bait. However, these fish are frequently not recorded and the quantity of blue cod used as bait cannot be accurately determined.

Cod pots covered in 38 mm mesh frequently catch undersized blue cod. It has been estimated that in Southland, 65% of blue cod caught in these pots are less than 33 cm. (The commercial MLS was increased from 30 cm to 33 cm in 1994.) When returned, the mortality of these fish can be high due to predation by mollymawks following commercial boats. It is estimated by the fishing industry that up to 50% of returned fish can be taken. To reduce the problem of predation of returned undersized fish, a minimum 48 mm mesh size was introduced to BCO 5 in 1994. However, no mesh size restrictions exist in any other area. An experiment conducted by Glen Carbines on commercial vessels in 2015 to quantify the reduction in undersized blue cod caught in pots with the alternative mesh size showed that almost all retained undersized fish were dead when returned to the water. Even though blue cod are not subject to barotrauma, because they have no swim bladders, the high mortality was the result of undersized blue cod being returned after the catch had been processed. In 2018 the mesh size in BCO 5 was increased to 54 mm, and on 1 July 2020 the mesh size for all areas was increased to 54 mm.

Recreational line fishing often results in the harvest of undersized blue cod. The survival of these fish has been shown to be a factor of hook size. A small-scale experiment showed that returned undersized fish caught with small hooks (size 1/0) experience 25% mortality, whereas those caught with large hooks (size 6/0) appear to have little or no mortality (Carbines 1999).

2. BIOLOGY

Blue cod is a bottom-dwelling species endemic to New Zealand. Although distributed throughout New Zealand near foul ground to a depth of 150 m, they are more abundant south of Cook Strait and around the Chatham Islands. Growth may be influenced by a range of factors, including sex, habitat quality, and fishing pressure relative to location (Carbines 2004a). Size-at-sexual maturity also varies according to location. In Northland, maturity is reached at 10–19 cm total length (TL) at an age of 2 years, whereas in the Marlborough Sounds it is reached at 21–26 cm TL at 3–6 years. In Southland, the fish become mature at 26–28 cm TL, at an age of 4–5 years. Blue cod have also been shown to be protogynous hermaphrodites, with some individuals over a large length range changing sex from female to male (Carbines 1998). Blue cod are a diandric species where males either develop directly from the undifferentiated state without sex inversion (primary males) or begin life as female and become male following sex inversion (secondary males) (Beentjes 2021). Validated age estimates using otoliths have shown that blue cod males grow faster and are larger than females (Walsh 2017). The maximum recorded age for this species is about 32 years.

An *M* of 0.17 was based on the empirical age distribution from the offshore Banks Peninsula survey in 2016, aged using the blue cod age determination protocol. The *M* estimate is based on the 1% tail of the distribution, which was 27 years, not the maximum age. The default *M* for blue cod was changed from 0.14 to 0.17 in April 2019 following the recommendation of the Inshore Working Group. Previous spawner-per-recruit ratio (SPR) analyses carried out using 0.14 are being updated following routine blue cod surveys.

Blue cod have an annual reproductive cycle with an extended spawning season during late winter and spring. Spawning has been reported within inshore and mid-shelf waters. It is also likely that spawning occurs in outer-shelf waters. Ripe blue cod are also found in all areas fished commercially by blue cod fishers during the spawning season. Batch fecundity was estimated by Beer et al (2013). Eggs are pelagic for about five days after spawning, and the larvae are pelagic for about five more days before settling onto the seabed. Juveniles (less than about 10 cm TL) are not caught by commercial potting or lining, and therefore blue cod are not vulnerable to the main commercial fishing methods until they are mature. Recreational methods do catch juveniles, but since this species does not have a swim bladder, the survival of these fish is good if they are caught using large hooks (6/0) (which do not result in gut hooking) and returned to the sea quickly (Carbines 1999).

Biological parameters relevant to stock assessment are shown in Table 8.

Table 8: Estimates of biological parameters for blue cod. These estimates are survey specific and reflect varying exploitation histories and environmental conditions. Only von Bertalanffy growth parameters derived from otoliths aged using the Age Determination Protocol for Blue Cod (Walsh 2017) are included in this table.

Fishstock	**Estimate**	**Source**
1. Natural mortality (*M*)		
All	0.17	Doonan (2020)

2. von Bertalanffy growth parameters

	Females			Males			
Survey/year	L_∞	K	t_0	L_∞	k	t_0	
Dusky Sound (2014)	46.7	0.129	-1.8	50.3	0.222	0.638	Beentjes & Page (2016)
Kaikōura (2015)	40.7	0.174	-1.12	52.3	0.171	-0.27	Beentjes & Page (2017)
Banks Peninsula (2016)	50.2	0.116	-2.07	58.7	0.134	-1.21	Beentjes & Fenwick (2017)
Marlborough Sounds (2017)	32.2	0.52	0.83	39.9	0.37	0.69	Beentjes et al (2018)
Paterson Inlet (2018)	40.0	0.20	-4.31	46.8	0.21	0.215	Beentjes & Miller (2020)

3. Weight = a(length)^b (Weight in g, length in cm total length).

Area			a	b	R^2	
Kaikōura	2011	Male	0.011793	3.09246	0.97	Carbines & Haist (2012b)
	2011	Female	0.007042	3.23949	0.95	
Motunau	2012	Male	0.01490	3.03796	0.98	Carbines & Haist (2012b)
	2012	Female	0.01384	3.05982	0.97	
Banks Peninsula	2012	Male	0.019138	2.98181	0.98	Carbines & Haist (2012a)
	2012	Female	0.016939	3.02644	0.96	
North Otago	2013	Male	0.01093	3.10941	0.98	Carbines & Haist (2014b)
	2013	Female	0.012023	3.09201	0.97	
South Otago	2013	Male	0.008472	3.19011	0.99	Carbines & Haist (2014c)
	2013	Female	0.008617	3.1863	0.99	
Fiordland	2002	Male	0.007825	3.1727	0.97	Carbines & Beentjes (2003)
(Dusky Sound)	2002	Female	0.00506	3.2988	0.98	
Stewart Island	2010	Male	0.00663	3.2469	0.98	Carbines & Haist (2014a)
(Paterson Inlet)	2010	Female	0.00663	3.2469	0.98	
Marlborough	2017	Male	0.00674	3.218	0.96	Beentjes et al (2018)
Sounds		Female	0.00648	3.238	0.94	

Tagging experiments carried out in the Marlborough Sounds in the 1940s and 1970s suggested that most blue cod remained in the same area for extended periods. A more recent tagging experiment carried out in Foveaux Strait (Carbines 2001) showed that although some blue cod moved as far as 156 km, 60% travelled less than 1 km. A similar pattern was found in Dusky Sound where from a total of 61 recaptures, four fish moved over 20 km but 65% had moved less than 1 km (Carbines & McKenzie 2004). The larger movements observed during this study were generally eastwards into the fiord. The inner half of the fiord was found to drain the outer strata and had 100% residency.

The preliminary results of a mitochondrial DNA analysis (Smith 2012) suggest that the Chatham Island blue cod are likely to be genetically distinct from mainland New Zealand fish. Over larger distances the mainland New Zealand blue cod appear to show a pattern of Isolation-by-Distance or continuous genetic change among populations. However, there is no evidence that blue cod are genetically distinct around the New Zealand mainland (Gebbie 2014).

3. STOCKS AND AREAS

The FMAs are used as a basis for Fishstocks, except FMAs 5 and 6, and FMAs 1 and 9, which have been combined. The choice of these boundaries was based on a general review of the distribution and relative abundance of blue cod within the fishery.

There are no data that would alter the current stock boundaries. However, tagging experiments suggest that blue cod populations may be geographically isolated from each other, and there may be several distinct sub-populations within each management area (particularly those occurring in sounds and inlets).

4. STOCK ASSESSMENT

4.1 Estimates of fishery parameters and abundance

4.1.1 South Island blue cod potting surveys

Potting surveys are used to monitor blue cod populations supporting nine important recreational fisheries around the South Island (Figure 2). Surveys are generally carried out every four years and are used to monitor relative abundance and size, age, and sex structure of the nine geographically separate blue cod populations. The surveys also provide an estimate of fishing mortality (*F*) and associated spawner-per-recruit ratios. All potting surveys (except Foveaux Strait) originally used a fixed-site design, with predetermined (fixed) locations randomly selected from a limited pool of such sites. The South Island potting surveys were reviewed by an international expert panel in 2009, which recommended that blue cod would be more appropriately surveyed using random-site potting surveys (Stephenson et al 2009). A random site is any location (single latitude and longitude) generated randomly from within a stratum. Following this recommendation, all survey series began the transition to fully random survey designs with interim sampling of both fixed and random sites allowing comparison of catch rates, length and age composition, and sex ratios between the survey designs. Random sites were the only site type used in Foveaux Strait, and all other areas except Dusky Sound have now transitioned to solely random-site surveys.

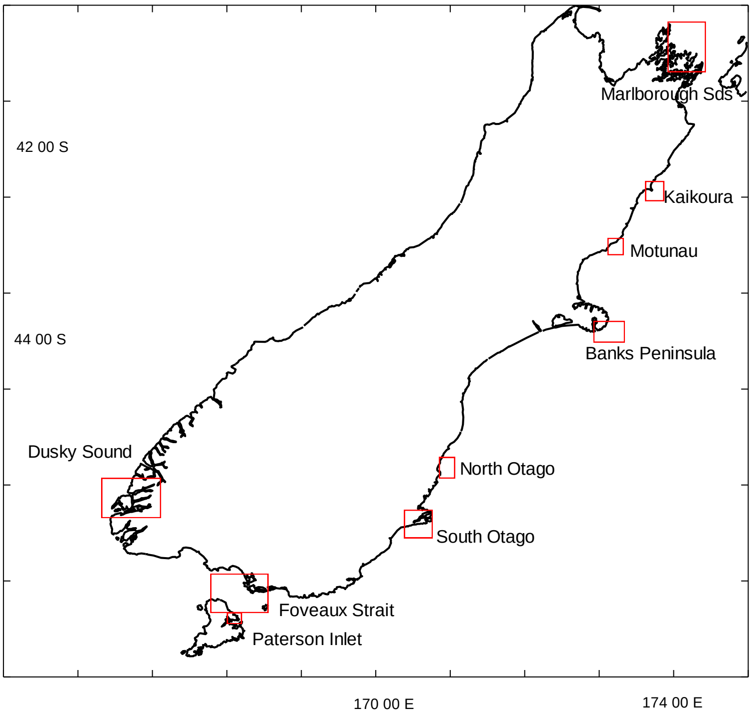


Figure 2: Map showing the nine South Island blue cod potting survey locations.

Marlborough Sounds

Fixed-site surveys were carried out using standardised cod pots (pot plan 1) between 1995 and 2017, either in all strata or partially, within five regions: Queen Charlotte Sound (QCH), Pelorus Sound (PEL), D'Urville Island (DUR), Cook Strait (CKST), and Separation Point (SEPR) (Table 9).

In 2010, experimental random sites using the same pot plan 1 were trialled in selected strata within Pelorus Sound, D'Urville Island, and the entire Cook Strait region (Table 9), and in 2013 and 2017 (Beentjes et al 2017, Beentjes et al 2018), full random-site and full fixed-site surveys were conducted concurrently. In 2021 the first solely random-site survey was carried out and this survey has now fully transitioned to the random-site design (Beentjes et al 2022a). The 2017 and 2021 random-site surveys also included Long Island Marine Reserve.

Table 9: Fixed-site and random-site blue cod potting survey time series in the Marlborough Sounds by region. QCH, Queen Charlotte Sound; PEL, Pelorus Sound; DUR, D'Urville Island; CKST, Cook Strait; SEPR, Separation Point; LIMR, Long Island Marine Reserve; all, all strata surveyed; partial, not all strata surveyed; – no survey.

	Fixed-site surveys by region					Random-site surveys by region				
Year	QCH	PEL	DUR	CKST	SEPR	QCH	PEL	DUR	CKST	LIMR
1995	all	partial	–	–	–	–	–	–	–	–
1996	–	all	partial	–	–	–	–	–	–	–
2001	all	all	partial	–	–	–	–	–	–	–
2004	all	all	all	–	all	–	–	–	–	–
2007	all	all	all	–	all	–	–	–	–	–
2008	–	–	–	all	–	–	–	–	–	–
2010	all	all	all	–	–	–	partial	partial	all	–
2013	all	all	all	–	–	all	all	all	all	–
2017	all	all	all	–	–	all	all	all	all	all
2021	–	–	–	–	–	all	all	all	all	all

Fixed-site surveys
Throughout the fixed-site surveys, catch rates of total blue cod (all sizes) have tended to be highest around D'Urville Island (Figure 3, Table 10). In Queen Charlotte Sound catch rates progressively declined from 2.1 to 1.1 kg pot^{-1} (CV range 16 to 26%) between 1995 and 2007 before increasing markedly in 2010 to 1.75 kg pot^{-1} (Figure 3). From October 2008 to April 2011, the inner sounds were closed to recreational blue cod fishing and the 2010 potting survey increased abundance in Queen Charlotte Sound is attributed to the closure. In Pelorus Sound, total blue cod catch rates declined from 2.4 to 1.1 kg pot^{-1} (CV range 7 to 19%) over the same period, then increased again in 2010, to 2.9 kg pot^{-1} (Figure 3). Pelorus Sound showed a similar trend in catch rates to Queen Charlotte Sound, dropping markedly from 1996 to 2007 and increasing again in 2010 after two years of closure. The overall Marlborough Sounds fixed-site surveys catch rates from 2004 onward (where survey strata are consistent among surveys) showed the large increase in 2010, consistent with the closure of the inner sounds, and a second increase in 2017. In April 2011, a seasonal opening with a 'slot limit' (which allowed the take of blue cod between 30 and 35 cm) was introduced for the Marlborough Sounds Management Area, an area that includes inner and outer Queen Charlotte Sound and Pelorus Sound and east D'Urville. The slot limit was removed in December 2015. There was no closure or slot limit for Cook Strait.

The 2013 survey was carried out two years after the slot limit had been in place, with total blue cod catch rates for both Queen Charlotte Sound and Pelorus Sound declining relative to the 2010 survey, but remaining higher than 2001 to 2007 for Pelorus Sound when the fishery was open, and about the same magnitude as pre-closure for Queen Charlotte Sound (Figure 3). In the D'Urville Island strata, which have been fished continuously over the same period, catch rates for total blue cod between 2004 and 2013 have been stable, ranging from 3.9 to 4.44 kg pot^{-1} (CV range 8 to 18%) (Figure 3). D'Urville Island was not closed to fishing in October 2008, but the east side of the island was included in the management area where the 'slot limit' has been applicable since April 2011. Cook Strait has had only one fixed-site survey, in 2008.The proportion of the total biomass within the slot limit (30–35 cm) in 2013 was 45%, 49%, and 49% for QCH, PEL, and DUR regions, respectively, and proportions of biomass above the slot limit were 26%, 25%, and 22%, respectively. Sex ratios have been dominated by males in all regions over all fixed-site surveys (Table 10). The 2017 survey took place 2 years after the slot limit was removed and in the Marlborough Sounds Area the MLS was increased to 33 cm. In 2017, catch rates from the fixed-site survey in Queen Charlotte Sound were similar to those in 2013, in Pelorus Sound they were similar to 2010, and at D'Urville Island they were about 40% higher than in 2013 (Figure 3, Table 10).

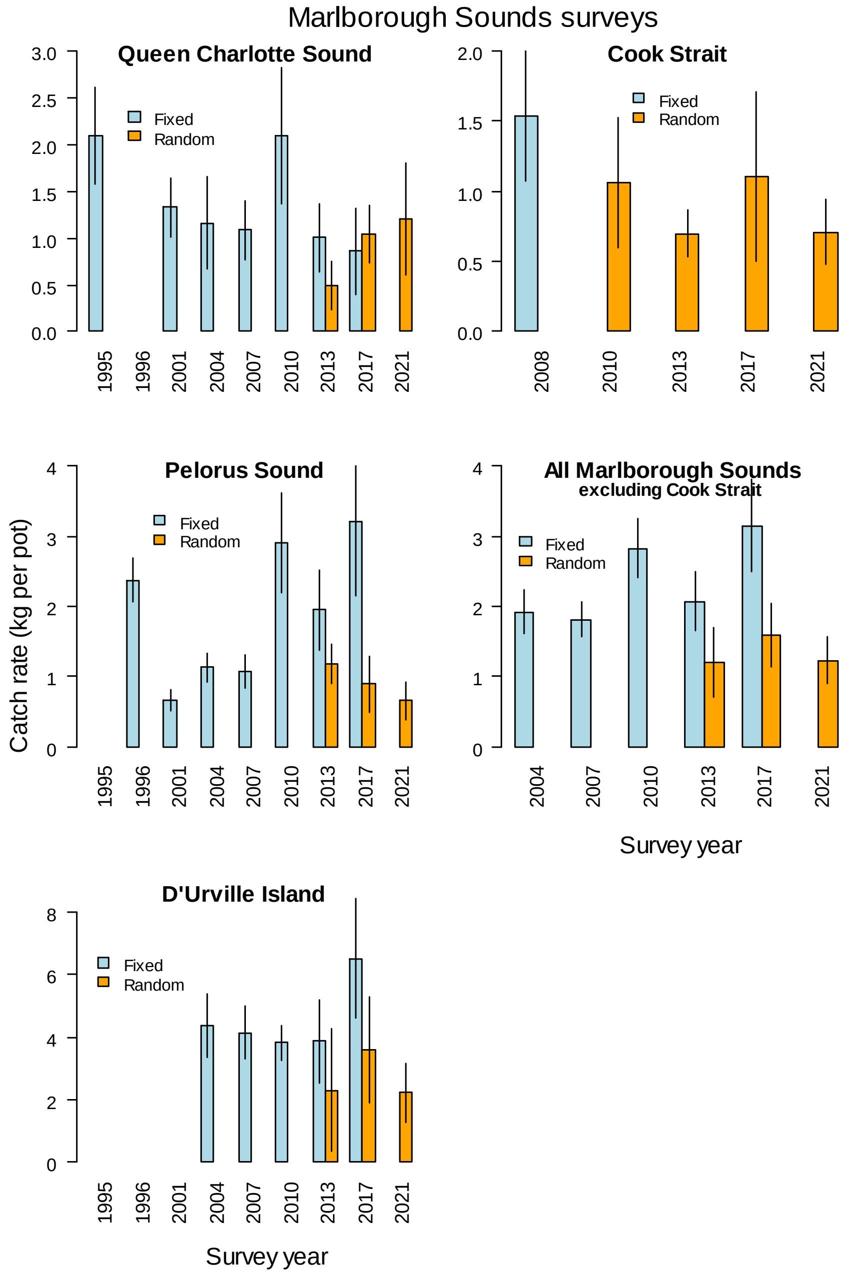


Figure 3: Marlborough Sounds fixed-site and random-site potting survey catch rates of all blue cod by survey year for each region and overall for the Marlborough Sounds. Error bars are 95% confidence intervals. There were no complete fixed-site surveys in Queen Charlotte Sound in 1996, Pelorus Sound in 1995, and D'Urville Island from 1995 to 2001 (see Table 9 above). For the overall Marlborough Sounds plot, the 2004 and 2007 fixed-site surveys exclude Separation Point, and the random-site surveys exclude Cook Strait, hence the strata are consistent among the surveys for fixed-site and random-site surveys.

Random-site surveys

The random-site surveys in 2013 and 2017 generally have lower catch rates than the concurrent fixed-site surveys, and, although the patterns among strata in each region are similar, they do not show the same overall trends as fixed sites by region and comparison between survey designs is problematic (Table 10, Figure 3). Queen Charlotte Sound random-site survey biomass increased markedly from 2013 to 2017 with no change in 2021; Pelorus Sound biomass shows a progressive decline between 2013 and 2021; D'Urville Island and Cook Strait show no trends. (Figure 3). Sex ratios have been dominated by males in all regions over all random-site surveys (Table 10). The Marlborough Sounds survey has now fully transitioned to random-site surveys and all future surveys will use the only the random-site design.

Table 10: Summary statistics from standardised blue cod fixed-site and random-site potting surveys in the Marlborough Sounds up to 2021 by region. Mean length and sex ratios are derived from the scaled population length distributions. Results for each region are shown only for surveys where strata have remained the same throughout the time series and results are for all blue cod. For the overall Marlborough Sounds (All MS), the 2004 and 2007 fixed-site surveys exclude Separation Point, and the random-site surveys exclude Cook Strait, hence the strata are consistent among the surveys for fixed-site and random-site surveys. QCH, Queen Charlotte Sound; PEL, Pelorus Sound; DUR, D'Urville; CKST, Cook Strait; LIMR, Long Island Marine Reserve; All MS, all Marlborough Sounds.

			Mean length (cm)			CPUE (kg pot^{-1})		Sex ratio
Region/stratum	Year	Site type	Male	Female	unsexed	Overall	range (CV)	(% male)
QCH	1995	Fixed	31.0	28.0		2.1	0.74–2.91 (12%)	59
	1996	–	–	–		–	–	–
	2001	Fixed	28.5	24.3		1.33	0.58–1.69 (12%)	61
	2004	Fixed	27.9	24.2		1.16	0.35–2.01 (22%)	51
	2007	Fixed	29.8	25.7		1.09	0.00–2.60 (15%)	69
	2010	Fixed	33.2	29.0		2.09	0.60–2.56 (18%)	71
	2013	Fixed	31.7	29.8		1.0	0.32–1.12 (18%)	62
		Random	32.1	30.3		0.49	0.22–1.07 (27%)	66
	2017	Fixed	32.2	29.6		0.86	0.18–1.95 (27.3%)	72
		Random	32.5	30.7		1.04	0.11–1.94 (15%)	73
	2021	Random	30.9	28.6		1.21	0.24–1.45 (25%)	74
QCH/LIMR	2017	Random	–	–	35.2	8.76	8.76 (14%)	–
	2021	Random	–	–	35.7	7.98	7.98 (13%)	–
PEL	1995	–	–	–		–	–	–
	1996	Fixed	29.8	26.2		2.4	1.00–3.30 (7%)	70
	2001	Fixed	27.8	22.2		0.67	0.19–1.46 (12%)	64
	2004	Fixed	28.2	23.5		0.96	0.20–2.70 (11%)	66
	2007	Fixed	29.2	24.5		1.07	0.28–3.24 (11%)	77
	2010	Fixed	32.8	28.3		2.9	1.60–3.86 (13%)	87
	2013	Fixed	31.3	27.2		1.95	3.30–4.94 (15%)	89
		Random	33.3	30.1		1.18	0.18–3.96 (12%)	77
	2017	Fixed	32.0	29.5		3.20	0.11–10.1 (17%)	86
		Random	32.4	29.8		0.90	0.07–2.77 (23%)	90
	2021	Random	31.9	29.2		0.66	0.19–1.19 (21%)	82
DUR	1995	–	–	–		–	–	–
	1996	–	–	–		–	–	–
	2001	–	–	–		–	–	–
	2004	Fixed	30.7	27.8		4.23	3.75–4.67 (11%)	50
	2007	Fixed	32.2	29.5		4.15	2.92–5.49 (10%)	71
	2010	Fixed	31.3	28.7		3.82	2.15–5.64 (8%)	64
	2013	Fixed	31.7	29.4		3.88	3.37–4.44 (18%)	70
		Random	32.8	29.9		2.31	1.42–3.28 (43%)	57
	2017	Fixed	32.9	30.6		6.52	4.50–8.70 (15%)	61
		Random	32.6	30.6		3.59	2.90–4.30 (24%)	65
	2021	Random	32.8	30.8		2.23	2.05–2.39 (21%)	63
CKST	2008	Fixed	31.9	26.4		1.50	0.30–4.20 (15%)	88
	2010	Random	30.5	25.6		1.06	0.11–1.74 (22%)	84
	2013	Random	31.7	28.4		0.70	0.14–1.62 (12%)	83
	2017	Random	32.3	28.2		1.10	0.08–2.67 (28%)	87
	2021	Random	32.3	27.5		0.71	0.07–2.13 (16%)	80
All MS	2004	Fixed	29.1	25.9		1.92	0.37–4.67 (8%)	54
	2007	Fixed	30.7	27.2		1.81	0.00–5.48 (7%)	72
	2010	Fixed	32.5	28.7		2.83	0.60–5.64 (7%)	75
	2013	Fixed	31.5	29.1		2.68	0.31–4.44 (10%)	76
		Random	32.9	30.0		1.20	0.22–3.96 (21%)	66
	2017	Fixed	32.4	30.2		3.15	0.11–8.73 (10%)	72
		Random	32.5	30.6		1.59	0.06–4.32 (14%)	72
	2021	Random	31.8	29.7		1.18	0.07–2.39 (13%)	72

Long Island Marine Reserve potting survey

Random-site surveys of Long Island Marine Reserve in 2017 and 2021, in which all fish were returned alive (unsexed), had mean catch rates of all blue cod of 8.76 kg pot^{-1} (CV of 15%) and 7.98 kg pot^{-1} (CV of 13%), respectively, and were 5.7 and 5.4 times higher than adjacent fished strata in Queen Charlotte Sound in 2017 and 2021, respectively (Table 10). In addition, the mean size was 3.2 cm (2017) and 5.2 cm (2021) greater in the marine reserve and length frequency distributions were bimodal in contrast to the unimodal distributions from adjacent strata in Queen Charlotte Sound. Blue cod were in better condition inside the marine reserve in 2021 with a mean Fulton condition factor (*K*) of 1.6, compared with 1.4 in adjacent strata.

Stock status

Growth rates and age compositions were similar for 2013 and 2017. Fixed-site survey Chapman-Robson total mortality estimates (*Z*) for males only, and for age at recruitment of 6 years, were 0.66 in 2013 and 0.77 in 2017 (Table 11). Similarly, random-site survey Chapman-Robson total mortality estimates (*Z*) at recruitment of 6 years were 0.60 in 2013 and 0.75 in 2017 (Table 11). In 2021, age compositions and *Z* estimates were similar to 2013 and 2017 random-site estimates (Z = 0.65), but growth was slightly faster in 2021.

The stock assessment plenary meeting on 18 July 2022 agreed that spawner-biomass-per-recruit (SPR) is not appropriate as a target reference point for blue cod in Marlborough Sounds for the following reasons:

1. As this species is a diandric protogynous hermaphrodite, with behavioural triggers for females changing to secondary males, it is difficult to reliably model this process, especially since the rate of sex change increases with the removal of dominant males by fishing, in an unpredictable manner.
2. Few females currently grow large enough to recruit to the fishery, presumably because the larger females change to males when dominant males are removed, so fishing mortality is mostly experienced by the males.
3. The standard spawner-per-recruit approach does not account for the reduction female spawner biomass resulting from the increased rate of sex change, implied by the sex ratio being heavily skewed to males.
4. Current growth rates of both males and females is likely to have been substantially modified by the increased rate of sex change induced by fishing. It is therefore not possible to estimate the growth rate of the virgin unfished population.

The Plenary recommended F=0.87M as an overfishing threshold for Marlborough Sounds blue cod, on the basis of Zhou et al (2012). Since none of the female age classes were fully recruited to the fishery, the Plenary recommend using the age composition of males for estimating total morality (*Z*). Table 11 was revised in July 2022; previous *SPR* results were removed and *Z* and *F* for males only are now presented, based on age at recruitment equivalent to age at which males reached minimum legal size, plus a one year to ensure more than 50% of males are recruited. The resulting high estimates of *F* (Table 11) are consistent with the relative catch rates inside and outside the Long Island Marine Reserve in adjacent Queen Charlotte Sound, where the catch rates outside were 18.6% and 17.5% of those inside the reserve, in 2017 and 2021, respectively.

Table 11: Mortality parameters (*Z*, *F*, and *M*) estimates for blue cod from the 2013, 2017, and 2021 Marlborough Sounds fixed-site and random-site potting surveys for all regions combined. *Z* (total mortality) and *F* (fishing mortality) estimates are for males 6 years and older. Otoliths from these surveys were aged using the Age Determination Protocol for blue cod (Walsh 2017). CIs, 95% confidence intervals;

Survey	Region	Site type	*M*	*Z* (CIs)	*F* (CIs)
2013	All regions combined	Fixed	0.17	0.66 (0.46–0.88)	0.49 (0.29–0.71)
2017			0.17	0.77 (0.54–1.03)	0.60 (0.37–0.86)
2013	All regions combined	Random	0.17	0.60 (0.42–0.81)	0.43 (0.25–0.64)
2017			0.17	0.75 (0.52–1.02)	0.58 (0.35–0.85)
2021			0.17	0.65 (0.43–0.90)	0.48 (0.26–0.73)

Banks Peninsula
There have been five fixed-site blue cod potting surveys off Banks Peninsula (2002, 2005, 2008, 2012, and 2016), split into geographically separate inshore and offshore areas (Beentjes & Carbines 2003, 2006, 2009, Carbines & Haist 2017, Beentjes & Fenwick 2017). In 2012 and 2016, concurrent random-site potting surveys were also carried out with the intention of replacing fixed-site surveys because the random-site surveys provide a more reliable indicator of stock status. The 2021 potting survey was the firstly solely random-site survey and the third in the time series (Beentjes et al 2022b).

Inshore survey. The most recent inshore random-site survey in 2021 recorded overall catch rates of 0.49. kg pot^{-1} (CV 20%), a sex ratio of 85% male, and mean lengths of 29 and 25 cm for males and females, respectively (Table 12) (Beentjes et al 2022b). The *SPR* ratio estimates from the 2016 and the current 2021 inshore random-site surveys were considered to be unreliable because of the poor estimates of *Z*, but they do reflect the extremely truncated nature of the age composition (oldest fish in 2021 was 6 years old) and indicate that *SPR* ratios are likely to be well below the target reference point of $F_{45\%SPR}$. This finding, together with the strongly skewed sex ratio toward males and very low catch rate estimates, indicates that the Banks Peninsula inshore blue cod population is heavily overfished. Further, as nearly all females and most males currently caught will be of sub-legal size (less than 33 cm), there is also likely to be significant mortality through catch and return of undersized fish. Notwithstanding the differences in catch rates ascribed to the survey design (fixed or random), there are strong indications that inshore blue cod biomass has declined substantially between 2005 and 2021 (Figure 4). For the 2012 random-site survey, sex ratios (all blue cod) were almost the same as those in fixed sites (about 70%), but in the 2016 random-site survey there were about 10% more males, increasing slightly in 2021 to 85% male; this indicates that male dominance in sex ratio may be increasing.

Offshore survey. The most recent offshore random-site survey in 2021 recorded overall catch rates of 1.90. kg pot^{-1} (CV 24%), a sex ratio of 66% male, and mean lengths of 37 and 34 cm for males and females, respectively (Table 12) (Beentjes et al 2022b). The 2016 and 2021 random-site survey spawner-per-recruit ratios were $F_{85\%SPR}$ and $F_{41\%SPR}$ indicating that the expected contribution to the spawning biomass over the lifetime of an average recruit was reduced to 85% and 41% of the contribution in the absence of fishing. The level of exploitation (F) of offshore blue cod stocks has therefore increased substantially in five years, and in 2021 slightly exceeded the F_{MSY} target reference point of $F_{45\%SPR}$ (Table 12). Notwithstanding the differences in catch rates that can be ascribed to the survey design (fixed or random), there were no trends in abundance until the 63% decline between the 2016 and 2021 random-site surveys (Figure 4); this decline was largest in stratum 7 (Pompey's Rock) which is the more accessible of the two offshore strata. Length distributions had fewer larger male fish than in the 2021 compared with 2016 random-site surveys. Random-site surveys had similar sex ratios to overlapping fixed-site surveys in 2012 and 2016, but the 2021 survey had the highest proportion of males (66%) for any survey in the time series. There was clear evidence of modal progression of strong and weak ages classes from 2016 to 2021. The offshore blue cod population has historically been considered to be a healthy blue cod population, with a broad age structure, relatively high abundance, and a balanced sex ratio. However, between 2016 and 2021, abundance declined by 63%, age structure narrowed with fewer older age classes, there were fewer larger fish, *Z* increased, *SPR* ratio decreased, and the sex ratio is trending toward more males in the population. This indicates that the offshore blue cod population, and particularly Pompey's Rock, is now showing signs of overfishing.

Table 12: Summary statistics from standardised blue cod potting surveys of the northeast coast of the South Island (BCO 3). CPUE (catch rates) – catch per unit effort (kg pot^{-1}); CV – coefficient of variation (set based); mean length is from population scaled length. *M* = 0.17 in *SPR* analyses. All survey results shown are compliant with the blue cod potting manual, and the blue cod age determination protocol (Beentjes 2019, Beentjes & Page 2021, Beentjes & Miller 2021, Beentjes & Fenwick 2017, Beentjes et al 2022b, Walsh 2017). –, no valid ageing; NA, no valid SPR estimates in fixed sites.

	Mean length (cm)		Survey	CPUE stratum range (kg pot^{-1})	Sex ratio	
Area/Year	Female	Male	(kg pot^{-1})	(CV) all	(% male)	$F_{\%SPR}$
North Canterbury						
Kaikōura						
2004 (fixed sites)	30.3	32.5	2.62	0.60–7.97 (11.1%)	48.7	–
2007 (fixed sites)	29.8	32.5	5.00	1.91–20.45 (12.6%)	48.1	–
2011 (fixed sites)	27.5	29.1	3.66	2.14–11.44 (13.3%)	53.0	–
2011 (random sites)	28.5	29.5	2.64	0.61–8.22 (16.7%)	46.8	–
2015 (fixed sites)	25.9	27.0	2.25	1.58–5.07 (20.2%)	66.3	NA
2015 (random sites)	29.0	30.0	2.21	0.48–9.41 (18.9%)	51.7	72
2017 (random sites)	28.6	28.4	1.90	0.00–6.92 (15.9%)	44.8	42
2019 (random sites)	29.4	29.2	1.56	0.01–8.26 (10.4%)	50.0	62
Motunau						
2005 (fixed sites)	25.7	29.6	10.2	8.7–15.4 (11.4%)	76.6	–
2008 (fixed sites)	25.2	29.3	5.50	4.1–8.9 (16.1%)	77.9	–
2012 (fixed sites)	24.6	29.1	5.55	4.43–8.70 (11.8%)	71.9	–
2012 (random sites)	23.5	28.2	3.01	1.81–6.95 (19.5%)	72.1	–
2016 (fixed sites)	22.4	25.8	3.32	2.94–4.66 (12.7%)	75.5	NA
2016 (random sites)	22.2	26.5	2.48	1.10–7.24 (26.8%)	76.3	22.2
2020 (random sites)	20.2	24.8	2.07	1.41–4.54 (18.9%)	74.5	21.4
Banks Peninsula						
Inshore						
2002 (fixed sites)	25.4	28.3	1.12	0.04–2.61 (23.2%)	67.9	–
2005 (fixed sites)	27.2	32.7	2.78	1.02–4.16 (12.2%)	74.2	–
2008 (fixed sites)	25.5	29.8	1.08	0.07–2.30 (17.8%)	70.2	–
2012 (fixed sites)	24.7	28.8	1.35	0.60–1.88 (12.4%)	67.2	–
2012 (random sites)	22.8	27.3	1.23	0.33–2.89 (16.6%)	66.1	–
2016 (fixed sites)	23.2	26.5	1.26	0.57–2.12 (11.8%)	67.5	NA
2016 (random sites)	23.8	26.1	0.53	0.09–0.94 (22.2%)	81.3	NA
2021 (random sites)	25.0	29.3	0.49	0.0–0.79 (19.7%)	84.8	NA
Offshore						
2002 (fixed sites)	36.6	37.6	3.39	2.04–4.74 (19.9%)	41.8	–
2005 (fixed sites)	37.4	41.2	6.48	5.68–7.27 (9.4%)	57.2	–
2008 (fixed sites)	35.6	41.8	4.48	3.13–5.80 (13.8%)	49.8	–
2012 (fixed sites)	33.5	37.4	4.88	3.49–6.28 (17.0%)	55.9	–
2012 (random sites)	34.1	39.3	3.77	3.69–4.09 (36.2%)	59.0	–
2016 (fixed sites)	33.6	36.8	5.60	5.09–6.10 (14.1%)	65.2	NA
2016 (random sites)	36.1	41.3	5.08	5.21–4.54 (19.5%)	57.5	85.1
2021 (random sites)	33.6	36.8	1.90	1.50–3.20 (23.9%)	65.6	41.5

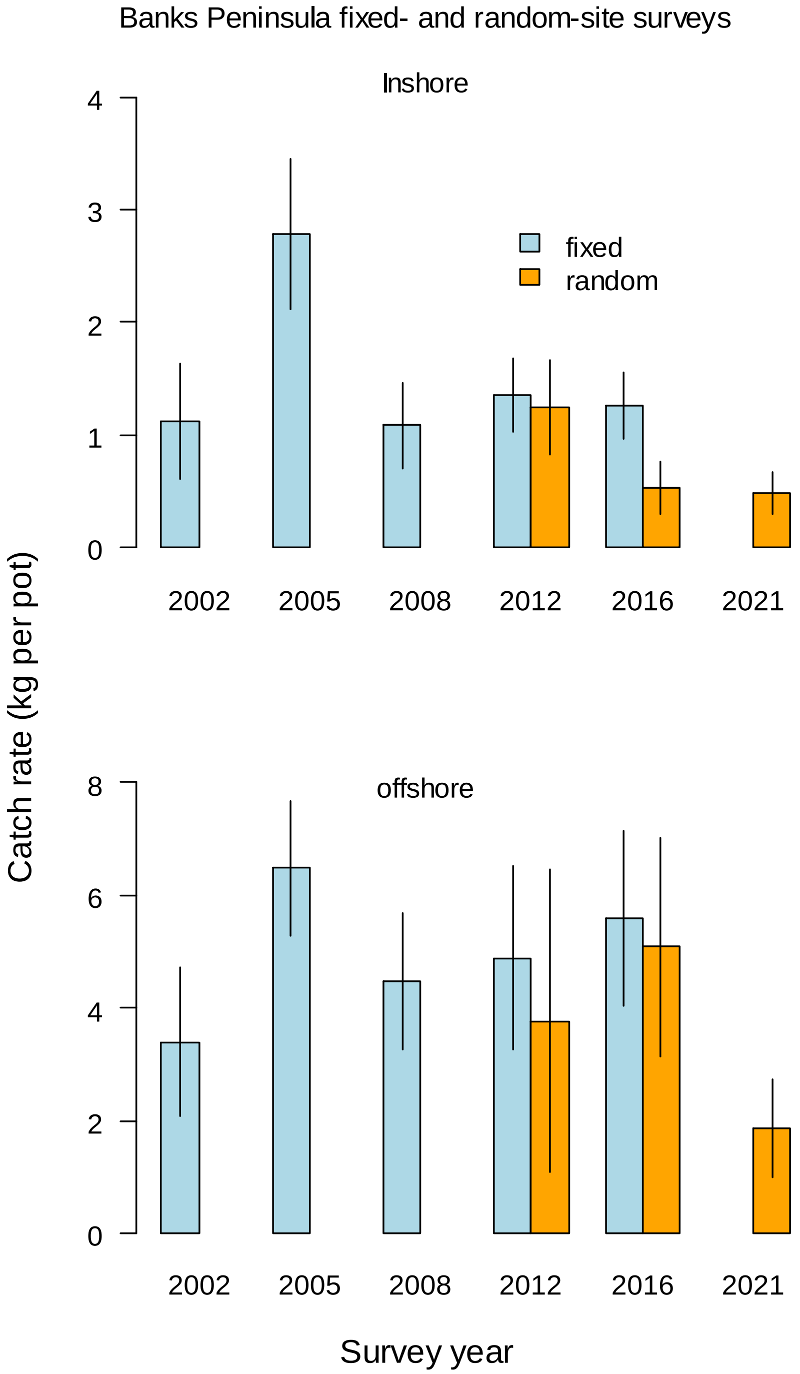


Figure 4: Banks Peninsula fixed-site and random-site potting survey catch rates of all blue cod by survey year shown for inshore and offshore populations. Error bars are 95% confidence intervals. Note the different y-axis scales for inshore and offshore (Beentjes et al 2022b).

North Canterbury

Kaikōura

There have been four fixed-site blue cod potting surveys off Kaikōura (2004, 2007, 2011, and 2015), (Carbines & Beentjes 2006a, 2009, Carbines & Haist 2018a, Beentjes & Page 2017). In 2011 and 2015 concurrent random-site potting surveys were also carried out with the intention of replacing fixed-site surveys. Subsequently solely random-site surveys were carried out in 2017, earlier than the standard four-year cycle, to assess the impact of the November 2016 earthquake (Beentjes & Page 2018), and in 2019 (Beentjes & Page 2021). Random surveys provide a more reliable indicator of stock status than fixed-site surveys and will be used in future.

The most recent random-site survey in 2019 recorded catch rates of 1.56 kg pot^{-1} (CV 10%), sex ratio of 50% male, and mean lengths of 29.4 cm and 29.2 cm for males and females, respectively (Table 12). For the four fixed-site surveys, catch rates increased nearly two-fold from 2004 to 2007, and then declined in both 2011 and 2015, and catch rates from the last survey were the lowest of all four surveys (Table 12, Figure 5). For the four random-site surveys there was a slight decline over time with a statistically significant difference (P<0.05) between the mean pot catch of 2011 and 2019 surveys (Figure 5). Notwithstanding the differences in catch rates that can be ascribed to the survey design (fixed or random), blue cod biomass declined by around 50% between 2007 and 2019. The sex ratio for all blue cod was close to parity for all surveys (fixed and random), with the exception of the 2015 fixed-site survey where two-thirds of the blue cod were male (Table 12).

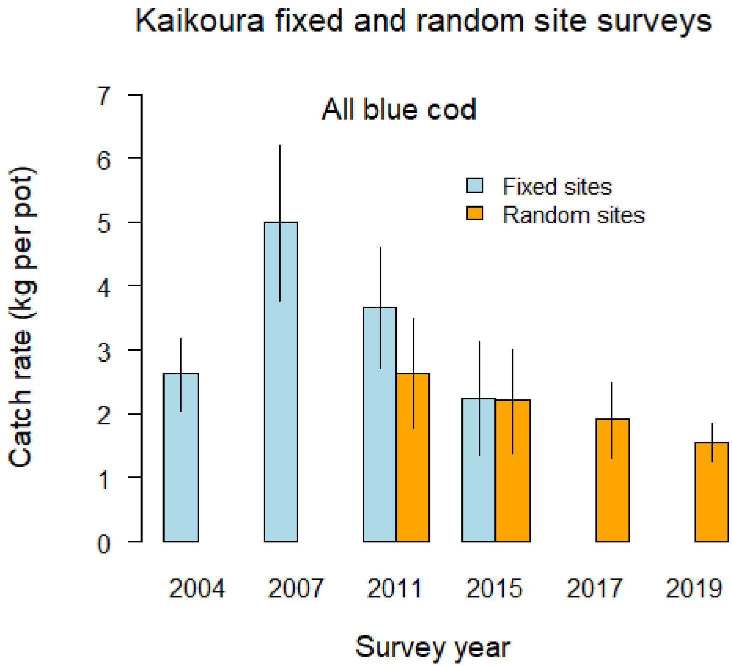


Figure 5: Kaikōura fixed-site and random-site potting survey catch rates of all blue cod by survey year. Error bars are 95% confidence intervals.

Ageing is only valid for the 2015, 2017, and 2019 random-site surveys (i.e., compliant with the blue cod age determination protocol, Walsh 2017). Cohort progression of blue cod age classes is apparent over the three random-site surveys from 2015 to 2019, showing both nominally strong and weak year classes. Length frequency distributions and mean lengths were similar among the four random-site surveys with any differences due to the strong recruitment of mainly juvenile male blue cod in 2015, progressing through to strong modes in 2017 and 2019. In 2015 and 2019 the random-site survey spawner-biomass-per-recruit ratios were 72% and 62% indicating that the level of exploitation (F) of Kaikōura blue cod stocks was below the F_{MSY} target reference point of $F_{45\%SPR}$ (underexploited) (Table 12). In 2017 the random-site survey spawner-biomass-per-recruit ratio was 42%, indicating that the level of exploitation of Kaikōura blue cod stocks was above the F_{MSY} target reference point of $F_{45\%SPR}$ (over-exploited). However, because recruitment is not constant, and there are relatively few age classes represented above the age at recruitment, the point estimates of Z, F, and SPR should be treated with caution.

Motunau

There have been four fixed-site blue cod potting surveys off Motunau (2005, 2008, 2012, and 2016), (Carbines & Beentjes 2006a, 2009, Carbines & Haist 2018a, Beentjes & Sutton 2017). In 2012 and 2016 concurrent random-site potting surveys were also carried with the intention of replacing the fixed-site surveys. Subsequently, a solely random-site survey was carried out in 2020 (Beentjes & Miller 2021). Random surveys provide a more reliable indicator of stock status than fixed-site surveys and will be used in future.

The most recent random-site survey in 2020 had catch rates of 2.1 kg pot^{-1} (CV 18.9%), sex ratio of 74% male, and mean lengths of 24.8 cm and 20.2 cm for males and females, respectively (Table 12).

For the four fixed-site surveys, catch rates decreased by about half in 2008 and then by half again in 2016 with a three-fold decline between 2005 and 2016 (Table 12, Figure 6). For the three random-site surveys there was a slight decline over time, but no statistically significant difference (P=0.19) between the mean pot catch of 2012 and 2020 surveys (Table 12, Figure 6). Notwithstanding the differences in catch rates that can be ascribed to the survey design (fixed or random), blue cod biomass appears to have declined by around 50% between 2005 and 2020. The sex ratio for all blue cod was around 75% male for fixed-site and random-site surveys with no trend (Table 12). Overall blue cod mean size shows a trend of declining size in both the fixed-site and random-site surveys.

Ageing is only valid for the 2016 and 2020 random-site surveys (i.e., compliant with the blue cod age determination protocol, Walsh 2017). Cohort progression of blue cod age classes is apparent from 2016 to 2020, showing both nominally strong and weak year classes. In 2016 and 2020 the random-site survey spawner-biomass-per-recruit ratios were 22% and 21% indicating that the level of exploitation (F) of Motunau blue cod stocks was well below the F_{MSY} target reference point of $F_{45\%SPR}$ (overexploited) (Table 12). However, because recruitment is not constant, and there are relatively few age classes represented above the age at recruitment, the point estimates of Z, F, and SPR should be treated with caution.

The very high estimate of total mortality, truncated age composition, small size, strongly skewed sex ratio toward males, and a spawner-per-recruit ratio less than half the target indicates the current level of exploitation is unlikely to be sustainable. Further, as nearly all females and most males currently caught will be of sub-legal size (less than 33 cm from 1 July 2020), there is also likely to be significant mortality through catch and return of undersize fish.

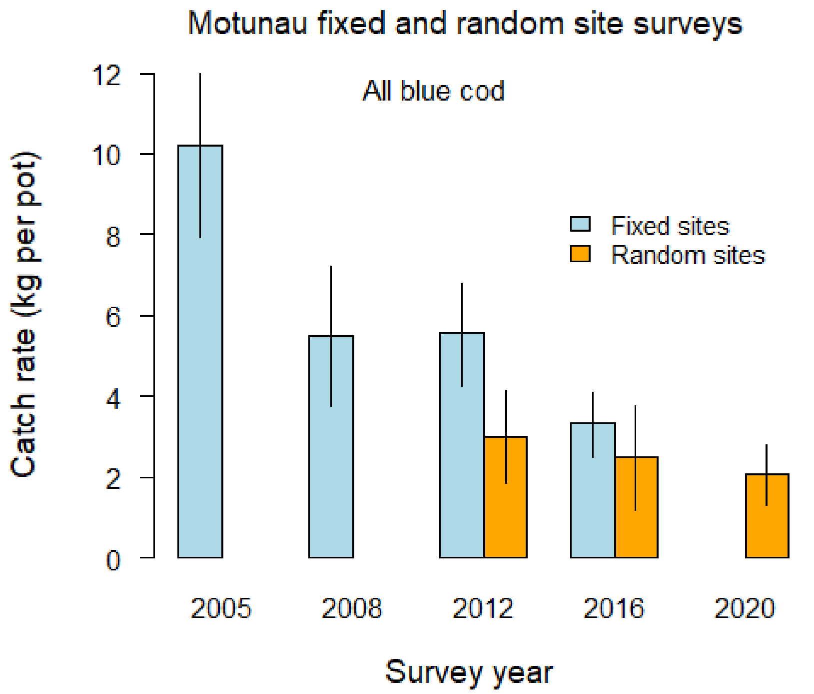


Figure 6: **Motunau fixed-site and random-site potting survey catch rates of all blue cod by survey year. Error bars are 95% confidence intervals.**

North Otago

There have been four fixed-site blue cod potting surveys (2005, 2009, 2013, and 2018), and two random-site surveys off north Otago (2013 and 2018) (Beentjes & Fenwick 2019a). Random-site potting surveys are intended to replace fixed-site surveys, because they provide a more reliable indicator of abundance. The most recent random-site survey in 2018 recorded catch rates of 2.35 kg pot^{-1} (CV 18%), sex ratio of 87% male, and mean lengths of 30.2 cm and 26.7 cm for males and females, respectively (Table 13, Figure 7).

Table 13: Summary statistics from standardised blue cod potting surveys carried out in the southeast coast of the South Island (BCO 3). CPUE – catch per unit effort (kg pot^{-1}); CV – coefficient of variation; Mean length, from population scaled length. All north Otago survey outputs from Beentjes & Fenwick (2019a). South Otago survey 2010 outputs from Beentjes (2012) and subsequent surveys from Beentjes & Fenwick (2019b). *, no stratum 6 in 2005; **, only strata 1, 3, and 6 surveyed in 2010; –, no valid ageing.

	Mean length (cm)		Survey CPUE		Sex ratio	
Area/Year	**Female**	**Male**	**(kg pot^{-1})**	**CPUE range (CV)**	**(% male)**	$F_{\%SPR}$
North Otago						
2005 (fixed sites)*	27.8	32.8	10.2	7.49–14.5 (7.9%)	72.5	–
2009 (fixed sites)	27.4	32.3	11.5	6.21–19.88 (6.6%)	73.1	–
2013 (fixed sites)	27.5	31.7	5.0	2.72–8.07 (12.6%)	75.9	–
2013 (random sites)	27.5	30.7	4.2	0.94–7.46 (13.9%)	67.8	–
2018 (fixed sites)	26.3	30.4	3.55	2.24–5.30 (17.7%)	84.9	23
2018 (random sites)	26.7	30.2	2.35	0.33–4.12 (14.3%)	87.0	23
South Otago						
2010 (fixed sites)**	29.4	33.6	9.7	3.3–16.9 (17.1%)	74.5	–
2010 (random sites)**	23.7	29.0	4.4	1.2–6.0 (17.8%)	66.9	–
2013 (random sites)	25.5	31.9	6.2	0.8–7.4 (19.9%)	57.4	–
2018 (random sites)	24.9	29.0	1.52	0.17–3.79 (28.5%)	68.4	25

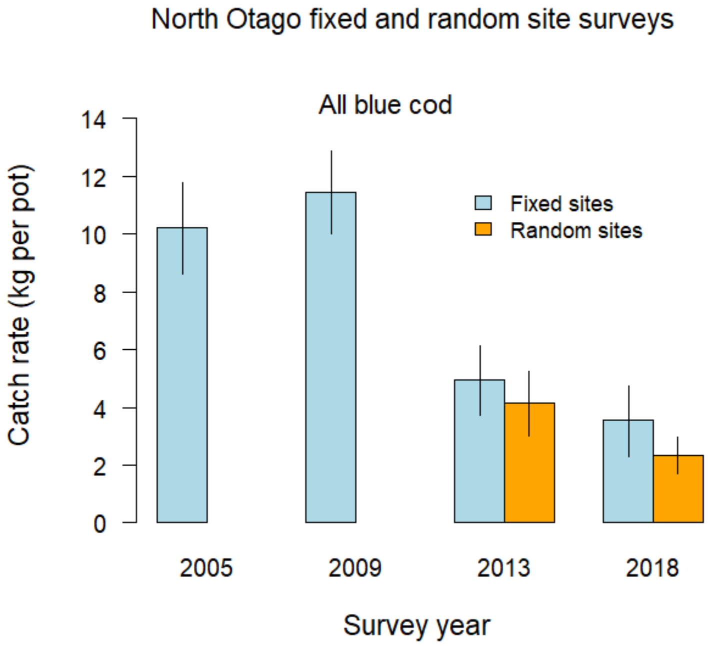


Figure 7: North Otago fixed-site and random-site potting survey catch rates of all blue cod by survey year. Error bars are 95% confidence intervals. Surveys after 2005 include a new stratum (stratum 6).

For the four fixed-site surveys, catch rate was similar in 2005 and 2009, but in 2013 there was a decline with no overlap in the confidence intervals, and catch rates remained low in 2018 (Table 13, Figure 7). There are only two random-site surveys in the time series, but relative abundance showed a similar decline between 2013 and 2018 with no overlap in the confidence intervals. The sex ratio for all fixed-site surveys was 72–76% male for all blue cod with no trend, and 75–87% for the two random sites (Table 13). A preponderance of males is thought indicate high fishing intensity. The fixed-site scaled length frequency distribution shapes were similar for 2005 and 2009 but changed in 2013 and again in 2018 with the latter having relatively fewer larger fish than earlier surveys. For the two random-site surveys the length frequency distributions were similar between years, but overall blue cod were slightly smaller in 2018 than 2013. Ageing is currently only valid for the 2018 survey (i.e., compliant with the blue cod age determination protocol, Walsh 2017) and showed strong modes at three, five, and eight years for both sexes, but particularly for males. The 2018 random-site survey spawner-biomass-per-recruit ratio was 30% (assuming $M = 0.17$), indicating that the level of exploitation (F) of north Otago blue cod stocks was above the F_{MSY} target reference point of $F_{45\%SPR}$, in 2018 (over-exploited) (Table 13).

South Otago

There has been one fixed-site blue cod potting survey (2010), and three random-site surveys off south Otago (2010, 2013, and 2018) (Beentjes & Fenwick 2019b). The random-site surveys in 2013 and 2018 replaced fixed-site surveys. Random surveys provide a more reliable indicator of stock status and will be used solely in the future off south Otago. The first survey in 2010 was designed to compare fixed- and random-site potting survey designs and used only three of the six strata (Beentjes & Carbines 2011), with catch rates in fixed sites double that from random sites (Table 13, Figure 8). The most recent random-site survey in 2018 had catch rates of 1.52 kg pot^{-1} (CV 28%), a sex ratio of 68% male, and mean lengths of 29.0 cm and 24.9 cm for males and females, respectively (Table 13, Figure 8). There was a four-fold drop in catch rates between 2013 and 2018 random-site full strata surveys with no overlap in the confidence intervals, and this was largely mirrored in the three strata survey.

The sex ratio has varied from 60 to 70% male with no trend (Table 13) – a preponderance of males indicating high fishing pressure. The scaled length frequency distribution shapes for the random-site full strata surveys differed with 2013 having a strong juvenile mode and relatively more larger fish than 2018. Ageing is currently only valid for the 2018 survey (i.e., compliant with the blue cod age determination protocol, Walsh 2017) and showed strong modes at three, five, and eight years for both sexes, but particularly for males. This age structure mirrored that for north Otago in 2018. The 2018 random-site survey spawner-biomass-per-recruit ratio was 34% (assuming M = 0.17), indicating that the level of exploitation (F) of south Otago blue cod stocks was above the F_{MSY} target reference point of $F_{45\%SPR}$, in 2018 (over-exploited) (Table 13).

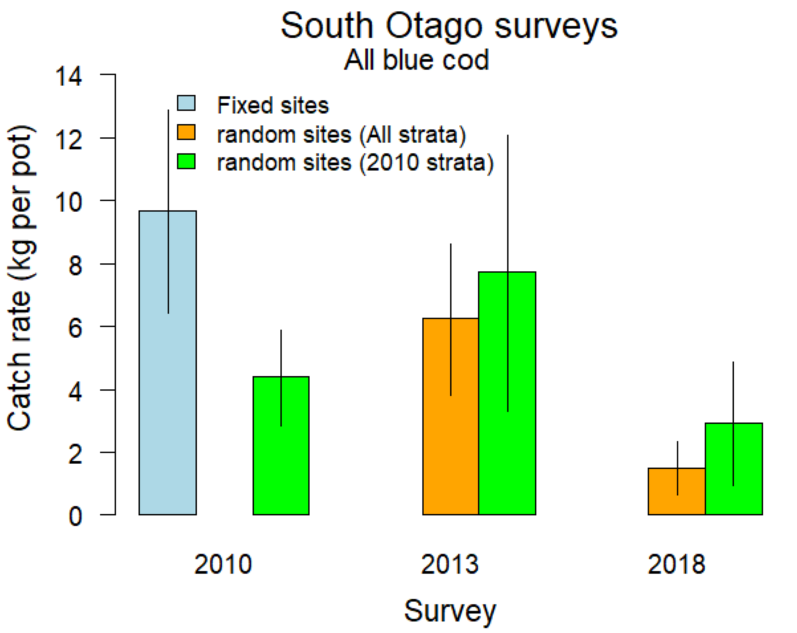


Figure 8: **South Otago fixed-site and random-site potting survey catch rates of all blue cod by survey year. Error bars are 95% confidence intervals. The 2010 survey used three strata, and subsequent surveys used 6 strata. Catch rates are also shown for the three strata used in 2010 for the random-site surveys.**

Foveaux Strait

There have been three random-site surveys in Foveaux Strait (2010, 2014, and 2018) (Beentjes et al 2019). The most recent random-site survey in 2018 had catch rates of 5.66 kg pot^{-1} (CV 20%), sex ratio of 51% male, and mean lengths of 30.6 cm and 28.4 cm for males and females, respectively (Table 14, Figure 9). There is no clear trend in catch rates over the time series. Catch rates in Foveaux Strait, as of 2018, are the highest of all South Island random-site surveys.

Table 14: Summary statistics from standardised blue cod potting surveys carried out in the south and southwest coast of the South Island (BCO 5). $F_{\%SPR}$ estimated for age at full recruitment and M = 0.14 except Paterson Inlet where M is 0.17. Mean length, mean age, and sex ratios are from population scaled length and age. Foveaux Strait survey - all results from Beentjes et al (2019); Paterson Inlet survey excludes Ulva Island Marine Reserve –all results from Carbines (2007), Carbines & Haist (2014a), Carbines & Haist (2018c), Beentjes & Miller (2020); Dusky Sound excludes Five Fingers Marine Reserve – all results from Carbines & Beentjes (2003, 2011a) and Beentjes & Page (2016). Only mean ages and $F_{\%SPR}$ based on otoliths aged with the Age Determination Protocol (Walsh 2017) are included in this table. CPUE, catch per unit effort (kg pot^{-1}); CV, coefficient of variation.

	Mean length (cm)		Mean age (years)		CPUE	CPUE range (CV)	Sex ratio % male	$F_{\%SPR}$
Area/Year	**Female**	**Male**	**Female**	**Male**	**(kg pot^{-1})**	**or set-based***	**(MWCV around age)**	
Foveaux Strait								
2010 (random sites)	27.7	30.4	5.8	5.2	5.25	0.81–14.14 (12.7%)	47.2	26.9
2014 (random sites)	27.7	30.3	6.0	4.9	7.57	3.16–16.22 (12.9%)	48.0	27.6
2018 (random sites)	28.4	30.6	6.8	5.7	5.66	1.47–8.40 (20.5%)	50.7	21.8
Paterson Inlet								
2006 (fixed sites)	26.9	32.8			4.8	1.47 – 8.42 (11.9%)	55.5	
2010 (fixed	27.5	32.2			4.2	1.5 – 6.6 (11.1%)	75.1	
2010 (random sites)	25.9	29.0			0.82	0.23 – 1.4 (24.1%)	61.5	
2014 (fixed	26.9	32.3			4.8	1.05 – 7.66 (12.9%)	75.3	
2014 (random sites)	27.0	29.9			1.94	0.44 – 2.73 (19.9%)	67.5	
2018 (random sites)	27.2	29.6	6.1	5.3	1.51	0.59–2.72 (17.7%)	67.0	68.0
Dusky Sound								
2002 (fixed sites)	29.9	34.7			2.95	1.29–8.43 (10.8%)		
2008 (fixed	32.2	37.9			4.20	2.49 – 8.13 (5.8%)		
2014 (fixed sites)	32.6	35.2	8.1	6.9	3.22	1.87–9.2 (11.9%)		48.3
2014 (random sites)	32.3	33.8	8.2	6.5	2.61	2.04–4.99 (8.6%)		49.0

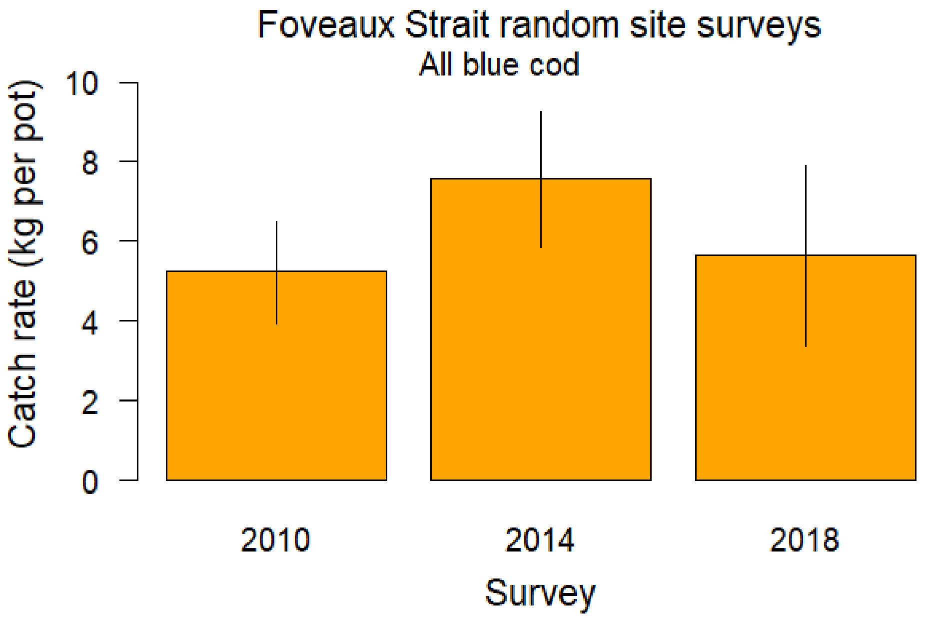


Figure 9: **Foveaux Strait random-site potting survey catch rates of all blue cod by survey year. Error bars are 95% confidence intervals.**

The sex ratio has varied from 47 to 51% male with no trend (Table 14). The scaled length frequency distributions and mean length of all blue cod were remarkably similar for all three surveys. Ageing is valid for all three surveys (i.e., compliant with the blue cod age determination protocol, Walsh 2017). The age structure of both males and females was generally similar among the three surveys with minor differences in the strength of some cohorts. The spawner-biomass-per-recruit ratios were 27%, 28%, and 22%, for 2010, 2014, and 2018, respectively, indicating that the level of exploitation (F) of Foveaux Strait blue cod stocks was above the F_{MSY} target reference point of $F_{45\%SPR}$, in all three surveys (over-exploited) (Table 14). However, a cautious approach should be taken in interpreting *SPR* estimates when so few age classes are included in the recruited population.

Paterson Inlet

There have been three fixed-site (2006, 2010, 2014), and three random-site blue cod potting surveys in Paterson Inlet (2010, 2014, and 2018) (Carbines 2007, Carbines & Haist 2014a, 2018c, Beentjes & Miller 2020). Random-site potting surveys have replaced fixed-site surveys because they provide a more reliable indicator of abundance. All surveys have included the Ulva Island Marine Reserve as an additional stratum but all results given here exclude the marine reserve. The most recent random-site survey in 2018 recorded catch rates of 1.5 kg pot^{-1} (CV 18%), sex ratio of 67% male, mean lengths of 29.6 cm for males and 27.2 cm for females, and mean ages of 5.3 years males and 6.1 years for females. Neither the fixed-site nor random-site survey time series show any clear indications of a change in relative abundance, size, or sex ratio, although there was a large increase in abundance between 2010 and 2014 for the random-site series (Figure 10). More random-site surveys are required before trends can be reliably identified. Ageing is only valid for the 2018 random-site survey, which is compliant with the blue cod age determination protocol (Walsh 2017). In 2018, using a default *M* of 0.17, estimated fishing mortality (*F*) was 0.08, and the associated spawner biomass-per-recruit ratio (SPR) was 68% (95% confidence interval 49–100%) (Table 14). The point estimates of *Z*, *F*, and *SPR* in 2018 should be treated with caution because the traditional catch curve did not follow the ideal straight-line descending limb, suggesting that the assumption of constant recruitment had been violated.

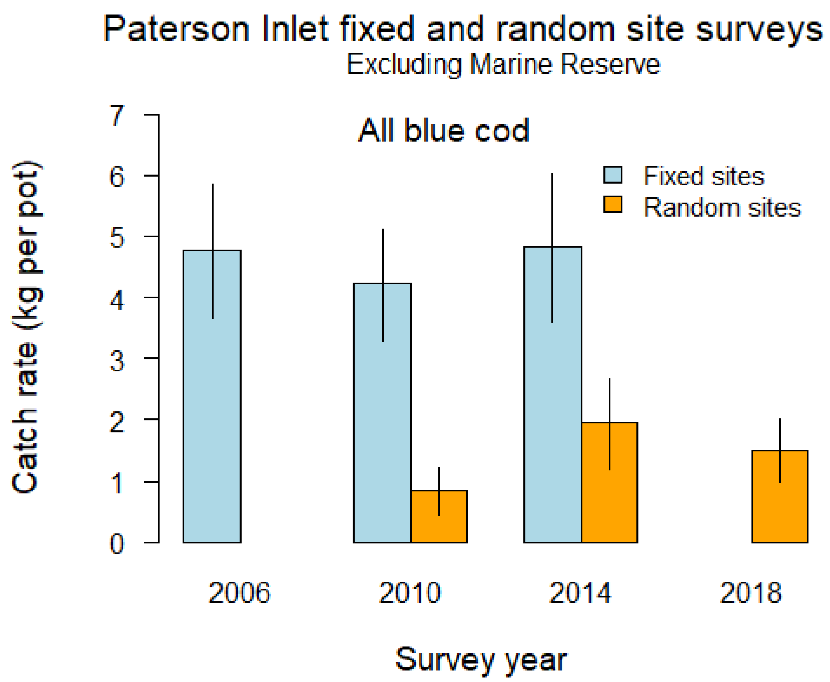


Figure 10: **Paterson Inlet random-site potting survey catch rates of all blue cod by survey year. Error bars are 95% confidence intervals.**

Dusky Sound

Three blue cod potting surveys have been carried out in the Dusky Sound. The surveys in 2002 and 2008 were both fixed-site surveys, whereas, in 2014, independent fixed-site and random-site surveys were carried out concurrently.

In 2002 the overall mean catch rates for all blue cod from fixed sites were 2.65 kg pot^{-1} (CV = 9.2%) and 1.81 kg pot^{-1} for recruited blue cod ≥ 33 cm (CV = 8.7%). Catch rates were highest on the open coast (i.e., at the entrance to the sound, Carbines & Beentjes 2003). The 2008 fixed-site survey catch rates were 4.2 kg pot^{-1} (CV = 5.8%) for all blue cod and 3.15 kg pot^{-1} (CV = 5.9%) for recruited blue cod, considerably higher than in 2002 and again highest catch rates were in the open coast stratum (Carbines & Beentjes 2011a). In 2014 the fixed-site catch rates had declined to 3.22 kg pot^{-1} (CV = 11.9%) and 2.35 kg pot^{-1} (CV = 11.9%), respectively, with highest catch rates on the open coast. The 2014 random-site catch rates were less than from fixed sites and were 2.61 kg pot^{-1} (CV = 8.6%) for all blue cod and 1.92 kg pot^{-1} (CV = 9.6%) for recruited blue cod, also with catch rates highest on the open coast (Beentjes & Page 2017). Overall scaled length and age distributions were similar between the fixed- and random-site surveys but the sex ratio favoured females in fixed sites (39% male) and was close to parity in random sites (52% male). Fixed-site surveys may not be suitable for monitoring the Dusky Sound blue cod population, but at least one more dual fixed- and random-site survey is required before moving exclusively to random-site surveys.

Total mortality (Z) for blue cod from the 2014 random-site survey was estimated at 0.25 with spawner-biomass-per-recruit (full recruitment at 8 years for females) estimated at $F_{49\%}$. Mortality estimates from the 2002 and 2008 surveys should not be used due to a recent change in the age determination protocol for blue cod.

4.1.2 Trawl survey estimates

Relative abundance indices from trawl surveys are available for BCO 3, BCO 5, and BCO 7, but these have not been used because of the high variance and concerns that this method may not appropriately sample blue cod populations.

4.1.3 CPUE Analyses

BCO 3

A standardised CPUE analysis was conducted in 2019 on the target blue cod potting fishery operating in BCO 3. This fishery accounted for two-thirds of the total BCO 3 landings in the 29 years from 1989–90 to 2017–18, predominantly in the two southernmost BCO 3 Statistical Areas 024 and 026. Together these two areas represented about 90% of the total target blue cod potting fishery over the same 29 years (Figure 11). As found in the previous analyses, there was misreporting of RCO 3 landings as BCO 3, probably due to data entry errors (Starr & Kendrick 2010). This problem was again resolved before undertaking the CPUE analysis.

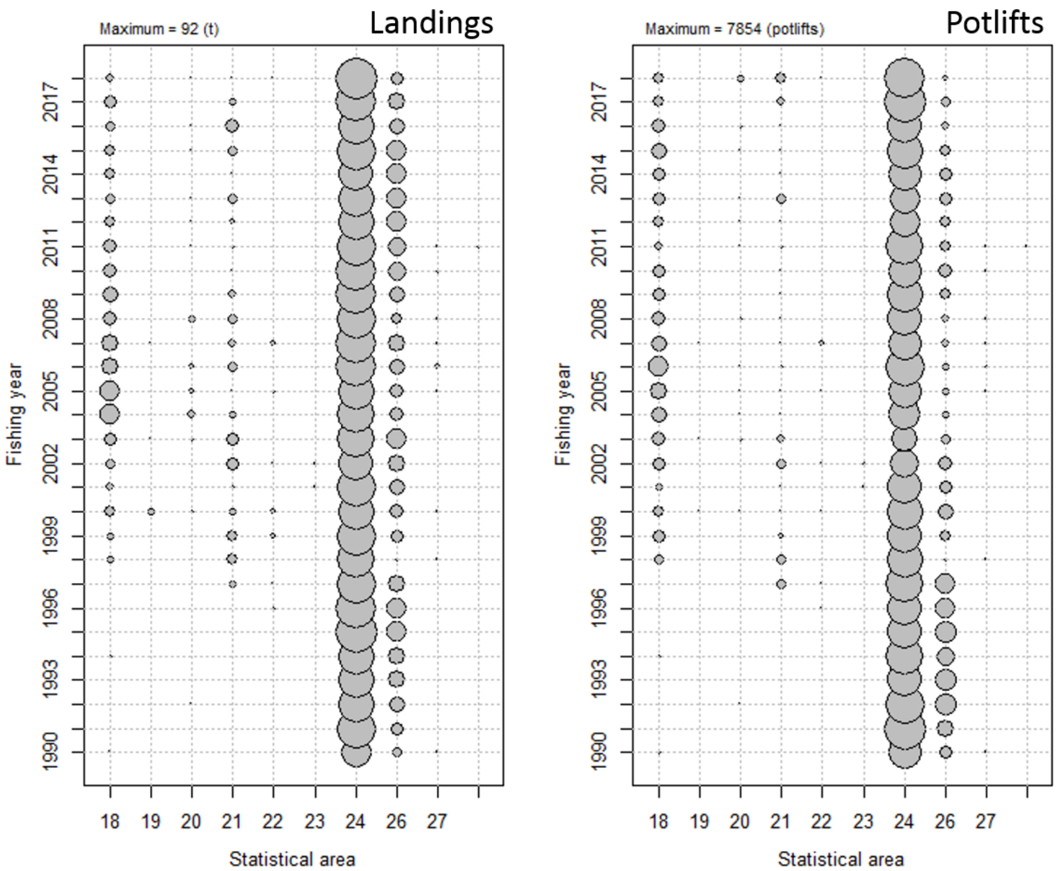


Figure 11: Distribution of landings and number of potlifts for the cod potting method by statistical area and fishing year from trips which landed BCO 3. Circles are proportional within each panel: [landings] largest circle = 92 t in 2011 for Statistical Area 024 (24); [number potlifts] largest circle = 7854 pots in 2006 for Statistical Area 024 (Holmes et al 2022a).

The effort data were matched with the landing data at the trip level and the 'trip-stratum' stratification inherent in the CELR data was maintained. The 2019 analysis used only data from Statistical Areas 024 and 026. The CPUE analysis was confined to a set of core vessels which had participated consistently in the fishery for a reasonably long period (5 trips in 3 years), resulting in keeping 61 vessels representing 94% of the landings. The explanatory variables offered to the model included fishing year (forced), month, vessel, statistical area, number of pots lifted in a day, and number of days fishing in the record. A log-logistic model (as used in the 2015 analysis) based on successful catch records was used because there were too few unsuccessful fishing events to justify pursuing a binomial model.

The log-logistic standardised model for BCO 3 (Figure 12) fluctuated without trend with the final data point close to the series mean. In the 2015 analysis, a model using estimated catches instead of scaled landings showed a similar trend up to 2012–13, when the series based on landed catch increased more rapidly than the estimated catch series. The Southern Inshore Working Group agreed in 2015 that the series based on landed catch was more reliable and consistent with other CPUE analyses done for the working group.

During 2002–03 to 2017–18, commercial catches in BCO 3 exceeded the TACC by 5%. The bulk of the total BCO 3 commercial catch (72%) was taken from Statistical Areas 024 and 026 (along with about 90% of the CPUE data). The CPUE series shown in Figure 12 is representative of the southern portion of BCO 3 (Statistical Areas 024 and 026) and is not applicable to those parts of BCO 3 north of Statistical Area 024.

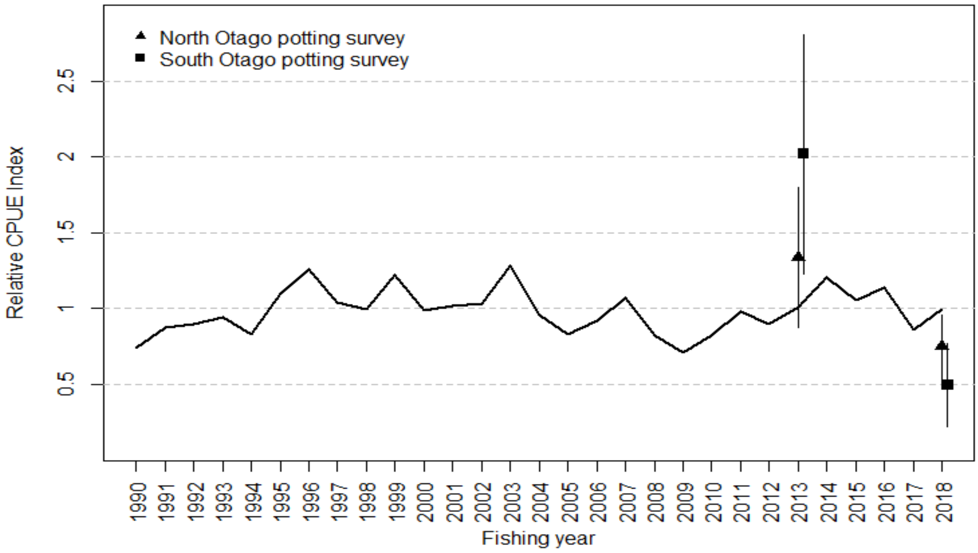


Figure 12: Comparison of BCO 3 standardised series (1989–90 to 2017–18) based on landed green weight catch data and the 2013 and 2018 observations from the north Otago and south Otago potting surveys conducted at random sites over all strata (Holmes et al 2022a). (Each relative series is scaled so that the geometric mean equals 1.0 from 2013 to 2018.)

Establishing B_{MSY} compatible reference points

In 2019, the Working Group accepted the mean CPUE from the target BCO cod potting series for the period 1994–95 to 2003–04 as the B_{MSY}-compatible proxy for BCO 3. This period was chosen because catches and CPUE were stable without trend and apparent productivity was good. This period was also used to determine average fishing intensity compatible with the selected B_{MSY}-compatible proxy. The Southern Inshore Working Group accepted the default Harvest Strategy Standard definitions for the Soft and Hard Limits at one-half and one-quarter the target, respectively. This conclusion was revisited in 2021 at which time the working group determined that it no longer had confidence in the consistency of the CPUE series, given that the series did not account for a 10 mm increase in the regulated mesh size (from 38 mm to 48 mm square mesh) in June 2009.

4.3 BCO 4

The cod potting fishery in BCO 4 is entirely targeted on blue cod and reported on the daily CELR form. The spatial resolution of the catch effort data is therefore defined by general statistical area and by day (or part of a day). CPUE was standardised for the cod pot fishery operating in Statistical Areas 049 to 052 up to 2017–18 (Holmes et al 2022b). The analysis was based on a Weibull model of positive allocated landed catches from a core fleet of vessels. This methodology follows that used in the previous CPUE standardisation (Bentley & Kendrick in prep). Detailed examination of model residuals and the distribution of catch per vessel day suggested that the Weibull distribution provided a better fit to the data than the lognormal distribution and other alternative distributions. The previous analysis found that there appears to have been a change in the underlying frequency distribution of catch categories in the late 1990s, which may be a result of several factors, including changes in the fleet composition, fishing methods, and/or reporting practices. Consequently, the indices for the fishing years up to, and including, 1996–97 are considered to be less reliable and may not be comparable with the indices from the latter part of the series. The working group considered that the current CPUE standardisation should only include analysis of the fishing years from 1997–98.

Overall, the annual indices from the standardisation model have fluctuated without trend since the late 1990s (Figure 13).

Figure 13: Standardised CPUE index for BCO 4 based on records of positive BCO catch by core vessels, 1997–98 to 2017–18 (Holmes et al 2022b).

4.4 BCO 5 (Southland)

The first fully quantitative stock assessment for blue cod in BCO 5 was carried out in 2013 (Haist et al 2013). A custom-built length-based model, which used Bayesian estimation, was fitted separately to data from Statistical Areas 025, 027, and 030. A second stock assessment was completed in 2019, but it switched to an age-based Bayesian model and the assessment was conducted using NIWA's CASAL2 assessment package (Doonan 2020). Again, the model was fitted separately to data from Statistical Areas 025, 027, and 030.

4.4.1 Methods

4.4.1.1 Model structure

The stock assessment model was aged-based with the population partitioned into six categories: male and female combined with three growth morphs (Doonan 2020). The growth morphs were fast, medium, and slow growth. Each morph had a normal length distribution at each age and they were constrained to combine into a normal length distribution-at-age with the same spread of length-at-age as observed in potting survey catches. Because fish cannot unambiguously be assigned to any one growth morph, observed data for each morph are not available. The pot fishery operates under a minimum legal size (MLS) and the morph construct helps the model 'remember' length distributional changes as a cohort grows past the MLS; i.e., once a cohort is completely recruited into the fishery, its length distribution is asymmetrical.

There are three fisheries: commercial line, commercial pot, and recreational line. Each fishery was modelled with a selectivity ogive and a retention ogive (Table 15), so catch data were a function of the selectivity ogive and landings data were a function of the product of selectivity and retention ogives. There were three time blocks for the pot fishery selectivity: pre-1994, 1994 to 2017, and 2018 onwards. These periods mirror the changes in regulations starting with the change in MLS (30 to 33 cm) in 1994, and the change in commercial pot mesh sizes in 2018. Discard mortality was assumed for fish that were caught but not landed.

Spawning stock biomass (*SSB*) is measured as the total mature biomass. A Beverton-Holt stock recruitment relationship was assumed. The CV of recruitment residuals was fixed at 0.6 and the steepness was assumed to be 0.75. Recruitment residuals were estimated for 1980 to 2014. Fish recruited to the model at age 1+ with 50% of fish recruiting as females. The populations were initialised at unexploited equilibrium conditions in 1900.

The informed prior distributions for model parameters are given in Table 16. Other parameters had uniform priors.

Table 15: Model selectivity and retention ogives by fishery, their parametric form, and parameter values if fixed or data fitted in the model to inform their estimation. AF, age frequency data; LF, length frequency data.

Ogives	Type	Parameters if fixed or data to inform
Selectivity		
Commercial line fishery	Logistic	50% selected at 280 mm; 95% selected at 305 mm
Commercial pot fishery ≤ 1993	Logistic	Mesh size trial LF
Commercial pot fishery 1994–2017	Logistic	Logbook sampling LF
Commercial pot fishery ≥ 2018	Logistic	2015 pot experiment & commercial AF
Recreational fishery	Logistic	Recreational catch LF
Survey	Logistic	Survey AF
Retention		
Commercial line fishery	Knife-edge	MLS (300 mm)
Commercial pot fishery ≤ 1993	Knife-edge	MLS (300 mm)
Commercial pot fishery 1994–2017	Knife-edge	MLS (330 mm)
Commercial pot fishery ≥ 2018	Knife-edge	MLS (330 mm)
Recreational fishery ≤ 1993	Knife-edge	MLS (300 mm)
Recreational fishery ≥ 1994	Knife-edge	MLS (330 mm)

Table 16: Assumed informed prior distributions for model parameters.

Model parameters	Distribution	Parameters/ bounds
Recruitment variation	Lognormal	CV: 0.60

As a sensitivity, sex change was modelled as a dynamic process, with the proportion of females transitioning to males as a function of age. Since there was little indication from the pot survey age data that sex change was occurring in the mature population, it was concluded that sex change probably occurred in the period before maturation. The sex ratio for mature fish was assumed to be 1:1.

4.4.1.2 Data

Separate data sets were compiled and analysed for Statistical Areas 025, 027, and 030. The data available for each of these areas differ, and few data were available for the remainder of the BCO 5 Statistical Areas. Data for Statistical Areas 025, 027, and 030, when combined, represent 92% of the recent commercial fishery landings. The general categories of data used in the stock assessment models included: landings, fishery length frequency data (LF), fishery and survey age frequency data (AF), abundance indices from standardised CPUE (all areas) and from fishery independent potting surveys (Statistical Area 025 only), and biological information on natural mortality, growth, and maturation.

Historical time series of BCO 5 landings were constructed for three gear types: commercial hand-line fishing, commercial pot fishing, and recreational line fishing. Additionally, non-reported blue cod catch used as bait in the CRA 8 rock lobster fishery was estimated and included with the commercial landings, and customary catch estimates were included with the recreational harvest. The constructed catch history prior to 2012 was the same as that used in the 2013 stock assessment (Haist et al 2013) and is presented in Figure 14.

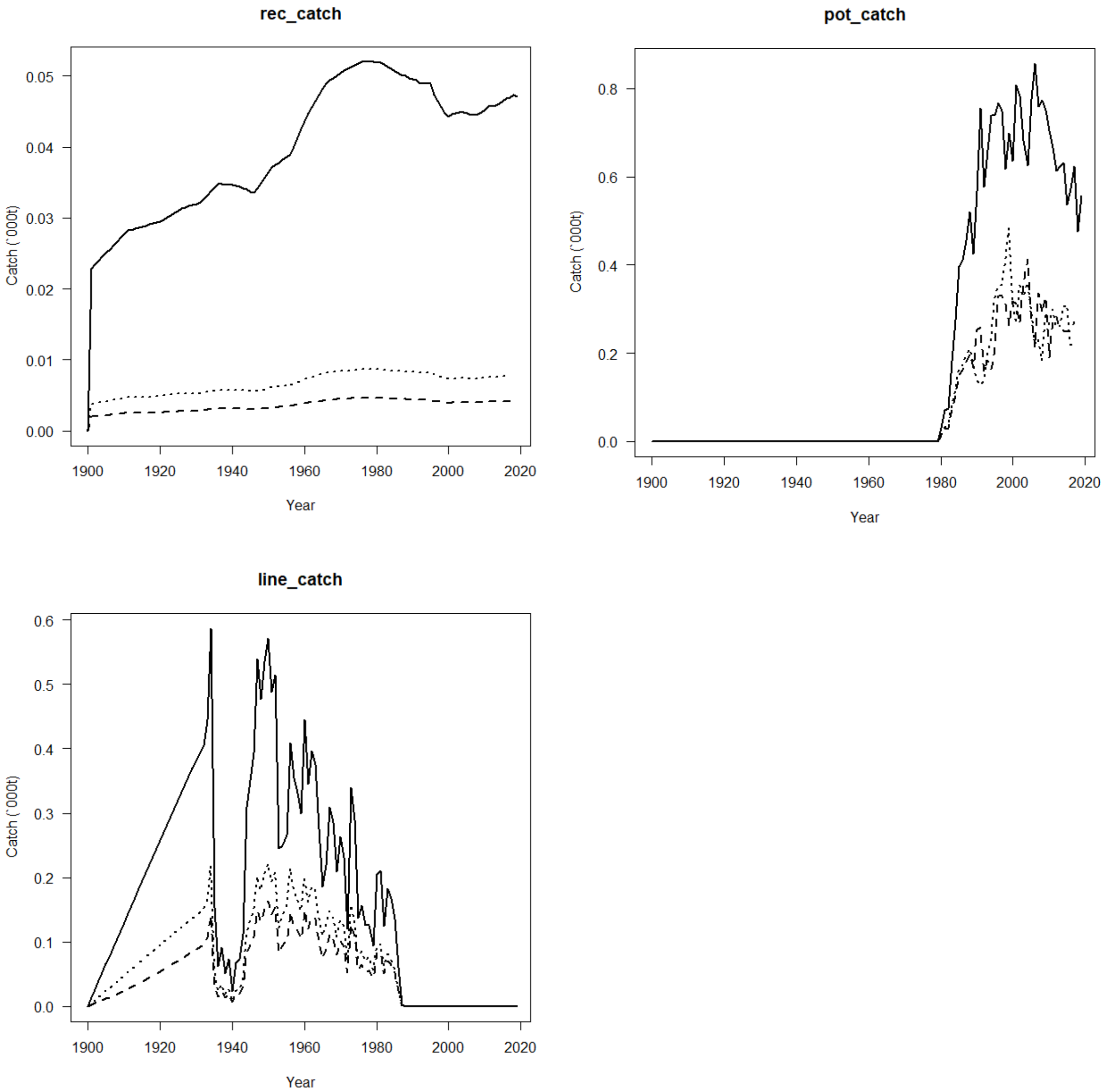


Figure 14: Constructed catch history used in the assessments by fishery and Statistical Areas 025 (solid line), 027 (dashed line), & 030 (dotted line).

Commercial landings data were available from 1931 (Warren et al 1997) and these were linearly decreased back to 1900, when the fishery was assumed to begin. The 1989–90 to 2011–12 average proportion of the total BCO 5 catch in each statistical area was used to prorate the earlier landings estimates to statistical area. A time series of non-reported blue cod used as bait in the rock lobster fishery was developed based on a 1985 diary study (Warren et al 1997), in conjunction with CRA 8 rock lobster landings.

A time series of recreational blue cod harvest was developed based on the 1991–92 and 1996 diary survey estimates of BCO 5 recreational catch. The average blue cod catch per Southland resident was estimated from the survey data and, assuming a constant per capita catch rate, was extrapolated to a time series using Southland District population census data.

Commercial fishery LF data were collected through a commercial fishers logbook project and a shed sampling project from 2009 to 2011. The shed sampling was sex-specific whereas the logbook sampling was not. Mean size of fish from the shed samples were smaller than those from the logbook programme (for Statistical Areas 025 and 027; there were no shed samples from Statistical Area 030), due to these data being from the last catch of the day, which was likely to be from inshore waters close to the sheds (so the fish would not spoil), where exploitation rates were higher. The logbook LF data were fitted to model predictions of the commercial catch size distribution for 2010, and, as a sensitivity, the logbook LFs were replaced by the shed LFs.

Recreational fishery LFs were obtained from a 2009–10 study of the Southland recreational blue cod fishery (Davey & Hartill 2011). This study included a boat ramp survey (Bluff, Riverton/Colac Bay, and Halfmoon Bay) and a logbook survey of charter and recreational vessels. Blue cod measured through the boat ramp programme were assumed to represent the landings, and fish measured through the logbook programme were assumed to represent the catch. Only the logbook data were fitted in the model.

Length frequency data from a blue cod mesh-size selectivity study, conducted by MAF in 1986 at Bluff and Stewart Island, were available. The LF from pots fitted with the then-standard 38 mm mesh were assumed to represent the size composition of the BCO 5 commercial pot fishery catch before the 1994 pot regulation changes. In preparation for a further change in mesh size regulations in 2018, different mesh sizes were trialled at various sites close to land in 2015 (Glen Carbines, pers. comm.). The data for the new mesh sizes were fitted to the 2018 size frequency. Both experiments did not catch a representative sample of the larger fish given the restricted range of sites used. Consequently, the model was fitted to just the left-hand limb (LHS) since its use was for catch selectivity estimation.

Length frequency data were also available from random stratified potting surveys conducted in Statistical Areas 025 and 030 in 2010, 2014, and 2018. These surveys also provide age frequency (AF) data by sex.

There are two stock abundance estimates: fishery-based standardised CPUE estimates (Table 17), and pot survey estimates of abundance.

The data fitted in the models for each statistical area are shown in Table 18, and the assumed error structure of each data series is shown in Table 19.

Table 17: Standardised CPUE indices for Statistical Areas 025, 027, and 030, for fishing years 1990–2018.

	Statistical Area				Statistical Area		
Fishing Year	**025**	**027**	**030**	**Fishing Year**	**025**	**027**	**030**
1990	1.01	0.59	1.04	2005	1.32	1.25	1.24
1991	0.81	0.62	0.97	2006	1.26	1.18	1.27
1992	0.79	0.66	1.00	2007	1.09	0.96	1.14
1993	0.80	0.85	0.89	2008	1.02	0.88	0.95
1994	0.81	0.61	0.65	2009	1.03	0.88	1.04
1995	0.84	0.91	0.69	2010	0.90	0.82	1.01
1996	0.97	1.07	0.70	2011	0.98	1.01	0.86
1997	1.08	1.24	1.15	2012	0.98	0.98	0.81
1998	1.06	1.13	1.20	2013	0.96	0.92	0.91
1999	0.96	1.11	1.32	2014	1.00	0.84	0.96
2000	1.12	1.32	1.13	2015	0.93	0.92	0.96
2001	1.23	1.65	1.18	2016	0.92	0.97	0.85
2002	1.31	1.75	1.35	2017	0.92	1.01	0.89
2003	1.27	1.51	1.35	2018	0.76	0.90	0.82
2004	1.23	1.63	1.23				

Table 18: Data series fitted in the stock assessments for Statistical Areas 025, 027, and 030. AF is age frequency data; LF is length frequency data.

Data type	Series	Area 025	Area 027	Area 030
AF data				
	Survey	✓	–	–
	Pot fishery	✓	✓	✓
LF data:				
	Logbook	✓	✓	✓
	Mesh selectivity trials (1986)	data common to all areas		
	Recreational catch	data common to all areas		
	Mesh selectivity trials (2015)	data common to all areas		
Abundance Index:	CPUE	✓	✓	✓
	Survey	✓	–	–

Table 19: Assumed distributions for data fitted in the models. AF, age frequency data; LF, length frequency data. N, effective sample size.

Data type	Distribution	Parameters
Survey abundance	Lognormal	CV: 0.20
Survey AF	Multinomial	N: 100
Pot fishery AF 2018	Multinomial	N: 100
2019	Multinomial	N: 5
CPUE	Lognormal	CV: 0.10
Logbook LF	Multinomial	N: 100
Mesh size trials LF (1986)	Multinomial	N: 20
Mesh size trials LF (2015)	Multinomial	N: 20
Recreational catch LF	Multinomial	N: 100
Ages	Off-by-one, binominal	P: 0.086
Sensitivities		
Shed samples LF	Multinomial	N: 100

4.4.1.3 Further assumptions

Age data to estimate sex-specific von Bertalanffy growth parameters were available from the random-stratified potting surveys and the commercial AFs. The same growth model was assumed for all areas. For males, the L_∞ parameter was not well estimated because data were sparse at L_∞ due to fishing pressure. Male L_∞ was therefore estimated within the model. The potting surveys also had maturity data which gave maturity as logistic with A_{50} of 4.1 y and A_{50to95} of 2.47 y for both sexes.

4.4.1.4 Biomass estimates

The assessment was conducted in two steps. First, a set of initial exploratory model runs was carried out generating point estimates (MPD runs, which nominally estimate the mode of each posterior distribution). The purpose of the MPD runs was to decide which sets of assumptions should be carried forward to the final runs and to quantify the sensitivities of the MPD to the assumptions used. The final runs were fully Bayesian, estimating posterior distributions for all quantities of interest. The base-case model run consisted of separate stock assessments for Statistical Areas 025, 027, and 030, with the results combined to provide results for BCO 5. Natural mortality was fixed at 0.17.

The MPD $B_{CURRENT}$ (% B_0) for the base case was estimated at 31.2%. When M was set at 0.15, $B_{CURRENT}$ was 29.4%, and when M was set to 0.19, it was 33.1%. The largest change occurred when the LF data from the logbook programme were replaced with that from the shed sampling programme; this reduced $B_{CURRENT}$ to 23.9%. The latter was considered unlikely, because the shed length data have a lower proportion of large fish than that from the logbook data because of the differences in the way the fish were sampled. The logbook length data were preferred by the working group. Other sensitivities model runs included:

Sensitivity	$B_{CURRENT}$ (% B_0)
Commercial discard mortality of 50%	31.6
Sex change in model (also single growth path)	32.0
Single growth path	31.6
Single stock assessment	33.0

Bayesian posterior distributions were estimated for the base-case model using a Markov chain Monte Carlo (MCMC) approach. For each run a chain of 1 million was completed and the chains thinned to produce a posterior sample of 1000. BCO 5 summary statistics are calculated by summing across Statistical Areas 025, 027, and 030, and BCO 5 catch is calculated assuming these areas account for 92% of the BCO 5 stock. The model estimates are summarised in Table 20 (estimates of spawning biomass), Figure 15 (biomass trajectories), and Figure 16 (recruitment trajectories).

Table 20: Estimates of BCO 5 unfished spawning stock biomass and current spawning stock biomass as a percentage of the unfished level for the final runs (medians of marginal posterior distributions, with 95% confidence intervals in parentheses). B_0 is calculated assuming Statistical Areas 025, 027, and 030 represent 92% of the BCO 5 blue cod stock.

Run	B_0 (000 t)	$B_{CURRENT}$ (%B_0)
base	21(20,23)	36 (31,41)

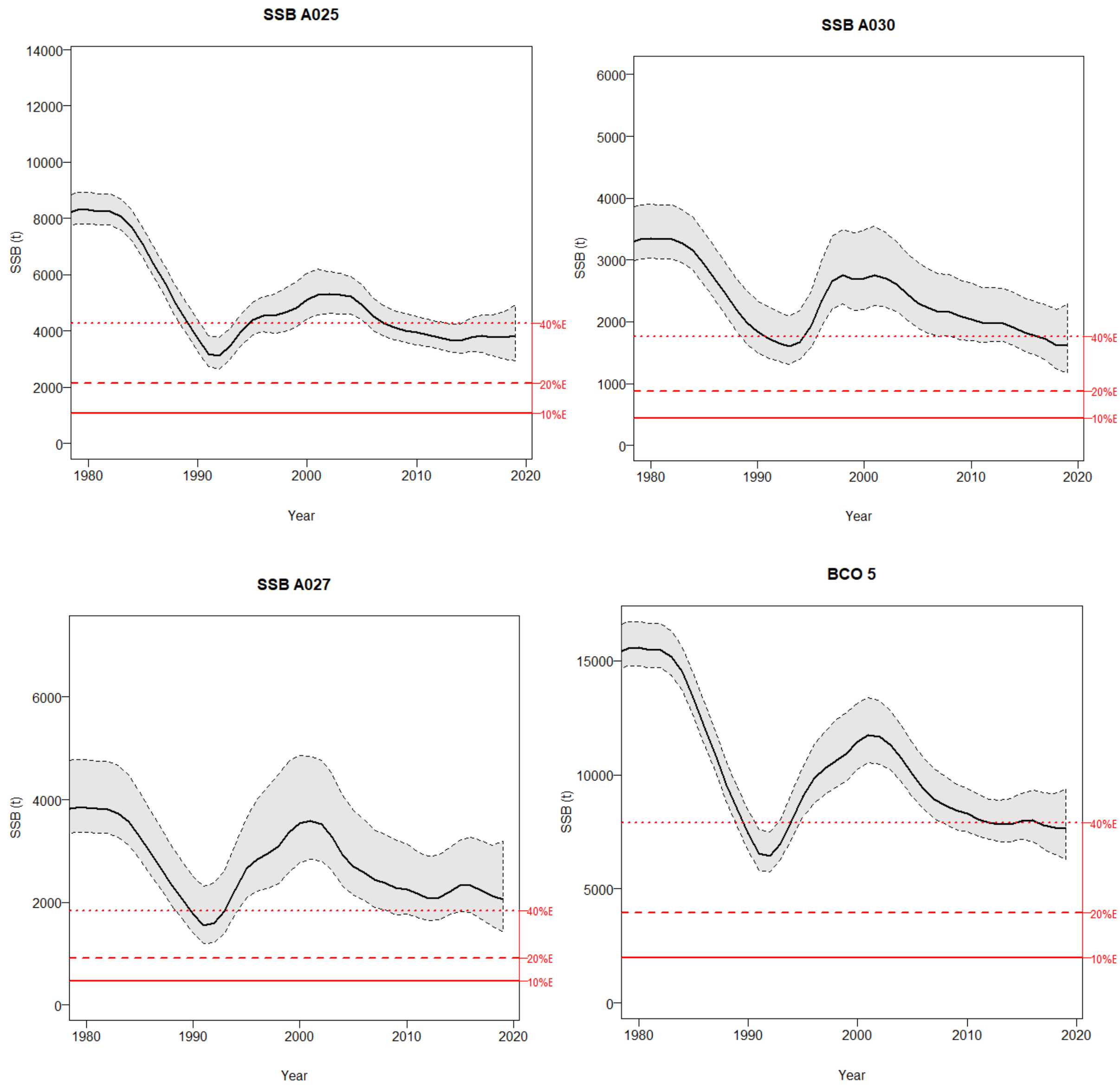


Figure 15: Median estimates of spawning biomass for Statistical Areas 025, 027, and 030, and the three areas combined, for the base-case model runs, 1980–2019.

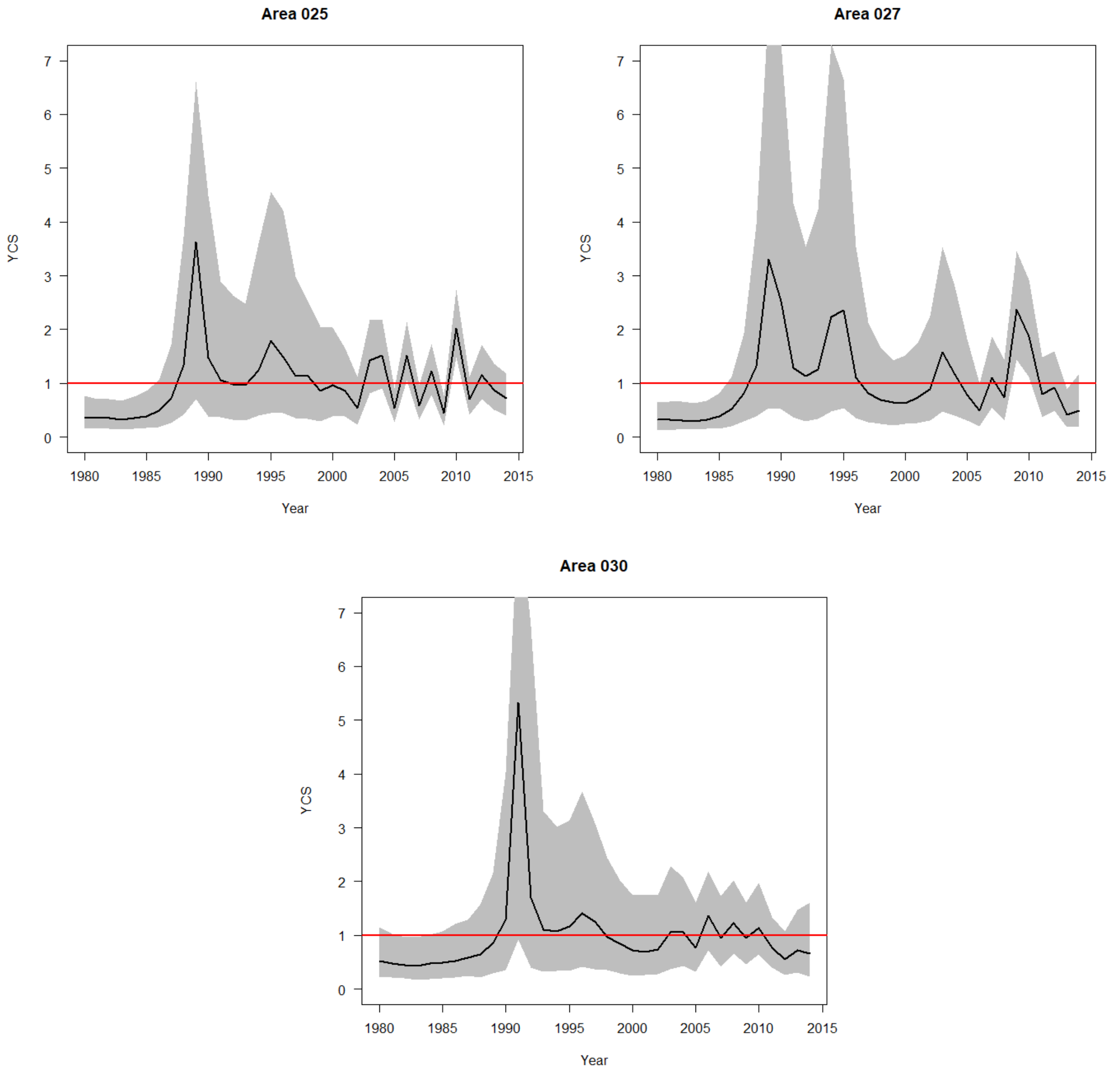


Figure 16: Year Class Strength (YCS) from the base-case runs for Statistical Areas 025, 027, and 030, for 1980–2014. Medians are shown by the black line and the shaded areas show the 95% range limits.

4.4.1.5 Yield estimates and projections

Ten-year stock projections were conducted for the three statistical areas at constant catch levels, with summary statistics calculated at the end of 5 and 10 years. These are based on the MCMC results.

In the stock assessment, the 2018–19 commercial catch level was set at the average of the years (2015–16, 2016–17, and 2017–18). This level of catch was also used in projections based on current catch for the years 2019–20 onwards, and the 2018–19 catch was recalculated based on returns-to-date (as of 8 November 2019) of 804.8 t, which was allocated to the assessment areas based on their fraction of catch to the total. An alternative catch scenario was simulated with commercial catch reduced by 20%.

Recruitment was simulated by randomly re-sampling (with replacement) from the 2005–14 recruitment deviates, applied to the stock-recruitment relationship. Summary statistics were calculated for the BCO 5 QMA by summing B_0 and projected biomass estimates across the three statistical areas.

The projections indicate that under the assumptions of commercial catch at current levels and recruitment at recent levels, the BCO 5 biomass is likely to decline gradually over the next 10 years (Figure 17). Although the spawning stock sex ratio is variable among the sensitivity trials, by 2013 and through the projection period, the sex ratio remains relatively constant.

The probabilities of the projected spawning stock biomass (2018 and 2023) being below the hard limit of 10% B_0 or the soft limit of 20% B_0, or above the target of 40% B_0, are presented in Table 21, for the base case model with recent recruitment for the sensitivity runs with recent recruitment and commercial catch at current levels and with a reduction of 20%. With catches at current levels, the probability of the stock being less than either the soft or hard limit over the next five years is negligible.

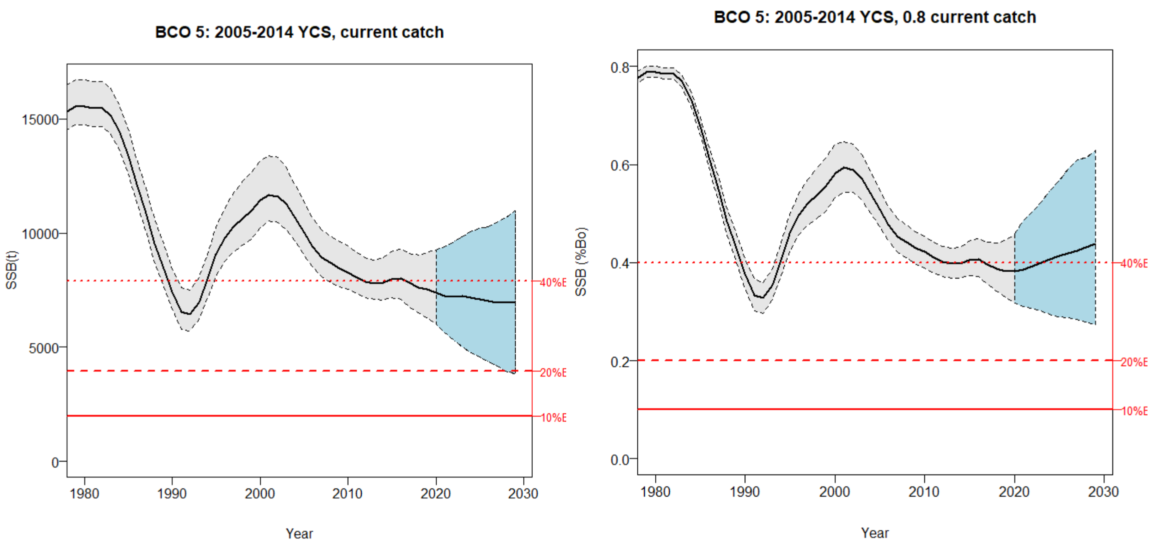


Figure 17: Projected BCO 5 spawning biomass (% B_0) assuming recent recruitment and catch at current levels and at 80% of current levels for the base case run. Median estimates are shown as solid lines and 95% confidence intervals as shaded polygons. Projections start in 2020.

Table 21: Probabilities of *SSB* being below B_0 reference levels in 2019, 2024, and 2029 at alternative catch levels for the base-case projections.

Run	**Base**		
Recruitment	**Recent**	**Recent**	**Recent**
Catch Level	TACC	Current	80% of Current
P(B_{2019}< 0.1 B_0)	NA	0	0
P(B_{2019}< 0.2 B_0)	NA	0	0
P(B_{2019}>= 0.4 B_0)	NA	0.279	0.269
5 year projection			
P(B_{2024}< 0.1 B_0)	NA	0	0
P(B_{2024}< 0.2 B_0)	NA	0.004	0
P(B_{2024}>= 0.4 B_0)	NA	0.286	0.535
10 year projection			
P(B_{2029}< 0.1 B_0)	NA	0	0
P(B_{2029}< 0.2 B_0)	NA	0.024	0.001
P(B_{2029}>= 0.4 B_0)	NA	0.301	0.69

4.5 Management procedure to set TACC

On the basis of the 2019 stock assessment (Doonan 2020), the TAC for BCO5 was reduced to 925 t, with a TACC of 800 t. Given recent poor recruitment and biomass declines estimated in the assessment model, a management procedure was developed in 2021 to monitor and manage the fishery between stock assessments on the basis of CPUE. According to the Medium Term Research Plan, the stock assessment for BCO 5 should be updated every 5 years. The harvest control rule was developed by industry stakeholders in consultation with Fisheries New Zealand and the Inshore Working Group, and robustness testing was undertaken using simulations based on the 2019 stock assessment model.

The harvest control rule relates CPUE (in kg per potlift) to TACC levels (Figure 18), leading to further reductions below the current 800 t TACC should CPUE decline further. The rule is meant to safeguard against further declines in biomass and minimise the risk of the fishery declining below limit reference points (i.e., $0.2 \times SSB_0$). Increases in catch include a latent year on CPUE increases; increases in CPUE from one year *y* to the next (*y*+1) are only realised if CPUE is still higher in the subsequent year (*y*+2). Any reductions in CPUE lead to immediate reductions in the TACC.

Simulation-testing of the control rule was carried out using a model that was modified from the 2019 stock assessment model to amalgamate all data (CPUE, composition data, catch) into a single area stock assessment. The revised operating model mirrored trends seen in the sum of the three single area models run by Doonan (2020), and the model was deemed adequate by the Plenary to test the robustness of the harvest control rule. The stakeholder-proposed rule was compared with a series of alternative control rules and constant catch levels to elicit its relative performance and risk. Recent estimated recruitment (2007–2016) was used as a basis for simulations, which represents some of the lowest recruitment in the model-estimated recruitment time series—simulation results could therefore be regarded as conservative because they assume that the recent low recruitment levels will continue.

Simulation testing concluded that the BCO 5 harvest control rule showed a low risk of reaching stock levels near limit reference points (Table 22, Figure 19), but also showed that the TACCs specified in the rule would lead to slow rebuilding of the stock based on the most recent 10 years of year class strength estimates, with a 46% change of rebuilding back to 40% SSB_0 by 2040 under the rule and recent recruitment.

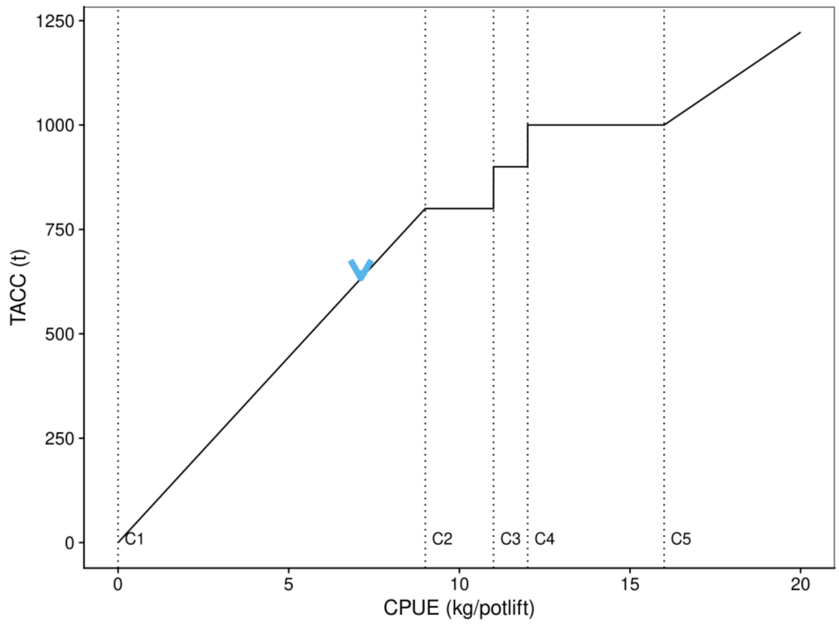


Figure 18: Harvest control rule relating the commercial TACC (t) to catch-per-unit-effort (CPUE, kg per potlift). The control rule is defined by CPUE parameters C1–C5 as well as corresponding TACC levels. The 2020 CPUE level is indicated by the light-blue arrow, suggesting a further reduction in TACC may be necessary to reduce fishing impacts under reduced current productivity.

Table 22: Probabilities of stock size being above 0.4 SSB_0 by 2025, 2030, and 2040, and the risk of the stock declining below 0.2 SSB_0 by 2025 or at any time between 2020 and 2040 under application of the harvest control rule using the 10 most recent years of estimated year class strengths.

	BCO 5 rule	TACC 800 t
P(SSB_{2025}>0.4 SSB_0)	0.23	0.15
P(SSB_{2030}>0.4 SSB_0)	0.37	0.26
P(SSB_{2030}>0.4 SSB_0)	0.46	0.32
P(SSB_{2025}<0.2 SSB_0)	<0.01	0.05
P(SSB_{2021}-SSB_{2040}<0.2 SSB_0)	<0.01	0.13

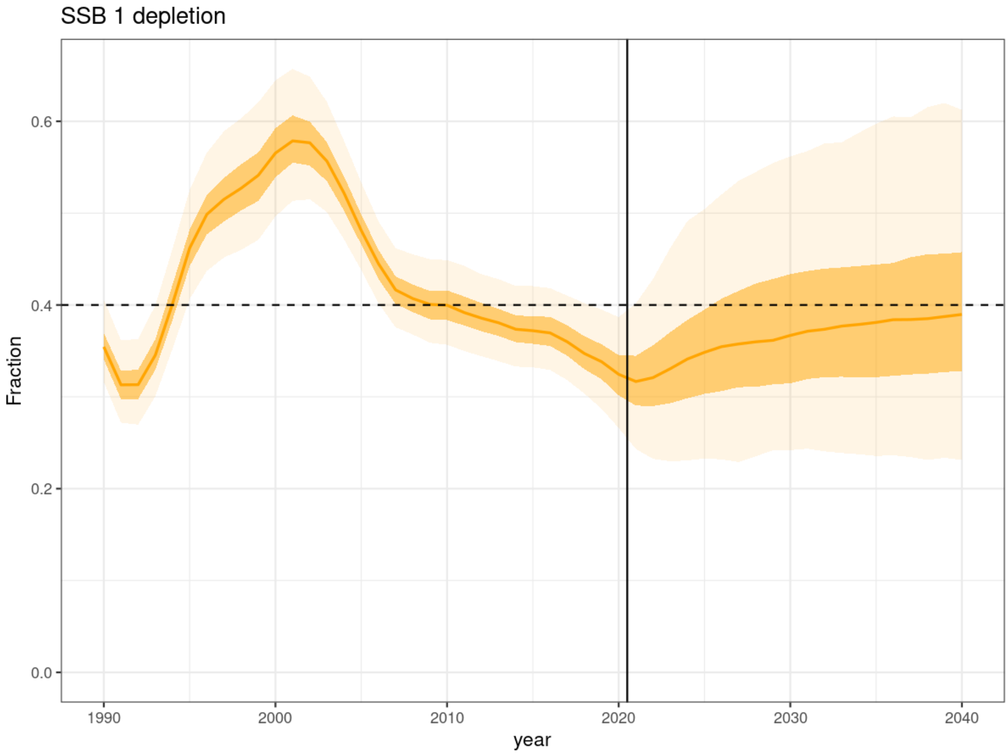


Figure 19: Stock trajectories estimated by the operating model used for harvest control-rule estimation up to 2020, with median (dark yellow), inter-quartile range (yellow), and 95% confidence bounds (tan). After 2020, trajectories show posterior medians of simulations under recent recruitment and application of the BCO 5 harvest control rule, compared with fixed total commercial catch (TCC) levels at the current TACC (800 t), recent catch (1000 t), and 600 t.

Breakout rules

To apply the harvest control rule, CPUE will be standardised and monitored annually, including standard diagnostics to ensure that changes in the fishery do not undermine the assumed relationship between CPUE and available biomass. Catch information will be used to monitor the spatial distribution of the fishery through time to determine whether this has changed. Trends and diagnostics will be presented annually to the Working Group to ensure that CPUE continues to reflect abundance and is therefore usable as input for the harvest control rule. The decision rule will be fully evaluated as part of the next stock assessment (2024). Catch and effort data collected from the recently-introduced Electronic Reporting System (ERS) will be monitored annually to determine whether there have been changes in reporting that affect the comparability of these data with data from CELR forms.

4.6 Other factors

Blue cod fishing patterns have been strongly influenced by the development and subsequent fluctuations in the rock lobster fishery, especially in the Chatham Islands, Southland, and Otago. Once a labour-intensive hand-line fishery, blue cod are now taken mostly by cod pots. The fishery had decreased in the past; however, with the advent of cod pots it rapidly redeveloped. Anecdotal information from recreational fishers suggests that there is local depletion in some parts of BCO 3, BCO 5, and BCO 7 where fishing has been concentrated. Blue cod abundance (Carbines & Cole 2009), catch (Cranfield et al 2001), and productivity (Jiang & Carbines 2002, Carbines et al 2004) may also be affected by disturbance of benthic habitat.

4.7 Future research considerations

<u>All BCO stocks</u>

- Explore the consequences of different mechanisms of sex change in blue cod in terms of how it might affect reference points as well as population parameters (Z, M, growth rates) through simulation studies.
- Explore the potential of tank experiments to understand the drivers of sex change in blue cod.

- Re-age otoliths from historical surveys (offshore Banks area) using new protocols with the aim to provide estimates of M.
- Investigate the potential of non-invasive approaches to sex blue cod from marine reserves (ultrasound, blood chemistry?).
- Investigate the potential for genetics for ageing (and sex) for marine reserves or closed areas.

BCO 3

- Account for the June 2009 regulatory mesh change in future CPUE analyses, probably by breaking the time series at 2010. A re-examination in 2021 of the BCO 3 standardised CPUE series that was accepted in 2019 resulted in the Inshore Working Group reassessing its utility given that this mesh size regulatory change had not been explicitly taken into account. A new reference period may also be required.
- More detailed analyses of the degree of representativeness of these surveys for the entire stock should be evaluated, with a view to combining them with other information (such as a reanalysed CPUE series) to determine whether a full stock assessment can be undertaken. An analysis of recently available high spatial resolution ERS commercial reporting data has shown that main BCO 3 commercial potting fishery more strongly coincides with the north Otago and south Otago fisheries-independent potting survey areas than previously thought.
- Analysis of fine scale effort data from the Electronic Reporting System should be included in planning for future surveys. Consideration should be given to adding additional strata if this would improve coverage of the commercial potting fishery.
- Estimates of recreational harvest should be provided for the different sub-areas in BCO 3.
- Further analyses to better estimate growth are needed. The %SPR estimates reported in the Status of Stocks tables are based on a single year of ageing in each survey, largely because ageing of otoliths from previous surveys before about 2015 was unreliable.
- Ageing more otoliths from earlier surveys and commercial catches (if available), obtaining survey-specific estimates of size or age at maturity, and refining other biological parameters should be considered before a full stock assessment would be feasible.

BCO 5

- Further examine the potting survey data to determine spatial structuring (e.g., using GAM surfaces).
- Try to find otoliths from early surveys or experiments and re-read using current protocols.
- Re-age otoliths from other early surveys in lightly fished areas to provide a better estimate of M.
- Obtain and examine market grading data. More commercial length and age data by area would be useful to determine spatial differences in size structure and growth.
- Re-examine the selectivity priors, including collecting more information about the effects of the 2018 mesh size regulations on fishing behaviour and CPUE. (This should also be done for other blue cod fisheries.)
- Consider interviewing fishers to ascertain changes in fishing behaviour that might affect the relationship between the CPUE indices and abundance. If there is evidence of increasing catchability, possible changes to the assessment include splitting vessel identifiers by time period(s) or including an additional parameter for representing increasing catchability.
- Evaluate the comparability of the ERS data to the CELR data, including potential changes in reporting behaviour.
- Use a wider range of values of M in sensitivities.
- Use empirical data for maturity rather than a logistic function.
- Conduct alternative runs to better understand the behaviour of the model: e.g., start estimating year classes earlier than 1980 to see how this affects early recruitments and the early part of the biomass trajectory; remove the age composition data to determine their relative influence.
- As part of next assessment, re-examine the magnitude of the catches outside the three main statistical areas to determine whether these should be included in the assessment, perhaps by merging them into adjacent statistical areas.

BCO 5 Control rule

- Consider a wider family of future harvest control rules.
- Try to define an optimal control rule based on input from stakeholders. Output a range of indicators of importance to stakeholders in a form that makes it easier to inform trade-offs.
- Explore other forms of breakout rules.

BCO 7

- Undertake a stock characterisation and CPUE analysis for BCO 7.
- Consider developing reference points from BCO 7 surveys once the time series are sufficiently long.
- Record width of blue cod habitat at each station within the BCO 7 potting surveys and explore the implications of scaling biomass to strata area rather than strata length.

5. STATUS OF THE STOCKS

For BCO 1 and 8 recent commercial catch levels are considered sustainable. The status of the remaining fish stocks is summarised below. A summary of TACCs and reported landings for blue cod from the most recent fishing year is given in Table 22.

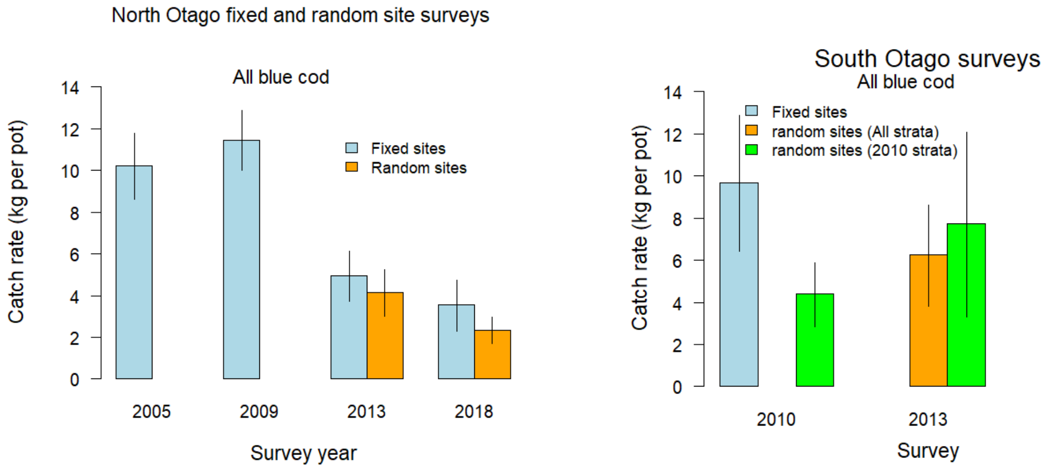
- **BCO 3 (Statistical Areas 024 and 026)**

Stock Structure Assumptions

Tagging experiments suggest that blue cod populations may be isolated from each other and there may be several distinct sub-populations within management areas. For the purposes of this summary, BCO 3 is split into two sub-areas along the Statistical Areas 022/024 boundary: Statistical Areas 018, 020, and 022 (Northern); and Statistical Areas 024 and 026 (Southern). There were insufficient data to produce a standardised CPUE series for the northern sub-area.

Stock Status	
Year of Most Recent Assessment	2019 (corrected 2021)
Assessment Runs Presented	North and south Otago potting surveys
Reference Points	Target: $SPR_{45\%}$ Soft Limit: $SPR_{22.5\%}$ Hard Limit: $SPR_{11.25\%}$ Overfishing Threshold: $F_{SPR45\%}$
Status in relation to Target	Unknown
Status in relation to Limits	Soft Limit: Unlikely (< 40%) to be below Hard Limit: Very Unlikely (< 10%) to be below
Status in relation to Overfishing	Unknown

Historical Stock Status Trajectory and Current Status



North Otago and south Otago fixed-site and random-site potting survey catch rates of all blue cod by survey year. Error bars are 95% confidence intervals. For north Otago, surveys after 2005 include a new stratum (stratum 6). For south Otago, the 2010 survey used three strata, and subsequent surveys used 6 strata. Catch rates are also shown for the three strata used in 2010 for the random-site surveys. Note that the fixed-site and random-site surveys are not directly comparable. Only the random sites are included for the status of stocks evaluation; however, the fixed sites are included because they provide context, particularly for north Otago.

Fishery and Stock Trends	
Recent Trend in Biomass or Proxy	The north Otago and south Otago potting surveys each have two annual indices based on the random survey design, both of which have exhibited substantial declines between 2013 and 2018, particularly that for north Otago. There is good overlap between the survey areas and BCO commercial fishing grounds in Statistical Areas 024 and 026, where most of the BCO 3 commercial catch is taken. Earlier fixed station surveys also showed a decline for north Otago.
Recent Trend in Fishing Intensity or Proxy	-
Other Abundance Indices	Spawning biomass per recruit ratios were 30% and 34% for 2018 north and south Otago Potting surveys, respectively. These are above the soft and hard limits of 22.5% *SPR* and 11.25% *SPR*, respectively.
Trends in Other Relevant Indicators or Variables	-

Projections and Prognosis	
Stock Projections or Prognosis	Current catch has exceeded the TACC since 2014–15, but there are anecdotal reports from both commercial and recreational fishers that blue cod catch rates in this area have declined.
Probability of Current Catch or TACC causing decline Biomass to remain below or to decline below Limits	Soft Limit: Unlikely (< 40%) Hard Limit: Very Unlikely (< 10%)
Probability of Current Catch causing Overfishing to continue or to commence	Unknown

Assessment Methodology and Evaluation		
Assessment Type	Level 2 - Partial Quantitative Stock Assessment	
Assessment Method	Fisheries-independent potting surveys	
Period of Assessment	Latest assessment: 2019 (2021 correction)	Next assessment: 2023

Overall Assessment Quality	1 – High Quality	
Main Data Inputs (Rank)	- Catch and effort data - North and south Otago potting surveys	1 – High Quality 1 – High Quality
Data not used	N/A	
Changes to Model Structure and Assumptions	- Use of the potting surveys to report stock status has replaced the previous CPUE series because pot mesh size changes in June 2009 will have impacted on the comparability of the CPUE indices over time.	
Major Sources of Uncertainty	- The degree of overlap between the potting surveys and the extent of the commercial fisheries and the stock needs further investigation. - The *SPR* estimates are based on one survey in each of the north and south Otago areas. - The impact of the change in mesh size for blue cod pots from 38 mm mesh to 48 mm mesh in 2009 on commercial CPUE is unknown, which means that the previously accepted CPUE index is no longer presented in the table.	

Qualifying Comments
Because the bulk of the commercial catch (72%) is taken from Statistical Areas 024 and 026, both CPUE and catch trends for BCO 3 are strongly influenced by catches in these areas. A June 2009 change in regulations governing commercial pots (change from 38 mm mesh to 48 mm square grids) will have affected CPUE indices and comparison of trends before and after this date. The impact of this regulation change is unknown, and it led to the CPUE index being excluded from this table.

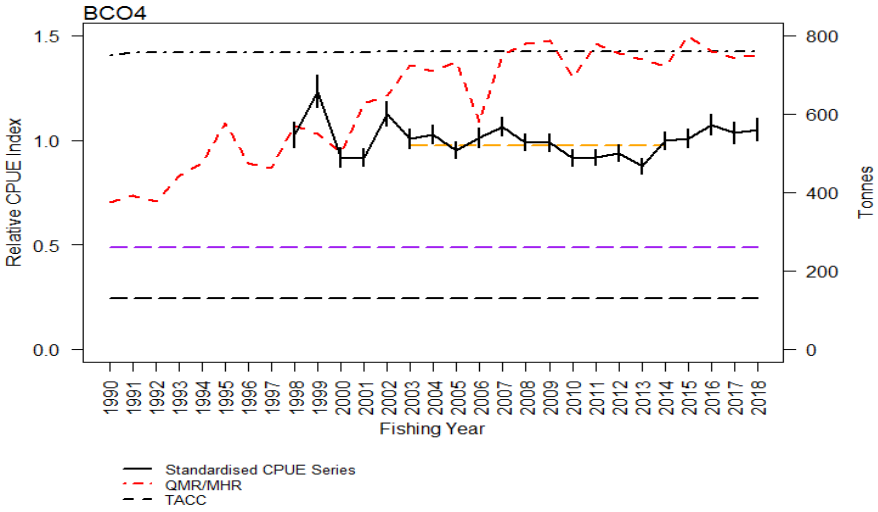
Fishery Interactions
Over two thirds of BCO 3 commercial catches are taken in a target cod-potting fishery which has very little interaction with other species. Most of the remaining BCO 3 catch is taken in the inshore bottom trawl fishery operating off the east coast of the South Island, largely directed at flatfish, red cod, and tarakihi.

- **BCO 4**

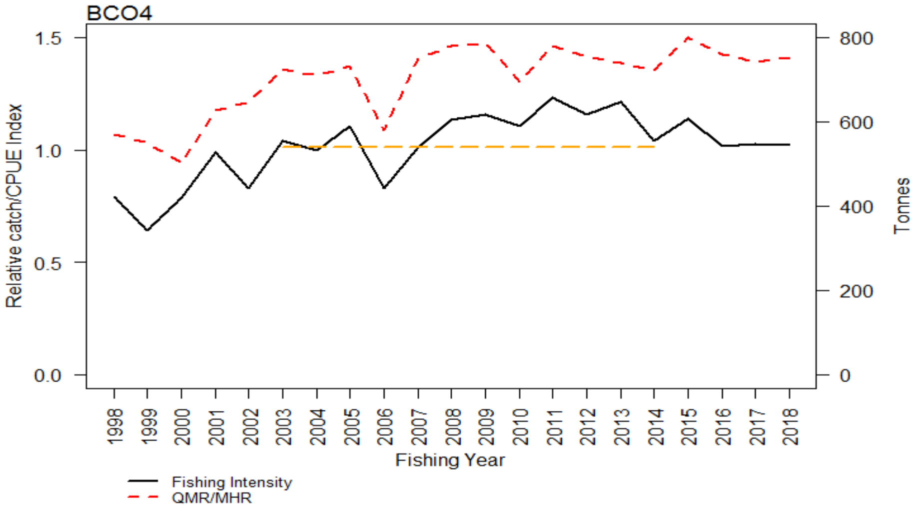
Stock Structure Assumptions
For the purposes of this summary BCO 4 is considered to be a single management unit.

Stock Status	
Year of Most Recent Assessment	2019
Assessment Runs Presented	CPUE index based on landed catch
Reference Points	Interim Target: B_{MSY} proxy based on mean CPUE for the period 2002–03 to 2013–14 (a period with high yield when both catch and CPUE were stable) Soft Limit: 50% B_{MSY} proxy Hard Limit: 25% B_{MSY} proxy Overfishing threshold: F_{MSY} proxy based on mean relative exploitation rate for the period 2002–03 to 2013–14
Status in relation to Target	Likely (> 60%) to be at or above the target
Status in relation to Limits	Soft Limit: Very Unlikely (< 10%) to be below Hard Limit: Very Unlikely (< 10%) to be below
Status in relation to Overfishing	About as Likely as Not (40–60 %) to be occurring

Historical Stock Status Trajectory and Current Status



BCO 4 standardised CPUE series for 1998–2018. Also plotted are the QMR/MHR landings and the BCO 4 TACC. The orange line represents the B_{MSY} proxy of mean CPUE from 2003 to 2014. The purple line is the Soft Limit=0.5*[B_{MSY} proxy] and the grey line is the Hard Limit=0.25*[B_{MSY} proxy].



BCO 4 fishing intensity (=catch/CPUE) plot based on the standardised CPUE series from 1997–98 to 2017–18 and the QMR/MHR landings. Horizontal orange line represents the mean 2003–2014 fishing intensity associated with the interim B_{MSY} proxy.

Fishery and Stock Trends	
Recent Trend in Biomass or Proxy	CPUE has fluctuated without trend since 1997–98.
Recent Trend in Fishing Intensity or Proxy	Relative exploitation rate has declined since 2010–11 and in 2017–18 was near the overfishing threshold.
Other Abundance Indices	-
Trends in Other Relevant Indicators or Variables	-

Projections and Prognosis	
Stock Projections or Prognosis	The current catch and TACC are Unlikely (< 40%) to cause the stock to decline
Probability of Current Catch or TACC causing Biomass to remain below or to decline below Limits	Soft Limit: Very Unlikely (< 10%) Hard Limit: Very Unlikely (< 10%)
Probability of Current Catch or TACC causing overfishing to continue or to commence	-

Assessment Methodology and Evaluation		
Assessment Type	Level 2 - Partial Quantitative Stock Assessment	
Assessment Method	Fishery characterisation and standardised CPUE analysis	
Assessment Dates	Latest assessment: 2019	Next assessment: 2023
Overall assessment quality rank	1 – High Quality	
Main data inputs (rank)	- Catch and Effort 1997–98 to 2017–18	1 – High Quality
Data not used (rank)	- Catch and Effort 1989–90 to 1996–97	2 – Moderate or mixed Quality: compromised by changes in fleet composition and reporting practices
Changes to Model Structure and Assumptions	-	
Major Sources of Uncertainty	-	

Qualifying Comments
-

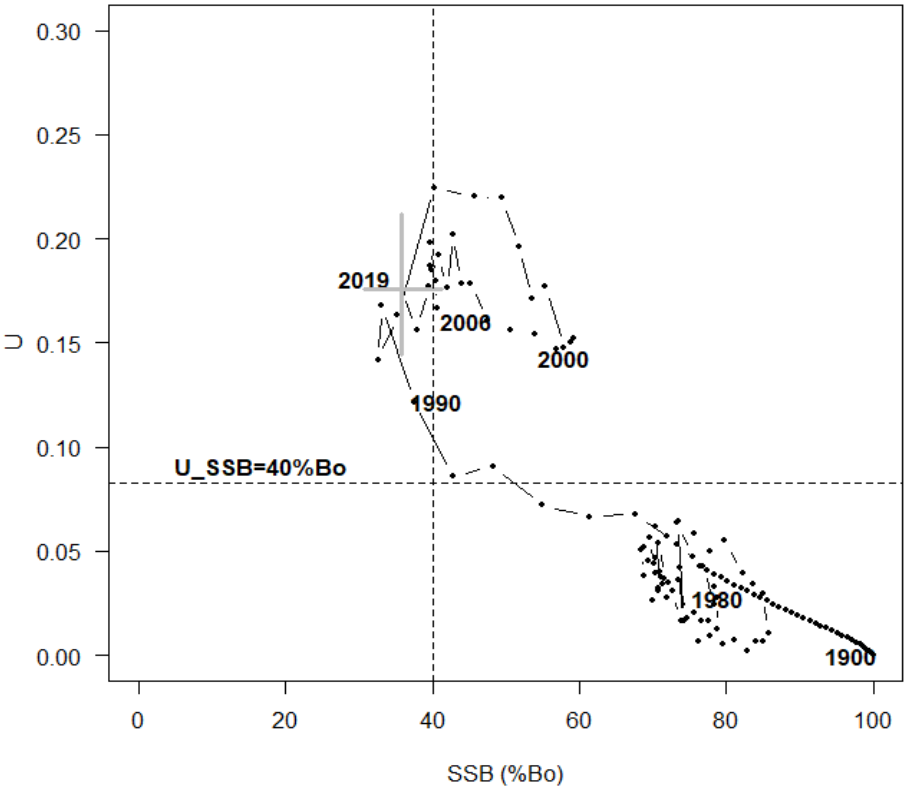
Fishery Interactions
The catch is almost entirely taken by target cod potting and there is little interaction with other species.

- **BCO 5**

Stock Structure Assumptions

Tagging experiments suggest that blue cod populations may be isolated from each other and there may be several distinct populations within management areas. For the purposes of this summary, blue cod in Statistical Areas 025, 027, and 030 of BCO 5 are treated as a unit stock. Dusky Sound and Paterson Inlet are assumed to contain discrete populations of BCO, which are monitored with potting surveys.

Stock Status	
Year of Most Recent Assessment	2020
Assessment Runs Presented	One base case model
Reference Points	Management Target: 40% B_0 Soft Limit: 20% B_0 Hard Limit: 10% B_0 Overfishing threshold: $U_{40\%SB}$
Status in relation to Target	B_{2019} was estimated to be 36% B_0; and is Unlikely (< 40%) to be at or above the Management Target
Status in relation to Limits	B_{2019} 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 Likely (> 60%) to be occurring

Historical Stock Status Trajectory and Current Status

Annual spawning biomass and fishing mortality compared with *SSB40%* and the corresponding fishing mortality reference.

Fishery and Stock Trends	
Recent Trend in Biomass or Proxy	Biomass has been decreasing since about 2000.
Recent Trend in Fishing Intensity or Proxy	The exploitation rate has been above the target since 1990.
Other Abundance Indices	-
Trends in Other Relevant Indicators or Variables	There have been three random-site potting surveys in Foveaux Strait (2010, 2014, and 2018) with no clear trend in catch rates over the time series.
Projections and Prognosis	
Stock Projections or Prognosis	BCO 5 biomass is expected to decline over the next 5 to 10 years at current catch levels.
Probability of Current Catch or TACC causing Biomass to remain below or to decline below Limits	For current catch in the next 3–5 years: Soft Limit: Very Unlikely (< 10%) Hard Limit: Very Unlikely (< 10%)
Probability of Current Catch or TACC causing Overfishing to continue or to commence	The current catch (average of 2015–16 to 2017–18), which is lower than the TACC, is Likely (> 60%) to cause overfishing to continue.

Assessment Methodology and Evaluation		
Assessment Type	Level 1 - Full Quantitative Stock Assessment	
Assessment Method	Age-based model with Bayesian estimation of posterior distributions	
Assessment Dates	Latest assessment: 2020	Next assessment: 2024
Overall assessment quality rank	1 – High Quality	
Main data inputs (rank)	- CPUE time series - Proportions-at-length and -age from commercial catch for 2017–18 and 2018–19	1 – High Quality 1 – High Quality

	-Proportions-at-length from commercial catch for 2010 - Relative biomass and proportions-at-length and at-age from potting surveys - Estimates of biological parameters - Potting survey abundance estimates	2 – Medium or Mixed Quality: sampling potentially unrepresentative 1 – High Quality 1 – High Quality 1 – High Quality
Data not used (rank)	Shed sampling LF by sex; only used in a sensitivity	3 – Low Quality: sampling potentially unrepresentative of the overall population
Changes to Model Structure and Assumptions	- Changed from length-based to age-based model - Maturity ogive age-based - *M* assumed to be 0.17 instead of 0.14 - No sex change assumed in base case	
Major Sources of Uncertainty	- Year classes prior to 2000 - Lack of adequate catch at age data - Lack of contrast in age data and CPUE - Relationship between abundance and sex change dynamics	

Qualifying Comments
There have been potential changes in fisher behaviour that are not captured in the assessment; for example, changes in responses to new pot mesh sizes and changes in areas fished (local versus long distance). Also, anecdotal information suggests some fishers have modified their fishing behaviour to maintain catch rates in a manner that cannot be standardised. Specifically, they move pots after each lift instead of re-setting them in the same place. It is not known to what degree this behaviour was adopted by core fleets in each statistical area, but this behaviour may have biased high recent CPUE, thereby masking declines in abundance.

Fishery Interactions
Historically, significant quantities of blue cod, taken by potting, were used as bait in the commercial rock lobster fishery. Since 1996, reporting of blue cod used for bait is mandatory and included as part of the commercial catch reporting. Some blue cod are landed as bycatch in rock lobster pots and oyster dredges.

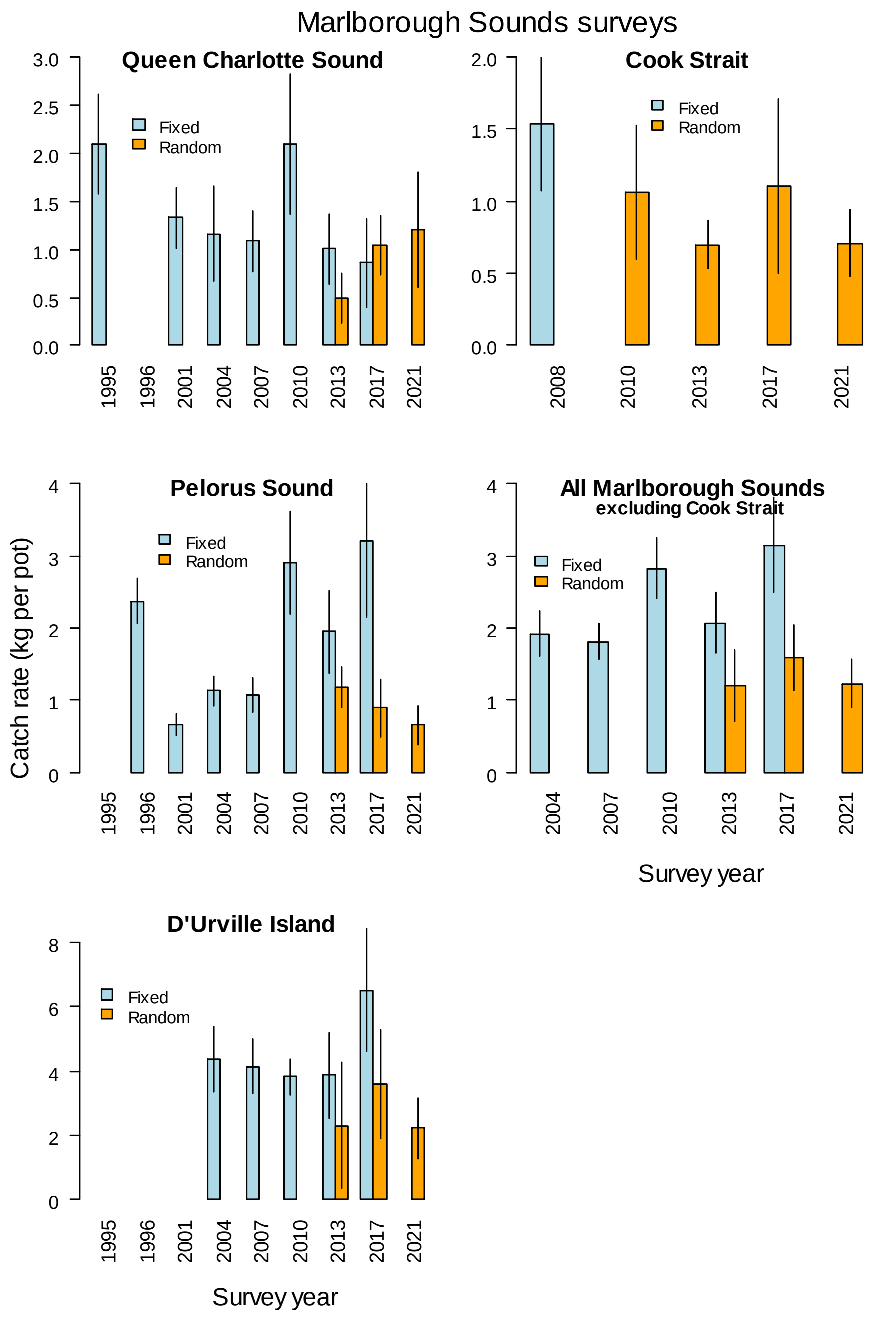
- **BCO 7 - Marlborough Sounds only**

Stock Structure Assumptions
For the purposes of this summary BCO - Marlborough Sounds is considered to be a single management unit.

Stock Status	
Year of Most Recent Assessment	2022
Assessment Runs Presented	Catch rates and mortality estimates from random-site Marlborough Sounds potting surveys
Reference Points	Target1: B_{MSY}-compatible proxy based on the Marlborough Sounds potting survey (to be determined) Target 2: F=0.87, M = 0.15 Soft Limit: 20% B_0 Hard Limit: 10% B_0 Overfishing threshold: F=0.87, M = 0.15
Status in relation to Target	F estimated at 0.48 is Very Unlikely (< 10%) to be at or below the target
Status in relation to Limits	Unknown

Status in relation to Overfishing	Overfishing is Very Likely (> 90%) to be occurring

Historical Stock Status Trajectory and Current Status



Marlborough Sounds fixed-site and random-site potting survey catch rates of all blue cod by survey year for each region and overall for the Marlborough Sounds. Error bars are 95% confidence intervals. There were no complete fixed-site surveys in QCH in 1996, PEL in 1995, and DUR in 1995, 1996, and 2001 (see Table 9). For the overall Marlborough Sounds plot, the 2004 and 2007 fixed-site surveys exclude Separation Point, and the random-site surveys exclude Cook Strait, hence the strata are consistent among the surveys for fixed-site and random-site surveys.

Fishery and Stock Trends

Recent Trend in Biomass or Proxy	The Marlborough Sounds fixed-site potting survey indices of abundance increased markedly in 2010 in the Queen Charlotte Sound and Pelorus regions following the closure of the fishery in the inner sounds in 2008 (QCH, PEL). The survey indices were stable in the D'Urville region where the fishery remained open (DUR). The QCH and PEL fisheries were reopened to a limited size range of blue cod (slot limit) in April 2011 and the estimated 2013 survey abundance in those regions declined, but no change

	was observed in DUR. In 2017, abundance in QCH was not different to 2013, whereas for PEL and DUR abundance was the highest of any of the surveys. The overall Marlborough Sounds catch rate from 2004 onward (where survey strata are consistent among surveys) indicates that blue cod were more abundant in 2017 than any of the previous surveys. Queen Charlotte Sound random-site survey biomass increased markedly from 2013 to 2017 with no change in 2021; Pelorus Sound biomass shows a progressive decline between 2013 and 2021; D'Urville Island and Cook Strait show no trends.
Recent Trend in Fishing Mortality or Proxy	Regulatory changes to the recreational fishery (e.g., fishery closures, changes to MLS, and daily bag limits) are likely to have resulted in a reduction in fishing mortality up to April 2011, after which mortality increased with the re-opening of the fishery. Fishing mortality was at least twice natural mortality for the random-site surveys in 2017 and 2021.
Other Abundance Indices	Blue cod catch rates in the open area of the Marlborough Sounds were 18.6% and 17.5% of those inside the Long Island Marine Reserve in 2017 and 2021, respectively. Mean length of BCO from the Marine Reserve was 5 cm longer than in the fished area.
Trends in Other Relevant Indicators or Variables	Sex ratio is strongly skewed in favour of males. For Marlborough Sounds overall, the percent male from random-site surveys was 72% in 2017 and 2021.

Projections and Prognosis	
Stock Projections or Prognosis	Biomass is expected to decrease under current management controls.
Probability of Current Catch or TACC causing Biomass to remain below or to decline below Limits	Soft Limit: Unknown Hard Limit: Unknown
Probability of Current Catch or TACC causing overfishing to continue or to commence	Current catches are Very Likely (> 90%) to cause overfishing to continue.

Assessment Methodology and Evaluation		
Assessment Type	2 - Partial Quantitative Stock Assessment	
Assessment Method	Catch rates, mortality estimates, and sex ratios from fishery-independent potting surveys.	
Assessment Dates	Latest assessment: 2022	Next assessment: 2026
Overall assessment quality rank	2 – Medium Quality: mortality estimates compromised by regulation changes	
Main data inputs (rank)	- Potting survey catch rates from fixed-site and random-site surveys. - Length and age composition of catches from random-site and fixed-site potting surveys.	1 – High Quality 1 – High Quality
Data not used (rank)	N/A	
Changes to Model Structure and Assumptions	-	
Major Sources of Uncertainty	- Uncertainty in the estimate of *M*. - Frequent regulatory changes for this fishery are likely to have resulted in inconsistent fishing mortality over the lifetime of recent cohorts. - The predominance of males suggests fishing mortality may be higher than estimated.	

	-Lack of understanding about the triggers that drive sex change from female to male, as well as the degree, timing, and spatial nature of the sex change.

Qualifying Comments

Fishery Interactions
Most of the BCO catch is taken by recreational fishers using line methods. There is a reasonably high catch of associated species in this fishery, such as spotted and other wrasses as well as other targeted species such as tarakihi. Most of the commercial catch is taken by potting and has little bycatch. The recreational and commercial catches are of similar magnitude

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