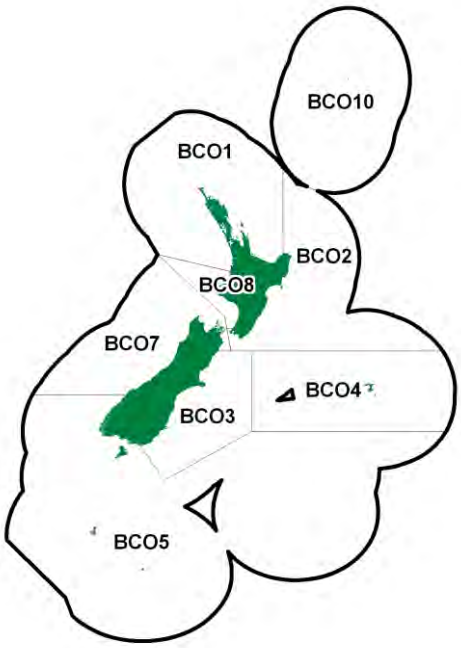
BLUE COD (BCO)

(Parapercis colias)
Rawaru



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.

Fishstock	Recreational Allowance	Customary non-commercial allowance	Other mortality	TACC	TAC
BCO 1	2	2	–	46	46
BCO 2	–	–	–	10	10
BCO 3	–	–	–	163	163
BCO 4	–	–	–	759	759
BCO 5	191	2	20	1 239	1 452
BCO 7	–	–	–	70	20
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 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 up to 1989, but have since increased, coinciding with a change in the main fishing method from hand-lines to cod pots. Historical landings are shown in Table 2, recent reported landings are shown in Table 3, and Figure 1 shows the historical landings and TACC values for the five main BCO fish stocks.

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. 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.

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

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

Table 3: Reported landings (t) of blue cod by Fishstock from 1983 to 2018–19 and actual TACCs (t) from 1986–87 to 2018–19. QMS data from 1986-present. FSU data 1983–1986.

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

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	50	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
2017–18	71	70	4	34	0	10	2 049	2 332
2018–19	64	70	14	34	0	10	1 844	2 332

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

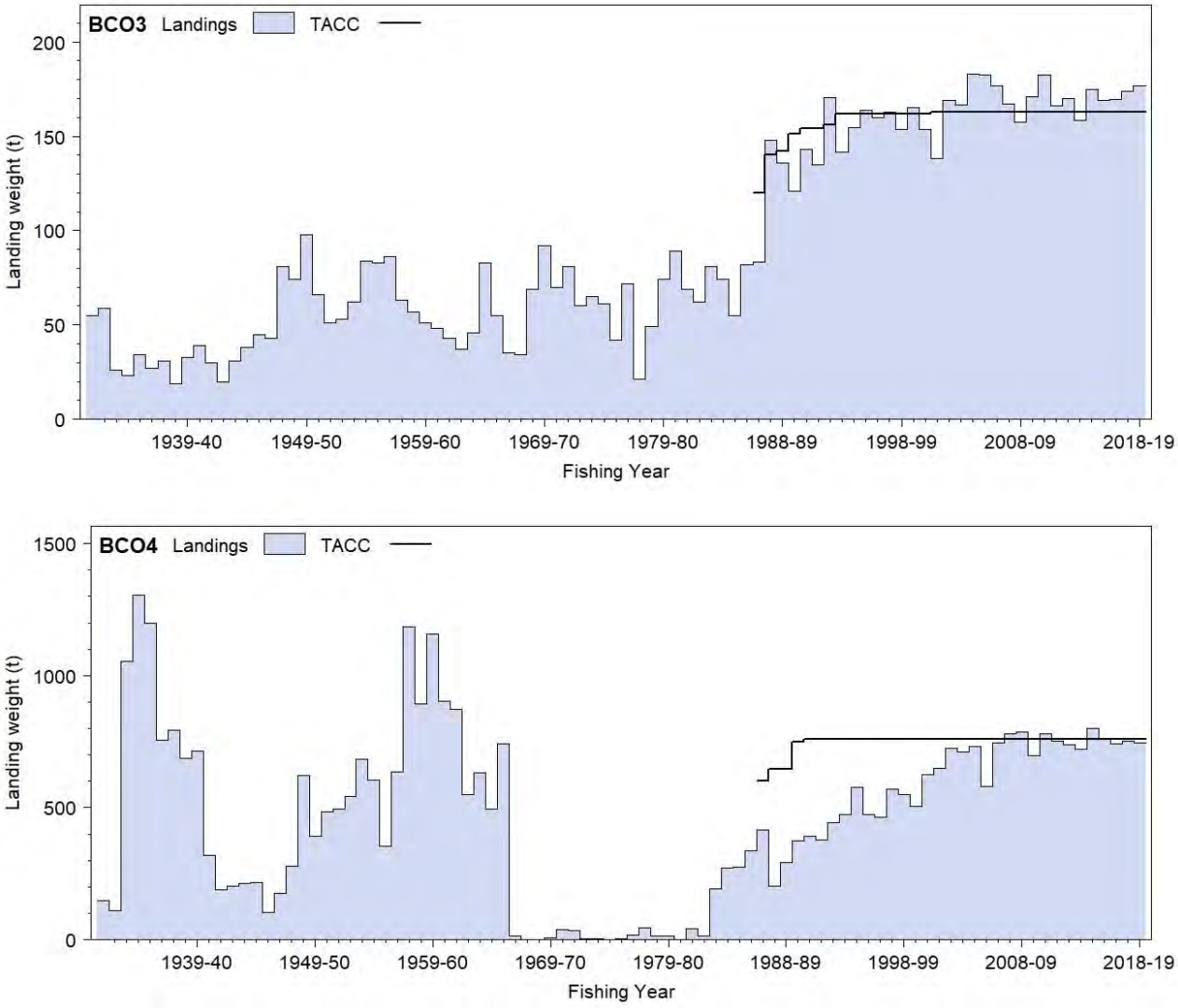


Figure 1: Reported commercial landings and TACC for the five main BCO stocks. From top: BCO 3 (South East Coast) and BCO 4 (South East Chatham Rise) [Continued on next page].

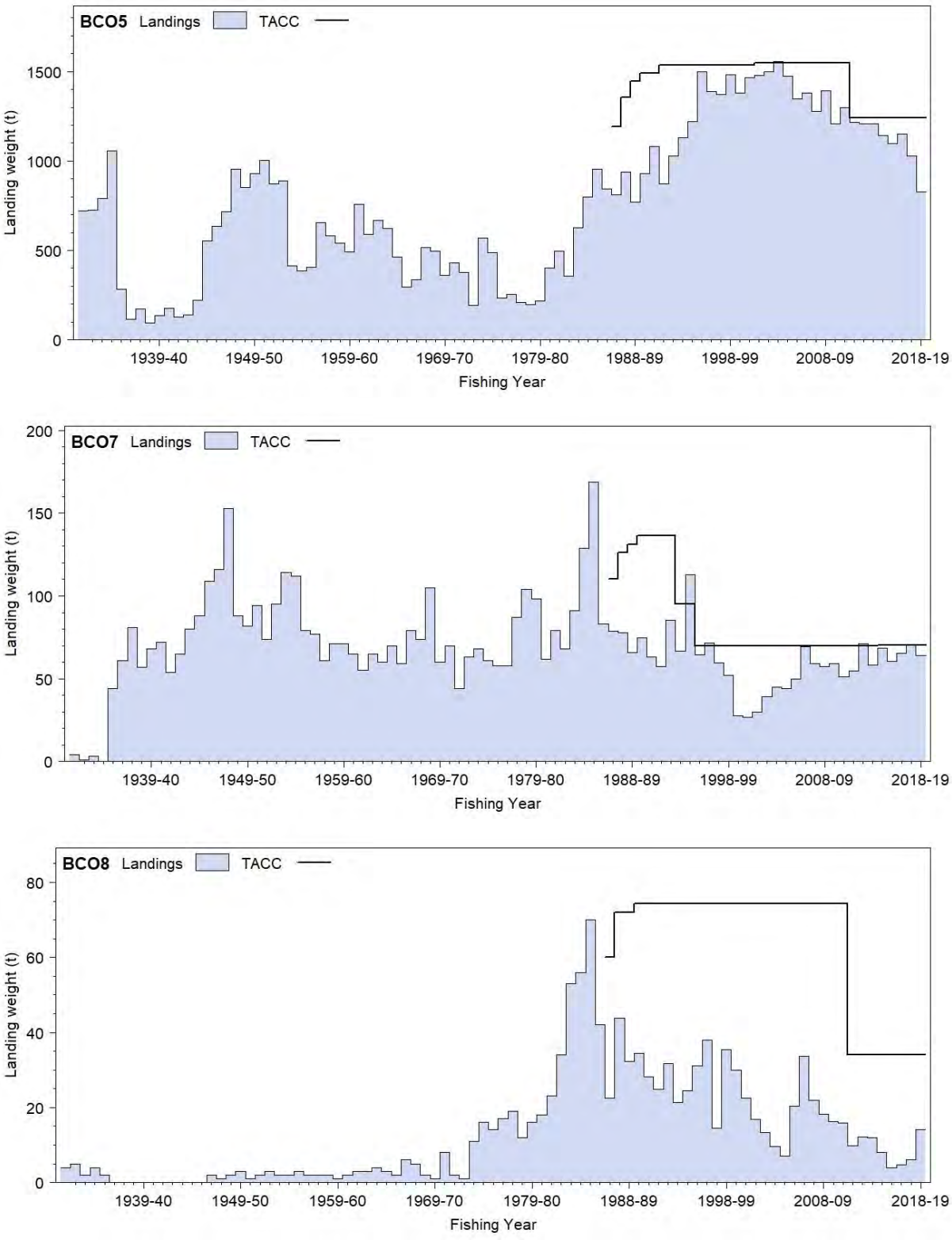


Figure 1 [Continued]: Reported commercial landings and TACC for the five main BCO stocks. From top: BCO 5 (Southland), BCO 7 (Challenger), and BCO 8 (Central Egmont).

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 limits (MLS), 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: Changes to 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's Sound, BS = Bradshaw Sound. ** C = inner sounds closed. # excluding Challenger East. ^bag limit of 6 inside Te Whaka ā Te Wera Mātaitai Reserve.

Fishstock	BCO 1		BCO 2		BCO 3		BCO3		BCO3		BCO 4	
Area	Auckland		Central (East)		South East (Otago)		North Canterbury		Kaikoura 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

Fishstock	BCO5		BCO5		BCO 5		BCO5		BCO 7		BCO7	
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

Fishstock	BCO8		BCO10	
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

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. In 2014, the Kaikoura Marine Area in BCO 3 was established and the MLS of blue cod in this area was set at 33 cm.

The recreational daily bag limit (DL) has remained unchanged since 1993 in BCO 1, BCO 2, BCO 3 (South East Otago area), BCO 4, BCO 7 (Challenger West and South area), and BCO 10. In 2001, the recreational daily bag limit (DL) was reduced to 10 in the North Canterbury area (BCO 3). In 2014, the DL was set at 6 in the newly established Kaikoura 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's Sound, and Bradshaw Sound were closed to all blue cod fishing for 10 years. The closure was lifted in 2015 to 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 five-fold 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.

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 2002) 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 estimates the proportion of the population that is eligible (likely to fish). A "soft refusal" bias in the eligibility proportion arises if interviewees who do not wish to co-operate falsely state that they never fish. The proportion of eligible fishers in the population (and, hence, the harvest) is 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 of 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. 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 collected 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 through 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 E 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 Maori 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. 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 once the catch had been processed.

Recreational line fishing often results in the harvest of undersized blue cod. The survival of these 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 individuals over a large length range changing sex from female to male (Carbines 1998). 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, because these fish were 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. All spawner-per-recruit ratio (SPR) analyses carried out using 0.14 will need to be recalculated.

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).

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 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.

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 et al (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)
Kaikoura (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			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		
Kaikoura	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		

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. Over larger distances the mainland New Zealand blue cod appear to show a pattern of Isolation-by-Distance or continuous genetic change among populations.

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 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, 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.

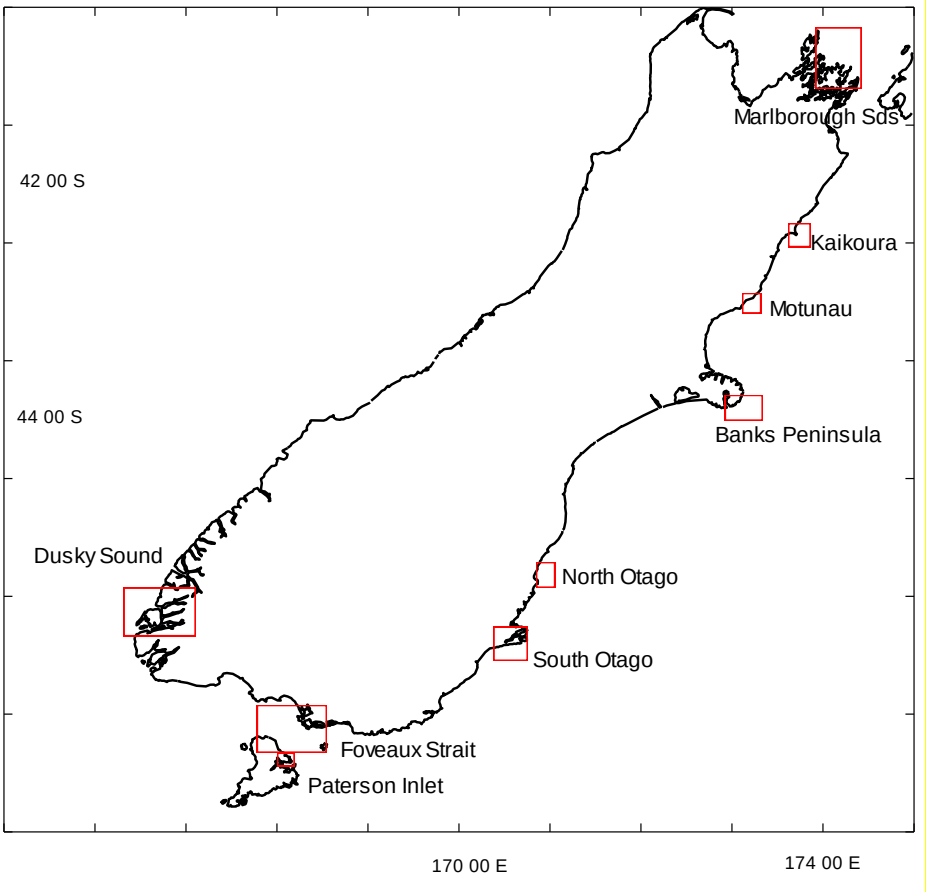


Figure 11: East coast South Island showing statistical areas, Fishery Management Areas (FMA) and the survey area.

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

Figure 1: Key statistical areas in BCO 3 and BCO 7 and quota management areas

Marlborough Sounds

In 1995, a fishery-independent survey using standardised cod pots at fixed stations provided catch rate estimates for recruited blue cod in Queen Charlotte Sound and outer Pelorus Sound. In 1996 a second potting survey covered all of Pelorus Sound as well as the east coast of D'Urville Island (Blackwell 1997, 1998). A 2001 survey (Blackwell 2002) included Queen Charlotte Sound, Pelorus Sound, and east D'Urville, and a survey in 2004 covered the same areas as 2001 but was expanded to include west D'Urville and Separation Point (Blackwell 2005). In 2007, the surveyed area was the same as 2004 except that Separation Point was dropped. In 2008 a standalone survey of a Cook Strait stratum was carried out and in 2010 the Cook Strait stratum was added to the surveyed area along with those strata used in 2007 (Beentjes & Carbines 2012). A new survey in 2013 used the same strata as 2010 (Beentjes et al 2014). The 2001 to 2008 surveys were reanalysed as part of the 2010 survey so that they were consistent with methods used for recent surveys (Beentjes & Carbines 2012). The 1995 and 1996 surveys, similarly, have been reanalysed as part of the 2013 survey analyses (Beentjes et al 2014). All surveys before 2010 used fixed sites which were selected randomly from a wider list of fixed sites within a given stratum. These fixed locations are available to be used repeatedly on subsequent surveys in that area (Beentjes & Francis 2011). In 2010, experimental random sites were trialled in selected strata. Random sites may have any location (single latitude and longitude) and are generated randomly within each stratum. In 2013 and 2017 (Beentjes et al 2017, Beentjes et al 2018), full random and full fixed site surveys were conducted concurrently. Of the three random-site surveys only the last two are (2013 and 2017) are comparable.

Throughout the fixed-site surveys, catch rates of total blue cod (all sizes) have tended to be highest around D'Urville Island, lowest in Cook Strait, and similar between Queen Charlotte Sound and Pelorus Sound (Figure 3, Table 9). 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. 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 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 compared with 2010 rates, 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 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 three comparable random-site surveys (2010, 2013, and 2017) with the first survey in 2008 being a fixed-site survey which was not comparable. Total blue cod catch rates from the Cook Strait random surveys ranged from 0.7 to 1.1 kg pot^{-1} with no trend (Table 9). There were no closures or slot limit management measures for Cook Strait. 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 surveys (Table 9). 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 9).

The random-site surveys in 2013 and 2017 generally have lower catch rates than 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 (Table 9, Figure 3). In Queen Charlotte Sound survey biomass increased markedly, whereas for Pelorus Sound and D'Urville Island there are no significant changes. Cook Strait random-site catch rates show no significant difference from 2010 to 2017. The overall Marlborough Sounds catch rates from 2004 onward (where survey strata are consistent among surveys) indicates that blue cod were more abundant in 2017 than any of the previous years (Figure 3). It is the intention to transition to random-site surveys and conducting both fixed- and random-site surveys allows comparison of catch rates, length and age composition, and sex ratios between survey designs in the interim. The next survey in the time series will use only a random-site design.

A random-site survey of Long Island Marine Reserve in 2017, 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%), substantially higher than adjacent fished strata in Queen Charlotte Sound (Table 9). In addition, the mean size was 3.2 cm greater in the marine reserve and length frequency distributions were bimodal in contrast to the unimodal distributions from adjacent strata in Queen Charlotte Sound.

Growth rates and age compositions were similar for 2013 and 2017. Fixed-site survey Chapman-Robson total mortality estimates (Z) for age at recruitment of 6 years were very close at 0.51 in 2013 and 0.53 in 2017 (Table 10). Spawner-per-recruit ratios ($F_{SPR\%}$), however, differed substantially and were 25% in 2013 and 39% in 2017 (the Fisheries New Zealand target is $F_{45\%}$). The difference was primarily a result of having different selectivity ages to the fishery because the MLS increased from 30 cm in 2013 to 33 cm in 2017, and hence these ratios cannot be validly compared. Similarly, random-site survey Chapman-Robson total mortality estimates (Z) for age at recruitment of 6 years were very close at 0.46 in 2013 and 0.52 in 2017 (Table 10). Spawner-per-recruit ratios ($F_{SPR\%}$) also differed substantially and were 27% in 2013 and 39% in 2017 for the same reasons.

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 and these are intended to replace fixed-site surveys because the random surveys provide a more reliable indicator of stock status.

The most recent fixed-site inshore survey in 2016 recorded catch rates of 1.26 kg pot^{-1} (CV 12%), a sex ratio of 67% male, estimated fishing mortality (F) of 1.73 and associated spawner-per-recruit ratio of 4.7% (Table 11). Corresponding values for the 2016 inshore random site survey were 0.53 kg pot^{-1} (CV 22%), 81% male, F = 2.1 and a spawner-per-recruit ratio of 4.3%. For both fixed and random site surveys, the level of exploitation of Banks Peninsula inshore blue cod stocks in 2016 greatly exceeded the Fisheries New Zealand F_{MSY} target reference point of $F_{45\%SPR}$. The very high estimate of total mortality, truncated age composition, strongly skewed sex ratio toward males and extremely low spawner-per-recruit ratio, 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 30 cm), there is also likely to be significant mortality through catch and return of undersize fish. For the five inshore fixed site surveys there were no trends in survey abundance, length distribution, mean length, or sex ratio. A strong juvenile mode in 2016 can be expected to contribute to increased abundance in about three years when these blue cod recruit to the fishery at 30 cm.

The most recent fixed site offshore survey in 2016 had catch rates of 5.6 kg pot^{-1} (CV 14%), sex ratio of 65% male, estimated fishing mortality (F) of 0.12, and associated spawner-per-recruit ratio of 40.7% (Table 11). Corresponding values for the 2016 offshore random site survey values were 5.08 kg pot^{-1} (CV 19%), 57% male, F = 0.05, and a spawner-per-recruit ratio of 64.3%. For both fixed- and random-site surveys the level of exploitation (F) of Banks Peninsula offshore blue cod stocks in 2016 is close to or less than the Fisheries New Zealand F_{MSY} target reference point of $F_{45\%SPR}$. The offshore blue cod population, in contrast to inshore, have high catch rates, a wide size

range of both males and females, a more balanced sex ratio, and spawner-per-recruit ratio above the target, indicating that they are not overfished. For the five offshore fixed-site surveys there were no trends in survey abundance, length distribution, mean length, or sex ratio.

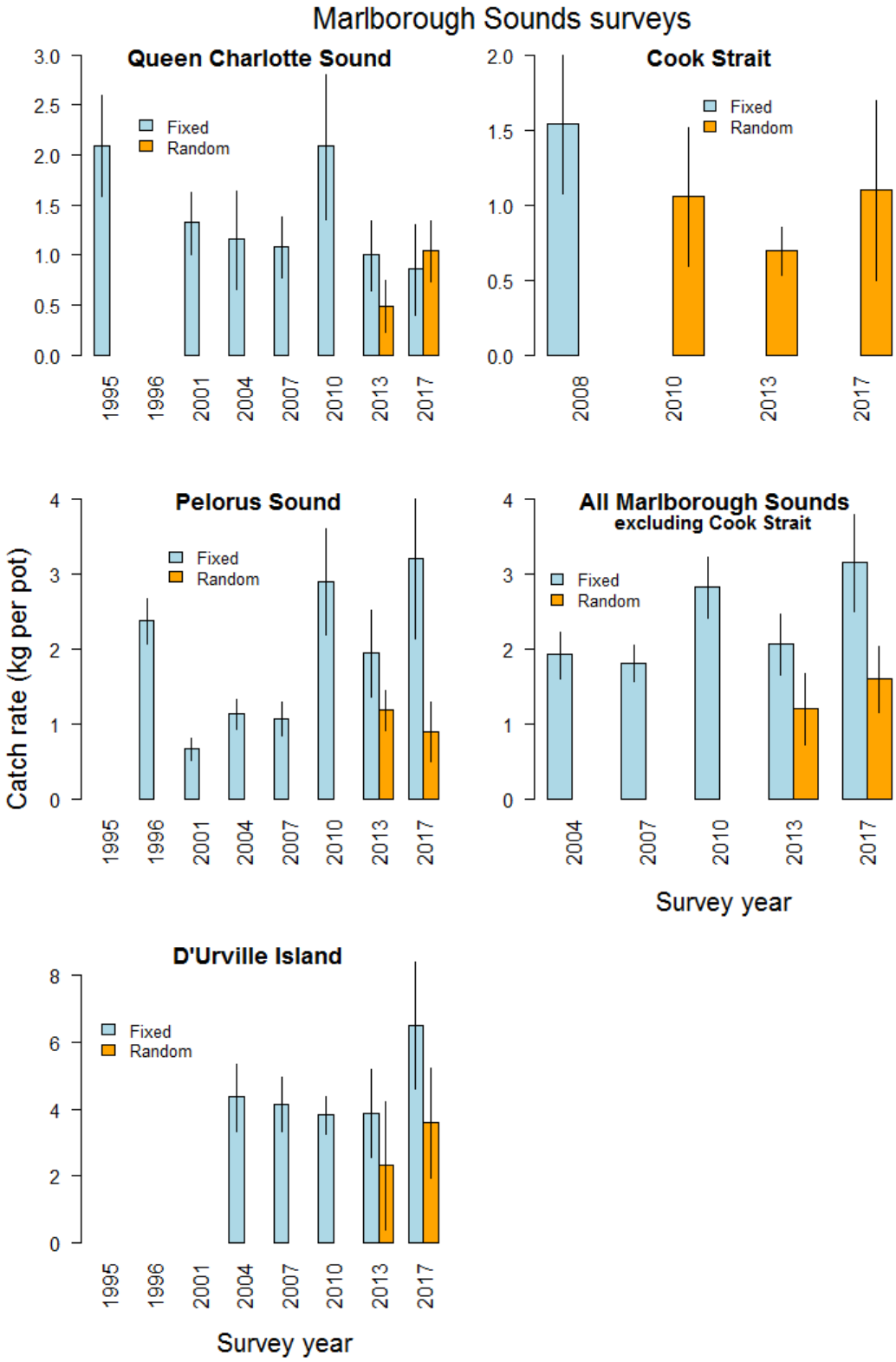


Figure 3: Marlborough Sounds fixed-site and random-site potting survey catch rates of all blue cod by survey year for each region and overall for the Marlborough Sounds. Error bars are 95% confidence intervals. There were no complete fixed-site surveys in Queen Charlotte Sound in 1996, Pelorus Sound in 1996, and D'Urville Island from 1995 to 2001. 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 and random site surveys.

Table 9: Summary statistics from standardised blue cod fixed-site and random-site potting surveys in the Marlborough Sounds up to 2017 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 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/strat	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%
QCH/LIMR	2017	Random	–	–	35.2	8.76	8.76 (14%)	–
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%
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%
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%
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

Table 10: Mortality parameters (*Z*, *F*, and *M*) and spawner-per-recruit ($F_{SPR\%}$) estimates for blue cod from the 2013 and 2017 Marlborough Sounds fixed-site and random-site potting surveys for all regions combined. *F*, fishing mortality; *M*, natural mortality; *Z*, total mortality; Age at recruitment = 6 years equivalent to age at which females reach MLS of 30 cm in 2013, and males and females combined reach MLS of 33 cm in 2017. Otoliths from both 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*	$F_{\%SPR}$
2013	All regions combined	Fixed	0.14	0.56 (0.40–0.74)	0.42	$F_{25.5\%}$
2017			0.14	0.53 (0.38–0.72)	0.39	$F_{39.0\%}$
2013	All regions combined	Random	0.14	0.53 (0.38–70	0.39	$F_{26.7\%}$
2017			0.14	0.52 (0.37–0.69)	0.38	$F_{39.4\%}$

North Canterbury

Kaikoura

There have been four fixed-site blue cod potting surveys off Kaikoura (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 and these are intended to replace fixed-site surveys. Subsequently a solely random-site survey was carried out in 2017, earlier than the standard four-year cycle, to assess the impact of the November 2016 earthquake (Beentjes & Page 2018). Random surveys provide a more reliable indicator of stock status and will be used in future.

The most recent random-site survey in 2017 recorded catch rates of 1.9 kg pot^{-1} (CV 16%), sex ratio of 45% male, and mean lengths of 28.4 cm and 28.6 cm for males and females respectively (Table 11). 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 were the lowest of all four surveys (Table 11, Figure 4). For the three random-site surveys there was no trend in relative abundance. 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 11).

Ageing is currently only valid for the 2015 and 2017 surveys (i.e., compliant with the blue cod age determination protocol, Walsh 2017). Strong age classes at three and five years were apparent in 2017 for both sexes, and progression of age classes from 2015 to 2017 was evident. Length frequency distributions and mean lengths were similar among the three 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. In 2015 the random-site survey spawner-biomass-per-recruit ratio was 58% indicating that the level of exploitation (F) of Kaikoura blue cod stocks was below the F_{MSY} target reference point of $F_{45\%SPR}$ (underexploited) (Table 11). However, in 2017 the random-site survey spawner-biomass-per-recruit ratio was 34%, indicating that the level of exploitation (F) of Kaikoura blue cod stocks was above the F_{MSY} target reference point of $F_{45\%SPR}$ (over-exploited).

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 out and these are intended to replace fixed-site surveys in the future because the random surveys provide a more reliable indicator of stock status.

The most recent fixed site survey in 2016 had catch rates of 3.3 kg pot^{-1} (CV 13%), sex ratio of 76% male, estimated fishing mortality (F) of 0.62, and associated spawner-per-recruit ratio of 19% (Table 11). Corresponding values for 2016 random site survey were 2.5 kg pot^{-1} (CV 27%), 76% male, F = 0.61, and a spawner-per-recruit ratio of 19.2%. For both fixed- and random-site surveys, the level of exploitation of Motunau blue cod stocks in 2016 was greater than the Fisheries New Zealand F_{MSY} target reference point of $F_{45\%SPR}$.

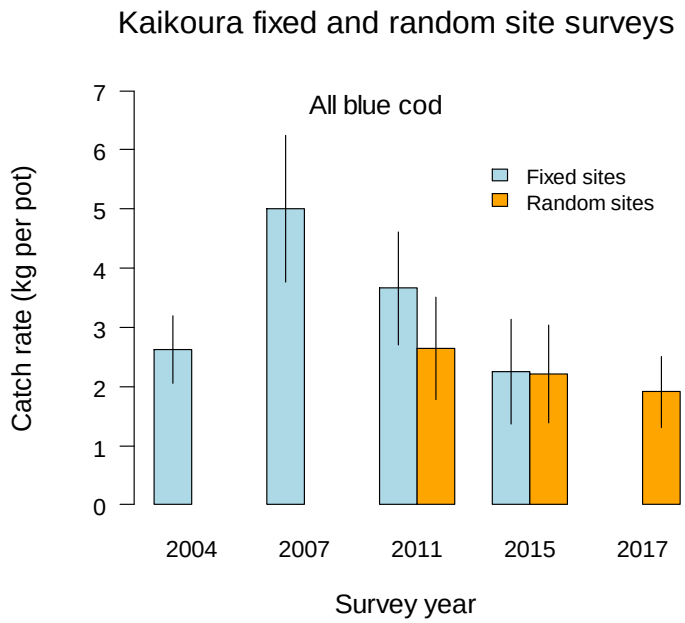


Figure 4: **Kaikoura fixed-site and random-site potting survey catch rates of all blue cod by survey year. Error bars are 95% confidence intervals.**

For the four fixed-site surveys, catch rates decreased markedly in 2008 and then again in 2016 with a three-fold decline between 2005 and 2016 (Table 11). Overall blue cod mean size steadily declined from 2005 to 2016, with the biggest decreases in 2016. The sex ratio for all blue cod was around 75% male for all fixed-site surveys with no trend. A strong juvenile mode in 2015 can be expected to contribute to increased abundance in about three to four years when these blue cod recruit to the fishery at 30 cm. Blue cod abundance and mean size off Motunau has declined and spatial distribution contracted over the eleven years from 2005 to 2016. The very high estimate of total mortality, truncated age composition, strongly skewed sex ratio toward males, and a spawner-per-recruit ratio less than half the target indicates that the blue cod population off Motunau was over-exploited in 2016. Further, as nearly all females and most males currently caught will be of sub-legal size (less than 30 cm), there is also likely to be significant mortality through catch and return of undersize fish.

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 12, Figure 5).

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 12, Figure 5). 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 12). A preponderance of males is thought indicate high fishing intensity. The fixed-site scaled length frequency distribution shapes were similar for the 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 23%, 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 12).

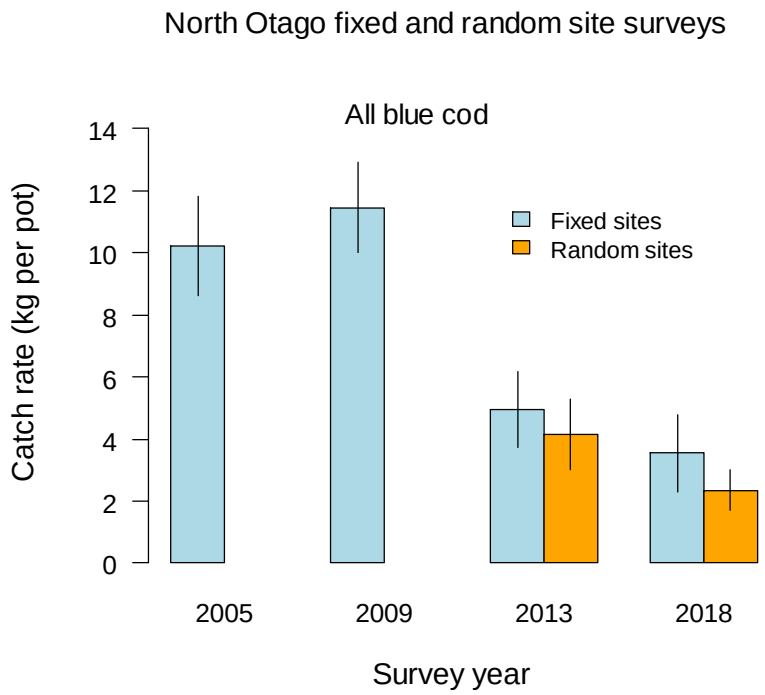


Figure 5: **North Otago fixed-site and random-site potting survey catch rates of all blue cod by survey year. Error bars are 95% confidence intervals. Surveys after 2005 include a new stratum (stratum 6).**

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 future 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 12, Figure 6). 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 12, Figure 6). 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 60–70% male with no trend (Table 12) – 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 in north Otago in 2018. The 2018 random-site survey spawner-biomass-per-recruit ratio was 25%, 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 12).

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 13, Figure 7). 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 surveys.

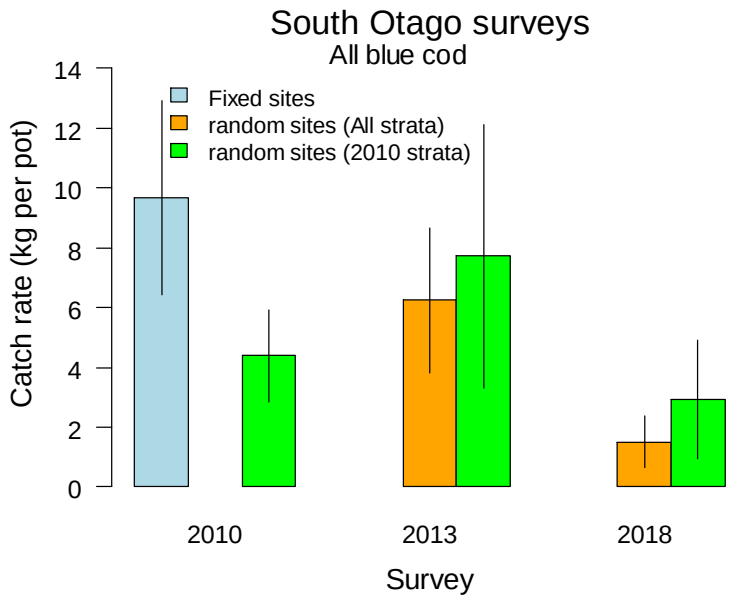


Figure 6: **South Otago fixed-site and random-site potting survey catch rates of all blue cod by survey year. Error bars ıta.**

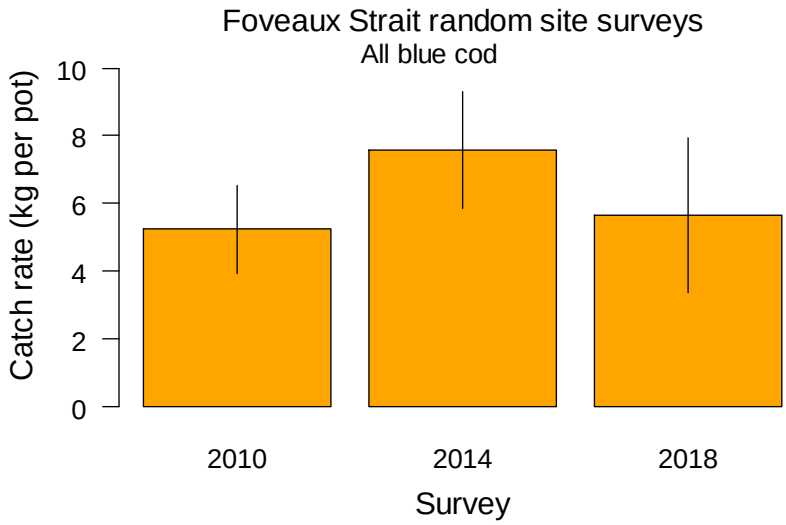


Figure 7: **Foveaux Strait random-site potting survey catch rates of all blue cod by survey year. Error bars are 95% confidence intervals.**

The sex ratio has varied from 47–51% male with no trend (Table 13). 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 13). 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, 2018, 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 in this report 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 8). 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 13). 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.

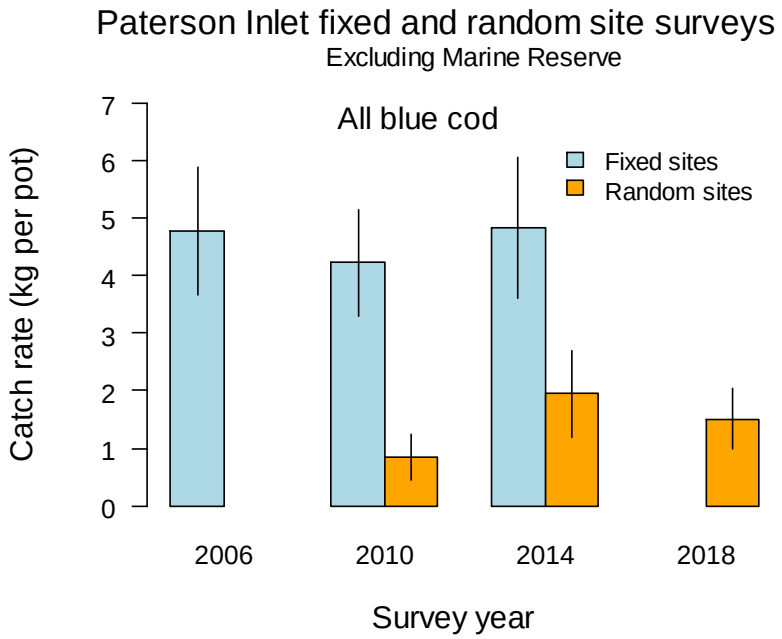


Figure 8: **Paterson Inlet random-site potting survey catch rates of all blue cod by survey year. Error bars are 95% confidence intervals.**

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.

Table 11: Summary statistics from standardised blue cod potting surveys of the northeast coast of the South Island (BCO 3). CPUE – catch per unit effort (kg.pot^{-1}); CV – coefficient of variation; Mean length is from population scaled length. All surveys from these three areas were reanalysed and reported in Beentjes & Page (2017) Beentjes & Sutton (2017), and Beentjes & Fenwick (2017), respectively. –, no valid ageing.

	Mean length (cm)		Survey	CPUE stratum range (CV) are	Sex ratio	$F_{\%SPR}$
Area/Year	**Female**	**Male**	**(kg pot^{-1})**	**(kg pot^{-1})**	**% male**	
North Canterbury						
Kaikoura						
2004 (fixed sites)	30.3	32.5	2.62	0.60–7.97 (11.1%)	48.7%	–
2007 (fixed sites)	29.8	32.5	5.0	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%	–
2015 (random sites)	29.0	30.0	2.21	0.48–9.41 (18.9%)	51.7%	58%
2017 (random sites)	28.6	28.4	1.9	0.00–6.92 (15.9)	44.8%	34%
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	5.5	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%	
2016 (random sites)	22.2	26.5	2.48	1.10–7.24 (26.8%)	76.3%	
Banks Peninsula						
Inshore						
2002	25.4	28.3	1.12	0.04–2.61 (23.2%)	67.9%	
2005	27.2	32.7	2.78	1.02–4.16 (12.2%)	74.2%	
2008	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%	
2016 (random sites)	23.8	26.1	0.53	0.09–0.94 (22.2%)	81.3%	
Offshore						
2002	36.6	37.6	3.39	2.04–4.74 (19.9%)	41.8%	
2005	37.4	41.2	6.48	5.68–7.27 (9.4%)	57.2%	
2008	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	5.6	5.09–6.10 (14.1%)	65.2%	
2016 (random sites)	36.1	41.3	5.08	5.21–4.54 (19.5%)	57.5%	

Table 12: 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, are 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	$F_{\%SPR}$
Area/Year	Female	Male	(kg pot^{-1})	CPUE range (CV)	(% male)	
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%

Table 13: 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 (2018), 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	47.2%	26.9%
2014 (random sites)	27.7	30.3	6.0	4.9	7.57	3.16 – 16.22	48.0%	27.6%
2018 (random sites)	28.4	30.6	6.8	5.7	5.7	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 sites)	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 sites)	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%
Dusky Sound								
2002 (fixed sites)	29.9	34.7			2.95	1.29–8.43 (10.8%)		
2008 (fixed sites)	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%

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 9). 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.

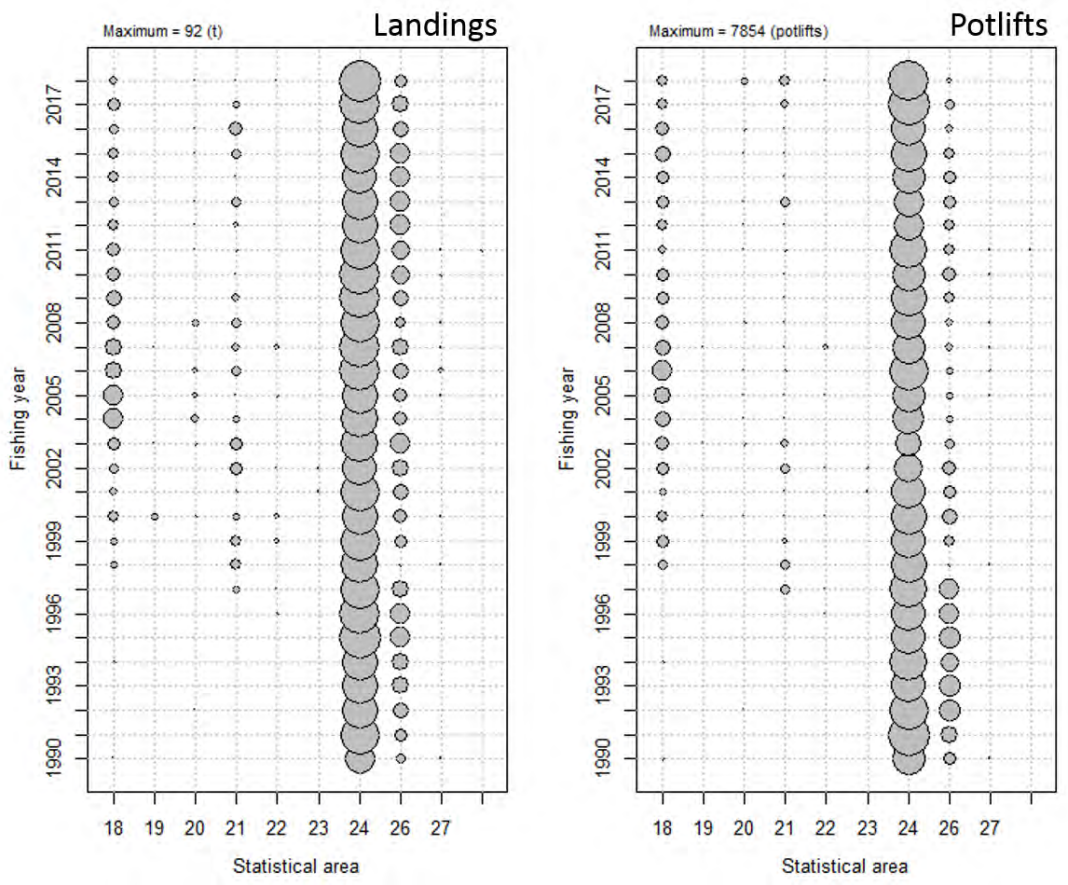


Figure 9: Distribution of landings and number of potlifts for the cod potting method by statistical area and fishing year from trips which landed BCO 3. Circles are proportional within each panel: [landings] largest circle = 92 t in 2011 for 024; [number potlifts] largest circle = 7854 pots in 2006 for 024 (Large et al in prep.).

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 10) 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 10 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.

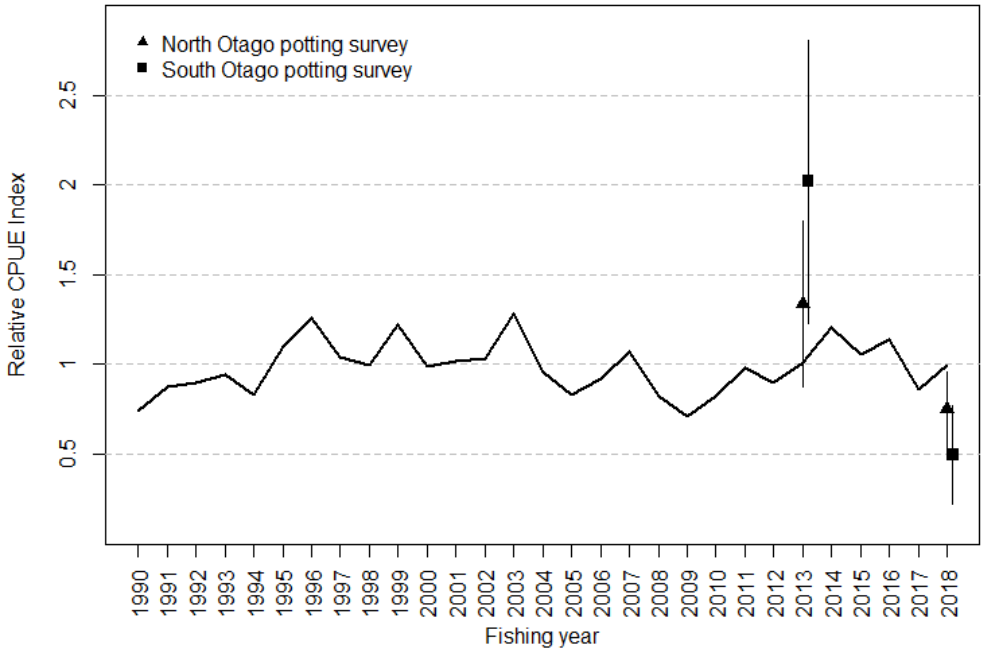


Figure 10: Comparison of BCO 3 standardised series (1989–90 to 2017–18) based on landed green weight catch data and the 2013 and 2018 observations from the North Otago and South Otago potting surveys conducted at random sites over all strata (Large et al in prep.). (Each relative series is scaled so that the geometric mean equals 1.0 from 2013 to 2018.)

Establishing B_{MSY} compatible reference points

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 Working Group accepted the default Harvest Strategy Standard definitions for the Soft and Hard Limits at one-half and one-quarter the target, respectively.

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 (Large et al in prep.). 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 11).

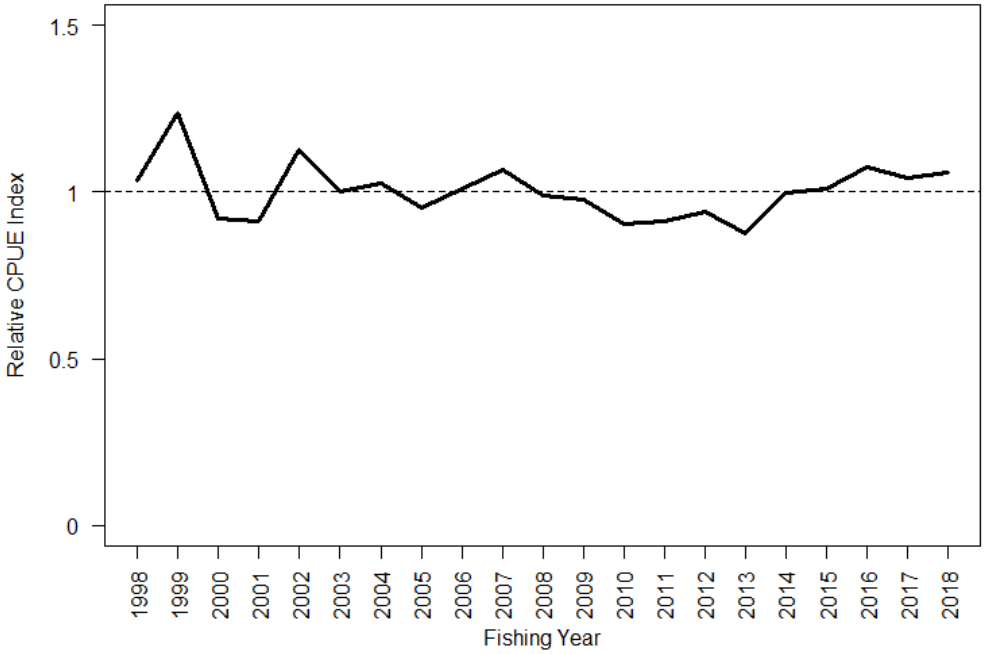


Figure 11: Standardised CPUE index for BCO 4 based on records of positive BCO catch by core vessels, 1997–98 to 2017–18 (Large et al in prep.).

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. 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. 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 legal minimum 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 14), 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 15. Other parameters had uniform priors.

Table 14: 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 is age frequency data; LF is 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 15: 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 differs, and little 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 12.

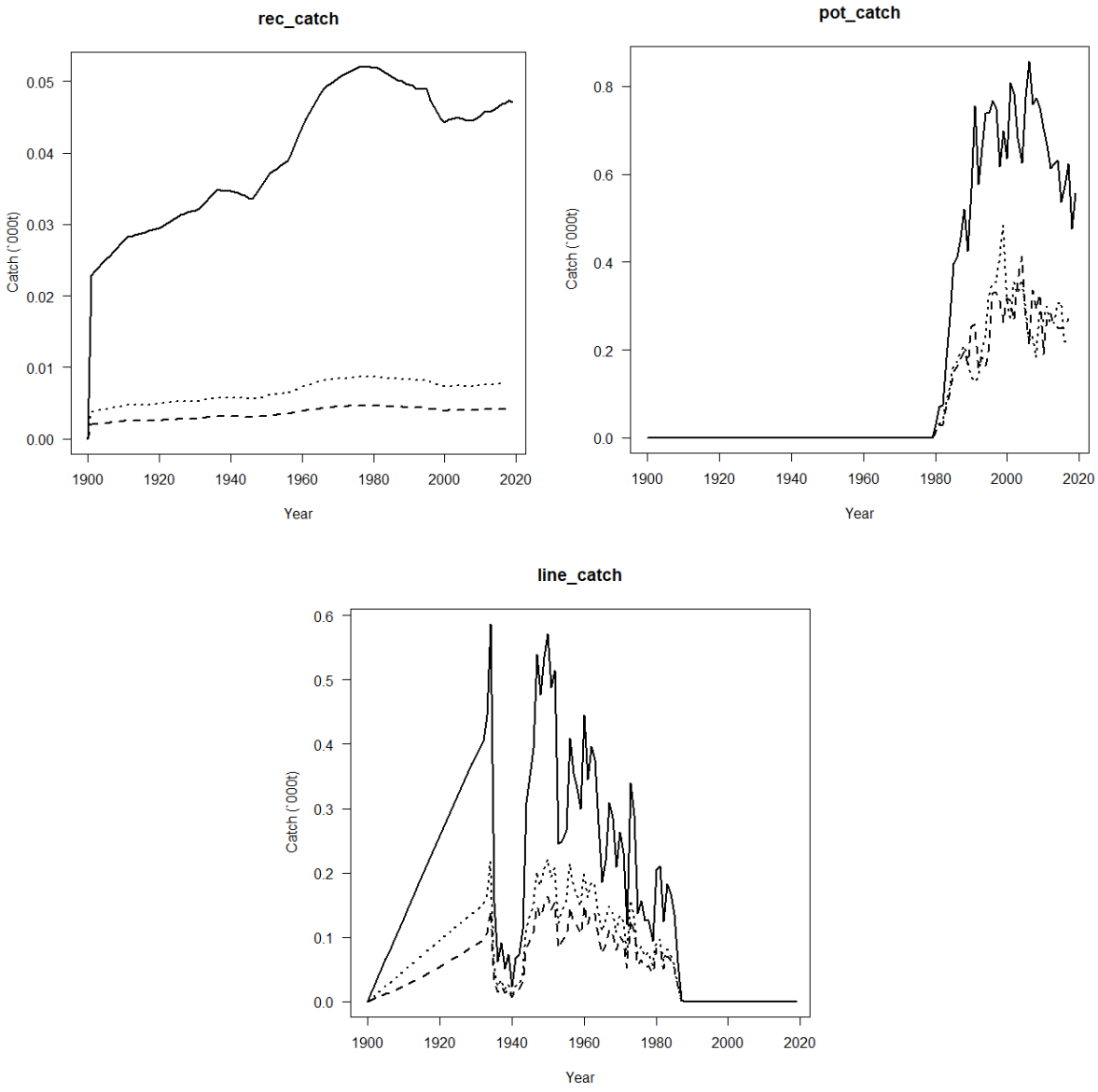


Figure 12: Constructed catch history used in the assessments by fishery and Statistical Areas 025 (solid line), 027 (dashed line), & 030 (dotted line).

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 2009–2011. 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 not 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 16), and pot survey estimates of abundance.

The data fitted in the models for each Statistical Area are shown in Table 17, and the assumed error structure of each data series is shown in Table 18.

Table 16: Standardised CPUE indices for Statistical Areas 025, 027, and 030, for fishing years 1990–2018.

Fishing Year	Area 025	Area 027	Area 030	Fishing Year	Area 025	Area 027	Area 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	2007	1.09	0.96	1.14
1993	0.8	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	0.9	0.82	1.01
1996	0.97	1.07	0.7	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	1.2	2013	0.96	0.92	0.91
1999	0.96	1.11	1.32	2014	1	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	0.9	0.82
2004	1.23	1.63	1.23				

Table 17: 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 18: Assumed distributions for data fitted in the models. AF is age frequency data; LF is length frequency data. N is 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 19 (estimates of spawning biomass), Figure 13 (biomass trajectories), and Figure 14 (recruitment trajectories).

Table 19: 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 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)

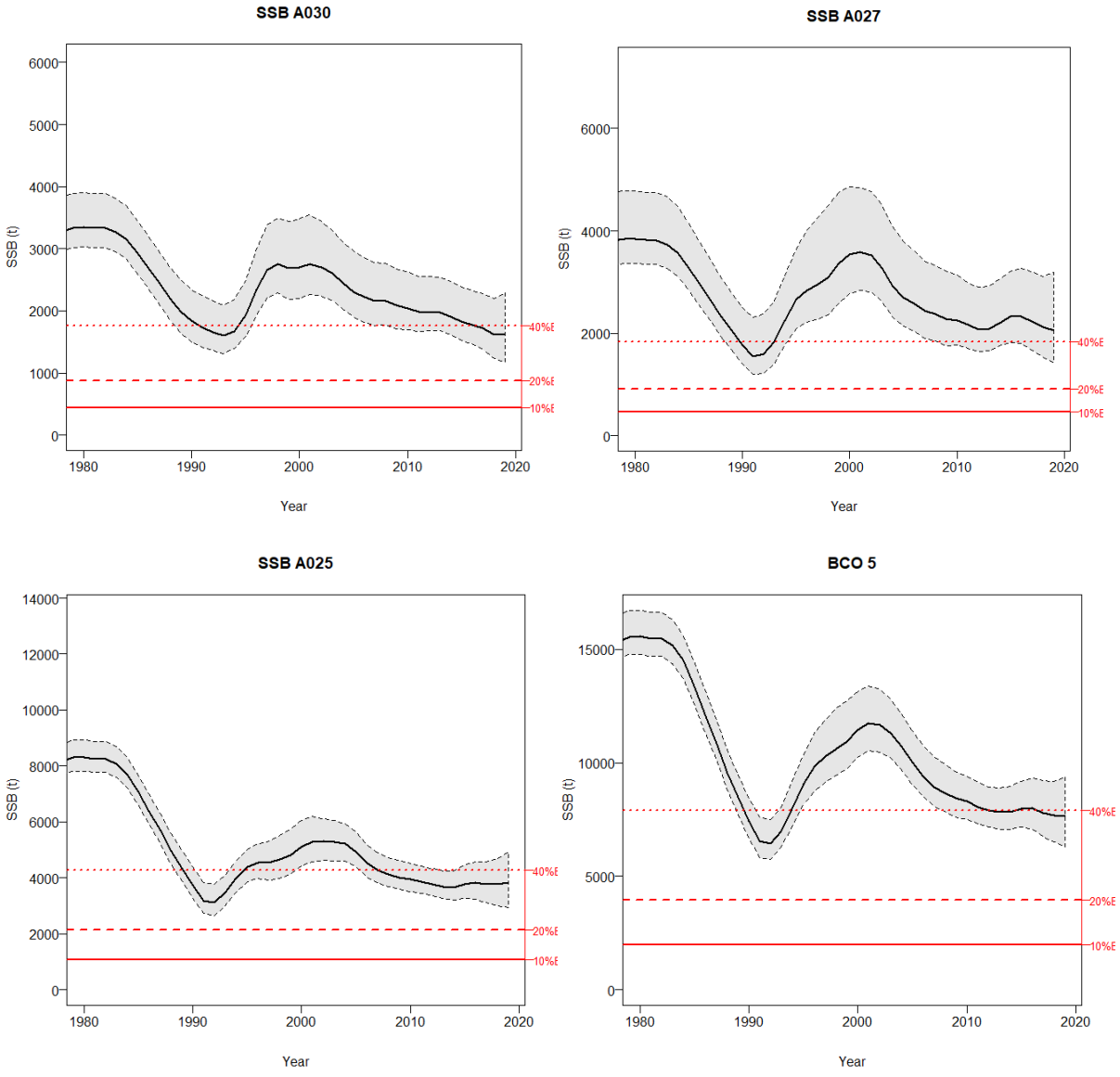


Figure 13: Median estimates of spawning biomass for Statistical Areas 025, 027, and 030, and the three areas combined, for the base-case model runs, 1980–2019.

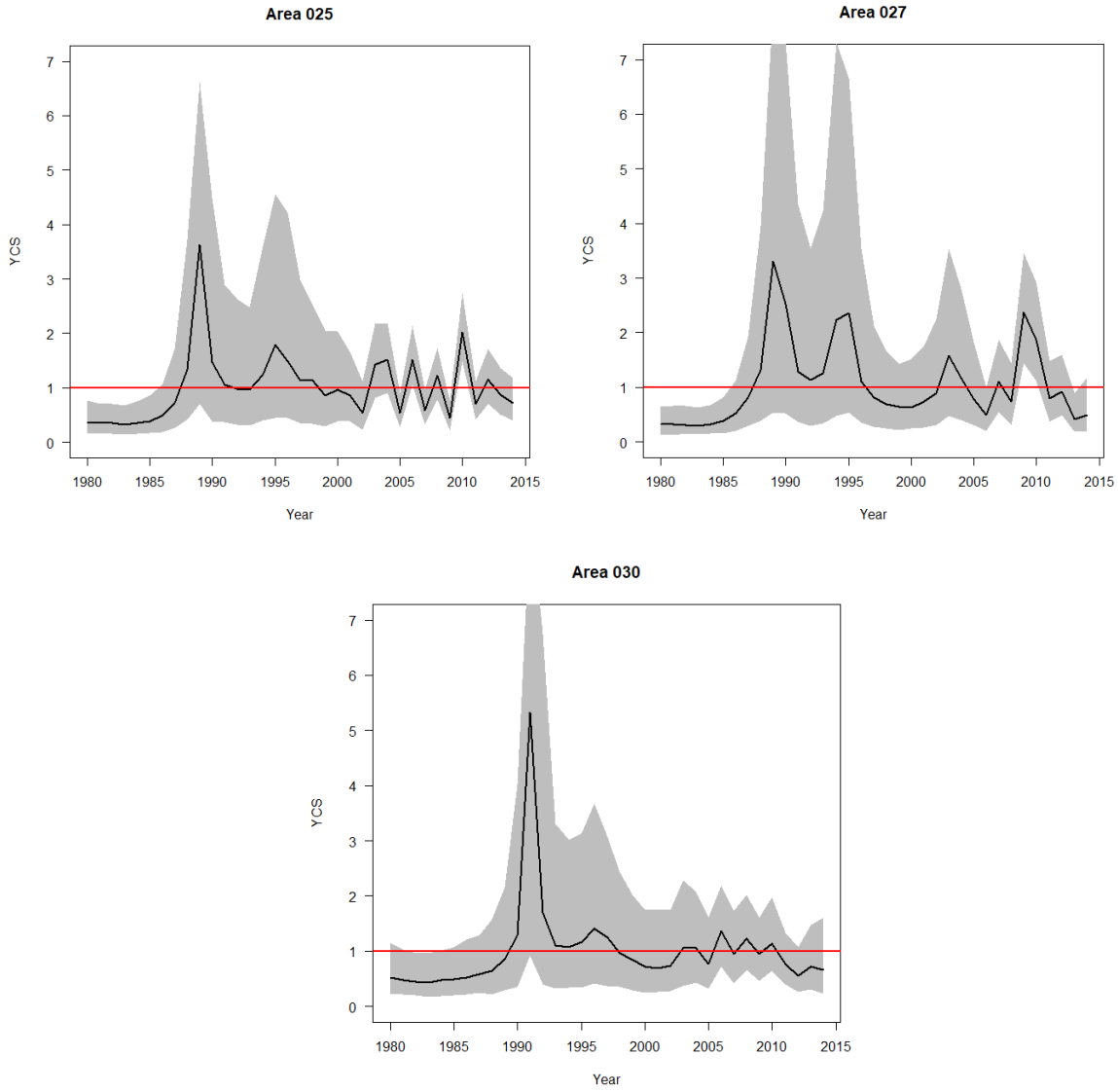


Figure 14: Year Class Strength (YCS) from the base-case runs for Statistical Areas 025, 027, and 030, for 1980–2014. Medians are shown by the black line and the shaded areas show the 95% range limits.

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 15). 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 (Table 20).

The probabilities of the projected spawning stock biomass (2018 and 2023) being below the hard limit of 10% B_0, 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.

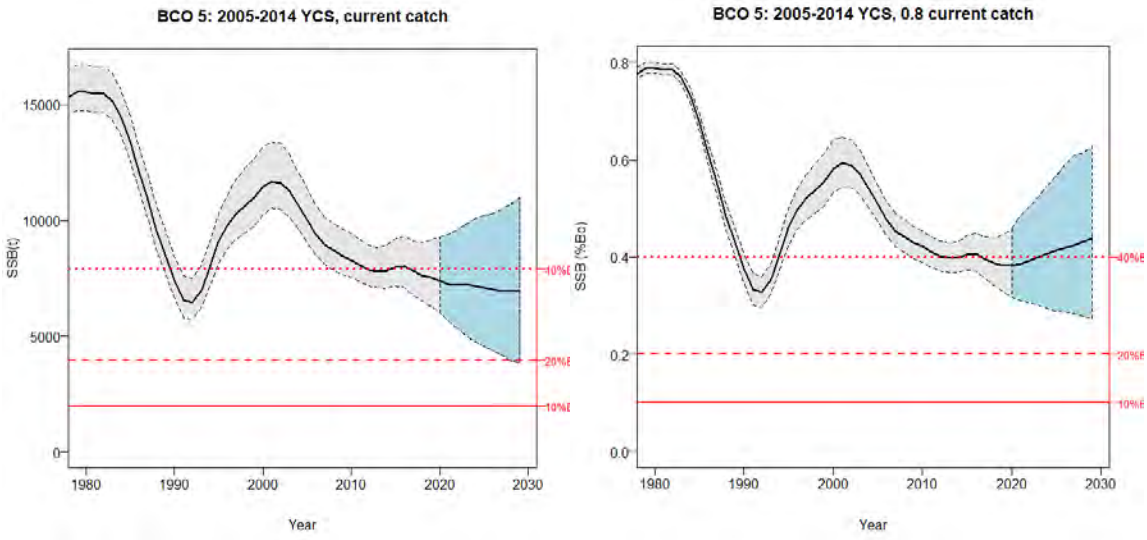


Figure 15: Projected BCO 5 spawning biomass (%B_0) assuming recent recruitment and catch at current levels and at 80% of current levels for the base case run. Median estimates are shown as solid lines and 95% confidence intervals as shaded polygons. Projections start in 2020.

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	0.8·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 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.

4.6 Future research considerations

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*.
- More commercial length and age data by area would be useful for determining spatial differences in size structure and growth; obtain and examine market grading data for this purpose.
- Consider interviewing fishers to ascertain changes in fishing behaviour that might affect the relationship between the CPUE indices and abundance.
- Use a wider range of values of *M* in sensitivities.
- Use empirical data for maturity rather than a logistic.
- 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.

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.

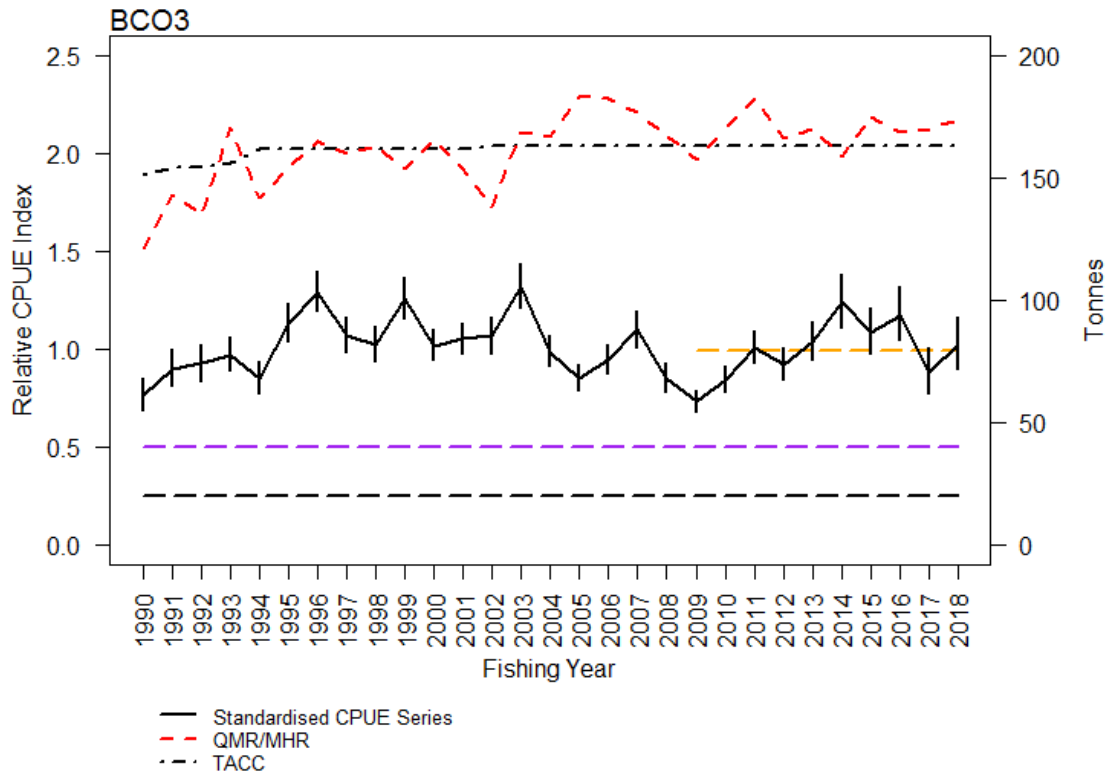
- **BCO 3 (Statistical Areas 024 and 026)**

Stock Structure Assumptions

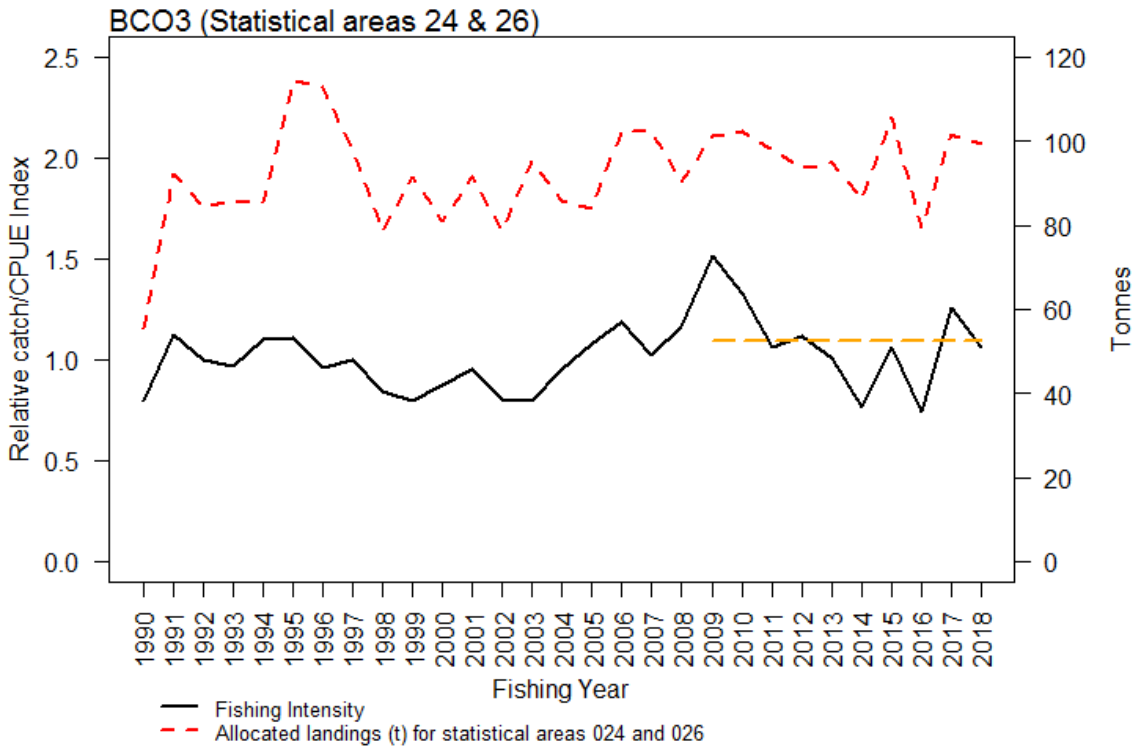
Tagging experiments suggest that blue cod populations may be isolated from each other and there may be several distinct populations within management areas. For the purposes of this summary, BCO 3 is split into two sub-areas along the Statistical Area 022/024 boundary: Statistical Areas 18, 20 and 22 (Northern); and 24 and 26 (Southern). There were insufficient data to produce a standardised CPUE series for the northern sub-area.

Stock Status	
Year of Most Recent Assessment	2019 (CPUE analysis)
Assessment Runs Presented	Standardised CPUE index based on landed catch of BCO target pot fishery
Reference Points	Target: B_{MSY} proxy based on mean CPUE for the period – 1998–99 to 2017–18 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 1998–99 to 2017–18
Status in relation to Target	About as Likely as Not (40–60%) to be at or above
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	Overfishing is About as Likely as Not (40–60 %) to be occurring

Historical Stock Status Trajectory and Current Status



Cod-potting CPUE index (CP-landed), along with catches and TACC for BCO 3. Also plotted are the QMR/MHR landings and the BCO 3 TACC. The orange line represents the interim B_{MSY} proxy of mean CPUE from 2009–2018. The purple line is the interim Soft Limit=0.5*[B_{MSY} proxy] and the grey line is the interim Hard Limit=0.25*[B_{MSY} proxy].



Relative Fishing Intensity (catch/CPUE) for BCO 3 based on the standardised CPUE series and the sum of the allocated landings for statistical areas 024 and 026. 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	Biomass has declined during the last five years with the 2017–18 index near the series mean.
Recent Trend in Fishing Intensity or Proxy	Relative exploitation has fluctuated without trend since 2011–12, and the 2017–18 level was at the overfishing threshold.
Other Abundance Indices	The North Otago and South Otago potting surveys each have two annual indices based on the random survey design. The declines in abundance since 2013 were similar to the CPUE series for the North Otago survey, but much steeper for the North Otago survey.
Trends in Other Relevant Indicators or Variables	-

Projections and Prognosis	
Stock Projections or Prognosis	At current catches biomass is likely to remain stable. Current catch has exceeded the TACC in 14 of the last 16 years (beginning 1999-2000).
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	About as Likely as Not (40–60%)

Assessment Methodology and Evaluation		
Assessment Type	Level 2 - Partial Quantitative Stock Assessment	
Assessment Method	Standardised CPUE analysis of a target cod-potting fishery	
Main data inputs	Catch and effort data derived from the MPI catch reporting data	
Period of Assessment	Latest assessment: 2019	Next assessment: 2023
Overall Assessment Quality	1 – High Quality	
Main Data Inputs (Rank)	- Catch and effort data	1 – High Quality
Data not used	- North and South Otago potting surveys	1 – High Quality: Monitors abundance in restricted survey areas supporting local recreational fisheries.
Changes to Model Structure and Assumptions	-	
Major Sources of Uncertainty	-	

Qualifying Comments
As 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.

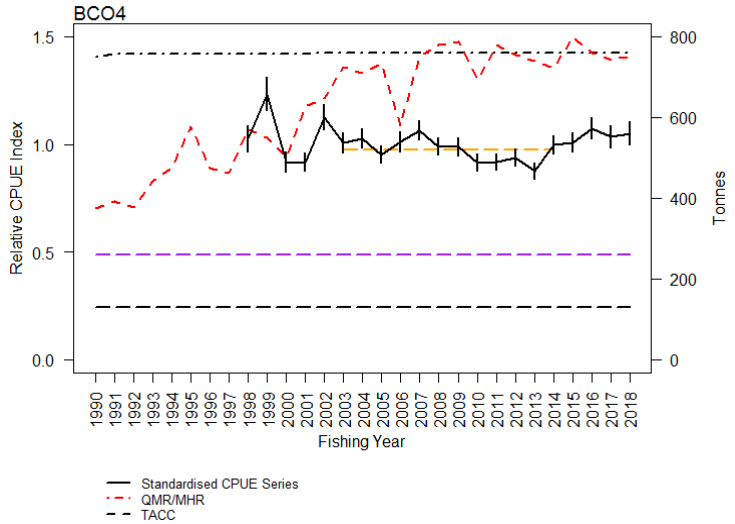
Fishery Interactions
Over two thirds of BCO 3 commercial catches are taken in a target cod-potting fishery which has very little interaction with other species. Most of the remaining BCO 3 catch is taken in the inshore bottom trawl fishery operating on the east coast of the South Island, largely directed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

- **BCO 4**

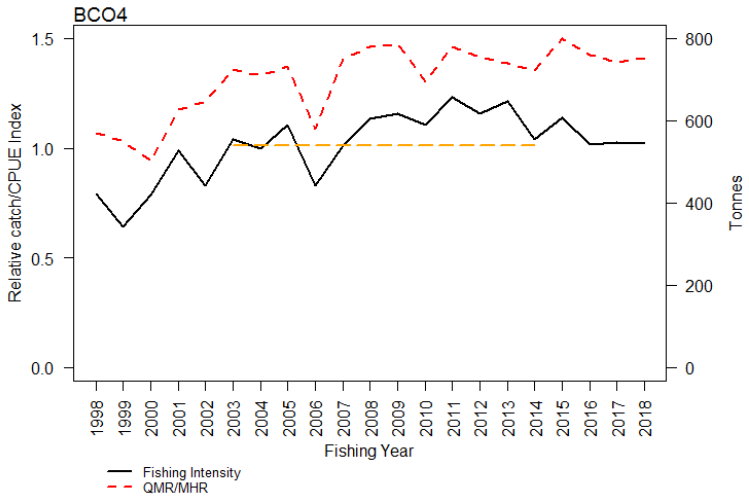
Stock Structure Assumptions
For the purposes of this summary BCO 4 is considered to be a single management unit.

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 2003–2014. 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**

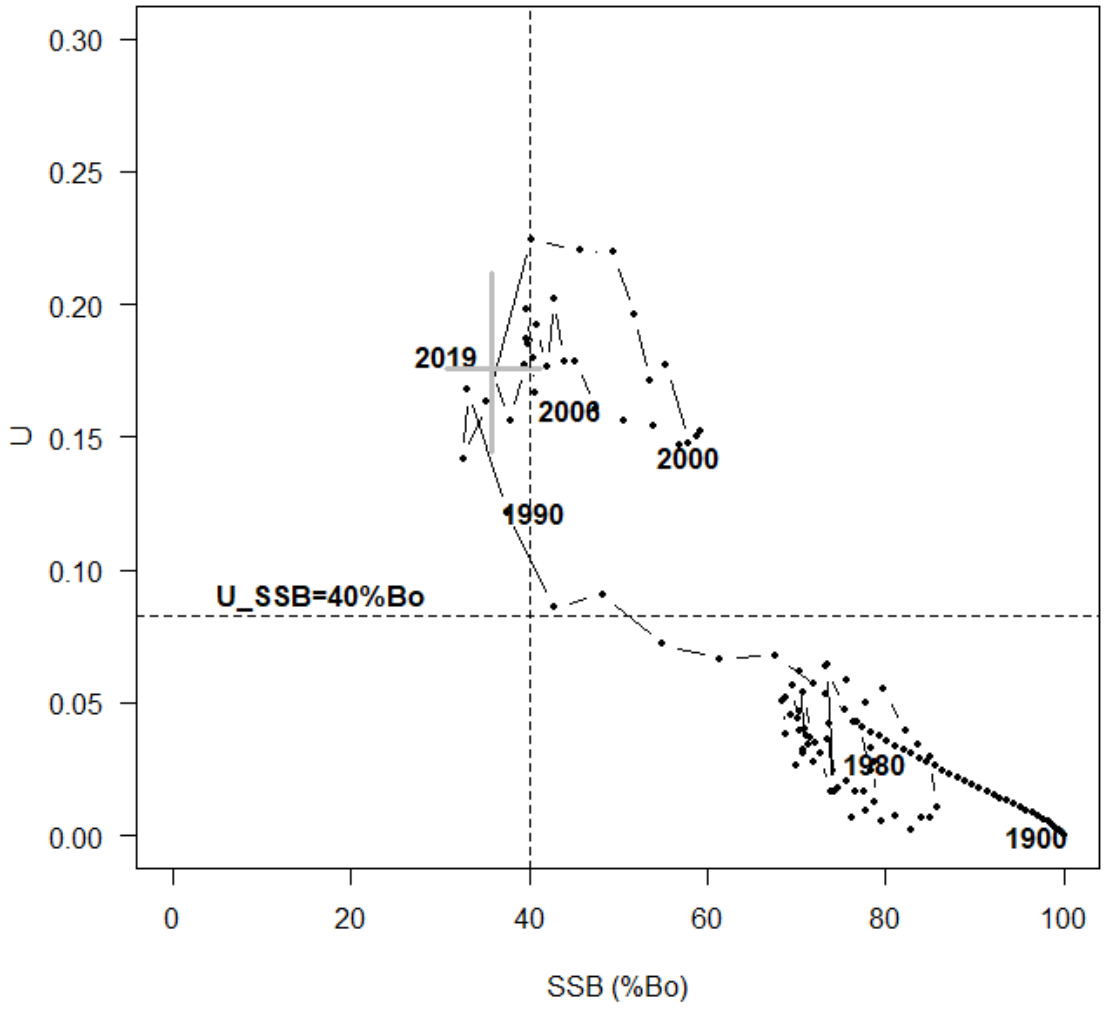
Stock Structure Assumptions

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 discreet 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



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	-

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 – 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 -Proportions at length from commercial catch for 2010 - Relative biomass and proportions at length and age from potting surveys - Estimates of biological parameters - Potting survey abundance estimates	1 – High Quality 1 – High Quality 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**

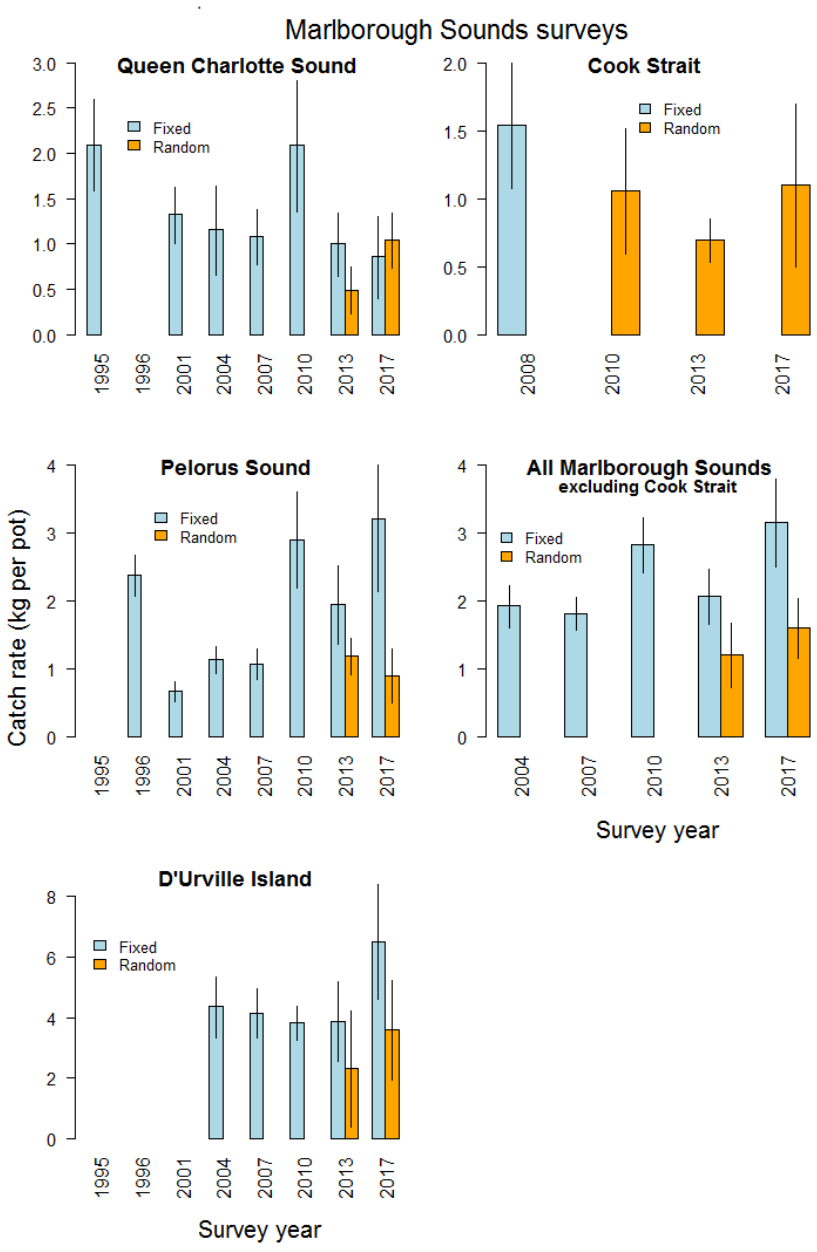
Stock Structure Assumptions

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

Stock Status	
Year of Most Recent Assessment	2018

Assessment Runs Presented	Catch rates from the fixed and 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: $F_{SB45\%}$ ($F_{SB45\%}$ = 0.26). Soft Limit: 20% B_0 Hard Limit: 10% B_0 Overfishing threshold: $F_{SB45\%}$
Status in relation to Target	F is Unlikely (< 40%) to be at or below the target
Status in relation to Limits	Unknown
Status in relation to Overfishing	Overfishing is Likely (> 60%) 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 1996, and DUR from 1995 to 2001. 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 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 rates 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. Cook Strait random-site surveys show no trend in abundance from 2010 to 2017. There are only two random site surveys for the other regions (2013 and 2017), not enough to comment on 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 and fixed site surveys in 2017, and the spawning biomass per recruit ratio was 39% (i.e. lower than the target of 45%).
Other Abundance Indices	The mean length of catches taken during the 2010 blue cod potting survey (following the closure) tended to be larger than those observed in previous surveys and this has generally been maintained in 2013 and 2017.
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 sites surveys in 2013 was 66%, and in 2017 it was 72% (Table 9). - Blue cod catch rates were about 10-fold higher, and length about 5 cm larger overall in the Long Island Marine Reserve (head of QCH) compared to adjacent fished strata in Queen Charlotte Sound. This is a strong indication that fishing pressure has reduced the size and abundance of blue cod in the Marlborough Sounds.

Projections and Prognosis	
Stock Projections or Prognosis	Biomass is expected to increase 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 Likely (> 60%) to cause overfishing to continue.

Assessment Methodology and Evaluation		
Assessment Type	2 - Partial Quantitative Stock Assessment	
Assessment Method	Fishery-independent potting survey. Fixed and random sites in QCH, PEL, DUR, and random sites in CKST.	
Assessment Dates	Latest assessment: 2018	Next assessment: 2022
Overall assessment quality rank	2 – Medium or Mixed Quality: mortality estimates compromised by	

	regulation changes	
Main data inputs (rank)	- Potting survey catch rates from fixed and random site surveys. - Length and age composition of catches from random and fixed site potting surveys in 2017	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. - Trends for random and fixed site surveys between 2013 and 2017 were contradictory in some areas. Random site surveys are believed to be better indicators of population abundance.	

Qualifying Comments
The survey has been transitioning from a fixed-site to a random-site stratified potting survey. The 2010 survey comprised a full fixed-site survey along with a partial random-site survey in selected strata, whereas 2013 and 2017 included full fixed and full random site surveys carried out simultaneously. The next survey will be based on random sites only.

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.

Table 22: Summary of yields (t), TACCs (t), and reported landings (t) for blue cod from the most recent fishing year.

Fishstocks	QMA	FMA	2018–19 Actual TACC	2018–19 Reported landings
BCO 1	Auckland	1 & 9	46	8
BCO 2	Central (East)	2	10	9
BCO 3	South-East (Coast)	3	163	177
BCO 4	South-East (Chatham Rise)	4	759	744
BCO 5	Southland and Sub-Antarctic	5 & 6	1 239	827
BCO 7	Challenger	7	70	64
BCO 8	Central (Egmont)	8	34	14
BCO 10	Kermadecs	10	10	0
Total			2 332	1 844

6. FOR FURTHER INFORMATION

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