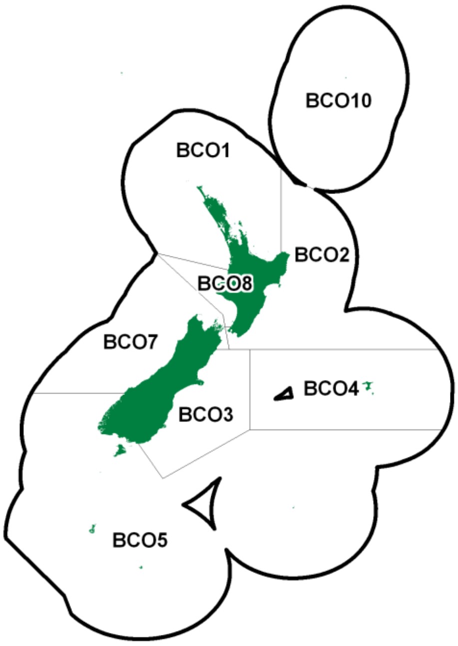
BLUE COD (BCO)

(Parapercis colias)
Rawaru



1. FISHERY SUMMARY

Allowances, TACCs and TACs in Table 1.

Table 1: Recreational and Customary non-commercial allowances, other mortality, TACCs and TACs 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 3000 t were reported in the 1930s and catches of 2500 t were sustained for many years in the 1950s and 1960s. 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 fishstocks 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 built up to a peak 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. Recent reported landings are shown in Table 3 and historical landings in Table 4, while Figure 1 shows the historical landings and TACC values for the five main BCO fish stocks.

Since 1994-95, total landings have exceeded 2000 t annually, peaking at 2501 t in 2003-04. Historically, the largest catches of blue cod have been taken in BCO 5 (1556 t in fishing year 2003-04). The total catch from this fishery remained relatively stable from 1982 to 1993 and subsequently increased to approach the level of the TACC in 1995-96. Catches have remained stable at this higher level in recent years.

Since 1989-90, a large proportion of the total catch from the BCO 5 fishery has been taken from Foveaux Strait (statistical area 025) and catches from this area have remained relatively stable. The recent increase in total catch has been attributed to an increase in catch from the western approaches to Foveaux Strait (stat area 030) and, to a lesser extent, from off eastern Stewart Island (statistical area 027). In BCO 3, catches have consistently fluctuated around the TACC of 163 t exceeding it in most years since 1997-98. In other Fishstocks, landings have generally been lower than the TACC. In BCO 7, commercial landings declined in response to a reduction in TACC (to 70 t) implemented in 1995-96, but from 2000-01 annual landings in this QMA have increased steadily.

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

Year	BCO 1	BCO 2	BCO 3	BCO 4	Year	BCO 1	BCO 2	BCO 3	BCO 4
1931-32	29	0	55	148	1957	2	5	63	1185
1932-33	12	0	59	111	1958	2	4	57	892
1933-34	24	5	26	1055	1959	1	2	51	1158
1934-35	17	5	23	1306	1960	1	4	48	903
1935-36	18	23	34	1197	1961	1	2	43	871
1936-37	3	7	27	755	1962	1	9	37	550
1937-38	2	8	31	793	1963	1	12	46	633
1938-39	2	3	19	686	1964	1	107	83	495
1939-40	1	4	33	715	1965	1	18	55	742
1940-41	3	7	39	320	1966	1	395	35	13
1941-42	2	5	30	189	1967	1	437	34	0
1942-43	3	5	20	204	1968	1	312	69	0
1943-44	4	12	31	212	1969	6	232	92	8
1944	3	10	38	216	1970	0	402	70	39
1945	8	6	45	102	1971	1	105	81	36
1946	11	9	43	175	1972	0	137	60	3
1947	8	22	81	278	1973	1	127	65	4
1948	7	24	74	623	1974	0	67	61	1
1949	37	6	98	390	1975	0	5	42	2
1950	5	5	66	485	1976	0	103	72	17
1951	4	9	51	494	1977	2	3	21	46
1952	5	7	53	543	1978	0	9	49	14
1953	7	20	62	682	1979	0	17	74	13
1954	5	9	84	603	1980	1	1	89	1
1955	4	8	83	355	1981	1	2	69	40
1956	1	7	86	636	1982	7	0	62	13

Table 2 [Continued]

Year	BCO 5	BCO 7	BCO 8	Year	BCO 5	BCO 7	BCO 8
1931-32	719	4	4	1957	581	61	2
1932-33	726	1	5	1958	542	71	2
1933-34	792	3	2	1959	492	71	1
1934-35	1057	0	4	1960	757	65	2
1935-36	284	44	2	1961	590	55	3
1936-37	113	61	0	1962	668	65	3
1937-38	172	81	0	1963	621	60	4
1938-39	94	57	0	1964	462	70	3
1939-40	135	68	0	1965	296	59	2
1940-41	177	72	0	1966	337	79	6
1941-42	128	54	0	1967	518	74	5
1942-43	139	65	0	1968	494	105	2
1943-44	221	80	0	1969	361	60	1
1944	552	88	0	1970	432	70	8
1945	634	109	0	1971	375	44	2
1946	715	116	2	1972	194	63	1
1947	955	153	1	1973	571	68	11
1948	852	88	2	1974	486	61	16
1949	929	82	3	1975	232	58	14
1950	1005	94	1	1976	254	58	17
1951	873	74	2	1977	208	87	19
1952	889	95	3	1978	197	104	12
1953	414	114	2	1979	217	98	16
1954	385	112	2	1980	403	62	18
1955	405	79	3	1981	494	79	23
1956	656	77	2	1982	356	68	34

Table 3: Reported landings (t) of blue cod by Fishstock from 1983 to 2012-13 and actual TACCs (t) from 1986-87 to 2012-13. QMS data from 1986-present. FSU data 1983-1986. [Continued on next page].

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

Fishstock		**BCO 7**		**BCO 8**		**BCO 10**		
FMA (s)		7		8		10		
	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

Table 3 [Continued]

Fishstock	BCO 7			BCO 8		BCO 10		
FMA (s)		7						
	Landings	TACC	Landings	TACC	Landings	TACC	Landings	**TACC**
1989-90	75	136	34	74	0	10	1527	2 666
1990-91	63	136	28	74	0	10	1 752	2667
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

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

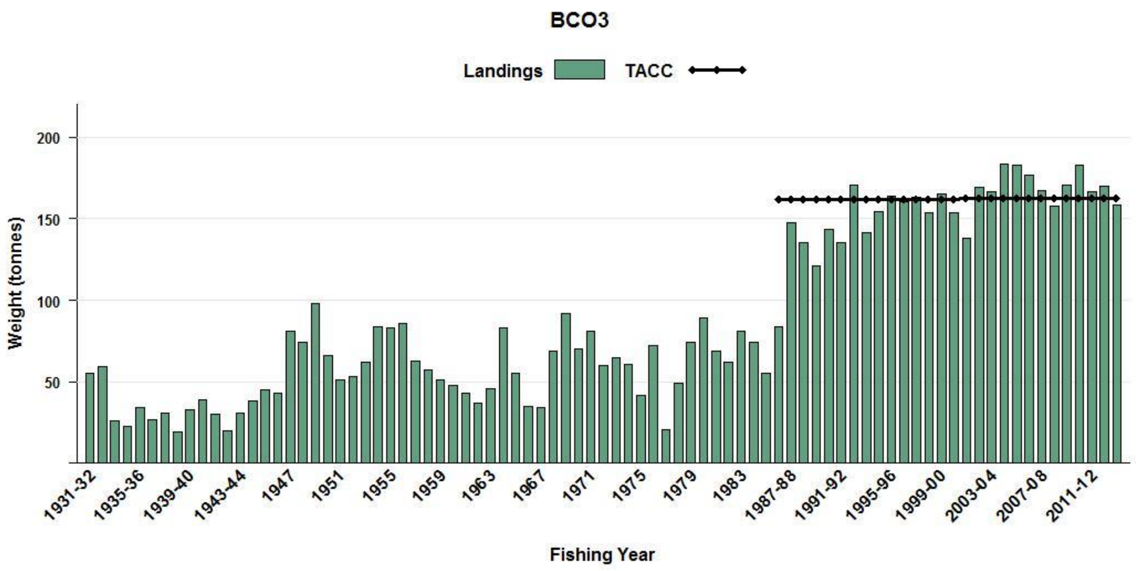
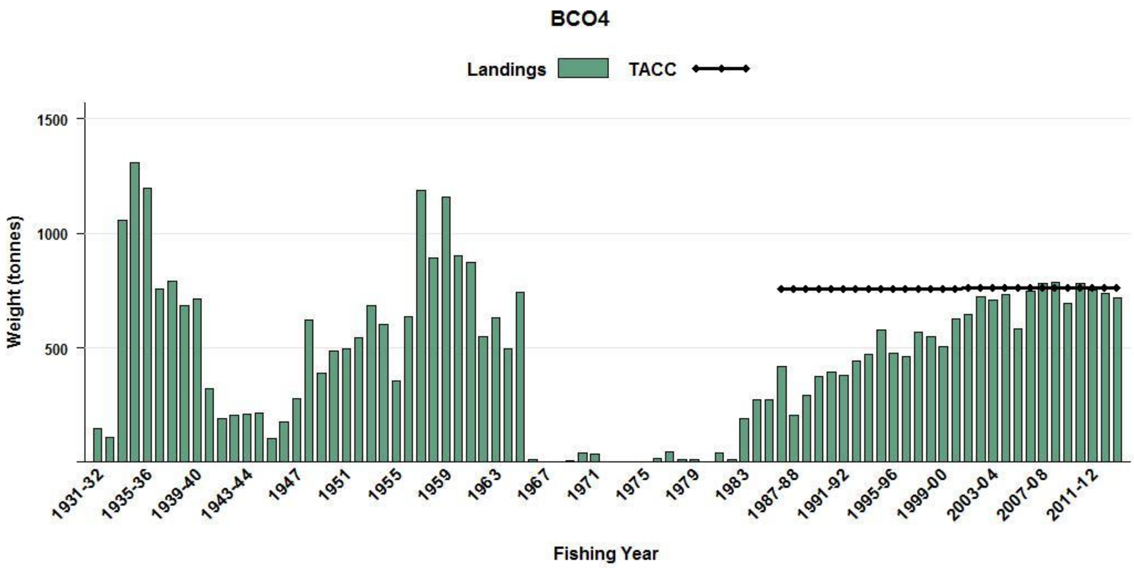
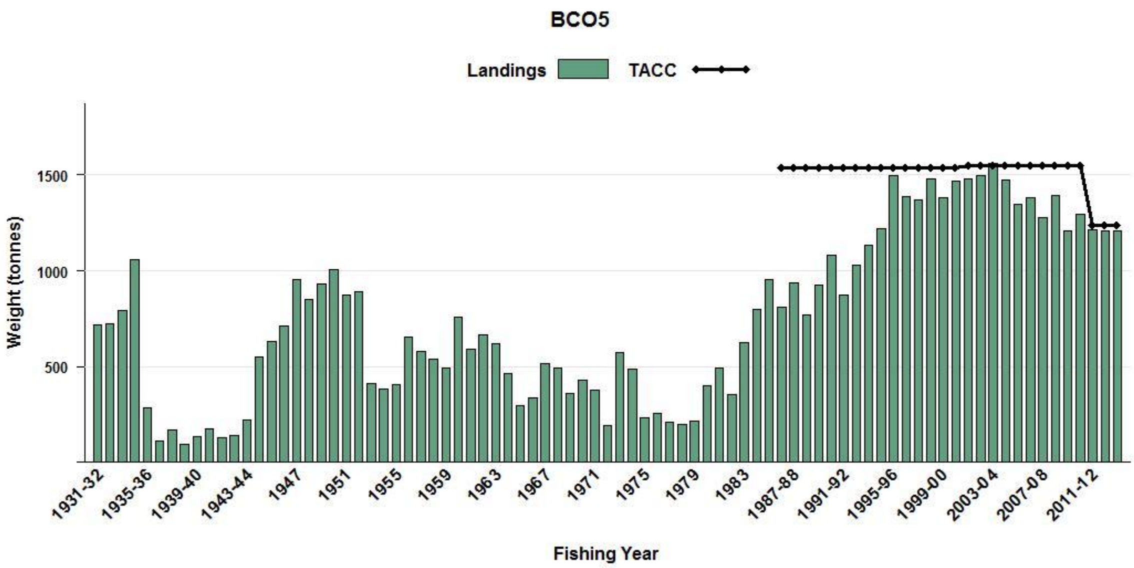


Figure 1: Reported commercial landings and TACC for the five main BCO stocks. From top: BCO3 (South East Coast) [Continued on next page].





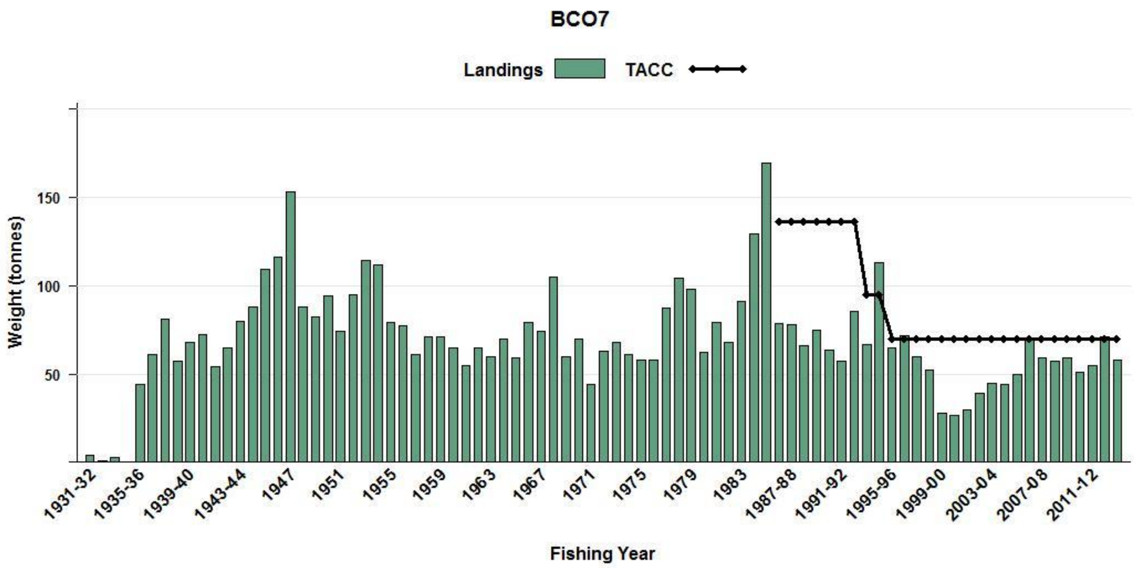


Figure 1: Reported commercial landings and TACC for the five main BCO stocks. From top: BCO4 (South East Chatham Rise), BCO5 (Southland), BCO7 (Challenger). [Continued on next page].

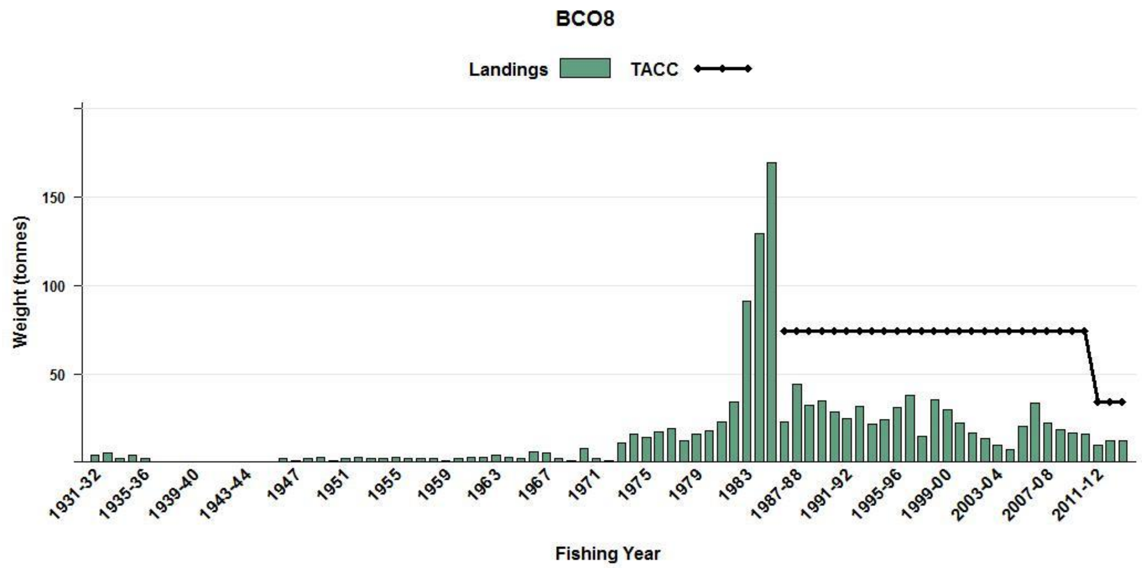


Figure 1 [Continued]: Reported commercial landings and TACC for the five main BCO stocks. BCO8 (Central Egmont).

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), a slot limit on size, method restrictions and daily bag limits. Both of these have changed over time and vary by Fishstock (Table 5).

Table 5: Changes to minimum legal size (MLS in cm) and amateur maximum daily limits (MDL) of blue cod by Fishstock from 1986 to present.*

Fishstock	BCO 1		BCO 2		BCO 3		BCO 4		BCO 5		Sub area provisions:	
QMA(s)	1&9		2		3		4		5 &6		Paterson Inlet	
	MLS	MDL	MLS	MDL	MLS	MDL	MLS	MDL	MLS	MDL	MLS	MDL
1986	30	30	30	30	30	30	30	30	30	30	30	30
1993	33	20	33	20	30	30	33	30	33	30	33	30
1994	33	20	33	20	30	30	33	30	33	30	33	15
	-	-	-	-	-	*30	*10	-	-	-	-	-

Fishstock	BCO 7		BCO 7		BCO 8		BCO 10	
QMA(s)	7		Marlborough Sounds		8		10	
	MLS	MDL	MLS	MDL	MLS	MDL	MLS	MDL
1986	30	30	30	12	30	30	30	30
1993	33	20	33	10	33	20	33	20
1994	33	20	28	6	33	20	33	20
2001	33	10	-	-	-	-	-	-
2003			30	3				
2011			SLOT 30-35	2				

All maximum daily limits are restricted within mixed species maximum daily bag limits which may vary between areas - (for the in north Canterbury area only).

During 1992-93, the amateur bag limit for blue cod was reduced and the minimum size increased from 30 cm to 33 cm for both amateur and commercial fishers (except for BCO 3). However, this was amended in 1993-94 for the Marlborough Sounds where the size limit was reduced to 28 cm. Bag limits were also reduced for the Marlborough Sounds and Paterson Inlet (Stewart Island), in 2003 the minimum legal size and daily bag limit in the Marlborough Sounds was changed to 30 cm and 3 per person per day respectively. In April 2011 a slot limit of 30-35cm and a bag limit of two blue cod per person per day were introduced for the Marlborough Sounds.

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 2005) and a rolling replacement of diarists in 2001 (Boyd & Reilly 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 are likely to be an underestimate due to less sampling coverage than planned for two key reasons. Less flights occurred than planned for the outer Marlborough Sounds due to poor flying conditions (low cloud), and sampling of harvest at boat ramps was not as complete as intended due to the higher than anticipated proportion of fishers who departed and returned to a bach/crib within BCO 7, or Wellington, without being intercepted at a boat ramp within BCO 7.

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.

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 survey ran through the October to September fishing year but is 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	8	0.20
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
BCO 3	1996	Telephone/diary	217, 000	151	11
	2000	Telephone/diary	1, 026, 000	752	0.29
	2012	Panel survey	212, 184	101	0.20
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
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	75	0.17
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

1.2.3 Charter vessel harvest

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

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

Fishstock	Number caught	CV(%)	Estimated landings (number of fish killed)	Point Estimate (t)
BCO 1	430	18	2 500	2.4
BCO 2	34	50	300	0.2
BCO 3	17 272	29	72 000	58
BCO 5	16 750	36	63 000	51
BCO 7	32 026	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 traditionally 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.

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, whilst in the Marlborough Sounds it is reached at 21-26 cm (TL) at 3-6 years. In Southland, the fish become mature between 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 (Carbines 2004b). The maximum recorded age for this species is 32 years.

M was estimated using the equation $M = \log_e 100/\text{maximum age}$, where maximum age is the age to which 1% of the population survives in an unfished stock. Using the maximum age of 32 years, (Carbines *et al*. 2007) M was calculated to be 0.14. This estimate seems feasible as in lightly fished areas such as the offshore Banks Peninsula Z is thought to approximate M and was calculated at 0.14 to 0.15 (Beentjes 2012)

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 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 the survival of these fish is good if they are caught using large hooks (6/0) and returned to the sea quickly.

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 < 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

Fishstock	Estimate	Source
1. Natural mortality (*M*)		
All	0.14	Estimated from the maximum age in Carbines *et al*. 2007, using Hoenig's (1983) method.

2. Von Bertalanffy growth parameters

	Females			Males			
	L_∞	k	t_0	L_∞	k	t_0	
Banks Peninsula (inshore)	45.8	0.128	-0.7	47.0	0.152	-0.1	Carbines & Haist 2012a
Banks Peninsula (offshore)	46.7	0.089	-1.8	56.7	0.085	-1.6	Carbines & Haist 2012a
Kaikoura	45.2	0.082	-2.9	53.5	0.089	-1.5	Carbines & Haist 2012b
Motunau	40.0	0.114	-2.0	50.7	0.088	-1.9	Carbines & Haist 2012b
Paterson Inlet	47.3	0.109	-1.4	63.7	0.070	-2.0	Carbines & Haist 2014a
Southland (Sub area 025)	34.5	0.4	1.2	41.6	0.3	1.2	Carbines (1998)
Queen Charlotte Sound (Over all)	32.2	0.3	-0.70	*	*	*	Carbines (1998)
Inner Queen Charlotte Sound	†	†	†	41.4	0.1	-5.2	Carbines (2000)
Outer Queen Charlotte Sound	†	†	†	33.7	0.4	1.07	Carbines (2000)
Extreme Outer Queen Charlotte Sound	†	†	†	50.2	0.1	-1.9	Carbines (2000)
Pelorus Sound (Over all)	33.2	0.2	-2.0	*	*	*	Carbines (2000)
Outer Pelorus Sound	†	†	†	36.8	0.27	-0.3	Carbines (2000)
Extreme Outer Pelorus Sound	†	†	†	40.8	0.22	-0.3	Carbines (2000)

3. Weight = $a(\text{length})^b$ (Weight in g, length in cm total length).

Area	Year	Sex	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	

† Sub areas showed no significant difference from pooled area growth estimates
* Pooled area growth estimates showed significant differences from sub areas.

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 isolated from each other and there may be several distinct populations within each management area.

4. STOCK ASSESSMENT

4.1 Estimates of fishery parameters and abundance

4.1.1 South Island blue cod potting surveys

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 and Carbines 2012). A new survey in 2013 used the same strata as 2010 (Beentjes et al in prep). 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 and Carbines 2012). The 1995 and 1996 surveys, similarly, have been reanalysed as part of the 2013 survey analyses (Beentjes et al in prep). 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 and Francis 2011). In 2010, a suite of random locations were added to the fixed sites in selected strata. Random sites may have any location (single latitude and longitude) and are generated randomly within each stratum. In 2013, full random and full fixed site surveys were conducted. However, only the fixed site component of the 2010 and 2013 surveys are considered comparable to the earlier surveys.

Throughout the 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 (Figures 2 to 5)(Table 9). In Queen Charlotte Sound catch rates progressively declined from 2.1 to 1.1 kg.pot^{-1} (CVs range 16 to 26%) between 1995 and 2007 before increasing markedly in 2010 to 1.75 kg.pot^{-1} (Figure 2). 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} (CVs range 7 to 19%) over the same period, before increasing 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 and Pelorus Sounds and east D'Urville. The 2013 survey was carried out two years after the slot limit management regime had been in place, with total blue cod catch rates for both Queen Charlotte and Pelorus Sounds declining compared to 2010, 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 (Figures 2 and 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} (CVs range 8 to 18%) (Figure 4). D'Urville was not closed to fishing in October 2008, but was included in the management area where the "slot limit" has been applicable since April 2011. Cook Strait has had only two comparable surveys (which used a random design) (2010 and 2013) with the first survey in 2008 being a fixed site survey which was not comparable. Total blue cod catch rates

from the random survey years were 1.1 kg.pot^{-1} in 2010, declining to 0.70 kg.pot^{-1} in 2013. There have been no closures or slot limit management measures for this region in 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, while 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).

No ageing results, including estimates of total mortality (*Z*) and spawner biomass per recruit, are presented for Marlborough Sounds as there have been inconsistencies in the ageing of blue cod from this area. An ageing protocol is currently being developed for blue cod, and the age dependant results for the Marlborough Sounds survey will be presented once the otoliths have been read using the new protocol.

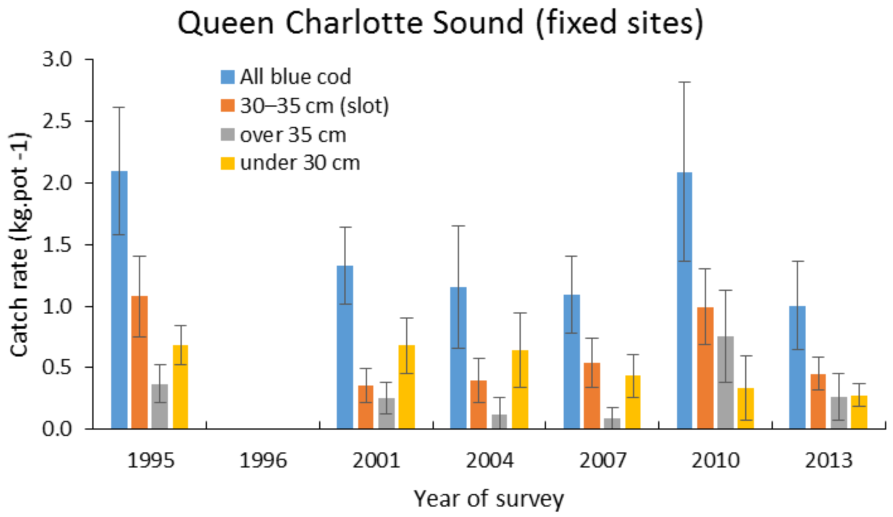


Figure 2: Scaled catch rates of blue cod from Queen Charlotte Sound fixed sites from 1995 to 2013. Catch rates are shown for all blue cod, slot limit blue cod (30–35 cm), blue cod above the slot limit (over 35 cm) and for pre-recruited blue cod (under 30 cm). Error bars are 95% confidence intervals.

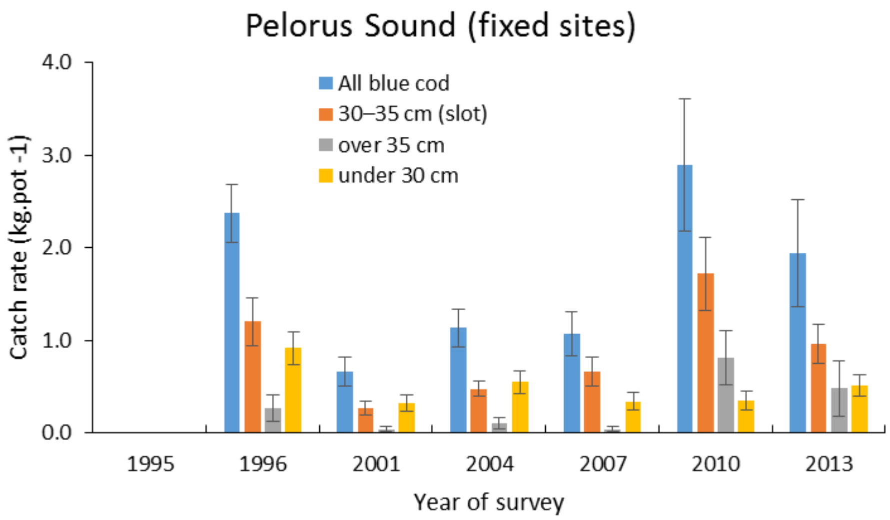


Figure 3: Scaled catch rates of blue cod from Pelorus Sound fixed sites from 1996 to 2013. Catch rates are shown for all blue cod, slot limit blue cod (30–35 cm), blue cod above the slot limit (over 35 cm) and for pre-recruited blue cod (under 30 cm). Error bars are 95% confidence intervals.

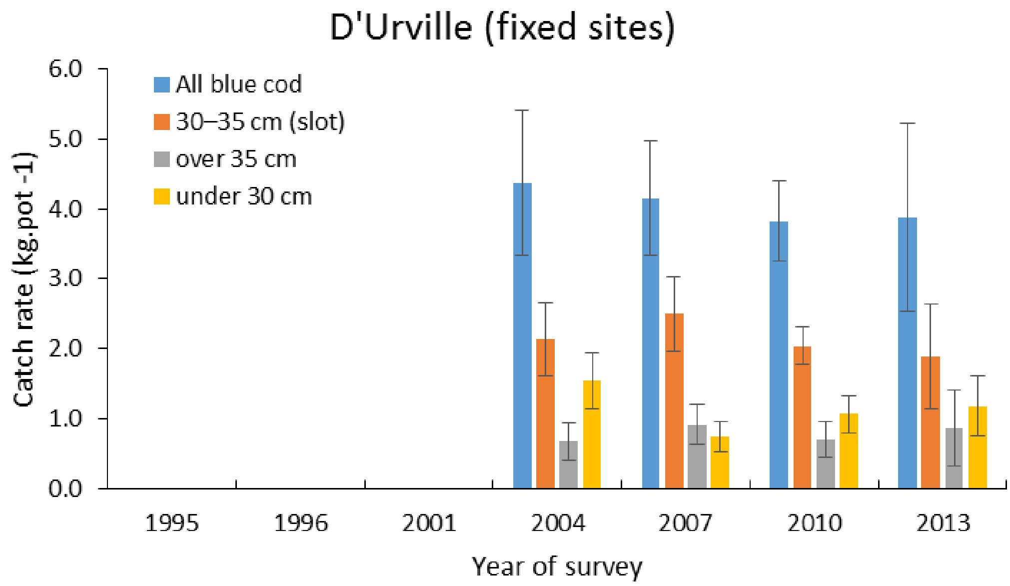


Figure 4: Scaled catch rates of blue cod from D'Urville region fixed sites from 2004 to 2013. Catch rates are shown for all blue cod, slot limit blue cod (30–35 cm), blue cod above the slot limit (over 35 cm) and for pre-recruited blue cod (under 30 cm). Error bars are 95% confidence intervals.

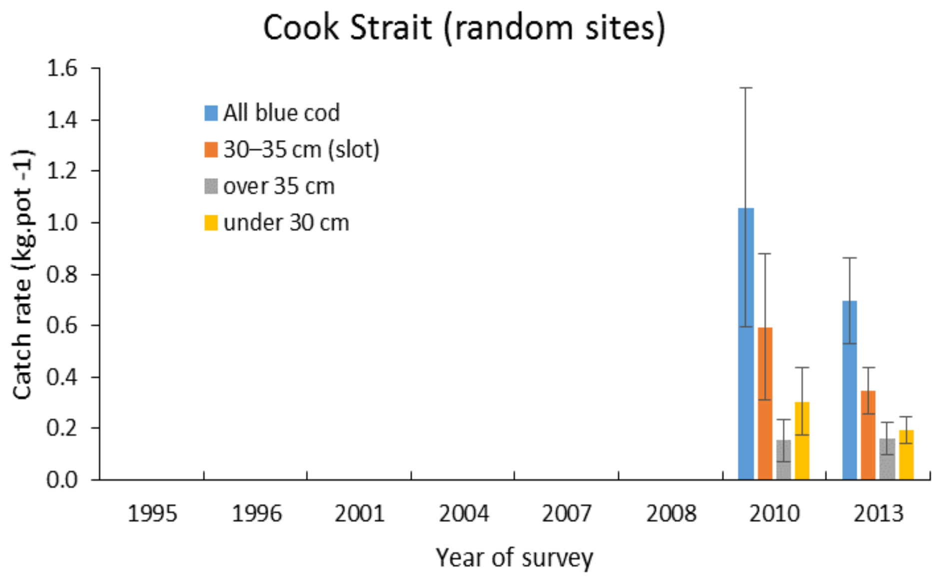


Figure 5: Scaled catch rates of blue cod from Cook Strait region random sites in 2010 and 2013. Catch rates are shown for all blue cod, slot limit blue cod (30–35 cm), blue cod above the slot limit (over 35 cm) and for pre-recruited blue cod (under 30 cm). Error bars are 95% confidence intervals.

Table 9: Summary statistics from standardised blue cod potting surveys in the Marlborough Sounds up to 2013 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 All surveys were fixed site except Cook Strait in 2010 and 2013 which were random. QCH, Queen Charlotte Sound; PEL, Pelorus Sound; DUR, D'Urville; CKST, Cook Strait.

			Mean length (cm)		CPUE ($kg.pot^{-1}$)		
Region	Year	Site type	Male	Female	Overall	range (CV)	Sex ratio (% 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	0–2.60(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%
PEL	1995	–	–	–	–	–	–
	1996	Fixed	29.8	26.2	2.4	1.0–3.3 (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	1.6–3.86(13%)	87%
	2013	Fixed	31.3	27.2	1.95	3.3–4.94(15%)	89%
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%
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%

Banks Peninsula

Results from a fishery independent fixed site potting survey off Banks Peninsula (part of BCO 3) in 2002 estimated total mean catch rates for all blue cod of 2.13 kg/pot hour (CV = 10.8%). This ranged from 0.04 kg/pot hour near Akaroa Harbour entrance to 4.74 kg/pot hour for the offshore stratum located over Pompeys Rock (Beentjes & Carbines 2003). The Banks Peninsula fixed site survey was repeated in 2005 and the estimated total mean catch rate for all blue cod was 4.43 kg/pot hour (CV = 5.7%), strata ranging from 1.02 to 7.27 kg/pot hour (Beentjes & Carbines 2004). The fixed site survey was repeated again in 2008 (Beentjes & Carbines 2009) and the mean catch rates of blue cod (all sizes) ranged from 0.07 kg per pot hour in stratum 2 (Akaroa Harbour entrance), to 5.80 kg per pot hour for offshore stratum 6 located over Le Bons Rocks. Overall mean catch rate and CV were 2.59 kg per pot per hour and 7.7%. For blue cod 30 cm and over (minimum legal size), highest catch rates were also in stratum 6 (5.74 kg per pot hour) and lowest catch rates in stratum 2 (0.04 kg per pot hour). Overall mean catch rate and CV for blue cod 30 cm and over were 2.30 kg per pot hour and 8.3% respectively. In 2008 the sex ratio for inshore strata (1-5) was 2.4:1 (male:female), for offshore strata (6 and 7) 0.98:1, and overall 1.5:1.

In 2012 the fixed site survey was repeated along with a concurrent random stratified site survey (Carbines & Haist 2012a). From fixed sites the mean catch rates of blue cod (all sizes) ranged from 0.60 kg per pot per hour in stratum 2 (Akaroa Harbour entrance), to 6.28 kg per pot per hour for offshore stratum 7 (Pompeys Rocks). Overall mean catch rate and CV were 4.32 kg per pot per hour and 18.09%. For blue cod 30 cm and over, highest catch rates were also in stratum 7 (6.02 kg per pot per hour) and lowest catch rates in stratum 2 (0.32 kg per pot per hour). Overall mean catch rate and CV for blue cod 30 cm and over at fixed sites were 4.08 kg per pot per hour and 19.54% respectively. From random sites the mean catch rates of blue cod (all sizes) ranged from 0.33 kg per pot per hour in stratum 5 (Le Bons Bay area), to 4.09 kg per pot per hour for offshore stratum 6 (Le Bons Rocks). Overall mean catch rate and CV at random stratified sites were 2.97 kg per pot per hour and 31.28%. For blue cod 30 cm and over, highest catch rates were also in stratum 6 (4.30 kg per pot per hour) and lowest catch rates

in stratum 5 (0.28 kg per pot per hour). Overall mean catch rate and CV for blue cod 30 cm and over at random stratified sites were 2.79 kg per pot per hour and 33.59% respectively.
In 2012 at fixed sites the sex ratio for inshore strata (1-5) was 2.1:1 (male:female), for offshore strata (6 and 7) 1.3:1, and overall 1.6:1. Mortality was markedly greater for blue cod inshore compared to those offshore. Estimates are consistent with those from 2002, 2005 and 2008 fixed site surveys. At random stratified sites in 2012 the sex ratio for inshore strata (1-5) was 2.0:1 (male:female), for offshore strata (6 and 7) 1.4:1, and overall 1.8:1. Mortality was also markedly greater for blue cod inshore compared to those offshore.

North Canterbury
A fishery independent fixed site potting survey of blue cod in North Canterbury (part of BCO 3) in 2004/05 produced an overall mean catch rate for all blue cod of 2.45 kg/pot (CV = 8.7%) for Kaikoura and 10.19 kg/pot (CV = 7.3%) for Motunau. The catch rate of blue cod ≥ 30cm was 1.91 kg/pot hour (CV = 7.9%) for Kaikoura and 5.97 kg/pot (CV = 9.8%) for Motunau (Carbines & Beentjes 2006a).

In 2008 (Carbines & Beentjes 2009) mean catch rates of blue cod (all sizes) in the Kaikoura ranged from 1.94 to 20.45 kg per pot per hour. Overall mean catch rate and CV were 5.00 kg per pot per hour and 8.2%. Overall mean catch rate and CV for blue cod 30 cm and over were 4.01 kg per pot per hour and 9.2%. The overall sex ratio was 0.7:1 (male:female), although the two strata with the lowest catches of blue cod were biased in favour of males (1.4:1). Total mortality (Z) for Kaikoura blue cod populations in 2007 was estimated between 0.31 and 0.47 and was higher than estimates from the 2004 survey.

In 2008 (Carbines & Beentjes 2009) mean catch rates of blue cod (all sizes) in Motunau ranged from 4.11 to 8.86 kg per pot per hour. Overall mean catch rate and CV were 5.50 kg per pot per hour and 8.8%. For blue cod 30 cm and over (minimum legal size), catch rates ranged from 2.10 to 4.93 kg per pot per hour. Overall mean catch rate and CV for blue cod 30 cm and over were 3.33 kg per pot per hour and 15.7%. The overall sex ratio was 3.2:1 (male:female) and the bias toward males was consistent for all strata. Total mortality (Z) for Motunau blue cod populations in 2008 was estimated between 0.53 and 1.12 and remained consistent with the 2005 survey.

The substantial decrease in catch rates in all Motunau strata in 2008 compared to 2005 could not be explained by the relatively weak cohort in 2005; or catchability, as environmental conditions at Motunau were similar for both surveys. The relatively high estimates of mortality and the overall 44% decline in catch rates of legal sized blue cod in Motunau since the 2005 potting survey is of concern.

In 2011/12 the Kaikoura and Motunau fixed site survey were repeated along with concurrent random stratified site surveys (Carbines & Haist 2012b). From the 2011 Kaikoura fixed site survey the overall mean catch rates and CV of blue cod (all sizes) were 3.96 kg per pot per hour and 14.99% (set based estimates). Overall mean catch rate and CV for blue cod 30 cm and over at fixed sites were 2.79 kg per pot per hour and 13.33% respectively. In 2011 the overall mean catch rate and CV from random stratified sites were 2.62 kg per pot per hour and 16.71%. Overall mean catch rate and CV for blue cod 30 cm and over at random stratified sites were 1.72 kg per pot per hour and 16.39% respectively.

From the 2012 Motunau fixed site survey the overall mean catch rates and CV of blue cod (all sizes) were 5.53 kg per pot per hour and 11.95% (set based estimates). Overall mean catch rate and CV for blue cod 30 cm and over at fixed sites were 3.01 kg per pot per hour and 16.62% respectively. In 2012 the overall mean catch rate and CV from random stratified sites in Motunau were 2.97 kg per pot per hour and 20.13%. Overall mean catch rate and CV for blue cod 30 cm and over at Motunau random stratified sites were 1.56 kg per pot per hour and 22.60% respectively.

North Otago
An initial fishery independent fixed site potting survey of blue cod was done in North Otago (also part of BCO 3) in 2005, it produced an overall mean catch rate for all blue cod of 10.14 kg/pot (CV =

5.4%). The catch rate of blue cod 30 cm and over (minimum legal size) was 8.22 kg/pot hour (CV = 5.3%) (Carbines & Beentjes 2006). In 2009 a second fixed site potting survey (Carbines & Beentjes 2011) in North Otago produced mean catch rates of blue cod (all sizes) from 6.21 to 19.88 kg per pot per hour. Overall mean catch rate and CV were 11.51 kg per pot per hour and 6.0%, which was consistent with the 2005 survey catch rates. Overall mean catch rate and CV for blue cod 30 cm and over were 8.89 kg per pot per hour and 6.7%, also similar to the 2005 survey results. The overall sex ratio in 2009 was 2.7:1 (male:female), maintaining the bias toward males observed in 2005. Total mortality (*Z*) for North Otago blue cod populations in 2009 was estimated between 0.25 and 0.36, and were lower than retrospective estimates of Z from the 2005 survey.

In the 2013 North Otago fixed site potting survey (Carbines & Haist 2014b) mean catch rates of blue cod (all sizes) ranged from 2.72 to 8.07 kg per pot per hour. Overall mean catch rate and CV were only 4.96 kg per pot per hour and 12.6%. For blue cod 30 cm and over (minimum legal size), catch rates ranged from 2.02 to 6.42 kg per pot per hour. Overall mean catch rate and CV for blue cod 30 cm and over had dropped to 3.94 kg per pot per hour and 13.7%. The overall sex ratio was 3.3:1 (male:female) and the bias toward males remained consistent for all strata. *Z* for North Otago blue cod populations in 2013 was estimated between 0.22 and 0.36 and remained consistent with the 2009 survey. The substantial decrease in catch rates in 2013 compared to 2005 and 2009 is of concern. Estimates of Z (0.26, recruitment at 6 years) and percent spawner biomass per recruit (F%SPR=34.11%) for the 2013 North Otago fixed site survey are also of some concern.

In the concurrent 2013 North Otago stratified random site potting survey (Carbines & Haist 2014b) mean catch rates of blue cod (all sizes) ranged from 0.94 to 7.46 kg per pot per hour. Overall mean catch rate and CV were 4.16 kg per pot per hour and 13.9%, similar to concurrent fixed sites. For blue cod 30 cm and over, catch rates ranged from 0.46 to 5.28 kg per pot per hour. Overall mean catch rate and CV for blue cod 30 cm and over were 3.01 kg per pot per hour and 14.4%, also similar to fixed sites. The overall sex ratio was 2.13:1 (male:female) and comparatively less bias toward males at random sites. Estimates of *Z* (0.27, recruitment at 6 years) and F%SPR (35.73%) for the 2013 North Otago stratified random site survey were consistent with equivalent estimates from the concurrent fixed site survey.

South Otago

A comparison of fixed and random stratified site potting survey designs was done in three strata off South Otago (also part of BCO 3) in 2009 (Beentjes & Carbines 2011) with similar results. In 2013 a fully stratified random site potting survey of blue cod was done in six strata off South Otago and produced an overall mean catch rate for all blue cod of 6.24 kg/pot (CV = 19.8%) (Carbines & Haist 2014c). The catch rate of blue cod ≥ 30cm was 5.06 kg/pot hour (CV = 23.03%). The overall sex ratio was 1.22:1 (male:female), with the bias toward males occurring mainly inshore, and some offshore strata having up to 58% females. Total mortality estimates for South Otago blue cod populations in 2013 were 0.22 for inshore sites (age of recruitment 9 years) and 0.18 for offshore sites (age of recruitment 8 years). Subsequent estimates of F%SPR were 57.34% for inshore sites and 74.23% for offshore sites.

Paterson Inlet

A fixed site potting survey of blue cod in Paterson Inlet (BCO 5) in 2006 produced an overall mean catch rate for all blue cod of 4.77 kg/pot and CV of 11.9% (set based estimates excluding the marine reserve). The catch rate of blue cod ≥ 33cm (minimum legal size), was 2.91 kg/pot hour (CV = 12.3%). In 2010 the fixed site survey was repeated along with a concurrent random stratified site survey (Carbines & Haist 2014). The overall mean catch rate for all blue cod was 4.21 kg/pot and CV of 11.1% from fixed sites, and 0.82 kg/pot and CV of 24.2% from random stratified sites. The overall mean catch rate for ≥ 33cm blue cod was 3.08 kg/pot and CV of 11.3% from fixed sites, and 0.4 kg/pot and CV of 23.4% from random stratified sites.

Total mortality, estimated from Z-analyses derived from age composition distributions, reduced from 2006 to 2010 at fixed sites. In 2010 higher mean lengths at fixed sites resulted in lower mortality estimates than at random sites, suggesting that comparing mortality estimates between fixed and random stratified site surveys may not be appropriate. Further fixed site and random stratified site surveys were carried out in 2014 and the results are pending.

Dusky Sound

A fixed site potting survey of blue cod in Dusky Sound (part of BCO 5) in 2002 produced an overall mean catch rate for all blue cod of 2.69 kg.pot^{-1} (CV = 6.7%). The catch rate of blue cod ≥ 30 cm was 2.23 kg/pot hour (CV = 7.2%). Catch rates for all blue cod and for fish ≥ 30 cm were highest on the open coast (i.e., at the entrance to the Sound), being 8.42 and 5.46 kg.pot^{-1} respectively (Carbines & Beentjes 2003). A fixed site survey in 2008 resulted in catch rates of 4.2 kg.pot^{-1} (CV = 5.8%) for all blue cod, considerably higher than in 2002 and again highest catch rates were in the open coast stratum (Carbines & Beentjes 2011). Full fixed site and full random site surveys were carried out in 2014 and the results are pending.

Other potting survey analyses

Carbines *et al.* (2007) and Beentjes (2012) have generated age frequency distributions using age length keys derived from otolith collected during potting surveys. Using catch-at-age, estimates of total mortality (Z) and Spawner Biomass per Recruit (at a range of age-at-full recruitment) were calculated and compared in conjunction with relative abundance estimates (CPUE [kg.pot^{-1}]) from potting surveys conducted in Kaikoura, Motunau, Banks Peninsula, North Otago, Foveaux Strait, Paterson Inlet and Dusky Sound (Tables 10-13).

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.

Table 10: Summary statistics from standardised blue cod potting surveys done in the northeast coast of the South Island (BCO 3). CPUE – catch per unit effort (kg/pot); CV – coefficient of variation; *Z* – Total mortality; $F_{\%SPR}$ estimated for age at full recruitment = 6 years and *M* = 0.14. Mean length, mean age and *Z* are from population scaled length and age. Mean length, mean age, *Z* and $F_{\%SPR}$ from Beentjes (2012). CPUE taken from Carbines & Beentjes (2006; 2009).

Area/Year	Mean length Female	Mean length Male	Mean age Female	Mean age Male	Survey CPUE kg.pot^{-1}	CPUE range (CV) CV is pot based or set based*	Mean Z (MWCV around age) * revised are at full recruitment	$F_{\%SPR}$
				North Canterbury				
Kaikoura								
2004 (fixed sites)	30.3	32.5	8.4	7.8	2.45	0.60 – 7.97 (8.7%)	0.30 (26%)	36.9%
2007 (fixed sites)	29.8	32.5	7.0	6.9	5.0	1.91–20.45 (8.2%)	0.35 (24%)	16.1%
2011 (fixed sites)	27.4	29.2	9.1	8.1	3.96	2.14 – 11.44 (15.0%*)	0.27 (19%) *11	51.8%
2011 (random sites)	28.4	29.4	9.9	8.2	2.62	0.61 – 8.22 (16.7%*)	0.26 (17%) *11	52.2%
Motunau								
2005 (fixed sites)	25.7	29.6	5.7	6.3	10.2	9.53 – 15.37 (7.3%)	0.80 (42%)	13.6%
2008 (fixed sites)	25.2	29.3	5.1	6.2	5.5	4.1–8.9 (8.8%)	0.60 (18%)	30.3%
2012 (fixed sites)	24.5	28.8	6.4	8.0	5.53	4.43–8.704 (12.0%*)	0.39 (18%) *11	45.4%
2012 (random sites)	23.4	28.3	5.9	7.6	2.97	1.81–6.95 (20.1%*)	0.42 (19%) *11	43.5%
				Banks Peninsula				
All strata								
2002	32.3	31.6	9.1	7.4	2.1	0.04 –4.74	–	–
2005	32.4	35.5	8.9	8.6	4.4	1.02-7.27(5.7%)		

Table 10 [Continued]

Area/Year	Mean length Female	Mean length Male	Mean age Female	Mean age Male	Survey CPUE kg.pot^{-1}	CPUE range (CV) CV is pot based or set based*	Mean Z (MWCV around age) * revised are at full recruitment	$F_{\%SPR}$
				Banks Peninsula				
2008	32.5	35.5	9.2	8.0	2.6	0.07-5.80 (7.7%)		
2012 (random sites, excl. MR)	27.9	31.6			1.29	0.33 –2.89 (16.3%*)	0.13 (15%) *9	100%
Inshore								
2002	25.4	28.3	5.0	5.6	*	0.04 – 2.61	0.69 (23%)	13.8%
2005	27.2	32.7	5.8	6.9	*	1.02 – 4.16	0.48 (24%)	19.7%
2008	25.5	29.8	4.5	5.1	*	0.07 – 2.3	0.54 (23%)	18.0%
2012 (fixed sites, excl. MR)	24.7	28.8	5.4	6.6	1.33	0.60 – 1.81 (13.2%*)	0.62 (21%) *8	24.5%
2012 (random sites, excl. MR)	23.0	27.6	4.9	6.1	1.29	0.33 – 2.89 (16.3%*)	0.61 (22%) *8	24.8%
Offshore								
2002	36.6	37.6	11.6	10.9	*	2.04 - 4.74	0.14 (45%)	100%
2005	37.4	41.2	11.7	12.1	*	5.68 - 7.27	0.17 (45%)	90.6%
2008	35.6	41.8	11.7	11.9	*	3.13 – 5.80	0.15 (47%)	90.8%
2012 (fixed sites, excl. MR)	33.0	36.9	11.4	12.0	5.74	3.49 – 6.28 (20.0%*)	0.15 (14%) *9	92.4%
2012 (random sites, excl. MR)	34.1	39.3	12.7	13.4	3.77	3.69 – 4.09 (36.3%*)	0.12 (15%) *9	100%

* The overall CPUE value for Banks Peninsula were not reported specifically for these inshore and offshore strata but, for all strata combined (Beentjes & Carbines 2003; 2006; 2009).

Table 11: Summary statistics from standardised blue cod potting surveys done in the southeast coast of the South Island (BCO 3). CPUE – catch per unit effort (kg/pot); CV – coefficient of variation; *Z* – Total mortality; $F_{\%SPR}$ estimated for age at full recruitment = 6 years and M= 0.14. Mean length, mean age and *Z* are from population scaled length and age. North Otago survey - mean length, mean age, *Z* and $F_{\%SPR}$ from Beentjes (2012) and Carbines & Haist (2014b), CPUE from Carbines & Beentjes (2006; 2011) and Carbines & Haist (2014b). South Otago survey - 2009 from Beentjes & Carbines (2011) and 2013 from Carbines & Haist (2014c).

Area/Year	Mean length Female	Mean length Male	Mean age Female	Mean age Male	Survey CPUE (kg.pot^{-1})	CPUE range (CV) CV is pot-based or set-based*	Mean Z (MWCV around age)	$F_{\%SPR}$
				North Otago				
2005 (no stratum 6) (fixed sites)	27.8	32.8	6.2	7.5	10.1	7.45 - 14.5 (5.4%)	0.44 (19%)	18.7%
2009 (incl. stratum 6) (fixed sites)	27.4	32.3	7.0	8.3	11.5	6.21 – 19.88 (*6.8%)	0.30 (23%)	31.7%
2013 (incl. stratum 6) (fixed sites)	26.9	31.6	7.9	8.6	5.0	2.72 – 8.07 (*12.6.8%)	0.46 (25%)	34.1%
2013 (incl. stratum 6) (random sites)	27.6	30.7	7.9	8.1	4.2	0.94 – 7.46 (*13.9%)	0.43 (23%)	35.7%
				South Otago				
2009** (fixed sites)	29.4	33.6	8.7	9.7	9.7	3.3–16.9 (*17.1%)	0.23 (23%)	50.3%
2009 (random sites)	23.7	29.0	6.0	7.8	4.4	1.2 – 6.0 (*17.8%)	0.28 (26%)	39.4%
2013 (random sites)	25.5	31.9	6.3	8.4	6.2	0.8 – 7.4 (*19.9%)	0.21 (27%)	74.2%

Table 12: Summary statistics from standardised blue cod potting surveys done in the south and southwest coast of the South Island (BCO 5). CPUE – catch per unit effort (kg/pot); CV – coefficient of variation; *Z* – Total mortality; $F_{\%SPR}$ estimated for age at full recruitment = 6 years and *M* = 0.14. Mean length, mean age and Z are from population scaled length and age. Foveaux Strait survey- all results from Carbines & Beentjes 2012; Paterson Inlet survey -all results from Carbines 2007, Carbines & Haist 2014; Dusky Sound survey - mean length, mean age, *Z*, and $F_{\%SPR}$ from Beentjes (2012) and CPUE from Carbines & Beentjes (2003; 2011).

	Mean length		Mean age		CPUE (kg.pot[-1])	CPUE range (CV) CV is pot-based or set-based*	Mean Z (MWCV around age) * revised are at full recruitment	$F_{\%SPR}$
Area/Year	Female	Male	Female	Male				
				Foveaux Strait				
2010 (random sites)	27.8	30.5	6.9	7.1	4.8	1.17 – 14.14 (*11.3%)	0.41 (23%)	35.3%
				Paterson Inlet				
2006 (fixed sites) (excl. marine reserve)	26.9	32.8	6.4	7.9	4.8	1.47 – 8.42 (*11.9%)	0.63 *8	22.1%
2010 (fixed sites) (excl. marine reserve)	27.5	32.2	6.9	8.5	3.2	1.43 – 3.29 (11.3%)	0.37 *8	40.4%
2010 (random sites) (excl. marine reserve)	25.9	29.0	6.2	7.1	0.4	0.22 – 0.53 (24.2%)	0.43 *8	36.9%
				Dusky Sound				
2002 (fixed sites)	29.9	34.7	7.0	7.7	2.69	1.28–8.42 (6.7%)	0.32 (17%)	34.3%
2008 (fixed sites) (excl. marine reserve)	32.2	37.9	7.9	10.1	4.20	2.49 – 8.13 (*5.5%)	0.27 (24%)	42.4%

Table 13: Total mortality estimates (*Z*) and 95% confidence intervals (CI) of blue cod for each blue cod potting survey, and corresponding spawner per recruit estimates ($F_{SPR\%}$). Fishing mortality (*F*) is calculated from *F* = *Z* - *M* where natural mortality (*M*) is set at 0.14. MR, marine reserve; ageR, age-at-full recruitment to the fishery; –, no estimate made (Beentjes 2012) [Continued on next page].

Survey Area	Year	Age R	Z	lowCI	upCI	F	*F%SPR*
Dusky Sound	2002	5	0.30	0.23	0.40	0.16	$F_{37.1\%}$
		6	0.32	0.24	0.41	0.18	$F_{34.3\%}$
		7	0.31	0.23	0.4	0.17	$F_{35.7\%}$
		8	0.28	0.21	0.37	0.14	$F_{40.4\%}$
		9	0.23	0.17	0.29	0.09	$F_{51.9\%}$
		10	0.23	0.17	0.30	0.09	$F_{51.0\%}$
Dusky Sound (excl. MR)	2008	5	0.22	0.17	0.29	0.08	$F_{55.5\%}$
		6	0.27	0.2	0.35	0.13	$F_{42.4\%}$
		7	0.29	0.21	0.38	0.15	$F_{38.8\%}$
		8	0.32	0.23	0.41	0.18	$F_{34.4\%}$
		9	0.36	0.27	0.46	0.22	$F_{30.0\%}$
		10	0.35	0.26	0.46	0.21	$F_{31.0\%}$
Dusky (MR)		5	0.19	0.14	0.24	0.05	$F_{66.7\%}$
		6	0.22	0.16	0.28	0.08	$F_{55.1\%}$
		7	0.24	0.17	0.31	0.1	$F_{49.2\%}$
		8	0.28	0.2	0.36	0.14	$F_{40.5\%}$
		9	0.33	0.24	0.44	0.19	$F_{33.2\%}$
		10	0.36	0.26	0.47	0.22	$F_{30.0\%}$

Table13 [Continued]

Survey Area	Year	Age R	Z	lowCI	upCI	F	*F%SPR*
North Otago	2005	5	0.35	0.25	0.47	0.21	$F_{25.1\%}$
		6	0.44	0.31	0.58	0.3	$F_{18.7\%}$
		7	0.47	0.33	0.63	0.33	$F_{17.3\%}$
		8	0.54	0.38	0.75	0.4	$F_{14.8\%}$
		9	0.62	41%	0.89	0.48	$F_{12.8\%}$
		10	0.52	0.33	0.76	0.38	$F_{15.4\%}$
North Otago	2009	5	0.25	0.18	0.34	0.11	$F_{41.2\%}$
		6	0.30	0.22	0.4	0.16	$F_{31.7\%}$
		7	0.35	0.25	0.45	0.21	$F_{25.6\%}$
		8	0.41	0.29	0.54	0.27	$F_{20.9\%}$
		9	0.50	0.36	0.67	0.36	$F_{16.6\%}$
		10	0.56	0.39	0.77	0.42	$F_{14.7\%}$
North Otago	2013	5	0.22	0.16	0.30	0.08	$F_{62.3\%}$
		6	0.26	0.19	0.35	0.12	$F_{52.9\%}$
		7	0.31	0.22	0.44	0.17	$F_{45.2\%}$
		8	0.36	0.26	0.50	0.22	$F_{40.3\%}$
		9	0.39	0.29	0.54	0.25	$F_{38.2\%}$
		10	0.46	0.33	0.66	0.32	$F_{34.1\%}$
South Otago	2013	5	0.17	0.13	0.24	0.03	$F_{76.8\%}$
		6	0.18	0.14	0.25	0.04	$F_{70.9\%}$
		7	0.20	0.15	0.27	0.06	$F_{63.6\%}$
		8	0.21	0.16	0.28	0.07	$F_{61.0\%}$
		9	0.21	0.16	0.29	0.07	$F_{60.1\%}$
		10	0.24	0.18	0.33	0.10	$F_{50.1\%}$
Banks Peninsula (all strata)	2002	5	0.22	0.16	0.28	0.08	$F_{52.6\%}$
(fixed sites)		6	0.19	0.14	0.25	0.05	$F_{64.6\%}$
		7	0.18	0.13	0.23	0.04	$F_{69.8\%}$
		8	0.17	0.13	0.23	0.03	$F_{75.7\%}$
		9	0.18	0.14	0.24	0.04	$F_{69.8\%}$
		10	0.19	0.14	0.26	0.05	$F_{64.6\%}$
inshore	5		0.65	0.43	0.93	0.51	$F_{14.6\%}$
(fixed sites)	6		0.69	0.45	0.96	0.55	$F_{13.8\%}$
	7		0.47	0.3	0.69	0.33	$F_{20.1\%}$
	8		0.59	0.34	0.89	0.45	$F_{16.0\%}$
	9		0.60	0.33	1	0.46	$F_{15.8\%}$
	10		0.78	0.38	1.4	0.64	$F_{12.5\%}$

Table13 [Continued]

Survey Area	Year	Age R	Z	lowCI	upCI	F	*F%SPR*
offshore		5	0.14	0.11	0.18	0	$F_{100\%}$
(fixed sites)		6	0.14	0.1	0.18	0	$F_{100\%}$
		7	0.15	0.11	0.2	0.01	$F_{90.6\%}$
		8	0.15	0.11	0.2	0.01	$F_{90.6\%}$
		9	0.17	0.13	0.22	0.03	$F_{75.7\%}$
		10	0.18	0.14	0.24	0.04	$F_{69.8\%}$
Banks Peninsula (all strata)	2005	5	0.23	0.16	0.29	0.09	$F_{49.4\%}$
(fixed sites)		6	0.23	0.17	0.3	0.09	$F_{49.4\%}$
		7	0.23	0.17	0.31	0.09	$F_{49.4\%}$
		8	0.23	0.17	0.31	0.09	$F_{49.4\%}$
		9	0.23	0.16	0.3	0.09	$F_{49.4\%}$
		10	0.21	0.15	0.28	0.07	$F_{56.1\%}$
inshore		5	0.43	0.31	0.58	0.29	$F_{22.2\%}$
(fixed sites)		6	0.48	0.33	0.67	0.34	$F_{19.7\%}$
		7	0.53	0.36	0.75	0.39	$F_{17.7\%}$
		8	0.62	0.41	0.89	0.48	$F_{15.2\%}$
		9	0.63	0.39	0.91	0.49	$F_{15.0\%}$
		10	0.64	0.36	0.99	0.5	$F_{14.8\%}$
offshore		5	0.13	0.1	0.17	0.01	$F_{100\%}$
(fixed sites)		6	0.15	0.11	0.19	0.01	$F_{90.6\%}$
		7	0.16	0.12	0.21	0.02	$F_{82.6\%}$
		8	0.18	0.13	0.23	0.04	$F_{69.8\%}$
		9	0.18	0.13	0.24	0.04	$F_{69.8\%}$
		10	0.19	0.13	0.24	0.05	$F_{64.6\%}$
Banks Peninsula (all strata)	2008	5	0.17	0.13	0.22	0.03	$F_{76.1\%}$
(fixed sites)		6	0.16	0.12	0.20	0.02	$F_{82.9\%}$
		7	0.17	0.12	0.22	0.03	$F_{76.1\%}$
		8	0.17	0.12	0.22	0.03	$F_{76.1\%}$
		9	0.16	0.12	0.21	0.02	$F_{82.9\%}$
		10	0.17	0.13	0.23	0.03	$F_{76.1\%}$
inshore		5	0.54	0.36	0.76	0.40	$F_{18.0\%}$
(fixed sites)		6	0.54	0.35	0.80	0.40	$F_{18.0\%}$
		7	0.69	0.43	1	0.55	$F_{14.4\%}$
		8	0.74	0.4	1.20	0.60	$F_{13.6\%}$
		9	0.58	0.29	1.07	0.44	$F_{16.8\%}$
		10	0.86	0.35	1.9	0.72	$F_{12.1\%}$

Table13 [Continued]

Survey Area	Year	Age R	Z	lowCI	upCI	F	*F%SPR*
offshore		5	0.14	0.1	0.17	0	$F_{100\%}$
(fixed sites)		6	0.15	0.11	0.19	0.01	$F_{90.8\%}$
		7	0.15	0.11	0.19	0.01	$F_{90.8\%}$
		8	0.16	0.12	0.21	0.02	$F_{82.7\%}$
		9	0.17	0.12	0.21	0.03	$F_{76.1\%}$
		10	0.17	0.13	0.22	0.03	$F_{76.1\%}$
Kaikoura	2004	5	0.27	0.20	0.36	0.13	$F_{42.1\%}$
		6	0.30	0.22	0.39	0.16	$F_{36.9\%}$
		7	0.30	0.22	0.40	0.16	$F_{36.9\%}$
		8	0.28	0.20	0.37	0.14	$F_{40.2\%}$
		9	0.26	0.19	0.35	0.12	$F_{44.1\%}$
		10	0.27	0.19	0.37	0.13	$F_{42.1\%}$
Kaikoura	2007	5	0.31	0.22	0.42	0.17	$F_{35.1\%}$
		6	0.35	0.25	0.47	0.21	$F_{30.3\%}$
		7	0.43	0.31	0.59	0.29	$F_{23.9\%}$
		8	0.47	0.32	0.63	0.33	$F_{21.8\%}$
		9	0.41	0.27	0.57	0.27	$F_{25.2\%}$
		10	0.33	0.22	0.46	0.19	$F_{32.5\%}$
Banks Peninsula (all strata,excluding marine reserve)	2012	5	0.15	0.12	0.20	0.01	$F_{90.5\%}$
(fixed sites)		6	0.16	0.13	0.22	0.02	$F_{82.5\%}$
		7	0.17	0.13	0.23	0.03	$F_{78.2\%}$
		8	0.16	0.13	0.22	0.02	$F_{82.4\%}$
		9	0.15	0.11	0.20	0.01	$F_{92.4\%}$
		10	0.16	0.12	0.21	0.02	$F_{87.9\%}$
inshore(excluding marine reserve)		5	0.39	0.27	0.56	0.25	$F_{35\%}$
(fixed sites)		6	0.47	0.33	0.70	0.33	$F_{29.9\%}$
		7	0.60	0.40	0.91	0.46	$F_{25.2\%}$
		8	0.62	0.42	0.93	0.48	$F_{24.5\%}$
		9	0.46	0.30	0.70	0.32	$F_{30.6\%}$
		10	0.47	0.30	0.74	0.33	$F_{29.7\%}$
offshore		5	0.13	0.10	0.17	0.00	$F_{100\%}$
(fixed sites)		6	0.15	0.11	0.20	0.01	$F_{95.9\%}$
		7	0.15	0.12	0.21	0.01	$F_{88.8\%}$
		8	0.15	0.12	0.21	0.01	$F_{89.4\%}$
		9	0.15	0.12	0.20	0.01	$F_{92.4\%}$
		10	0.16	0.12	0.21	0.02	$F_{86.7\%}$
Banks Peninsula (all strata,excluding marine reserve)	2012	5	0.14	0.10	0.18	0.00	$F_{100\%}$
(random sites)		6	0.14	0.11	0.19	0.00	$F_{97\%}$
		7	0.15	0.11	0.20	0.01	$F_{94.8\%}$

Table13 [Continued]

Survey Area	Year	Age R	Z	lowCI	upCI	F	*F%SPR*
Banks peninsula [Continued]		8	0.14	0.11	0.19	0.00	$F_{100\%}$
		9	0.13	0.10	0.17	0.00	$F_{100\%}$
		10	0.13	0.10	0.18	0.00	$F_{100\%}$
Inshore (excluding marine reserve)		5	0.42	0.29	0.63	0.28	$F_{32.5\%}$
(random sites)		6	0.48	0.34	0.71	0.34	$F_{29.1\%}$
		7	0.61	0.41	0.91	0.47	$F_{24.8\%}$
		8	0.61	0.41	0.93	0.47	$F_{24.8\%}$
		9	0.44	0.29	0.69	0.30	$F_{31.2\%}$
		10	0.49	0.31	0.78	0.35	$F_{28.9\%}$
Offshore		5	0.11	0.09	0.15	0.00	$F_{100\%}$
(random sites)		6	0.12	0.09	0.16	0.00	$F_{100\%}$
		7	0.13	0.10	0.17	0.00	$F_{100\%}$
		8	0.13	0.10	0.16	0.00	$F_{100\%}$
		9	0.13	0.10	0.17	0.00	$F_{100\%}$
		10	0.13	0.10	0.17	0.00	$F_{100\%}$
Kaikoura	2004	5	0.27	0.20	0.36	0.13	$F_{42.1\%}$
(fixed sites)		6	0.30	0.22	0.39	0.16	$F_{36.9\%}$
		7	0.30	0.22	0.40	0.16	$F_{36.9\%}$
		8	0.28	0.20	0.37	0.14	$F_{40.2\%}$
		9	0.26	0.19	0.35	0.12	$F_{44.1\%}$
		10	0.27	0.19	0.37	0.13	$F_{42.1\%}$
Kaikoura	2007	5	0.31	0.22	0.42	0.17	$F_{35.1\%}$
(fixed sites)		6	0.35	0.25	0.47	0.21	$F_{30.3\%}$
		7	0.43	0.31	0.59	0.29	$F_{23.9\%}$
		8	0.47	0.32	0.63	0.33	$F_{21.8\%}$
		9	0.41	0.27	0.57	0.27	$F_{25.2\%}$
		10	0.33	0.22	0.46	0.19	$F_{32.5\%}$
Kaikoura	2011	5	0.23	0.17	0.33	0.09	$F_{59.4\%}$
(fixed sites)		6	0.24	0.17	0.34	0.10	$F_{57.3\%}$
		7	0.27	0.20	0.37	0.13	$F_{51.3\%}$
		8	0.27	0.19	0.38	0.13	$F_{51.5\%}$
		9	0.24	0.18	0.33	0.10	$F_{57.1\%}$
		10	0.25	0.18	0.35	0.11	$F_{54.2\%}$
		11	0.27	0.19	0.39	0.13	$F_{51.8\%}$
Kaikoura	2011	5	0.21	0.15	0.29	0.07	$F_{65.8\%}$
(random sites)		6	0.22	0.16	0.30	0.08	$F_{62.7\%}$
		7	0.24	0.18	0.33	0.10	$F_{57.2\%}$
		8	0.25	0.18	0.33	0.11	$F_{55.9\%}$
		10	0.25	0.18	0.35	0.11	$F_{55.0\%}$
		11	0.26	0.19	0.37	0.12	$F_{52.2\%}$
Motunau	2005	5	0.53	0.33	0.77	0.39	$F_{19.5\%}$
(fixed sites)		6	0.80	0.47	1.23	0.66	$F_{13.6\%}$
		7	0.74	0.41	1.17	0.6	$F_{14.5\%}$

Table13 [Continued]

Survey Area	Year	Age R	Z	lowCI	upCI	F	*F%SPR*
Motunau		8	0.73	0.41	1.26	0.59	$F_{14.6\%}$
(fixed sites)		9	1.34	0.63	2.26	1.2	$F_{9.0\%}$
		10	1.13	0.48	2.13	0.99	$F_{10.8\%}$
Motunau	2008	5	0.53	0.37	0.72	0.39	$F_{18.2\%}$
(fixed sites)		6	0.60	0.42	0.83	0.46	$F_{16.1\%}$
		7	0.71	0.48	0.98	0.57	$F_{13.8\%}$
		8	0.79	0.49	1.16	0.65	$F_{12.6\%}$
		9	0.95	0.52	1.49	0.81	$F_{11.0\%}$
		10	1.12	0.50	2.29	0.98	$F_{9.8\%}$
Motunau	2012	5	0.29	0.21	0.41	0.15	$F_{53.9\%}$
(fixed sites)		6	0.34	0.23	0.48	0.20	$F_{49.1\%}$
		7	0.33	0.23	0.48	0.19	$F_{49.6\%}$
		8	0.38	0.27	0.54	0.24	$F_{46.1\%}$
		9	0.37	0.26	0.54	0.23	$F_{46.4\%}$
		10	0.45	0.31	0.64	0.31	$F_{42.2\%}$
		11	0.39	0.28	0.55	0.25	$F_{45.4\%}$
Motunau	2012	5	0.31	0.22	0.44	0.17	$F_{52.1\%}$
(random sites)		6	0.33	0.23	0.49	0.19	$F_{49.4\%}$
		7	0.32	0.22	0.46	0.18	$F_{51.1\%}$
		8	0.35	0.24	0.52	0.21	$F_{47.8\%}$
		9	0.36	0.25	0.53	0.22	$F_{47.2\%}$
		10	0.43	0.30	0.62	0.29	$F_{42.8\%}$
		11	0.42	0.28	0.60	0.28	$F_{43.5\%}$

4.2 BCO 3

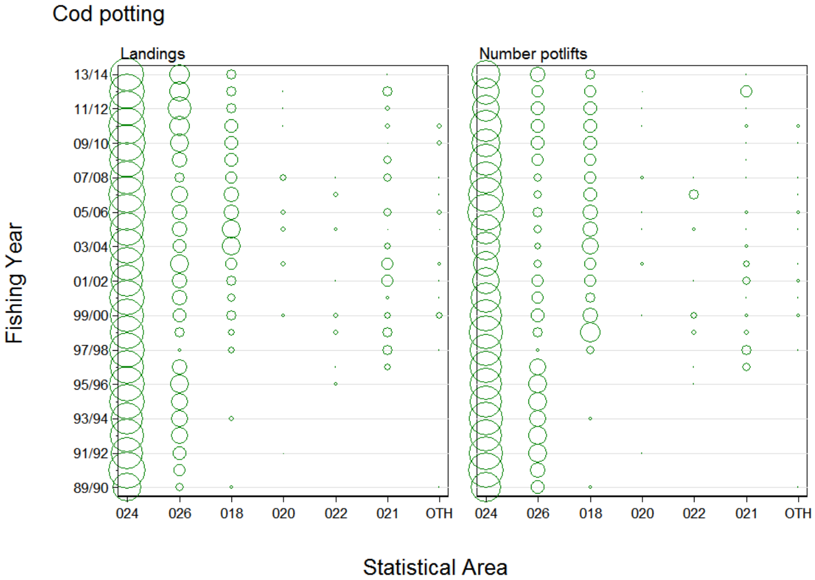


Figure 6: Distribution of landings and number of potlifts for the cod potting method by statistical area and fishing year from trips which landed BCO 3. Circles are proportional within each panel: [catches] largest circle = 95 t in 10/11 for 024; [number potlifts] largest circle = 9641 pots in 05/06 for 024 (Starr & Kendrick in prep).

A standardised CPUE analysis was conducted in 2015 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 25 years from 1989–90 to 2013–14, 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 25 years (Figure 6). As found in the previous 2010 analysis, 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.

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. Two data sets were prepared: one which defined the data set by only selecting trips which fished exclusively in the Areas 018–024 & 026 (designated "statarea") and the other restricted to trips which exclusively landed BCO 3 (designated "Fishstock"). There was no difference in the CPUE trends estimated by these two data sets. Each 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 68 vessels representing 85% of the landings for the "statarea" data set). 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. Because there was also an estimated catch of blue cod recorded with nearly every effort record, it was also possible to repeat the standardised analysis based on estimated catch as well as the landed catch. This was done to provide a check on the methods used to groom the landing data of the spurious RCO 3 landing data. Only a lognormal model based on successful catch records was used as there were too few unsuccessful fishing events to justify pursuing a binomial model.

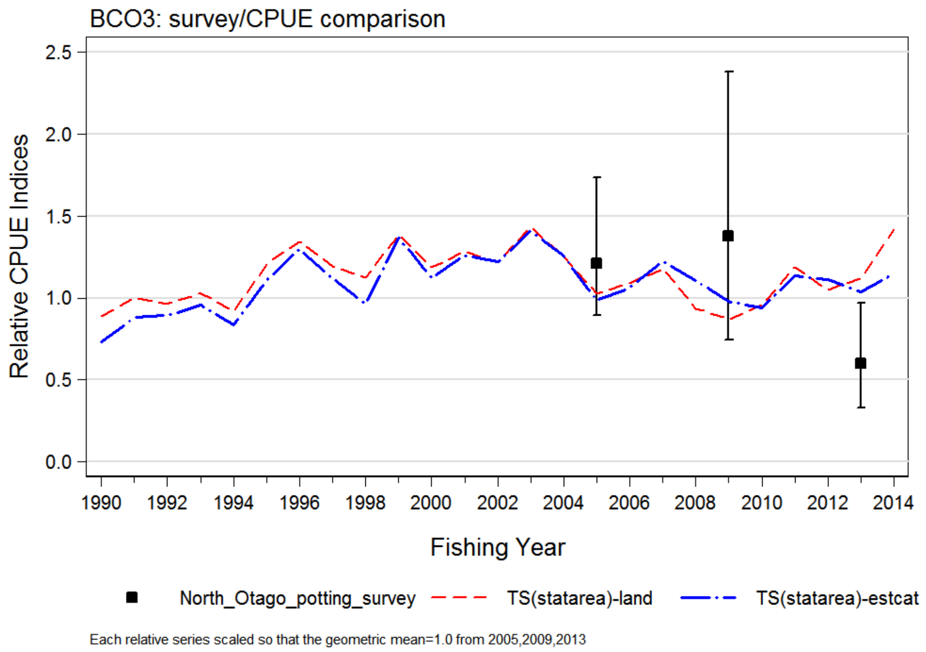


Figure 7: Comparison of BCO 3 standardised series based on landed greenweight catch data and estimated catch with the three observations from the North Otago potting survey (Starr & Kendrick in prep).

The lognormal standardised model for BCO 3 (Figure 7) showed a declining trend in commercial CPUE from 2002-03 to 2008–09 after a relatively long period of stability, followed by an increasing trend to 2013–14. 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 WG agreed in 2015 that the series based on landed catch was more reliable and consistent with other CPUE analyses done for the Southern Inshore WG.

During the period 2002–03 to 2013–14, commercial catches in all of BCO 3 exceeded the TACC by 5%. As 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), both the CPUE and catch trends for BCO 3 are strongly influenced by the catches in these areas. Therefore, the Working Group agreed that the CPUE trend presented for the Daily Landed Catch analysis in Figure 7 is representative of the southerly portion of BCO 3 (Areas 024 and 026) and is not applicable to those parts of BCO 3 north of Area 024.

Establishing BMSY compatible reference points

The Working Group accepted 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 (Bentley & Kendrick in prep). The analysis was based on a Weibull model of positive allocated landed catches from a core fleet of vessels. This methodology differs from the previous CPUE standardisation (Kendrick & Bentley 2011) which used a standardisation model with the assumption of a lognormal error distribution. 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. 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 to, the indices from the latter part of the series.

Overall, the annual indices from the standardisation model have fluctuated without trend since the late 1990s (Figure 8). From 2006/07 to 2012/13 there was a decline in the index, although this was almost fully reversed by a large increase in the index in 2013/14 The indices from the 1990s are lower than those during the latter part of the series and for the aforementioned reasons may not be fully comparable.

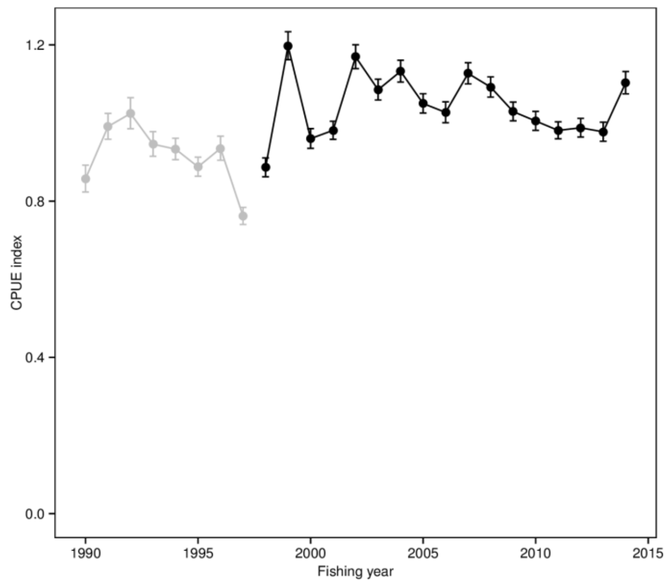


Figure 8: Standardised CPUE index for BCO 4 based on records of positive BCO catch by core vessels , 1989-90 to 2013-14 (Bentley & Kendrick 2015). The indices for the fishing years up to, and including, 1996/97 are considered to be less reliable due to possible changes in fleets, fishing methods and/or reporting practices and may not be comparable to the latter part of the series.

4.4 BCO 5 (Southland)

The first fully quantitative stock assessment for blue cod in BCO 5 was carried out in 2013. A custom-built length-based model, which used Bayesian estimation, was fitted separately to data from Statistical Areas 25, 27 and 30.

4.4.1 Methods

4.4.1.1 Model structure

The stock assessment model is length-based and sex-specific, using growth transition matrices calculated from the von Bertalanffy growth models to transition fish through size bins. This approach is similar to that used for New Zealand rock lobster (Haist et al. 2009).

The model is conditioned on the landings for the three modelled fisheries (commercial line, commercial pot, and recreational line), using a Newton-Raphson algorithm to calculate fishing mortality rates for each sex, length bin and fishery. Each fishery is modelled with a selectivity ogive and a retention ogive (Table 14). Catch and catch LFs are a function of the selectivity ogive and landings and landings LFs are a function of the product of selectivity and retention ogives. Separate pre-1993 and post-1992 commercial and recreational fishery retention functions account for the change in minimum legal size (MLS) in 1993. Separate pre-1993 and post-1993 commercial fishery selectivity functions account for change in mesh size regulation at that time, with the assumption that the selectivity change was gradual over 5 years. Discard mortality is assumed for fish that are caught but not landed.

Sex change is modelled as a dynamic process, with the proportion of females (at length) transitioning to males a function of male depletion. Spawning stock biomass (SSB) is measured as the total mature biomass.

A Beverton-Holt stock recruitment relationship is assumed. The standard deviation of recruitment residuals (log-scale) is fixed at 0.6 and the steepness prior is beta distributed (mean= 0.75, std. dev.=0.10). Recruitment residuals are estimated for 1980 to 2010. Fish recruit to the model at age 0+ with 65% of fish recruiting as females.

Natural mortality is modelled assuming a normal prior distribution with a mean of 0.14 and a standard deviation of 0.015. The majority of the prior density is in the range of 0.11 to 0.17, which is the range of uncertainty considered in blue cod potting survey analyses (Beentjes & Francis, 2011).

The populations are initialised at unexploited equilibrium conditions in 1900.

The assumed prior distributions for model parameters are given in Table 15.

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. DHN = double half normal.

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 <=1992	DHN	Mesh size trial LF
Commercial pot fishery >=1997	Logistic	Logbook & Shed sampling LF
Recreational fishery	DHN	Recreational catch LF
Survey	DHN	Survey LF
Retention		
Commercial line fishery	Knife-edge	MLS (330 mm)
Commercial pot fishery <=1992	Knife-edge	MLS
Commercial pot fishery >=1993	Knife-edge	MLS
Recreational fishery <=1992	Logistic	Recreational landings LF
Recreational fishery >=1993	Logistic	Shifted +3 cm from <=1992 retention curve

Table 15: Assumed prior distributions for model parameters.

Model parameters	Distribution	Parameters
M	Normal	Mean: 0.14 Std. dev: 0.015
S-R steepness	Beta (defined on 0.2 – 1.0)	Mean: 0.75 Std. dev: 0.10
Recruitment variation	Normal-log	Std. dev: 0.60
1995 sex-change *dmax*	Normal-log	Mean: ln(410) Std. dev: 0.05

4.4.1.2 Data

Separate data sets were compiled and analysed for Statistical Areas 25, 27, and 30. The data available for each of these areas differs, and little data are available for the remainder of the BCO 5 Statistical Areas. Combined, Statistical Areas 25, 27 and 30 represent 92% of the recent commercial fishery landings. The general categories of data used in the stock assessment models include: catch and landings; fishery and survey length frequency data (LFs); abundance indices; and biological information on growth, maturation, and sex change.

Historical time series of BCO 5 landings were constructed for 3 gear types: commercial hand line fishing, commercial pot fishing, and recreational 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.

Commercial landings data are available beginning in 1931 (Warren et al. 1997) and these were linearly decreased 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 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 through 2011. The shed sampling was sex-specific while the logbook sampling was not. It is unclear whether samples collected for shed sampling were of the entire catch or of landings. Mean size of fish from the shed samples were smaller than those from the logbook program (for Areas 25 and 27, there were not shed samples from Area 30), which may have resulted because the shed samples were not representative of the entire fishing area. The shed and logbook LF data are each fitted to model predictions of the average commercial catch size distribution for 2009 through 2011.

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, and Halfmoon Bay) and a logbook survey of charter and recreational vessels. Blue cod measured through the boat ramp program were assumed to represent the landings and fish measured through the logbook program were assumed to represent the catch.

Length frequency data from a blue cod mesh size selectivity study, conducted by MAF in 1986 at Bluff and Stewart Island, were available. The LFs 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 prior to the 1992 and 1994 pot regulation changes. In the model, this data is fitted to the predicted average size distribution of the 1985 through 1992 potting fishery.

LF data is also available from random stratified potting surveys conducted in Areas 25 and 30 in 2010. These surveys provide not only length frequency data, but also are one of the few information sources

about the population sex structure. These data are fitted in the model assuming domed survey selectivity.
Three sets of data are available that can inform stock abundance estimates: fishery-based standardised CPUE estimates (Table 16), survey-based estimates of total mortality (*Z*), and a drift underwater video survey (DUV) estimate of absolute stock abundance.

Z estimates were derived from the 2010 Area 25 and Area 30 random-stratified potting survey data using standard methods described in Beentjes and Francis (2011). The distributions of Z estimates are approximately lognormal and are fitted with lognormal priors in the stock assessment model. The mean Z estimate for Area 30 (0.377) is slightly lower than that for Area 25 (0.465).

A DUV survey was conducted in Area 25 in 2010, surveying a number of the random-stratified sites that were sampled during the potting survey. The survey estimate of the mean density of legal-sized blue cod was extrapolated to the total Area 25 area to generate a total abundance estimate. This was fitted to model-predicted 2010 legal-sized blue cod abundance.

The data fitted in the models for each Statistical Area are shown in Table 16 and the assumed error structure of each data series is shown in Table 17.

4.4.1.3 Further assumptions

Sex-specific von Bertalanffy growth parameters are available from Area 25 and Area 30 random-stratified potting surveys (refs.). The Area 25 growth models were assumed for Area 27. Both male and female blue cod are assumed to mature at a length of 280 mm (Carbines 2004).

Sex-change data was available from a 1995 Foveaux Strait study that characterised blue cod by state: male, female, or transitional (Carbines 2004). The proportions of transitional females by length bin were fitted with a parametric relationship to describe the sex-change process. The maximum proportion transitional was observed at 410 mm.

Assuming that sex-change is a function of the relative abundance of mature males was found to result in fewest model convergence issues. The length at 50% sex change (*dmax*) is modelled as a function of the ratio of mature male biomass in year y $\left(B_y^M\right)$ relative to mature male biomass in the virgin state $\left(B_0^M\right)$:

$$dmax = \lambda \left(B_y^M \big/ B_0^M \right)^{\delta},$$

where the parameters λ and δ are estimated through the model fitting. In practice, only λ was estimated and δ was fixed. This model results in the form of the sex-change relationship remaining the same except that it is shifted along the length-axis. With this parameterisation it is not possible to fix the 1995 length at 50% sex change (to 410 mm, as observed in the sex transition data set collected in 1995), so a penalty function is used to encourage that value.

Table 16: Standardised CPUE indices for Statistical Areas 25, 27 and 30.

Fishing Year	Area 25	Area 27	Area 30
1990	0.803	0.603	0.925
1991	0.748	0.607	0.860
1992	0.815	0.665	1.026
1993	0.854	0.835	0.846
1994	0.847	0.648	0.689
1995	0.808	0.796	0.669
1996	0.943	1.022	0.657
1997	1.043	1.241	1.011
1998	1.084	1.116	1.141
1999	0.972	1.152	1.224
2000	1.034	1.292	1.185
2001	1.143	1.466	1.098
2002	1.160	1.743	1.453
2003	1.256	1.532	1.422
2004	1.145	1.602	1.359
2005	1.283	1.219	1.262
2006	1.253	1.127	1.172
2007	1.035	0.881	1.093
2008	1.017	0.888	0.924
2009	1.023	0.894	0.939
2010	0.984	0.901	0.961
2011	1.006	0.888	0.839
2012	0.998	0.940	0.819

Table 17: Data series fitted in the stock assessments for Areas 25, 27, and 30.

Data type	Series	Area 25	Area 27	Area 30
LF data:	Shed	✓	✓	-
	Logbook	✓	✓	✓
	Survey	✓	-	✓
	Mesh sel. trials	data common to all areas		
	Rec. landings	data common to all areas		
	Rec. catch	data common to all areas		
Abundance Index:	CPUE	✓	✓	✓
	Survey Z	✓	-	✓
	DUV abundance	✓	-	-

Table 18: Assumed distributions for data fitted in the models.

Data type	Distribution	Parameters
Logbook LF	Multinomial	N: 100
Shed samples LF	Multinomial	N: 100
Mesh size trials LF	Multinomial	N: 100
Recreational catch LF	Multinomial	N: 100
Recreational landings LF	Multinomial	N: 100
Survey LF	Multinomial	N: 100
CPUE	Normal-log	Std. dev: 0.20
Survey Z –Area 25	Normal-log	Mean: -0.782 Std. dev: 0.178
Survey Z –Area 30	Normal-log	Mean: -0.991 Std. dev: 0.173
DUV LegalN	Normal-log	Mean: 15.163 Std. dev: 0.300

4.4.1.4 Calculation of fishing intensity and B_{MSY}

Fishing intensity is measured as the spawning biomass per recruit (SPR). $F_{\%SPR}$ is the ratio of spawning biomass per recruit at a given level of fishing mortality relative to the spawning biomass per recruit in the absence of fishing. This metric was selected to represent fishing intensity because estimates for the entire BCO 5 stock can readily be calculated from the Statistical Area estimates.

MSY statistics are calculated assuming deterministic recruitment and the final years' selectivity and retention ogives. The recreational and customary fisheries are held fixed at the current levels, and only the commercial fishery varied to determine MSY. B_{MSY} is measured as total mature biomass and MSY is presented as the commercial catch at B_{MSY}.

Caution about the interpretation of B_{MSY} estimates

There are several reasons why B_{MSY}, as calculated in this way, is not a suitable target for management of blue cod fisheries. First, it assumes a harvest strategy that is unrealistic in that it involves perfect knowledge (current biomass must be known exactly in order to calculate the target catch) and annual changes in TACC (which are unlikely to happen in New Zealand and not desirable for most stakeholders). Second, it assumes perfect knowledge of the stock-recruit relationship, which is actually very poorly known. Third, it makes no allowance for extended periods of low recruitment. Fourth, it would be very difficult with such a low biomass target to avoid the biomass occasionally falling below 20% B_0, the default soft limit according to the Harvest Strategy Standard.

4.4.1.5 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 estimate the mode of the posterior distribution). Their purpose was to decide which sets of assumptions should be carried forward to the final runs. The final runs were fully Bayesian, estimating posterior distributions for all quantities of interest.

The modelling assumptions and approaches investigated though the exploratory model runs included: the dynamics of sex-change; what assumptions to make about LF data from the logbook and shed sampling programs; the magnitude of recruitment variation; the magnitude of error in fits to the CPUE data; the form of the survey and recreational fishery selectivity; and sensitivity to alternative assumptions about recreational catch, bait usage, and discard mortality rates.

Four final runs were chosen by the Working Group: a *base case* and three sensitivities to the *base case*. The sensitivity runs each modify a single assumption of the *base case*. The sex-change power parameter (delta in equation above) is fixed at 0.4 for the *base case*. Two of the sensitivity runs modify this parameter to values of 0.2 and 0.6. The third sensitivity run reduces the recreational catch time series by 50%.

Label	Description
1.1	Base case
1.2	Sex-change power parameter=0.2
1.3	Sex-change power parameter=0.6
1.4	Recreational catch reduced by 50%

Bayesian posterior distributions were estimated for each of these runs 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 summing across Areas 25, 27, and 30. B_{MSY} and *MSY* are calculated assuming these areas account for 92% of the BCO 5 stock.

The model estimates are summarised in Table 19 (estimates of spawning biomass and *MSY*), Figure 9 (biomass trajectories), Figure 10 (current biomass distribution), Figure 11 (fishing intensity trajectories), and Figure 12 (recruitment trajectories).

The runs with the higher sex-change power parameter (run 1.3) have higher male and lower female spawning abundance in the unfished populations and runs with the lower sex-change power parameter (run 1.2) have lower male and higher female initial abundance. Current biomass and the combined male and female B_0 do not differ much among the runs. Assuming lower recreational catch (run 1.4) results in a slightly lower B_0 estimate and slightly higher current biomass. Area 25 is somewhat more depleted than Areas 27 and 30.

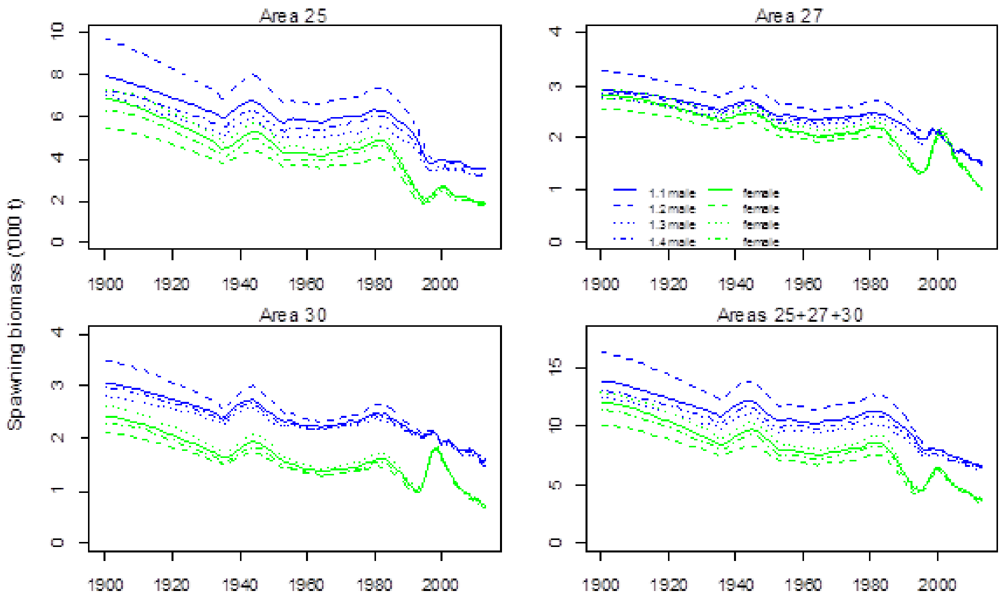


Figure 9: Median estimates of Area 25, Area 27, Area 30, and Areas combined male and female spawning biomass for the base case and sensitivity runs, 1900 – 2012.

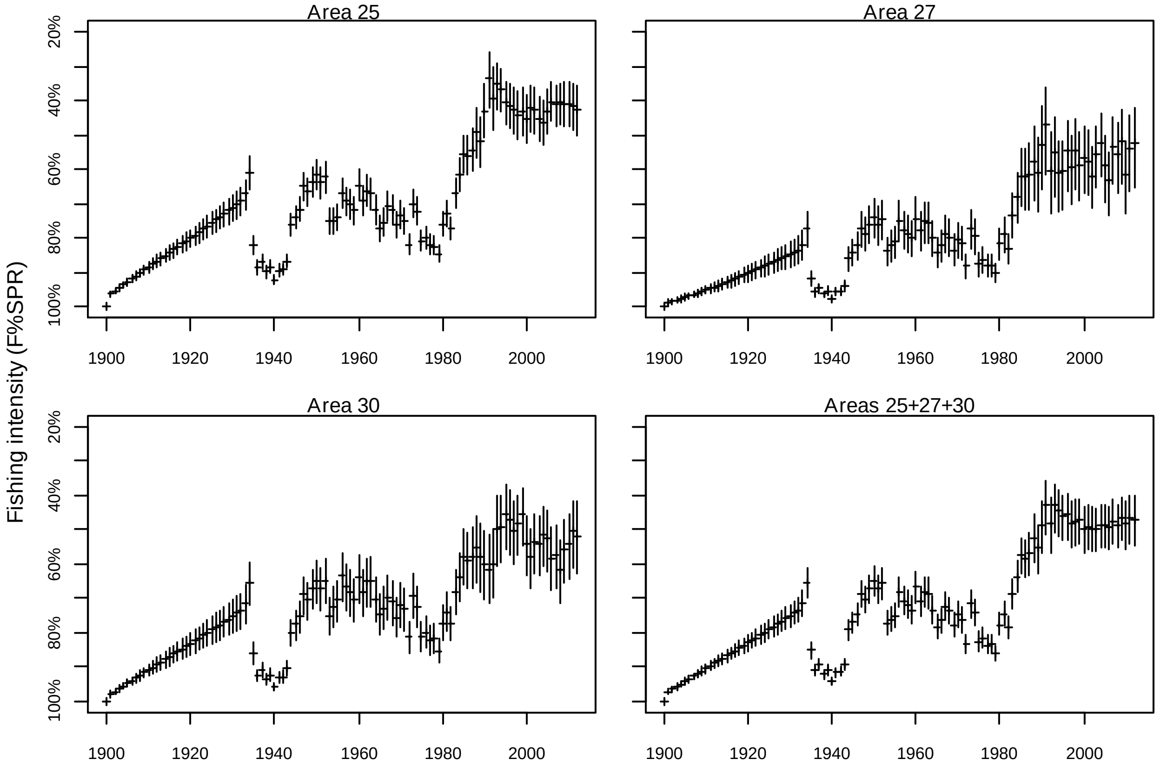


Figure 10: Fishing intensity ($F_{\%SPR}$) estimates from the base case runs for Areas 25, 27, 30, and the Areas combined, 1900-2012. The horizontal lines show the median and the vertical lines show the 90% confidence intervals.

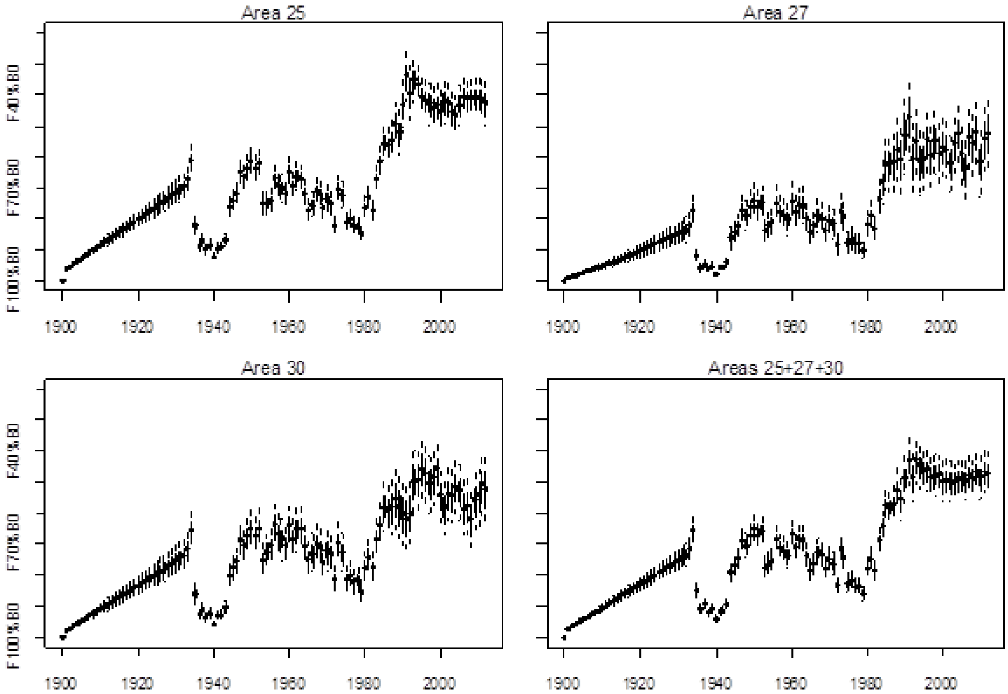


Figure 11: Fishing intensity ($F_{\%SPR}$) estimates from the base case runs for Areas 25, 27, 30, and the Areas combined, 1900-2012. The solid boxes show the interquartile range and the whiskers show the 90% confidence limits.

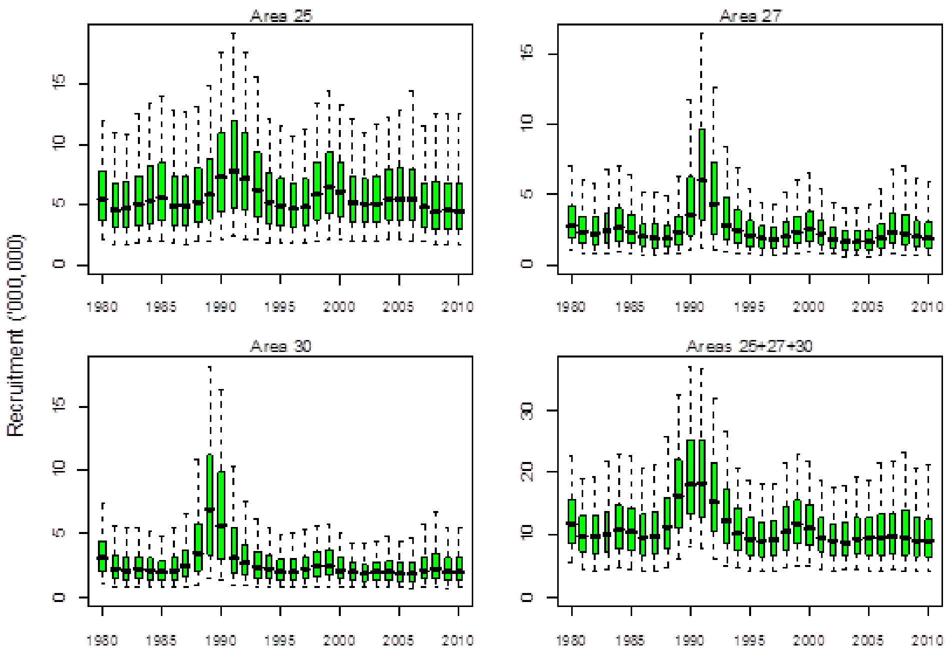


Figure 12: Recruitment estimates from the base case runs for Areas 25, 27, 30, and the Areas combined, 1980-2010. The boxes show the interquartile range, the whiskers show the 90% confidence limits, and the bars show the medians.

Fishing intensity has remained below $F_{40\%SPR}$, except in Area 25 for a brief period in the 1990s. Recruitment has been slightly below average in all three Areas over the last decade.

Table 19: Estimates of BCO 5 spawning stock biomass, *MSY* and B_{MSY} for final runs (medians of marginal posterior distributions, with 90% confidence intervals in parentheses). B_0 and *MSY* are calculated assuming Areas 25, 27 and 30 represent 92% of the BCO 5 blue cod stock.

Run	B_0 (,000 t)	$B_{current}$ (%B_0)	*MSY*	B_{MSY}(%B_0)
1.1	28(25,31)	39(31,51)	1336(1092,1589)	31(29,35)
1.2	28(26,31)	39(30,50)	1316(1088,1569)	32(29,35)
1.3	27(24,31)	39(30,50)	1345(1114,1607)	31(28,34)
1.4	26(24,29)	40(31,51)	1335(1115,1615)	31(29,35)

4.4.1.6 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.

Commercial catch levels were based on the current TACC and the average BCO 5 Statistical Area catch split over the past 10 years. Although only 90% of the BCO 5 TACC was caught on average over the past 10 years, with the reduction of the TACC to 1239 t in 2011-12, over 98% of the allowable catch was caught that year. Therefore stock projections based on the full TACC being caught appears reasonable. Alternative catch scenarios were simulated with commercial catch increased and reduced by 20%. Recreational and customary catch was assumed to remain constant at the 2011-12 levels.

Recruitment was simulated by randomly re-sampling (with replacement) from the time series of recruitment deviations, applied to the stock-recruitment relationship. Two alternative recruitment scenarios were simulated: recent recruitments were re-sampled from the 2001 through 2010 recruitment deviations and long-term recruitments were re-sampled from the 1980 through 2010 recruitments. Summary statistics were calculated for the BCO 5 FMA by summing B_0, B_{msy} and projection biomass estimates across the three Statistical Areas.

The projections indicate that under the assumptions of commercial catch at the current TACC and recruitment at recent levels the BCO 5 biomass is unlikely to change much over the next 10 years (Figure 13). Recruitments closer to the long-term average or a reduction in catch from the current TACC results in slight increases in biomass and an increase in catch above the TACC results in a slight decrease in biomass. 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, the target of 40% B_0, and 25%, 50% and 100% of B_{MSY} are presented in Table 22, for the base case model with recent or long-term recruitment and 3 catch levels and for the sensitivity runs with recent recruitment and commercial catch at the current TACC. With catches at the current TACC, the probability of the stock being less than either the soft or hard limit over the next five years is negligible.

There are no time series of length frequency observations for the BCO 5 stock assessment. So, while the assessment indicates a BCO 5 recruitment pulse in the early 1990s, the information to support this pulse comes solely from the CPUE data, and hence may be spurious.

The sex change predictions also need to be viewed with caution as there are few data to inform the parameters and the form of the equation.

Table 20: Median estimates of the proportion male in the 1900, 2013, 2018 and 2023 BCO 5 spawning stock at alternative recruitment and catch levels for the *base case* and sensitivity stock projections.

Run	1.1						1.2	1.3	1.4
Recruitment	Recent	Recent	Recent	Long-term	Long-term	Long-term	Recent	Recent	Recent
Catch Level	TACC	1.2·TACC	0.8·TACC	TACC	1.2·TACC	0.8·TACC	TACC	TACC	TACC
1900	0.41	0.41	0.41	0.41	0.41	0.41	0.47	0.39	0.41
2013	0.51	0.51	0.51	0.51	0.51	0.51	0.49	0.51	0.51
2018	0.48	0.51	0.51	0.47	0.51	0.51	0.50	0.48	0.49
2023	0.51	0.52	0.49	0.49	0.51	0.48	0.49	0.52	0.51

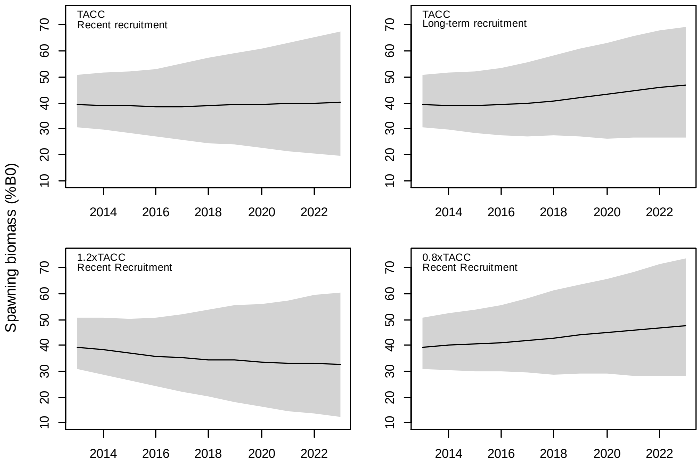


Figure 13: Projected BCO 5 spawning biomass (%B_0) assuming recent or long-term recruitment and catch at current TACC or increased/decreased by 20% for the base case run. Median estimates are shown as solid lines and 90% confidence intervals as shaded polygons.

Table 21: Probabilities of SSB being below B_0 and B_{msy} reference levels in 2013, 2018 and 2023 at alternative recruitment and catch levels for the *base case* and sensitivity stock projections.

Run	1.1						1.2	1.3	1.4
Recruitment	Recent	Recent	Recent	Long-term	Long-term	Long-term	Recent	Recent	Recent
Catch Level	TACC	1.2·TACC	0.8·TACC	TACC	1.2·TACC	0.8·TACC	TACC	TACC	TACC
$P(B_{2013}< 0.1\ B_0)$	0	0	0	0	0	0	0	0	0
$P(B_{2013}< 0.2\ B_0)$	0	0	0	0	0	0	0	0	0
$P(B_{2013}< 0.4\ B_0)$	0.538	0.538	0.538	0.538	0.538	0.538	0.576	0.549	0.532
$P(B_{2013}< 0.25\ B_{msy})$	0	0	0	0	0	0	0	0	0
$P(B_{2013}< 0.5\ B_{msy})$	0	0	0	0	0	0	0	0	0
$P(B_{2013}< B_{msy})$	0.095	0.095	0.095	0.095	0.095	0.095	0.116	0.091	0.078
$P(B_{2018}< 0.1\ B_0)$	0.001	0.002	0	0	0.001	0	0	0	0
$P(B_{2018}< 0.2\ B_0)$	0.010	0.048	0.002	0.003	0.024	0	0.012	0.007	0.015
$P(B_{2018}< 0.4\ B_0)$	0.543	0.694	0.379	0.470	0.622	0.288	0.578	0.578	0.605
$P(B_{2018}< 0.25\ B_{msy})$	0	0.002	0	0	0	0	0	0	0
$P(B_{2018}< 0.5\ B_{msy})$	0.002	0.014	0	0	0.006	0	0.004	0.002	0.005
$P(B_{2018}< B_{msy})$	0.230	0.377	0.114	0.153	0.294	0.069	0.249	0.215	0.262
$P(B_{2023}< 0.1\ B_0)$	0.003	0.024	0.002	0	0.005	0	0.007	0.004	0.006
$P(B_{2023}< 0.2\ B_0)$	0.053	0.173	0.008	0.019	0.077	0	0.052	0.051	0.074
$P(B_{2023}< 0.4\ B_0)$	0.498	0.681	0.271	0.289	0.533	0.110	0.491	0.505	0.553
$P(B_{2023}< 0.25\ B_{msy})$	0.001	0.014	0	0	0.002	0	0.004	0.003	0.002

Table 21 [continued]

$P(B_{2023} < 0.5\ B_{msy})$	0.021	0.107	0.004	0.009	0.037	0	0.025	0.018	0.040
$P(B_{2023} < B_{msy})$	0.256	0.473	0.105	0.113	0.306	0.030	0.272	0.257	0.305

4.5 Other factors

The target blue cod fishery is chiefly a pot fishery and there are few significant bycatch problems. However, in recent years bycatch associated with the inshore fleet of trawlers has increased in BCO 3 and BCO 7. Blue cod is only a very minor bycatch of the offshore fleet.

Before the introduction of the QMS, blue cod landings were affected by factory limits imposed in some parts of Southland, and there were economic constraints to the development of the fishery at the Chatham Islands (BCO 4).

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 handline 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. Large areas are currently not heavily fished and there are some areas such as the Mernoo Bank, the Puysegur Bank and South Traps which are potentially productive fisheries. 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.

5. STATUS OF THE STOCKS

For BCO 1 and 8 recent commercial catch levels are considered sustainable. The status of the remaining fishstocks is summarised below.

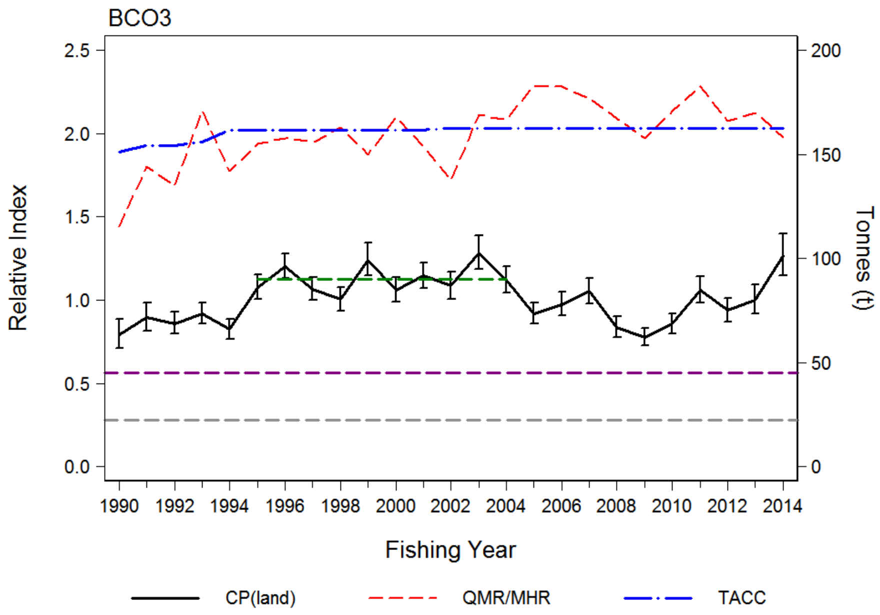
BCO 3 (Stat areas 24 and 26)

Stock Structure Assumptions

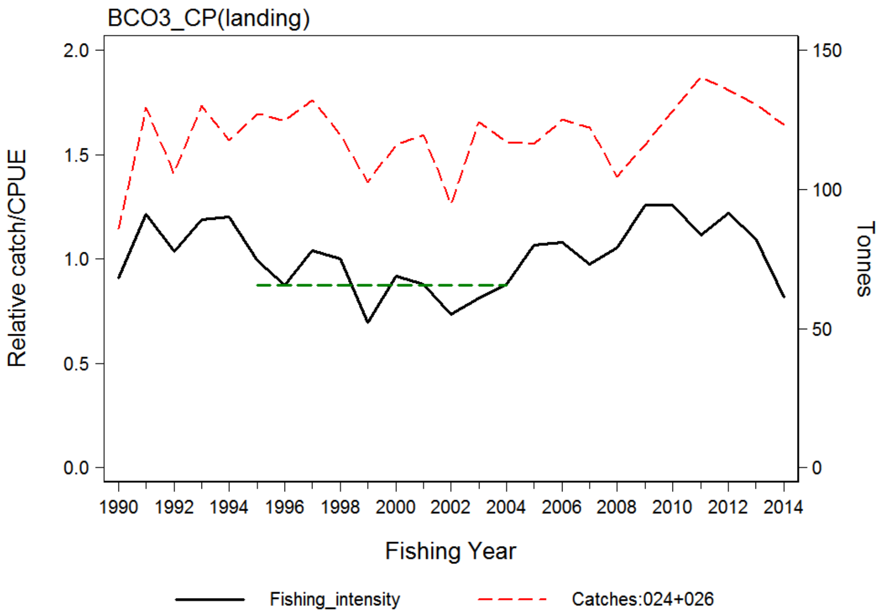
Tagging experiments suggest that blue cod populations may be isolated from each other and there may be several distinct populations within management areas. For the purposes of this summary, BCO 3 is split into two sub-areas along the Stat Area 022 and 024 boundary.

Stock Status	
Year of Most Recent Assessment	2015 (CPUE analysis)
Assessment Runs Presented	Potting survey CPUE index based on landed catch
Reference Points	Target: B_{msy} proxy based on mean CPUE for the period 1994–95 to 2003–04 Soft Limit: 50% B_{MSY} Hard Limit: 25% B_{MSY} Overfishing Threshold: F_{MSY} proxy based on mean relative exploitation rate for the period 1994–95 to 2003–04
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.



Relative Fishing Intensity (catch/CPUE) for BCO 3 (where CPUE=CP(land) and catch=Sum(024 & 026).

Fishery and Stock Trends	
Recent Trend in Biomass or Proxy	Biomass has increased in four of the five years since a nadir reached in 2008–09. It is now near the highest level in the series.
Recent Trend in Fishing Mortality or Proxy	Relative exploitation rate declined since 2011–12, and 2013–14 was below the overfishing threshold.
Other Abundance Indices	The North Otago potting survey has only three index values which do not form a trend and do not match the CP CPUE series very well. The South Otago potting survey has only two index values.
Trends in Other Relevant Indicators or Variables	-

Projections and Prognosis		
Stock Projections or Prognosis	Stock abundance, as monitored with cod potting CPUE, has fluctuated around a mean level since the early 1990s at levels of commercial catch averaging near 160 t/year. Recreational catch trends are not well known, but there seems to be little cause for concern as long as catches remain near current levels.	
Probability of Current Catch or TACC causing decline below Limits	Soft Limit: Unlikely (< 40%) Hard Limit: Very Unlikely (< 10%)	
Assessment Methodology		
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: 2015	Next assessment: 2017
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	3 – Low Quality: insufficient data points to describe trends and inconsistencies with BCO ageing have reduced the quality of age-based mortality estimates
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.

Fishery Interactions
Over 2/3 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

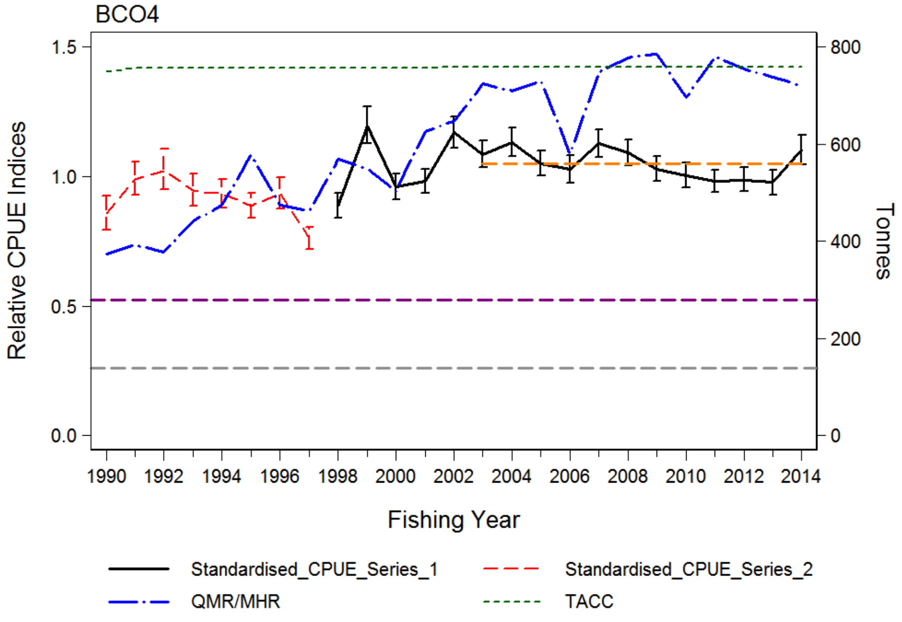
Stock Structure Assumptions

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

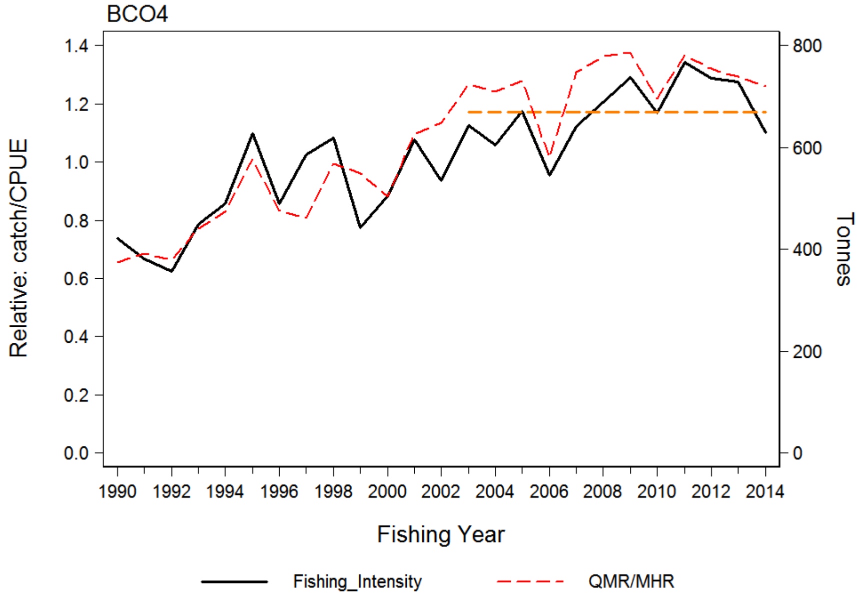
Stock Status	
Year of Most Recent Assessment	2015
Assessment Runs Presented	CPUE index based on landed catch
Reference Points	Interim Target: B_{MSY} proxy based on mean CPUE for the period 2002–03 to 2013–14 (a period with high yield when both catch and CPUE were stable) Soft Limit: 50% B_{MSY} proxy 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	About as Likely as Not (40–60%) 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 plotted as two series: 1990–1997 and 1998–2014, representing greater confidence in the latter series. Also plotted are the QMR/MHR landings and the BCO 4 TACC. The orange line represents the interim B_{MSY} proxy of mean CPUE from 2003–2014. 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].



BCO 4 fishing intensity (=catch/CPUE) plot based on the standardised CPUE series and the QMR/MHR landings. Horizontal orange line represents the mean 2003–2014 fishing intensity associated with the interim *Bmsy*_proxy.

Fishery and Stock Trends	
Recent Trend in Biomass or Proxy	CPUE has fluctuated without trend since 1997–98
Recent Trend in Fishing Mortality or Proxy	Relative exploitation rate has declined since 2010–11 and in 2013–14 was below 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 decline below Limits	Soft Limit: Very Unlikely (< 10%) Hard Limit: Very Unlikely (< 10%)	
Assessment Methodology		
Assessment Type	Level 2: Partial Quantitative Stock Assessment	
Assessment Method	Fishery characterisation and standardised CPUE analysis	
Assessment Dates	Latest assessment: 2015	Next assessment: 2019
Overall assessment quality rank	1 – High Quality	
Main data inputs (rank)	- Catch and Effort 1997–98 to 2013–14 - Catch and Effort 1989–90 to 1996–97	1 – High Quality 2 – Medium or Mixed Quality: compromised by changes in fleet composition and reporting practices
Data not used (rank)	N/A	
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.

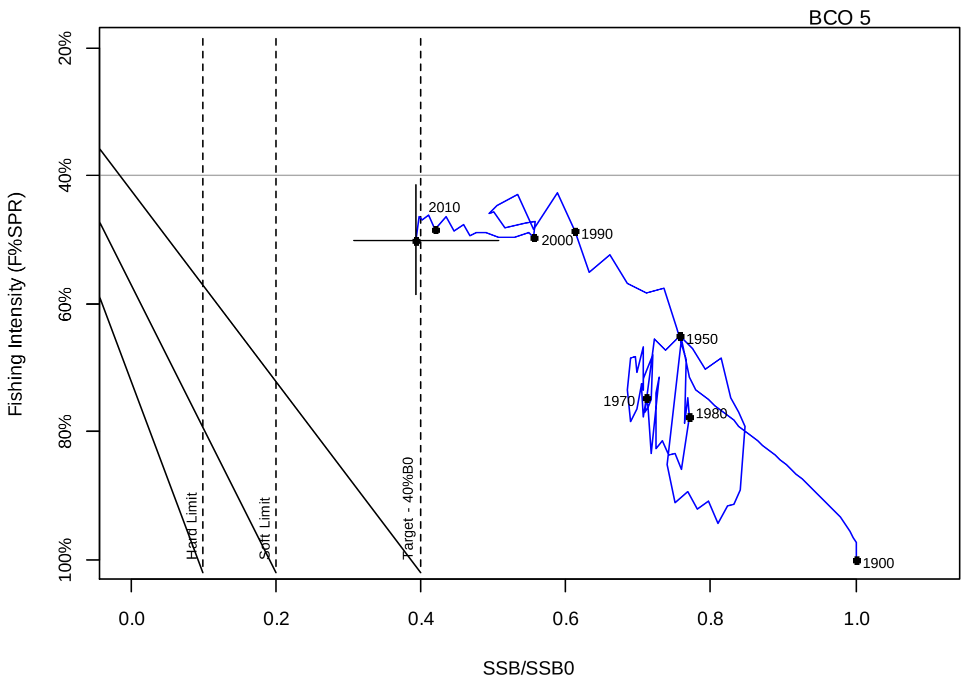
BCO 5

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, BCO 5 is treated as a unit stock.

Stock Status	
Year of Most Recent Assessment	2013
Assessment Runs Presented	One base case model was used to evaluate BCO 5 stock status in this assessment. Three sensitivity runs are also presented.
Reference Points	Interim Management Target: 40% B_0 Soft Limit: 20% B_0 Hard Limit: 10% B_0 Overfishing threshold: F_{MSY}
Status in relation to Target	B_{2013} was estimated to be 39.4% of B_0; About as Likely as Not (40–60%) to be at or above the Interim Management Target
Status in relation to Limits	B_{2013} 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	Unlikely (< 40%) that overfishing is occurring

Historical Stock Status Trajectory and Current Status



Trajectory of fishing intensity ($F_{\%SPR}$) and spawning biomass (%B_0) for BCO 5 from the start of the assessment period in 1990 to 2012. The vertical lines at 10%*B_0*, 20%*B_0* and 40%*B_0* represent the soft limit, the hard limit and the target, respectively, and the shaded area shows the *B_{MSY}* 90% CI. Estimates are based on MCMC medians and the 2012 90% CI is shown by the crossed lines

Fishery and Stock Trends	
Recent Trend in Biomass or Proxy	Biomass has been slowly decreasing since 2000.
Recent Trend in Fishing Intensity or Proxy	Fishing intensity is estimated to have been relatively constant since 2000.
Other Abundance Indices	-
Trends in Other Relevant Indicators or Variables	Recent recruitment (2002 – 2010) is estimated to be slightly below the long-term average.

Projections and Prognosis	
Stock Projections or Prognosis	BCO 5 biomass is expected to stay steady over the next 5 to 10 years at the 2012 TACC which approximates the 2012 catch.
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	Very Unlikely (< 10%)

Assessment Methodology and Evaluation		
Assessment Type	Level 1 - Full quantitative assessment	
Assessment Method	Length-based model with Bayesian estimation of posterior distributions	
Assessment Dates	Latest assessment: 2013	Next assessment: 2018
Overall assessment quality rank	1 – High Quality	
Main data inputs (rank)	- CPUE time series - Proportion at length data from surveys and commercial catch - Estimates of biological	1 – High Quality 1 – High Quality

	parameters - DUV survey absolute biomass estimate - Potting survey Z estimates	1 – High Quality 1 – High Quality 1 – High Quality
Data not used (rank)	-	-
Changes to Model Structure and Assumptions	New model	
Major Sources of Uncertainty	Degree to which CPUE reflects abundance; the age, size and sex structure of the population; relationship between abundance and sex change dynamics	

Qualifying Comments
-

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.

Research needs
Research into the sex change dynamics of blue cod would assist in improving the information that goes into the BCO 5 stock assessment. Histological analysis of gonads from the randomly stratified surveys would be a useful approach to assess sex change dynamics. Catch sampling should be undertaken in BCO 5 and needs to be scheduled as part of the medium term research plan.

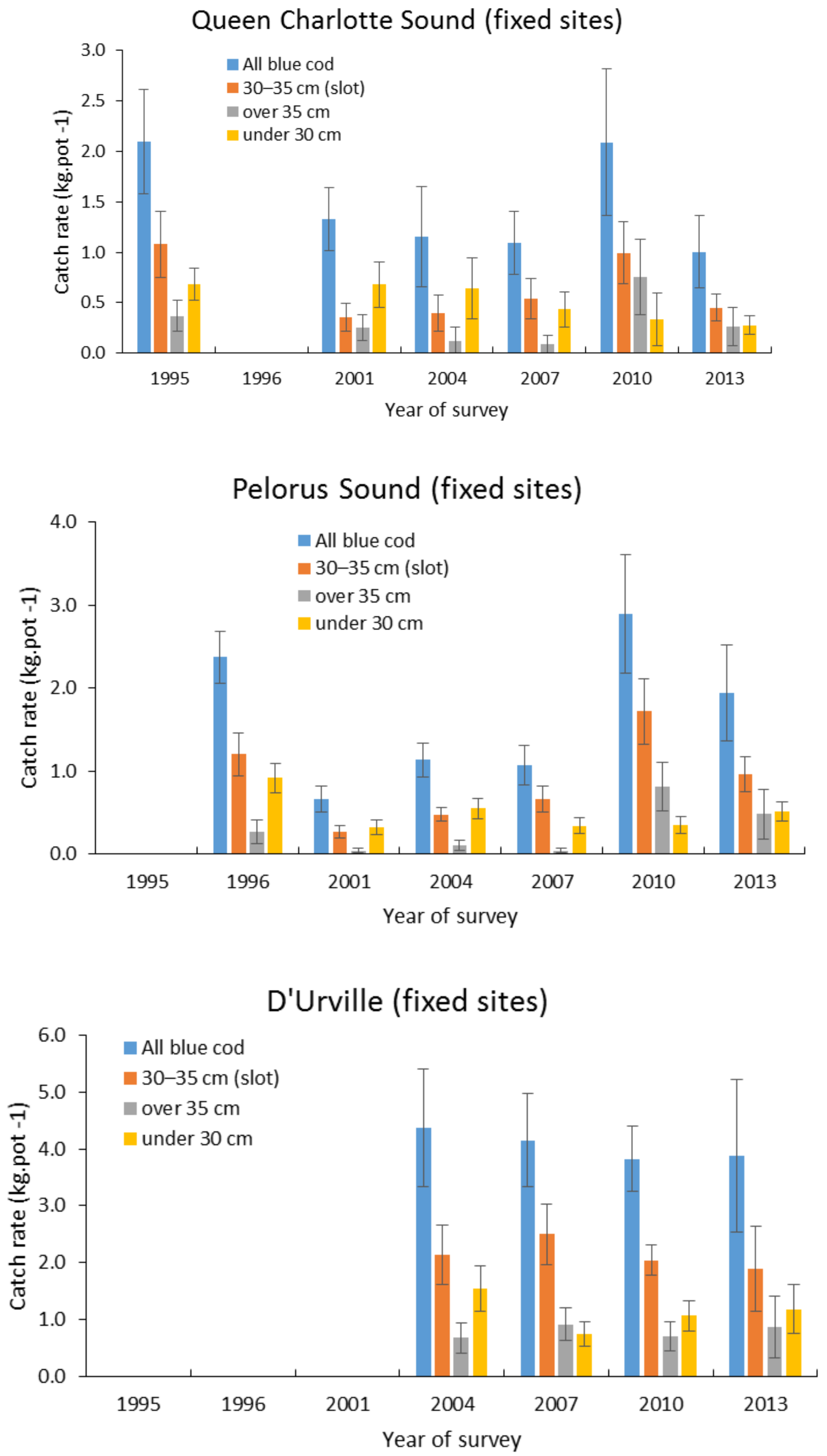
BCO 7 - Marlborough Sounds only

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	2014
Assessment Runs Presented	Catch rates from the fixed site Marlborough Sounds potting survey
Reference Points	Target: B_{MSY}-compatible proxy based on the Marlborough Sounds potting survey (to be determined) Soft Limit: 20% B_0 Hard Limit: 10% B_0 Overfishing threshold: F_{MSY}-compatible proxy (to be determined)
Status in relation to Target	Unknown
Status in relation to Limits	Unknown
Status in relation to Overfishing	Unknown

Historical Stock Status Trajectory and Current Status



Scaled catch rate rates by size category from the fixed site potting surveys in the Marlborough Sounds for Queen Charlotte Sound, Pelorus Sound and D'Urville regions. Error bars are 95% confidence intervals.

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 same areas 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 in April 2011 and the estimated 2013 survey abundance in those regions declined, but no change was observed in DUR.
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. It is not known if the mortality in 2014 is higher or lower than that which existed when the fishery was closed in 2008.
Other Abundance Indices	The mean length of catches taken during the 2010 blue cod potting survey tended to be larger than those observed in previous surveys. Mean length declined for the 2013 survey in QCH and PEL.
Trends in Other Relevant Indicators or Variables	Sex ratio is strongly skewed in favour of males.

Projections and Prognosis	
Stock Projections or Prognosis	It is unknown whether biomass will continue to decline under current management controls.
Probability of Current Catch or TACC causing decline below Limits	Soft Limit: Unknown Hard Limit: Unknown

Assessment Methodology and Evaluation		
Assessment Type	2 – Partial Quantitative Stock Assessment	
Assessment Method	Fishery-independent potting survey. Fixed sites in QCH, PEL, DUR, and random sites in CKST.	
Assessment Dates	Latest assessment: 2014	Next assessment: 2017
Overall assessment quality rank	1 – High Quality	
Main data inputs (rank)	- Potting survey catch rates - Length	1 – High Quality 1 – High Quality
Data not used (rank)	-Age	3 – Low Quality: Age has been determined by several otolith readers across time, and otolith interpretation varies greatly between readers.
	-$F_{\%SPR}$	3 – Low Quality: $F_{\%SPR}$ was not used due to the frequent regulatory changes for this fishery resulting in inconsistent fishing mortality over the lifetime of recent cohorts. Issues regarding age determination have also created problems with mortality estimation.
Changes to Model Structure and Assumptions	-	
Major Sources of Uncertainty	- The total removals from the recreational sector and the distribution of recreational effort are not well estimated in most years.	

Qualifying Comments
The survey is moving from a fixed site to a random site stratified potting survey, in the interim both survey types will be undertaken simultaneously so that the random survey can be calibrated to the historic data. The 2010 survey comprised a full fixed site survey along with a partial random site survey in selected strata, whereas 2013 included full fixed and full random site surveys carried out simultaneously.

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	Actual TACC	2013-14 Reported landings
BCO 1	Auckland	1 & 9	46	9
BCO 2	Central (East)	2	10	8
BCO 3	South-East (Coast)	3	163	159
BCO 4	South-East (Chatham Rise)	4	759	720
BCO 5	Southland and Sub-Antarctic	5 & 6	1 239	1 208
BCO 7	Challenger	7	70	58
BCO 8	Central (Egmont)	8	34	12
BCO 10	Kermadecs	10	10	0
Total			2 332	2 174

6. FOR FURTHER INFORMATION

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